

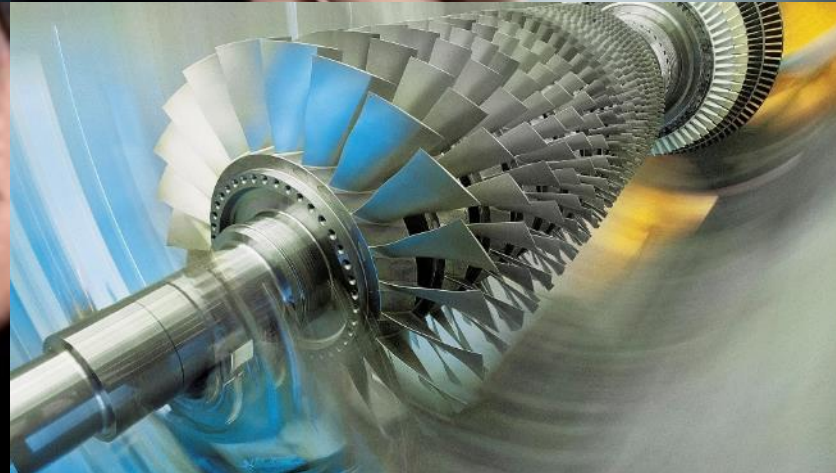
# Overview of NETL's Critical Minerals & Materials Program



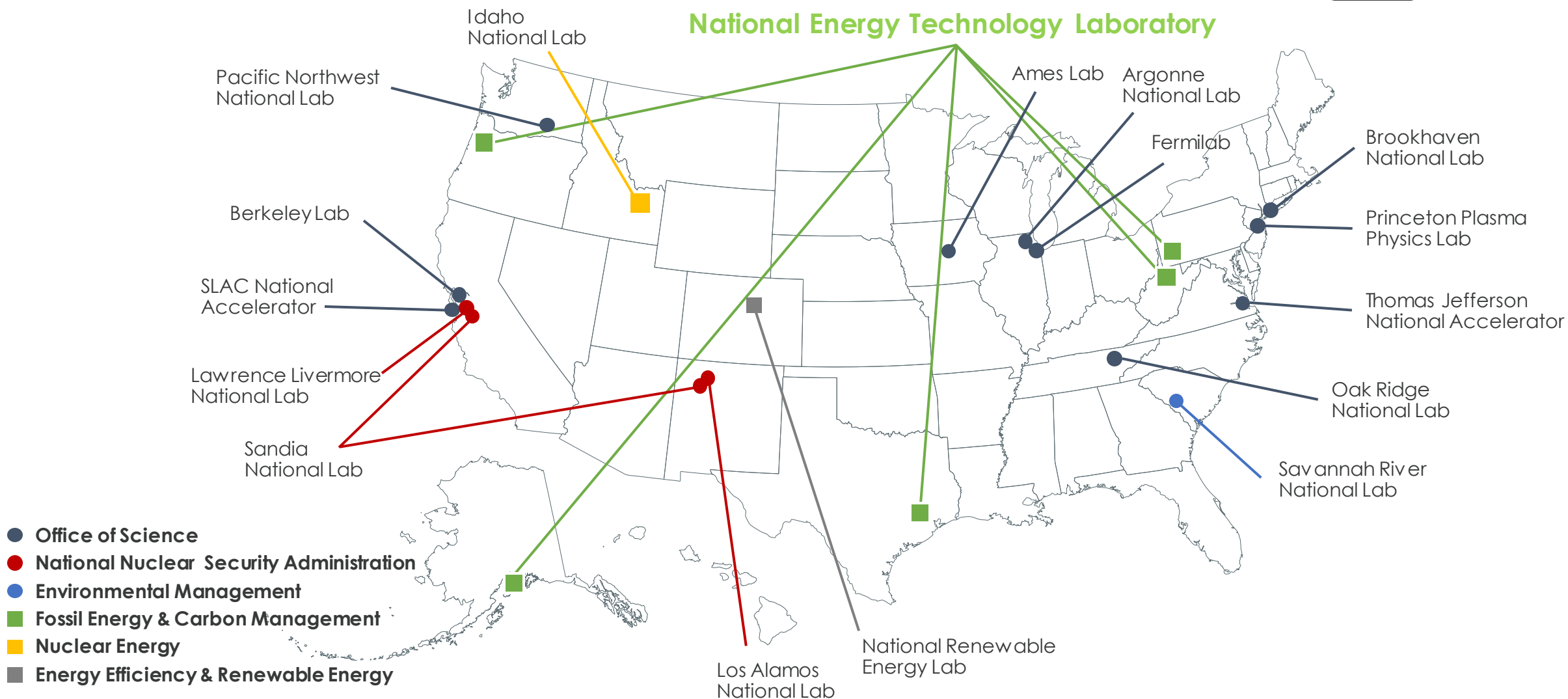
**Jessica Mullen, Ph.D.**

*Technology Manager  
Critical Minerals & Materials*

**Critical Materials Workshop  
Anchorage, Alaska  
February 22, 2023**



# The National Laboratory System



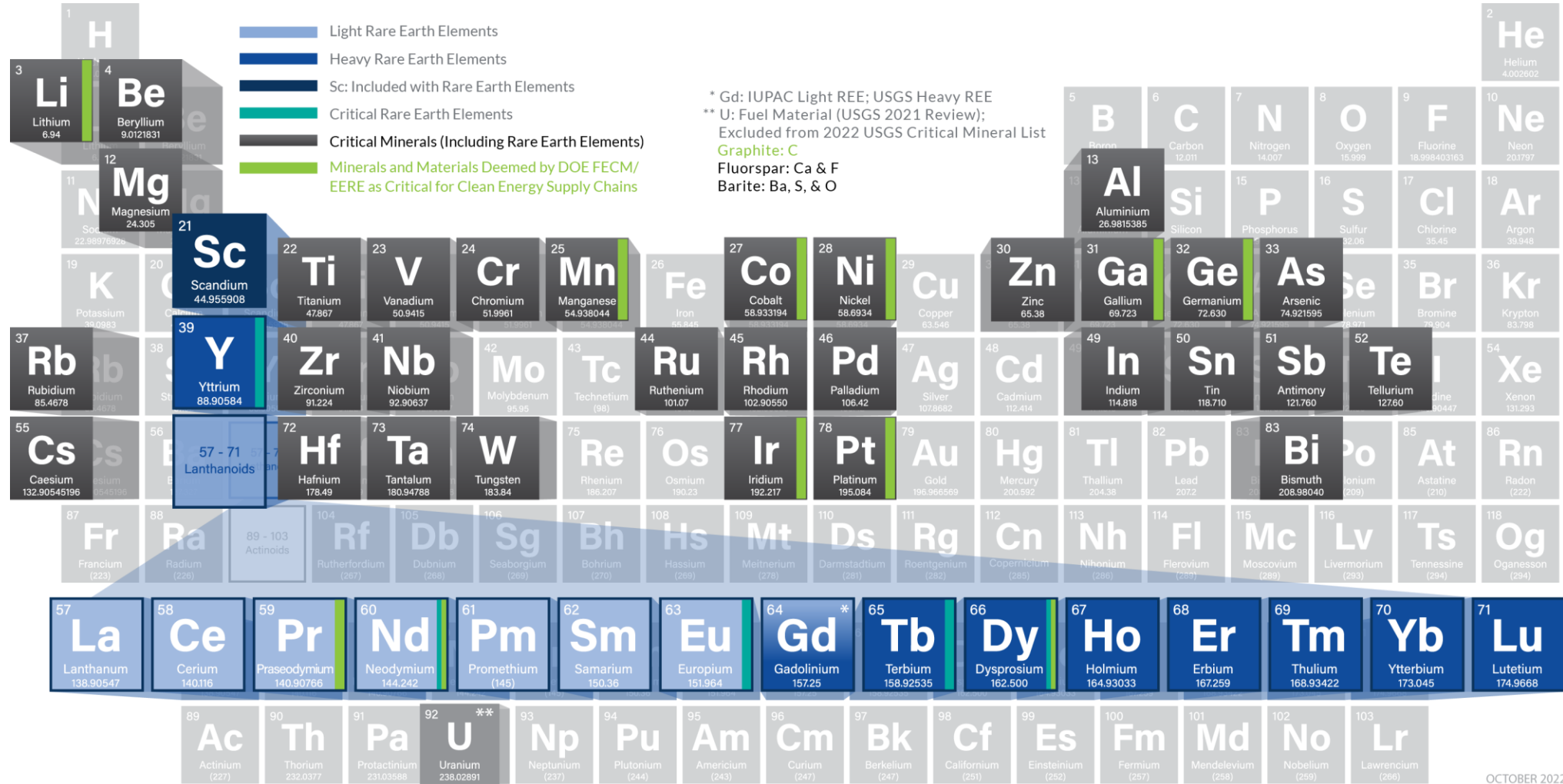


“We can't build a future that's made in America if we ourselves are dependent on China for the materials that power the products of today and tomorrow.”

President Joe Biden from the White House during a virtual meeting on securing critical mineral supply chains on February 22, 2022



# Critical Minerals (CM) & Rare Earth Elements (REE)



OCTOBER 2022

# Sources of CMs & REEs

## Primary

### Coal (Carbon Ore)

#### Conventional Mines

- Placer Deposits
- Hard Rock
- Carbonatites

*Within primary sources, NETL focused on coal as an unconventional feedstock*

## Secondary

### Coal Byproducts

- Coal Prep Plant Refuse
- Power Generation Ash (e.g., fly ash)
- Acid Mine Drainage (both solids, fluid)

### Overburden & Underlying Clays/Shales/Sediments

*“Bonus benefit”: mitigation of environmental byproducts of coal combustion*

## Unconventional

### Water

- Produced From O&G Wells
- Extracted During Carbon Storage

### Industrial Byproducts

(e.g., steel slag, red mud, phosphate processing waste)

### Municipal Solid Waste and/or Sludge

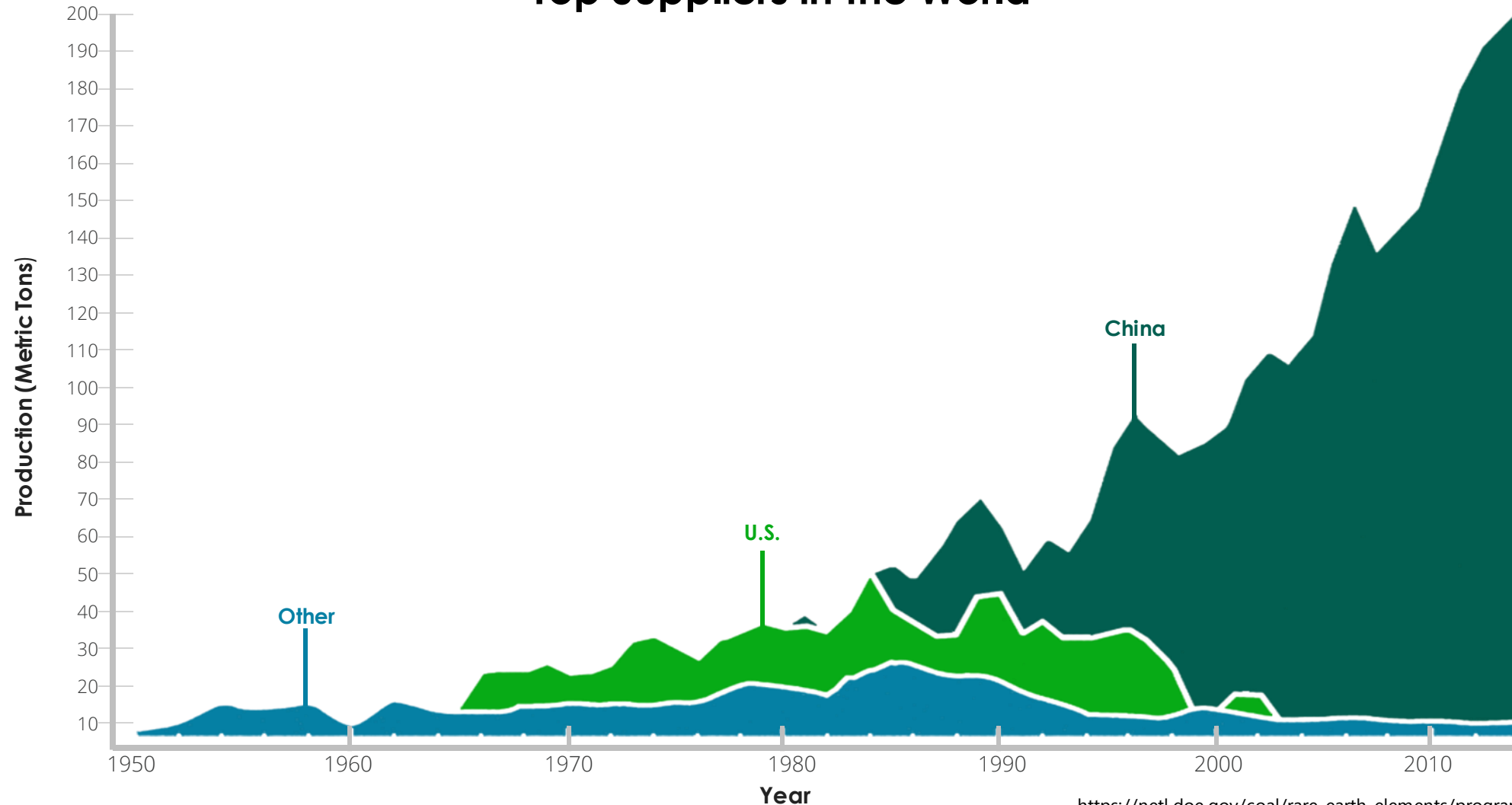
### Salt Flats

### Etc.

*Additional sources include recycling of electronic wastes (targeted outside of FECM)*

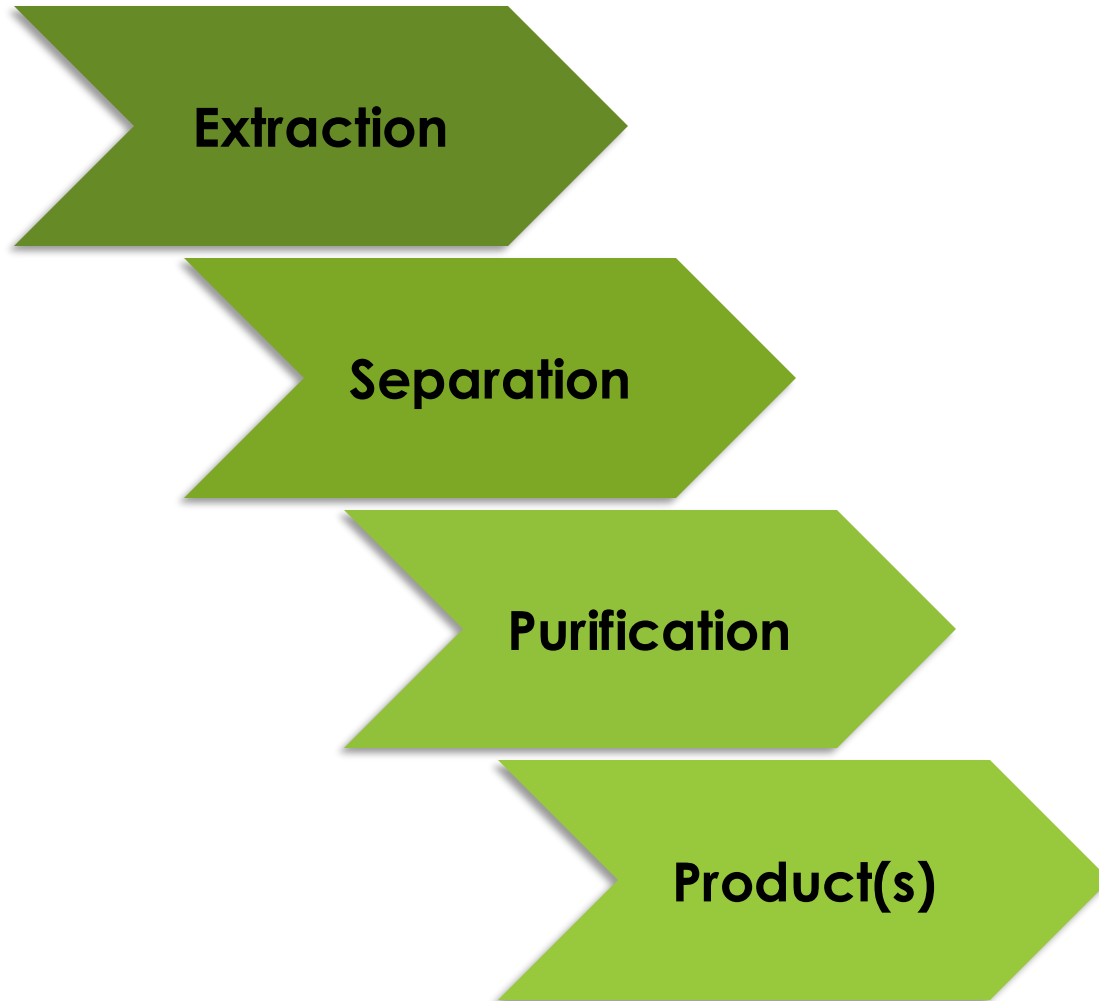
# Major International REE Suppliers

## Top Suppliers in the World

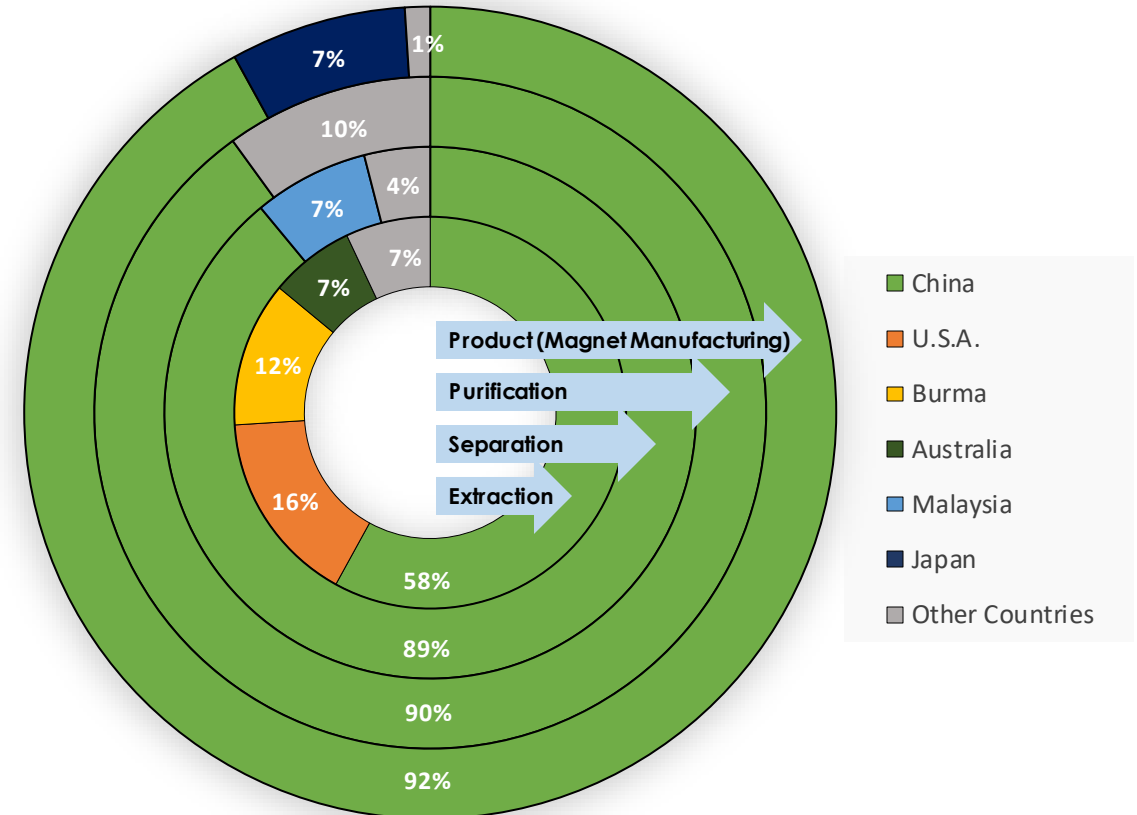


<https://netl.doe.gov/coal/rare-earth-elements/program-overview/background> (figure 4)

# Need to Grow U.S. Supply Chain

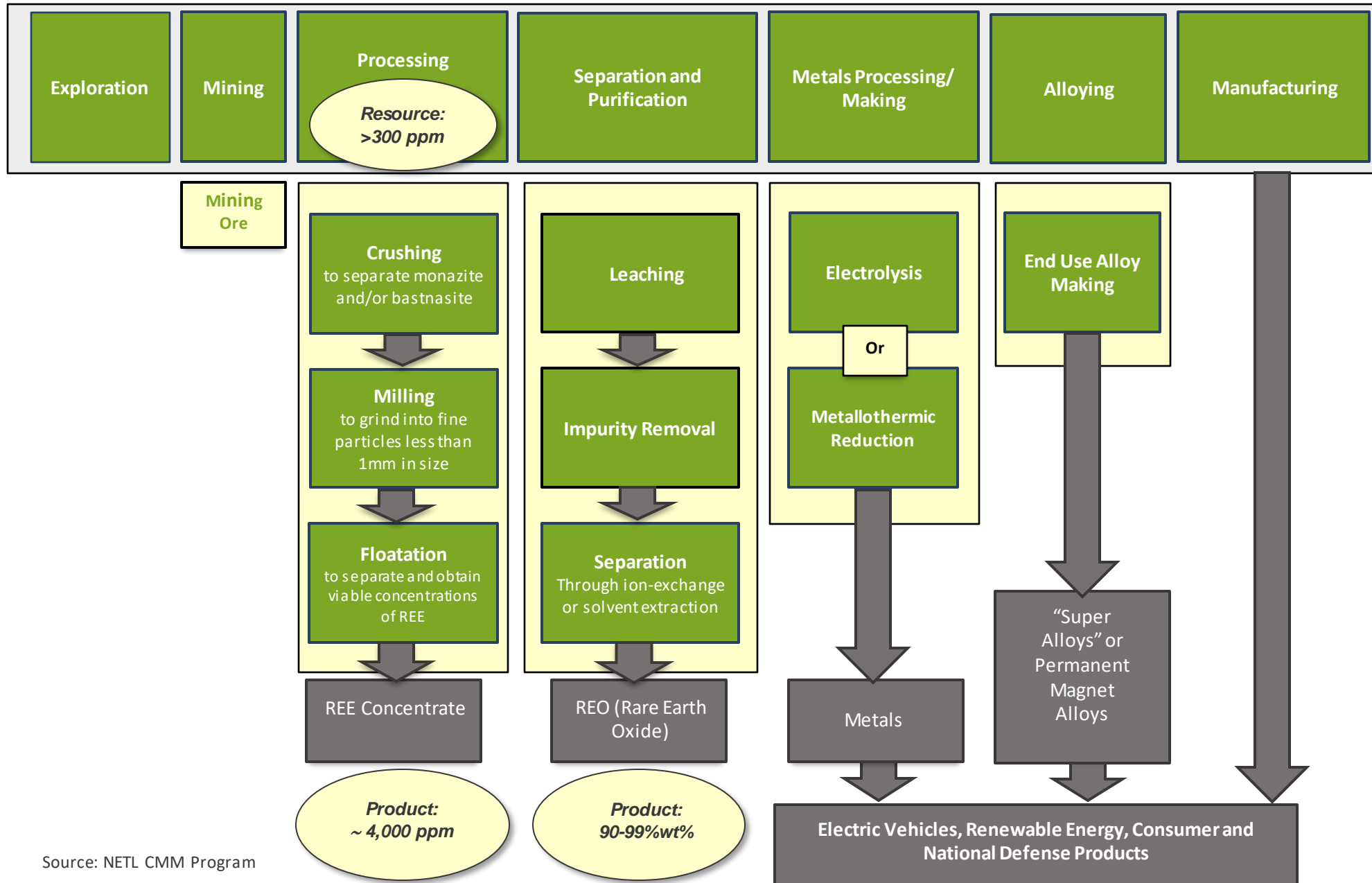


Example: Geographic concentration of supply chain stages for sintered NdFeB magnets



Source: <https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain>





Source: NETL CMM Program





## Mission

- Develop economic, competitive, sustainable domestic REE-CM supply
- Clean energy transition and economic and national security

## Objectives

- Recovery from unconventional and secondary resources
- Development and utilization of advanced CM separation systems
- Demonstration-scale separation and refining facility

## Drivers and Challenges

- Offshore supplier dominance
- Market volatility and potential price fluctuation/manipulation
- Low REE-CM content in heterogenous unconventional resources

# Domestic Demonstration-Scale Facility

## Goals Metrics

- Technical-economic REE-CM production under benign conditions
  - Commercial-grade mixed REO/RES (rare earth oxides/rare earth salts) concentrates+
  - Realize full value of natural resources across U.S. basins
- Production of **1-3 tonnes (t)/day** of mixed REO/RES
  - Minimum REO/RES concentration
    - **75% by weight** (preferred >98wt%)
  - Subsequently processed to individual or binary separated REOs or RESs at **>90wt%**
  - Refining to market-grade REMs (generally **>99.9wt%**, pending supply chain specifications)



**>99.9**

# CMS Program - Commercialization Pathway



## 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

Program Initiated 2014

PRODUCTION

PROCESSING

PROSPECTING



TRL 5-7

Operational – First-of-a-Kind Small Pilot-Scale Facilities

FOA-1718

Transformational Separation

TRL 3-5

FOA-1202

Conventional REE Separation & Recovery – 80-90% Purity

RFP 9067 & RFP 10982

Field Prospecting

2015

2020

2025

TRL 7-8

FOA-2618 Phase II

Demonstration-Scale Facility  
1-3 tonnes MREO/day

FOA-2618 Phase I

Demonstration Facility  
FEED Study

FOA-2404

Advanced Processing Phase 1

FOA-XXXX

Advanced Processing Phase 2 Planned\*

FOA-2364

CORE-CM Phase 1

FOA-XXXX

CORE-CM Phase 2 & Phase 3 Planned\*

RFP

Concept & Feasibility  
(Pre-FEED) Studies

FOA-2003

REE System Optimization & Efficiency Improvements : CM Production



\*Planned means solicitation or future phase(s) may possibly be funded via a future FOA that DOE may or may not issue.

# REE Demonstration-Scale Facility

DE-FOA-0002618



## Goal

- Develop a first-of-a-kind facility to extract and separate CM and REE from acid mine drainage, mine waste, or other deleterious materials

## Funding

- Funding provided from the Bipartisan Infrastructure Law Sections 40205 and 41003(b)
- **\$156 million DOE share (for Phases I and II)**

## Areas of Interest (Phase I)

- 1) Association for the Advancement of Cost Engineering (AACE) Class 3 Cost Estimate Supporting a FEED Study for REE Demonstration Facility
  - 4 anticipated number of awards
- 2) Completed AACE Class 3 Cost Estimate Supporting a FEED Study Separately Funded for REE Demonstration Facility
  - 4 anticipated number of awards
- **Awards Selections expected March 2023**

Phase I:  
Front-end Engineering  
Design (FEED)



Phase II (Down-select):  
Construction and Operation  
of Demonstration Scale  
Facility producing 1-3 tonnes  
MREO/MRES per day  
operating for min 2 years



# Notice of Intent – Further FEED Funding



- NOI (DE-FOA-0002846) October 12, 2022
  - Notice of intent to issue **DE-FOA-002854 – Bipartisan Infrastructure Law Front-End Engineering Design Studies for Production of Critical Minerals and Materials from Coal-Based Resources**
  - Fund additional AACE Class 3 cost estimates supporting FEED studies for the recovery and refining of Critical Minerals and Materials from coal and coal byproducts, with a primary focus on production of high purity rare earth metals, or alternate forms, as required for critical supply chain use.
  - Similar to DE-FOA-0002618 Phase I but academic prime not required

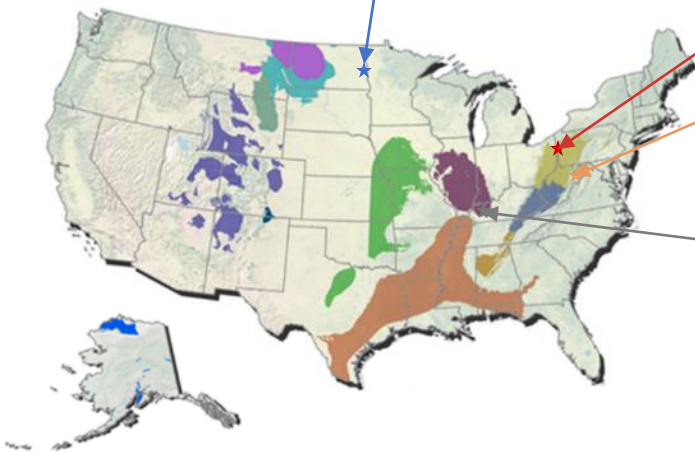
# Small-Scale Pilot Facilities

## NETL-funded Project Facilities Producing High Purity MREO & CMs (Co, Mn, Ni, Ga, Gd) from Domestic Coal-Based Sources



- Separating MREO concentrate from **lignite**.
- August 2022 pilot facility construction complete.
- October 2022 pilot facility start-up of testing.

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



- Small-scale pilot plant cumulatively produced > 1 kg mixed rare earths on an oxide basis from **post combustion coal ash** by 2021. Ended March 2022.

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



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

2018	2019	2020	2021
44 g 95 – 99% purity		Field pilot-scale Construction nearly completed Start up Fall 2022	

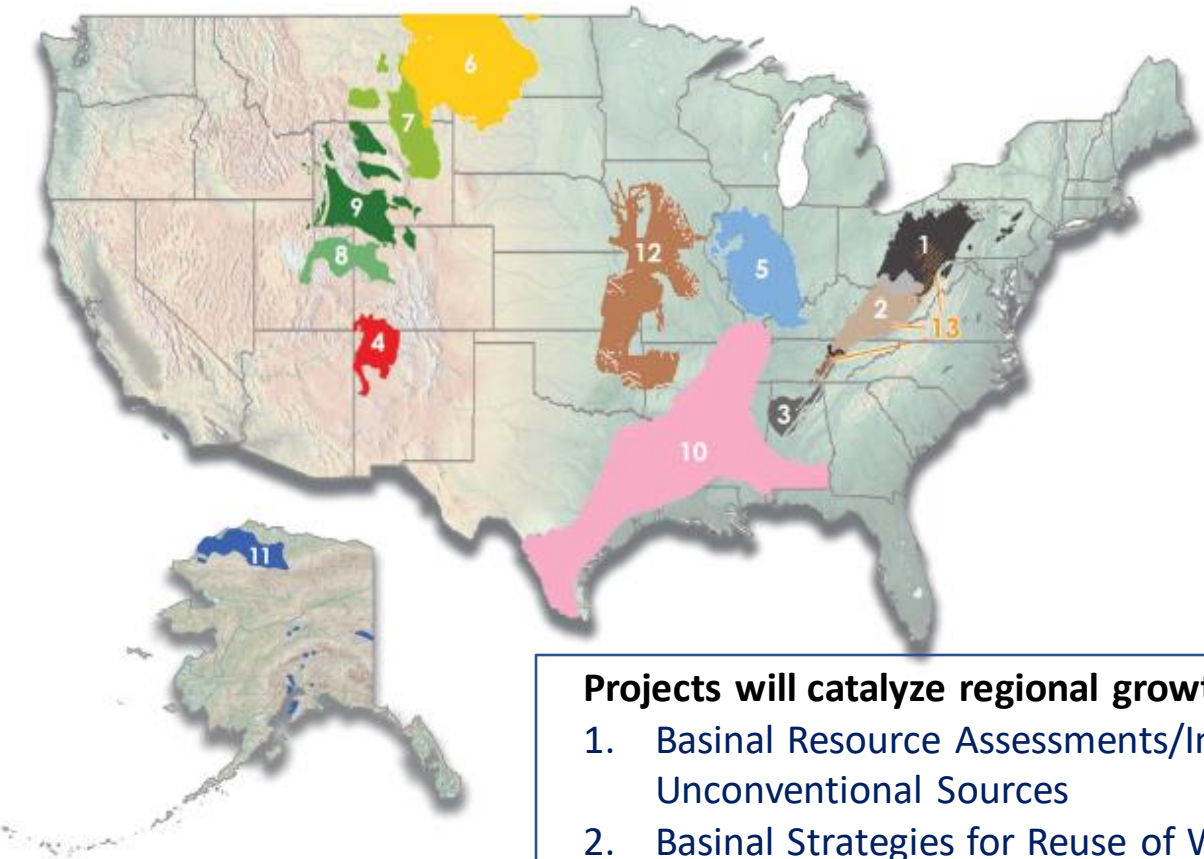


- Pilot operation began Q4 FY21. Ended Dec. 2022
- Produced quantities MREOs in its *modular* pilot-scale facility **from coal refuse materials**.

2018	2019	2020	2021	2022 (Q1)
0.6 kg 80% purity	1.5 kg > 90% purity	0.41 kg 98% purity	0.4 kg >50% purity & 4 kg 0.5% crude cake	0.72 kg >95% REE & 0.3 kg (8% Co, 30% Ni) & 0.27 kg (22% Mn)

# DE-FOA-0002364 (CORE-CM)

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



## U.S Basin Legend

- AOI 1: Appalachian Basin, North (MD, OH, PA, WV) — Pennsylvania State University
- AOI 2: Appalachian Basin, Central (KY, TN, VA, WV) — Virginia Tech
- AOI 3: Appalachian Basin, South (AL, GA, TN) — Collaborative Composite Solutions
- AOI 4: San Juan River-Raton Basin (CO, NM) — New Mexico Institute of Mining and Technology
- AOI 5: Illinois Basin (IL, IN, KY, TN) — University of Illinois
- AOI 6: Williston Basin (MT, ND, SD) — University of North Dakota
- AOI 7: Powder River Basin (MT, WY) — University of Wyoming
- AOI 8: Uinta Basin (CO, UT) — University of Utah
- AOI 9: Green River-Wind River Basin (CO, WY) — University of Wyoming
- AOI 10: Gulf Coast Basin (AL, AR, LA, MS, TX) — University of Texas Austin
- AOI 11: Alaska Basin (AK) — University of Alaska Fairbanks
- AOI 12: Other: Cherokee-Forest City Basin (IA, KS, MO, NE, OK, Osage Nation) — University of Kansas
- AOI 13: Other: Mid-Appalachian Basin (southwestern PA, WV, southwestern VA, eastern KY and eastern Tennessee) — West Virginia University

## Projects will catalyze regional growth through:

- Basinal Resource Assessments/Inventory for Unconventional Sources
- Basinal Strategies for Reuse of Waste Streams
- Basinal Strategies for Infrastructure, Industries, and Businesses
- Technology Assessment, Development and Field Testing
- Technology Innovation Centers
- Stakeholder Outreach and Education



# CMM Program

## Field Work Proposal (FWP) Projects



### R&D Portfolio Objectives

- Locate promising, domestic sources of unconventional CM
- Develop technologies to reduce the cost of CM extraction and concentration
- Reduce risk to deployment

### R&D Portfolio Snapshot

- Real Time Aqueous REE Fiber Optic Sensors & LIBS
- U.S. Coal Basin Sedimentary Assessment
- REE-CM Embedded Database – Industry Impact; TEA & LCA

### Technology

#### Commercialization Fund (TCF)

- NETL - University of Wyoming Small Pilot-Scale Facility for REE Recovery from Powder River Basin Coal Ash



- Chemistry & Mineralogy of Coal-Based Resources
- Raman-LIBS Back-Pack Instrumentation
- Completed Nov. 2022





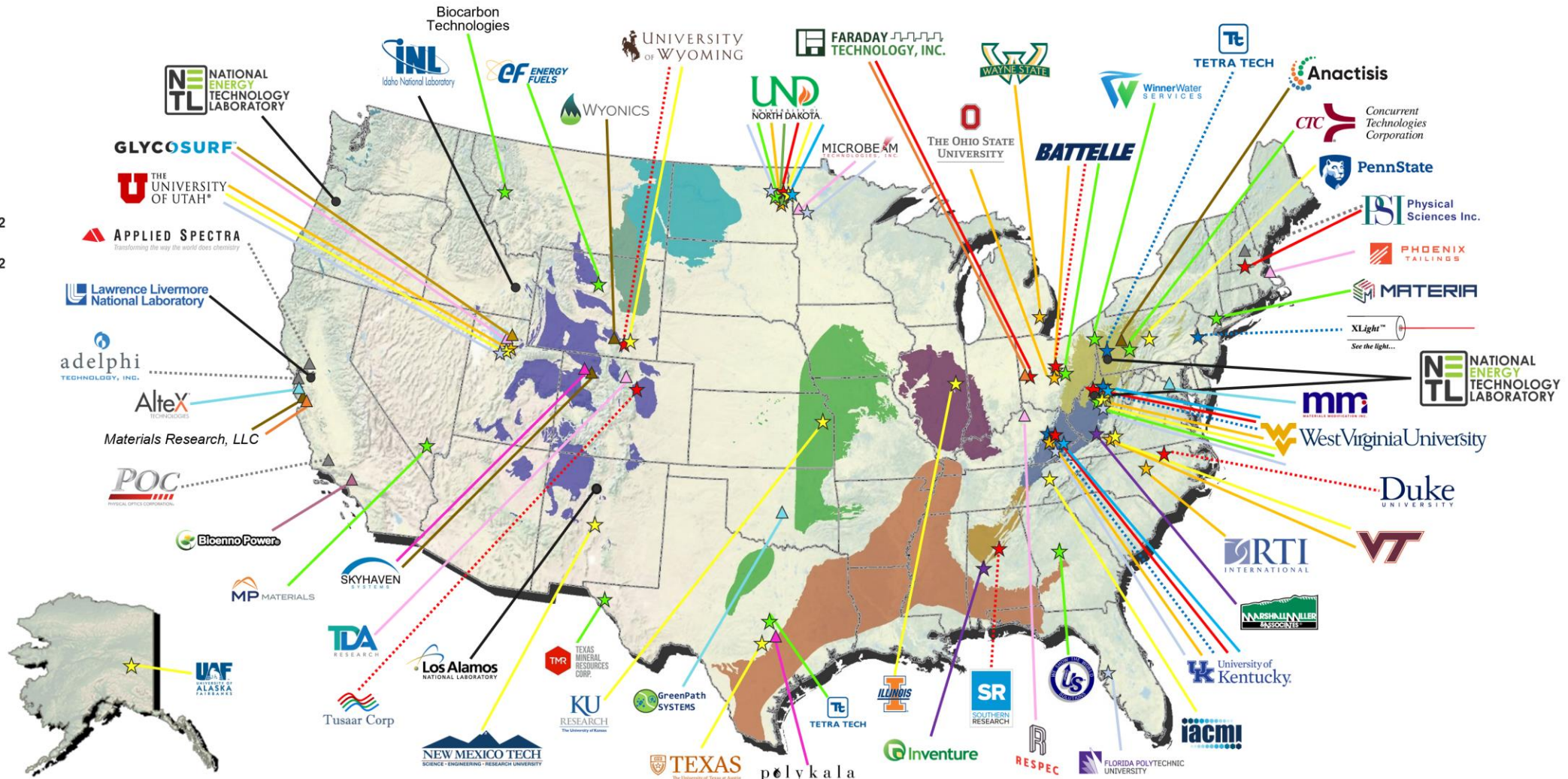
# CMM Program - Acknowledgements

## Prime Contract Award Location

- .....★ FOA-1202 (Phase 1)
- .....★ FOA-1202 (Phase 1 & 2)
- .....★ FOA-1627
- .....★ FOA-1718
- .....★ FOA-2003
- .....★ FOA-2404
- .....★ RFP DE-SOL-10982
- .....★ RFP DE-SOL-0009067
- .....★ SBIR (FY22) – Phase 1 Release 1
- .....★ SBIR/STTR (FY22) – Phase 1 Release 2
- .....★ STTR (FY22) – Phase 2 Release 2
- .....★ SBIR/STTR (FY21) – Phase 1 Release 2
- .....★ SBIR (FY21) – Phase 1 Release 1
- .....★ SBIR (FY19)
- .....★ SBIR (FY18)
- .....★ SBIR (FY17)
- .....● National Laboratories
- .....★ RFP-89243320RFE000032
- .....★ CORE-CM Phase 1

## Coal Basin

- ..... Central Appalachia
- ..... Central Interior
- ..... Gulf Lignite
- ..... Illinois Basin
- ..... Lignite
- ..... Northern Appalachia
- ..... Powder River Basin
- ..... Rocky Mountain
- ..... Southern Appalachia
- ..... West/Northwest



September 2022

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National Energy Technology Laboratory

**Visit Us at:**

<https://netl.doe.gov/carbon-management/critical-minerals>

<https://edx.netl.doe.gov/ree-cm/>

*Courtesy of NETL CMS Website*