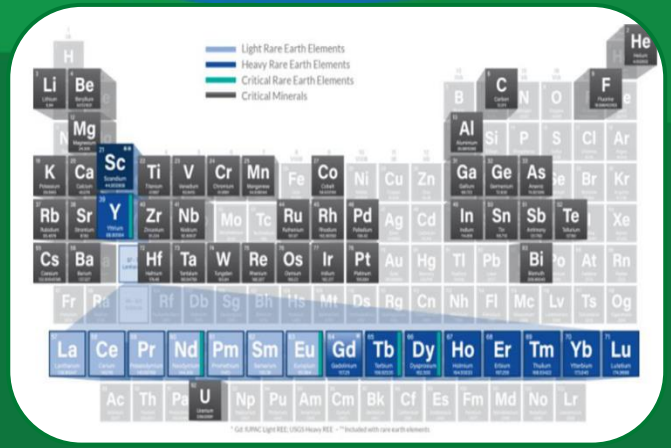
U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

Appalachian Regional Deploy Dialogue

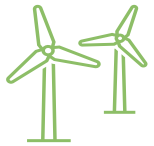
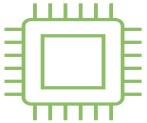
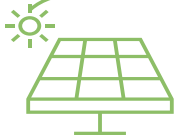
Grant S. Bromhal, PhD
Senior Science Advisor

Morgantown, WV
July 17, 2024



Critical Materials RDD&D needs reach across DOE

Domestic Critical Minerals & Materials Supply Chains Are Vital for the Clean Energy Transition

Neodymium, Praseodymium, Dysprosium, Terbium		**Magnets** for wind turbine generators & EV motors
Cobalt, Lithium, Graphite, Nickel, Graphite, Fluorine		**Batteries** for electric vehicles & grid storage
Iridium & Platinum		**Electrolyzers** for green hydrogen production & **fuel cells** used energy storage
Gallium & Silicon Carbide*		**Semiconductors** enable high voltage power & efficient lighting
Magnesium & Aluminum		**Lightweight alloys** in transportation
Silicon*		**Solar panels**, lightweight alloys, electrical steel
Copper* & Electrical Steel*		Wind turbine **generators** & EV **motors**

**Not on the U.S. Geological Survey Critical Minerals List*

White House Goals

- 100% clean electricity by 2035
- Net-zero economy by 2050
- 50% electric vehicle sales by 2030

DOE Goals

- 30 gigawatts offshore wind by 2030
- Cost of Clean Hydrogen $1/kg by 2031

Significant vulnerability across many supply chains

Graphite 100%

Manganese 100%

Rare Earths >95%

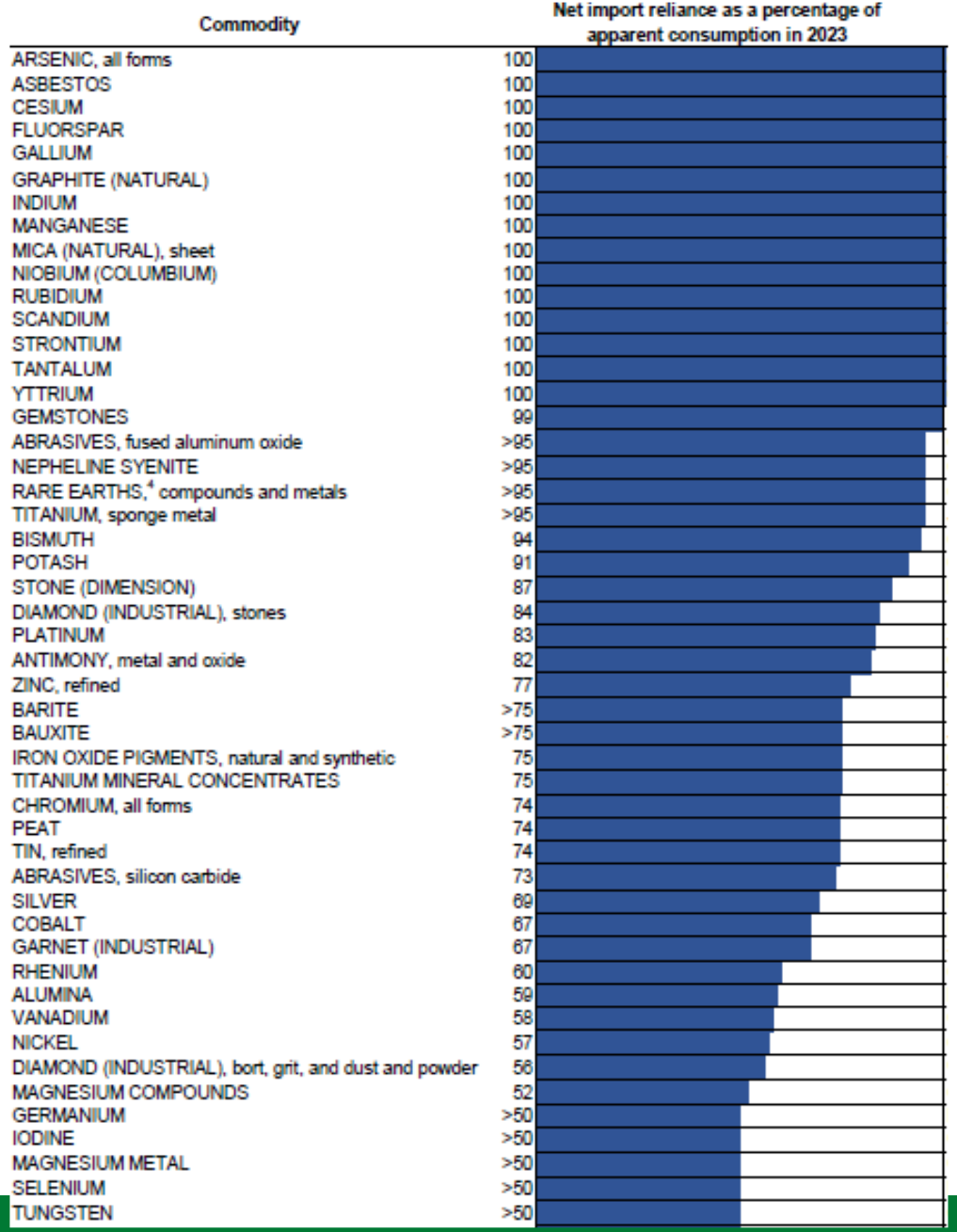
Platinum 83%

Maximum US Reliance on Fossil Imports Was 30% in 2005

Cobalt 67%
***100% of base metal is imported**

Nickel 57%
***100% of class 1 nickel is imported**

Magnesium 52%



Commodity	Net import reliance as a percentage of apparent consumption in 2023
ARSENIC, all forms	100
ASBESTOS	100
CESIUM	100
FLUORSPAR	100
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GRAPHITE (NATURAL)	100
INDIUM	100
MANGANESE	100
MICA (NATURAL), sheet	100
NIOBIUM (COLUMBIUM)	100
RUBIDIUM	100
SCANDIUM	100
STRONTIUM	100
TANTALUM	100
YTTRIUM	100
GEMSTONES	99
ABRASIVES, fused aluminum oxide	>95
NEPHELINE SYENITE	>95
RARE EARTHS,[4] compounds and metals	>95
TITANIUM, sponge metal	>95
BISMUTH	94
POTASH	91
STONE (DIMENSION)	87
DIAMOND (INDUSTRIAL), stones	84
PLATINUM	83
ANTIMONY, metal and oxide	82
ZINC, refined	77
BARITE	>75
BAUXITE	>75
IRON OXIDE PIGMENTS, natural and synthetic	75
TITANIUM MINERAL CONCENTRATES	75
CHROMIUM, all forms	74
PEAT	74
TIN, refined	74
ABRASIVES, silicon carbide	73
SILVER	69
COBALT	67
GARNET (INDUSTRIAL)	67
RHENIUM	60
ALUMINA	59
VANADIUM	58
NICKEL	57
DIAMOND (INDUSTRIAL), bort, grit, and dust and powder	56
MAGNESIUM COMPOUNDS	52
GERMANIUM	>50
IODINE	>50
MAGNESIUM METAL	>50
SELENIUM	>50
TUNGSTEN	>50

USGS 2024 Mineral Commodity Summaries 2024 (usgs.gov)

Federal Support for the Domestic Battery Supply Chain

(BIL, IRA, LPO, DPA, and BEYOND!)

DOE-MESC (BIL)	DOE-MESC (IRA)	DOE-LPO (Loan)	Defense (DPA)	Defense IBAS	Commerce	Ex-Im Bank	U.S. Development Finance Corp	National Science Foundation	Interior
Battery Manufacturing and Processing Section 40207(b)(c) $6 Billion **Battery Recycling** Sections 40207 and 40208 $335 Million	**Advanced Manufacturing Production Credit** Sec 13502 (45X) **Clean Vehicle [Tax] Credit** Sec 13401 (48C) $10 Billion **Conversion Grants** Sec 50143 $2 Billion	**Advanced Vehicle Technology Manufacturing Loans** **Loan Guarantees** $15-20 Billion to date	**Critical Minerals** $500 Million (Ukraine Stimulus) $250 Million (IRA 30001)	***Industrial Base Analysis and Sustainment Program*** *$2 Billion* *Invest in 6 priority industrial capability development areas:* *Shipbuilding* *Workforce* *Weapons* *Electronics* *Chemical* *Batteries*	**CHIPS ACT:** $52.7 billion in federal funding to revitalize the U.S. semi-conductor industry ***ITAC on Critical Minerals and Metal (Trade Policy)*** ***Select USA (FDI)*** ***USEACs*** ***FCS*** ***New Supply Chain Office***	**Make More in America Initiative:** Direct loans, loan guarantees, and insurance *Projects over $50 million* *Securing Importation of Processing Equipment and Modular Parts*	Targeted Investments in Mining and Minerals Projects Abroad to Support Global Clean Energy *Example: DFC equity investment in Mali, Brazil, and Mozambique*	*$160 Million Regional Innovation Engines Program to expand domestic innovation capacity through the prioritization of geographic regions that do not currently have well-established innovation*	**Mining Law Reform:** Interagency Working Group providing whole-of-government effort to reform the General Mining Law (non-financial)

MESC

Critical Minerals & Materials (CMM) Vision & Strategy

Vision:

- Build reliable, resilient, affordable, diverse, sustainable, and secure **domestic critical mineral and materials supply networks**.
- Support the clean energy transition and decarbonization of the energy, manufacturing, and transportation economies.
- Promote safe, sustainable, economic, and environmentally just solutions to meet current and future needs.

CMM Strategies:

https://www.energy.gov/critical-minerals-materials

CORE-CM: Developing National Prospectus by Assessing Regional Opportunities

AOI 7 – University of Wyoming; Laramie, WY

AOI 9 – University of Wyoming; Laramie, WY

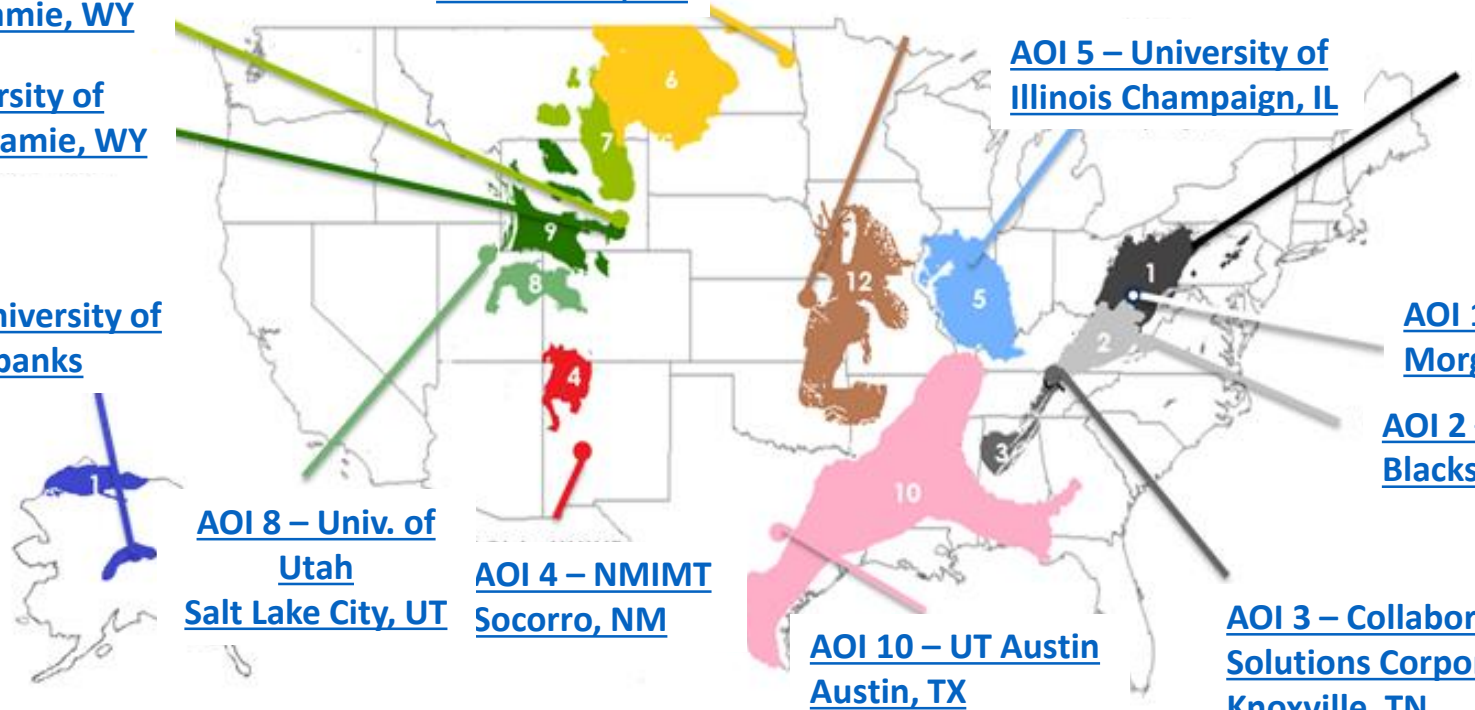
AOI 6 – UND Grand Forks, ND

AOI 12 – University of Kansas Center for Research; Lawrence, KS

AOI 5 – University of Illinois Champaign, IL

AOI-1 PSU University Park, PA

AOI 11 – University of Alaska Fairbanks



AOI 13 – WVU RC Morgantown

AOI 2 – Virginia Tech Blacksburg, VA

AOI 8 – Univ. of Utah Salt Lake City, UT

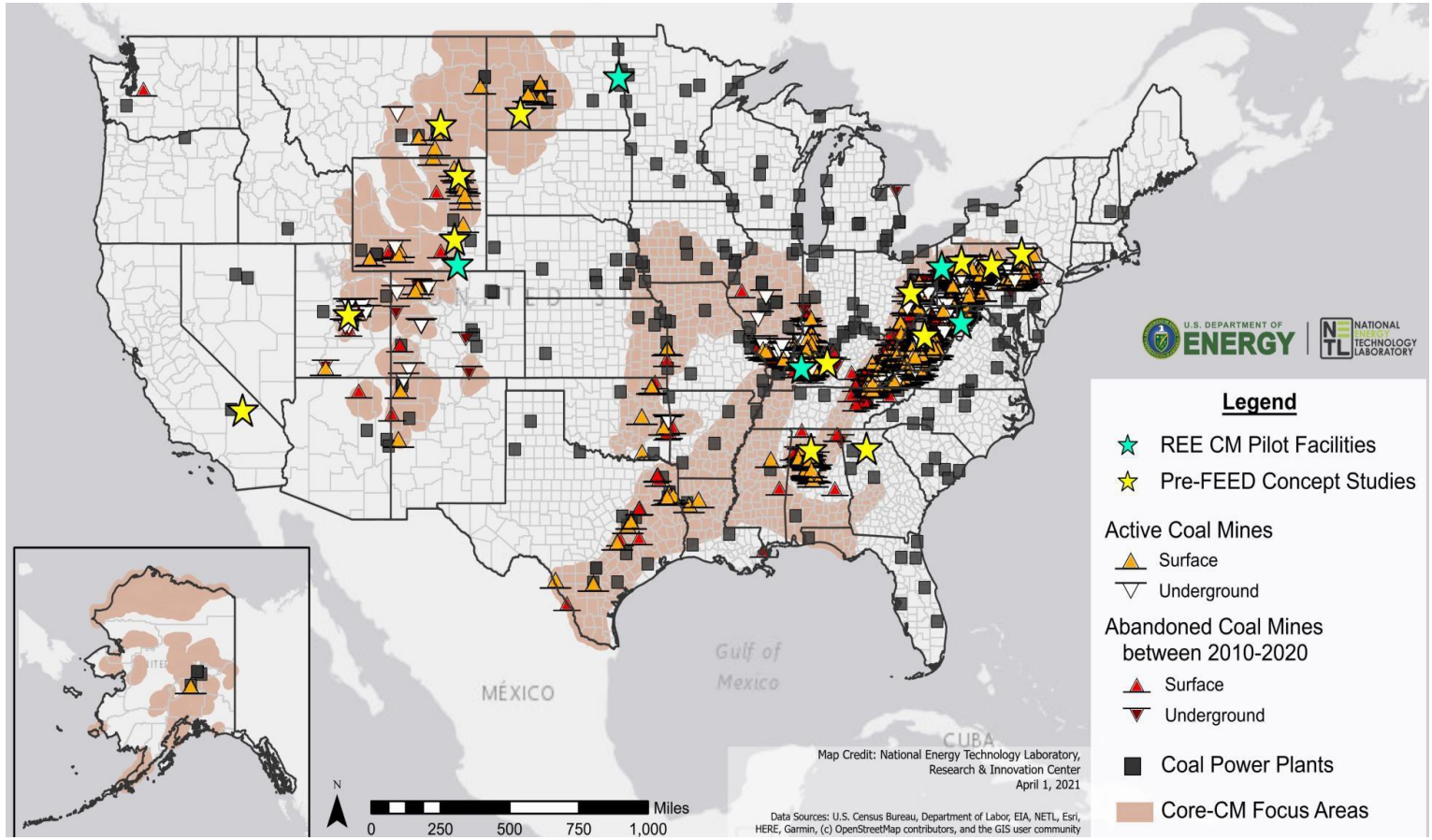
AOI 4 – NMIMT Socorro, NM

AOI 10 – UT Austin Austin, TX

AOI 3 – Collaborative Composite Solutions Corporation Knoxville, TN

- 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

A Taste of the Potential from Coal-Based Sources



From USGS. COALQUAL database

Potential In-Place Volume in U.S. Legacy Coal Ash

Critical Metal	Estimated Mass	Potential Supply (Years)
Nd	172,000 tons	40
Dy	62,000 tons	14
Li	288,000 tons	130
Co	110,000 tons	15
Ni	252,000 tons	1.1
Ir	40 tons	15
Pt	600 tons	15
Ga	20,000 tons	1,100
Ge	30,000 tons	3,900

Granite, Bromhal, Wilcox, Alvin. NAE The Bridge, Sept. 2023

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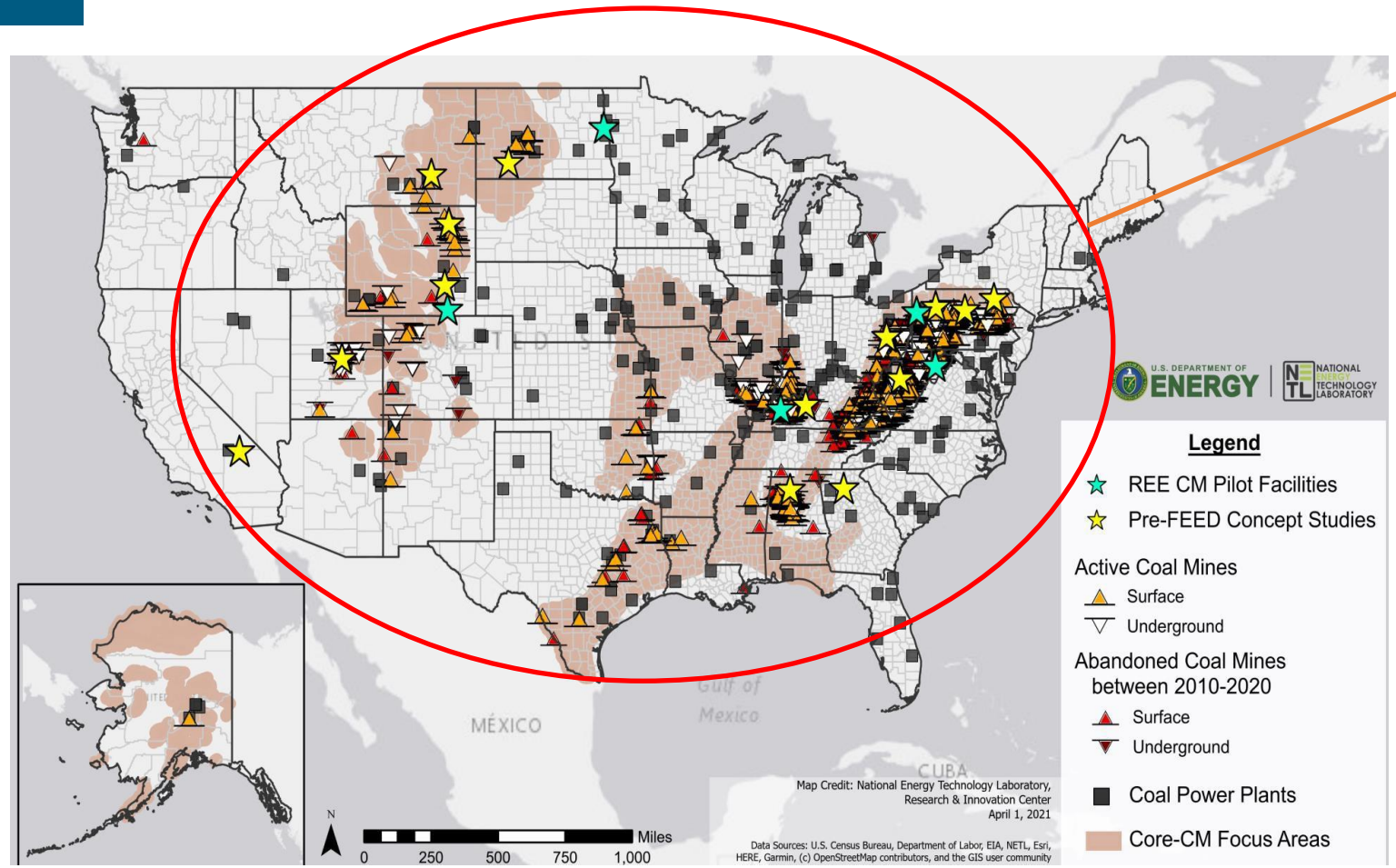

- ~30,000t/yr in current production

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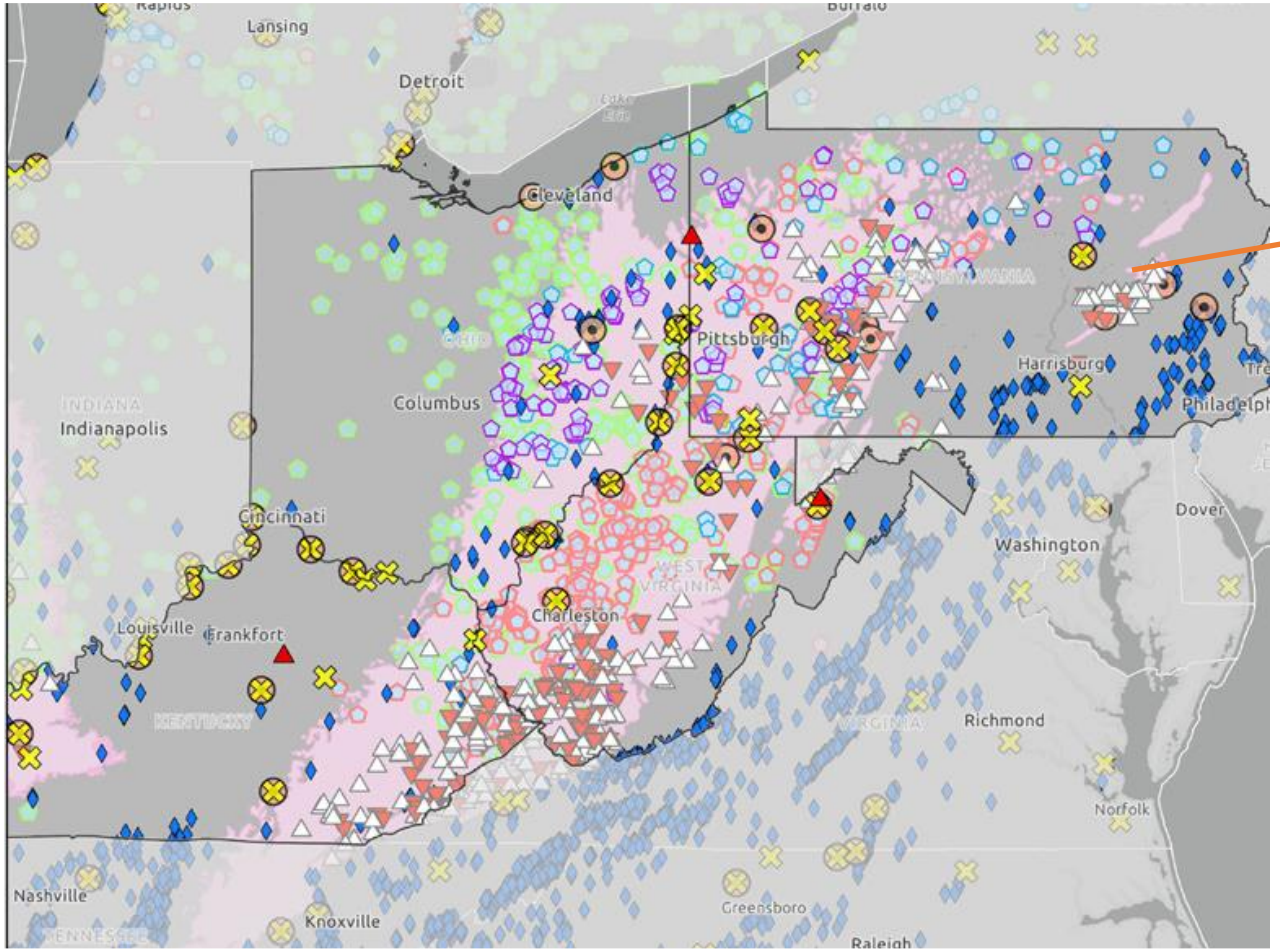

- ~30,000t/yr in current production
- 68,000 t from Appalachia coal refuse
  - 12,300 t/yr REE (2018*; 50% recovery), active refuse

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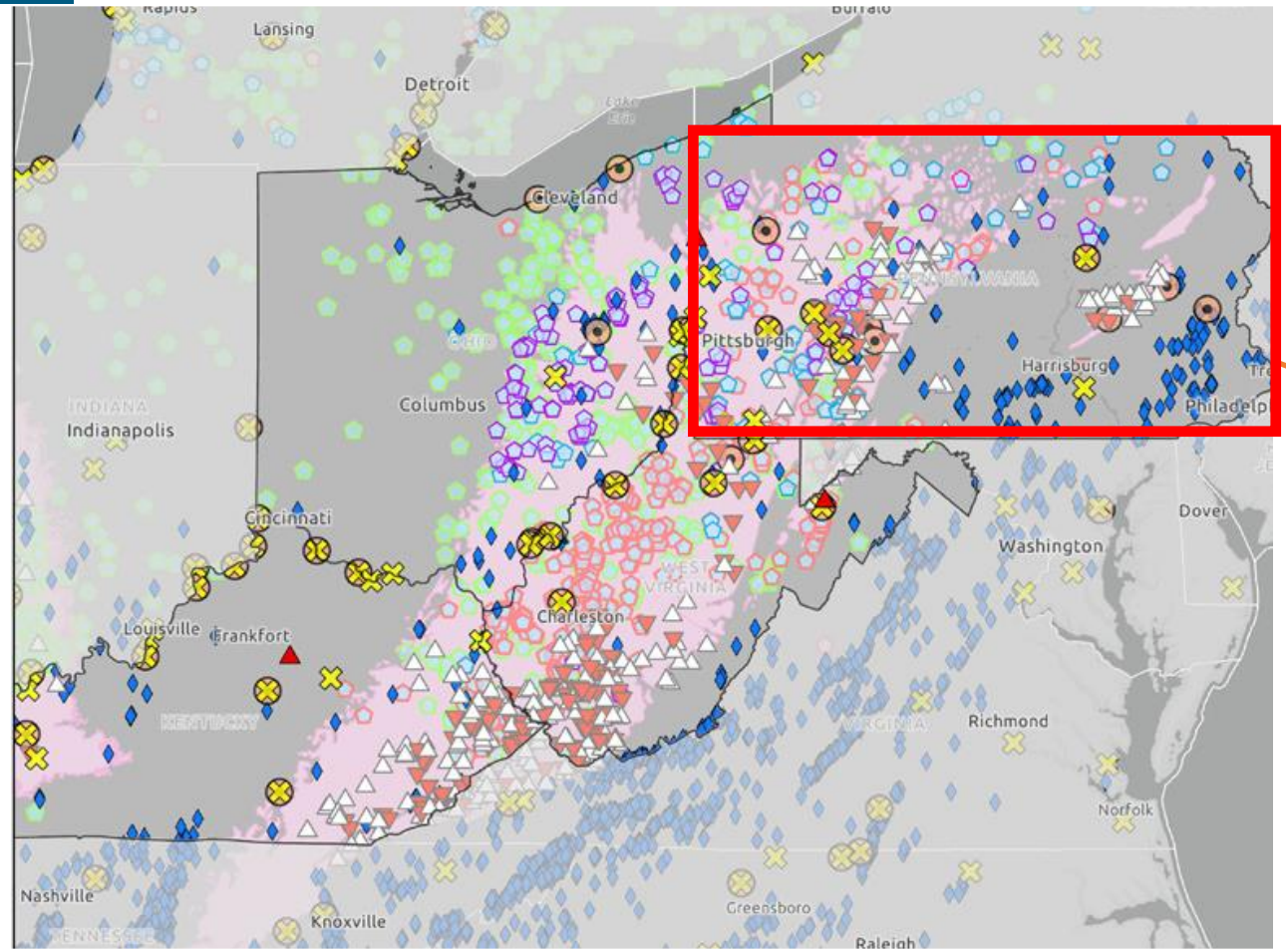

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  - Over 10,000 t/yr REE (2018*; 50% recovery), active ash

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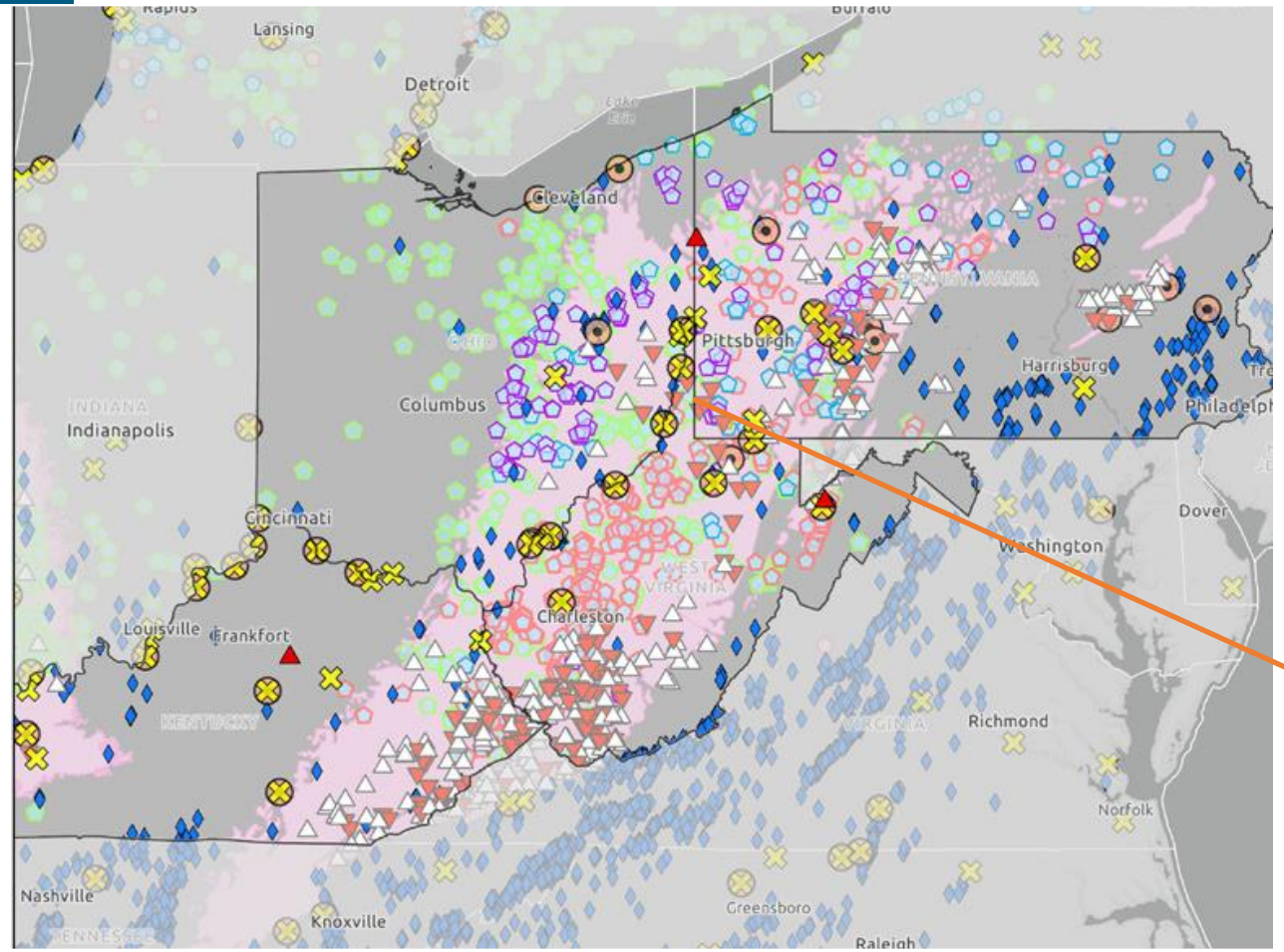

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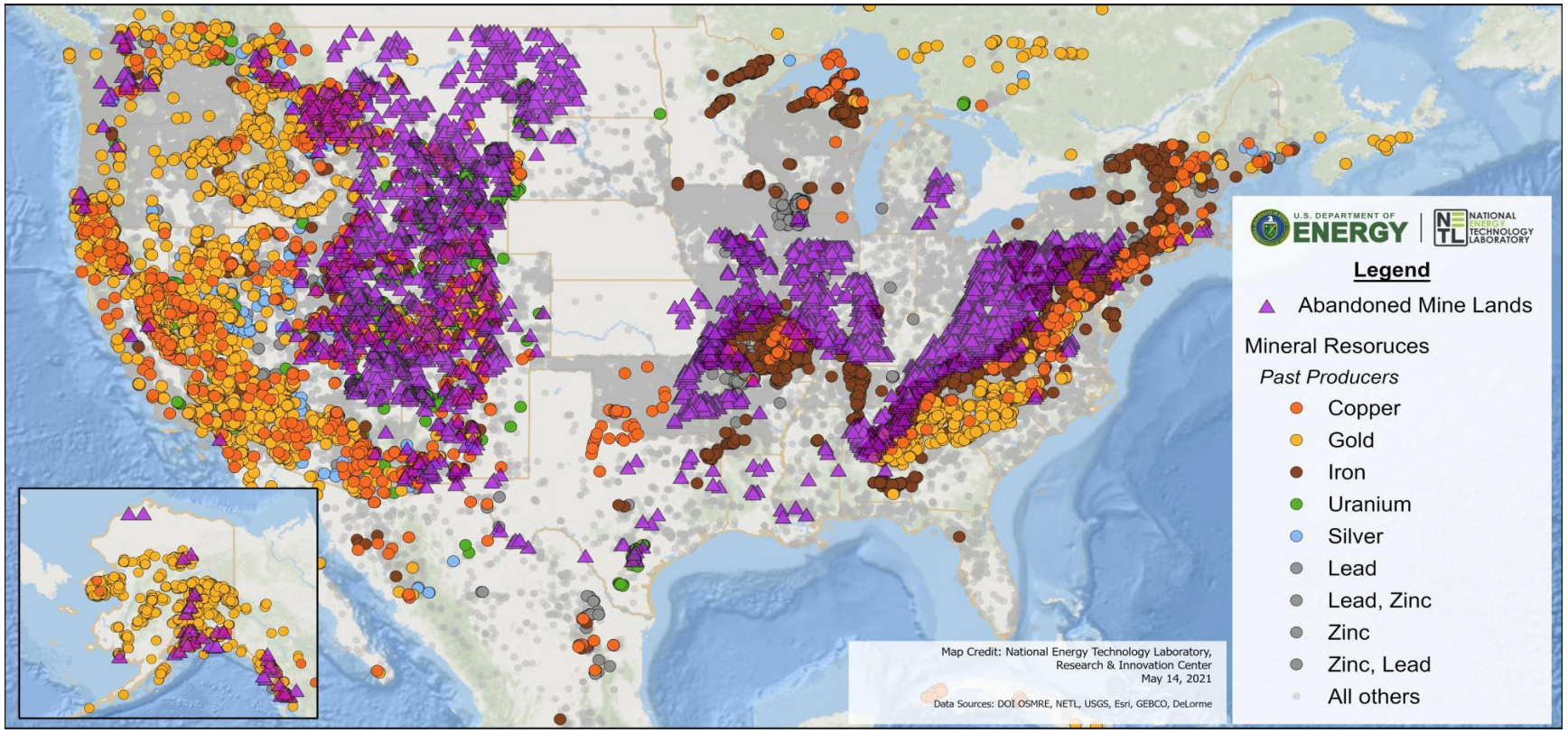
  - 12,300 t/yr REE (2018*; 50% recovery), active refuse
- 331,000 t from PA ash impoundments.
  - Over 10,000 t/yr REE (2018*; 50% recovery), active ash
- Between 400-1700 tons/yr REE (50% recovery), Appalachia AMD (HREE enriched)

Potential from Other Secondary & Unconventional Sources



From USGS, Abandoned non-coal Mines

Includes produced water, red mud, phosphate sludge, and metal mine wastes

CMM Processing from Waste Resources

Maturing Rare Earth Element (REE) Recovery from Legacy Coal Waste from Pilot to Demonstration Scale

PROSPECTING

PROCESSING

PRODUCTION

2015

2020

2025

Coal Refuse

Fly Ash

AMD

TRL 3-5

2016: FOA-1202
Conventional REE Separation & Recovery – 80-90% Purity

2016: RFP 9067 & 2017: RFP 10982
Field Prospecting

2017: FOA-1718
Transformational Separation

TRL 5-7

2019: 3 First-of-a-Kind Bench & Small Pilot-Scale REE Facilities

2020: FOA-2003
REE System Optimization & Efficiency Improvements – CM Production

TRL 5-7

2020 & 2021: RFP
Concept & Feasibility

2021: FOA-2404
Advanced Processing Phase 1

2021: FOA-2346
CORE-CM Phase 1

TRL 7-8

2023: FOA-2618
REE Demonstration Facility (Phase 1)

2027-2028: First-of-a-Kind REE Demonstration Facility

1,000 tonnes MREO/yr & CMM through Metals Refining

2021 & 2022: 2 Additional First-of-a-Kind Small Pilot-Scale REE & CM Facilities

Lignite

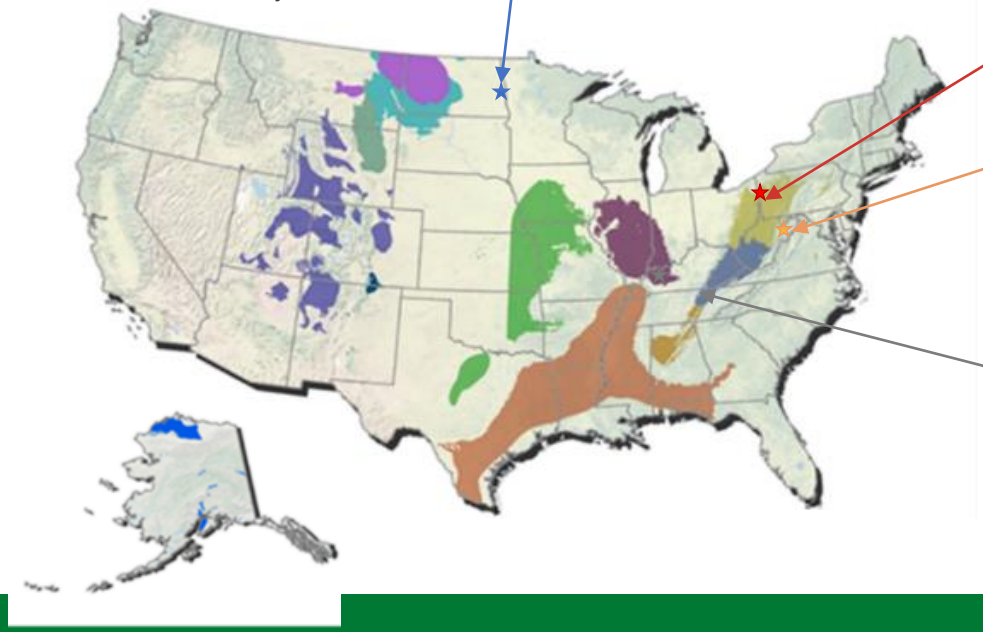
AMD

Small-Scale Pilot Facilities

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

- *Location*: Grand Forks, ND
- *Feedstock*: Lignite
- *Operation Period*: Not yet in operation, Period of Performance ends 06/30/2024
- *Production rate of highest grade/purity*: 140 g/week (85% REO; 88% REO/CM)*
- *Separation Beyond MREO/MRES*: Planned, but not yet achieved.
- *CMM Produced*: Ge (60% by weight) – Planning for Ga

** Data from bench-scale system*



- *Location*: Lexington, KY (Physical Separation); Sharon, PA (Chemical Processing)
- *Feedstock*: Post-combustion fly ash from two KY power plants
- *Operation Period*: November 2019 – March 2022
- *Production of highest grade/purity*: 16 g >90% REY oxide, 22 g of >85% REY oxide
- Separation Beyond MREO/MRES: Sc, Al only
- *CMM Produced*: 1 g Sc salt (>85%), 101 g Al (>70% oxide)

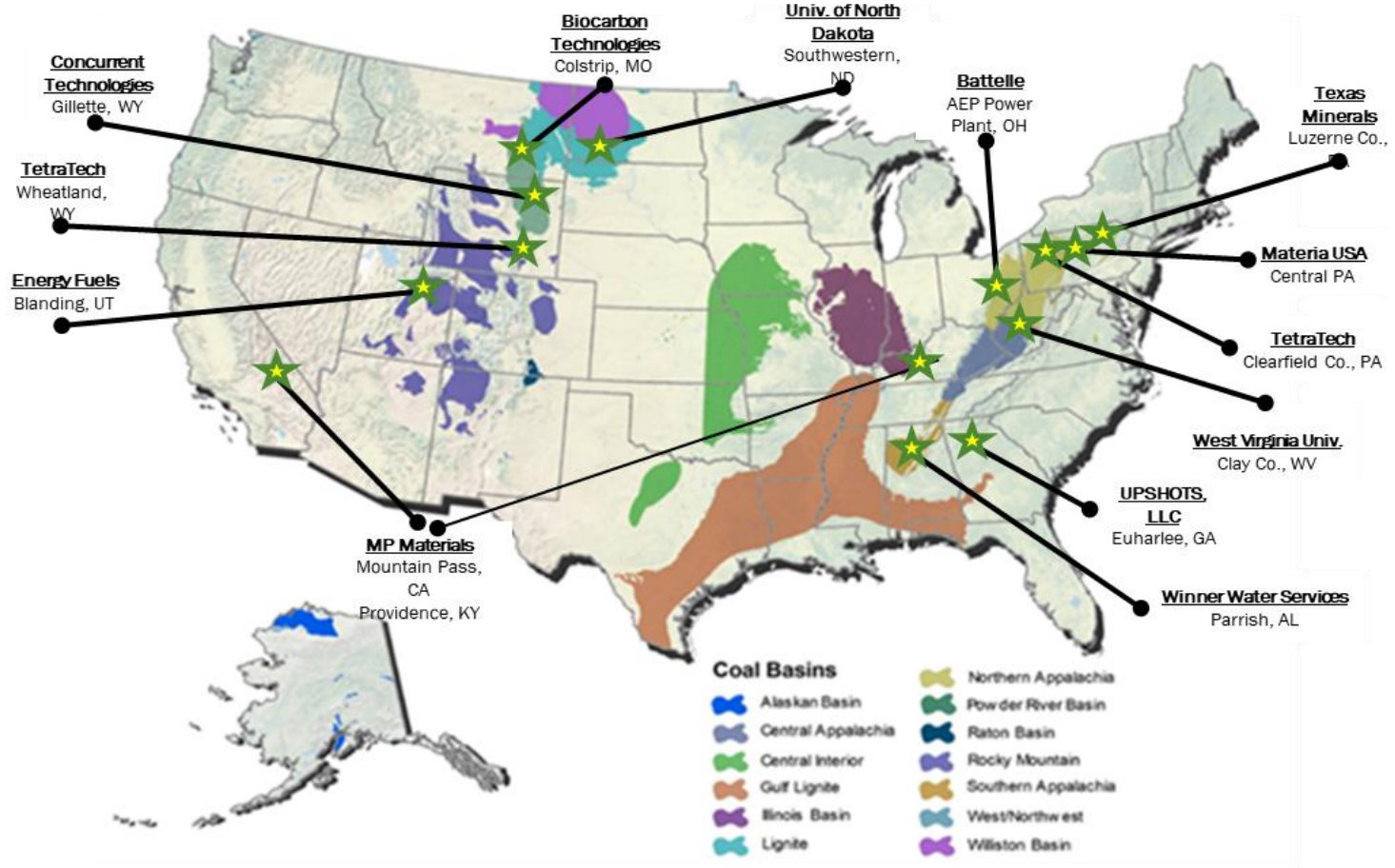
- *Location*: Mt. Storm, WV
- *Feedstock*: Acid Mine Drainage
- *Operation Period*: October 2022 – September 30, 2023
- *Production rate of highest grade/purity*: 82 g MREO/hr, 2.8 kg 95% LREO, 2.5 kg 65% HREO
- Separation Beyond MREO/MRES: Partially
- *CMM Produced*: Ni+Co, Mn, Zn

- *Location*: Webster County, KY
- *Feedstock*: Course Refuse and Lignite
- *Operation Period*: July 2021 – July 2022
- *Production of highest grade/purity*: 0.72 kg >80% REO (with coal refuse)
- Separation Beyond MREO/MRES: N/A
- *CMM Produced*: 0.3 kg (8% Co, 30% Ni); 0.27 kg (22% Mn)

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



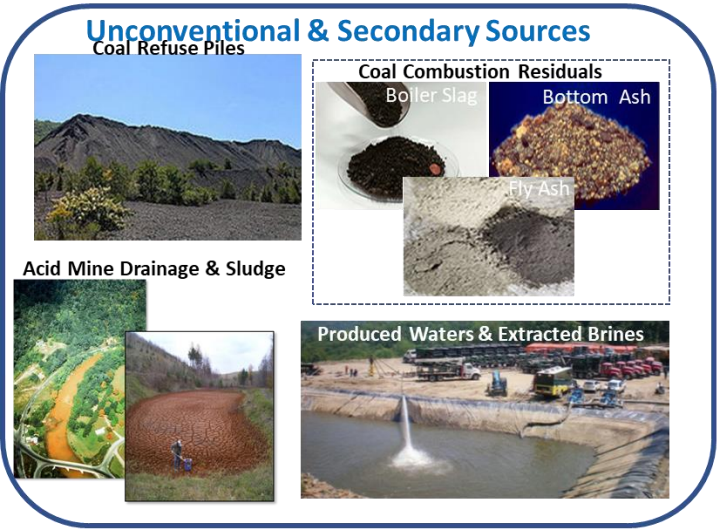
8 projects were selected from concept phase to perform a more detailed pre-FEED study

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

Opportunity: Waste Minimization and Circularity

Reclaiming, recycling waste materials

Maximizing use of feedstock materials

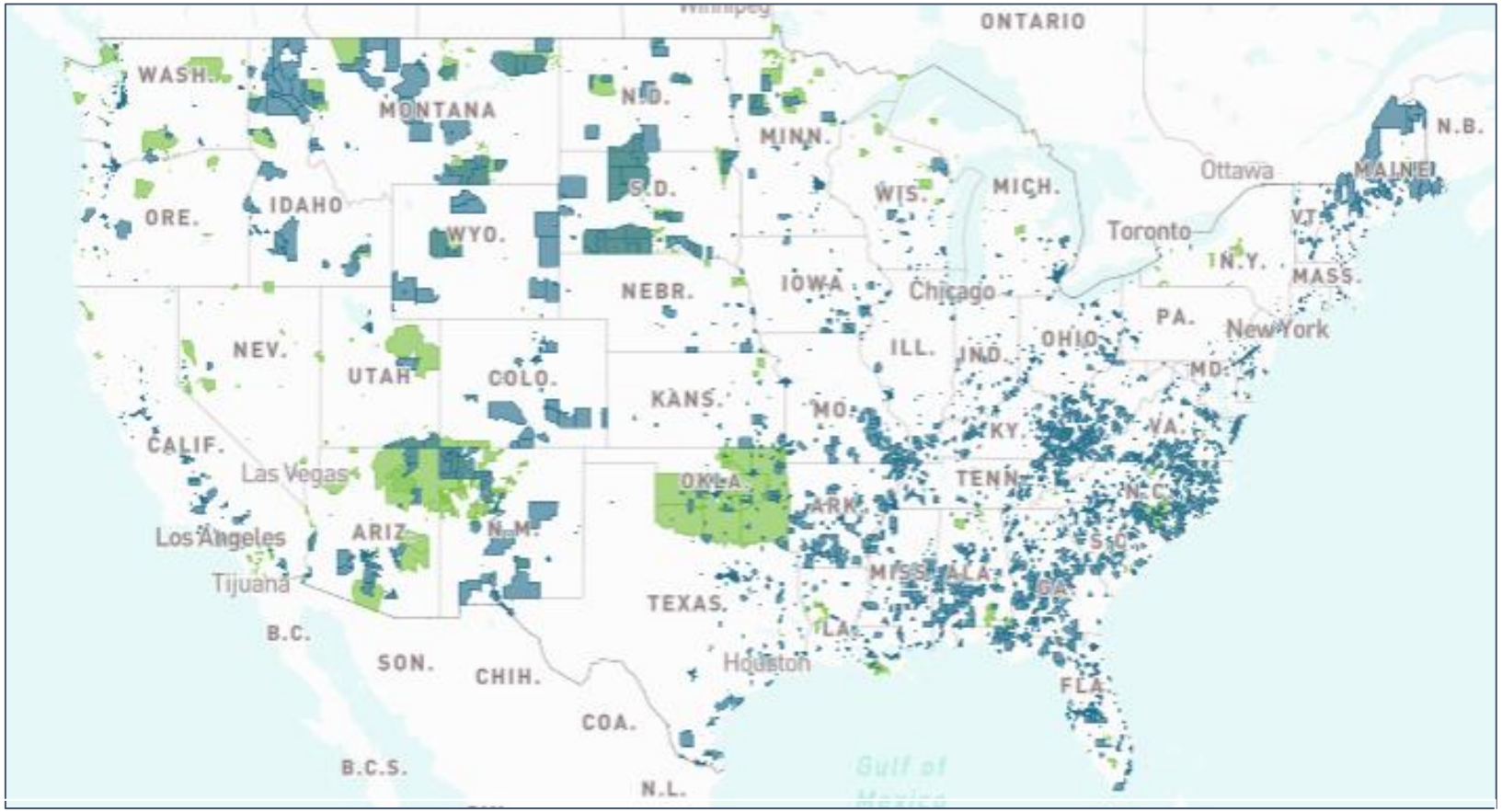


*Can change the **risk profile** of a project*

Community Engagement is Critical

Community Benefits Plans

- Benefit disadvantaged communities
- Equitable access to wealth building opportunities
- Good jobs and career-track training
- Impacted workers and communities have a voice throughout the process



Disadvantage was measured based on a score across 36 indicators. Census tracts with at least 30% low-income households and disadvantage scores >80% of those in their state are considered a disadvantaged

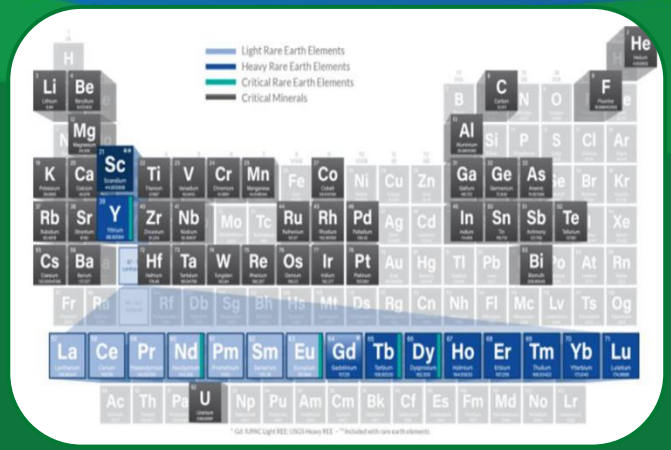
Things to consider

- Accelerating commercialization of novel feedstocks and next generation technology
- Engaging communities
- Engaging private capital
- Bringing upstream and midstream (and downstream) along together
- What is economic for waste streams? Different risk profile
- How do we compete internationally? Standards?

U.S. DEPARTMENT OF ENERGY

Fossil Energy and Carbon Management

Questions?



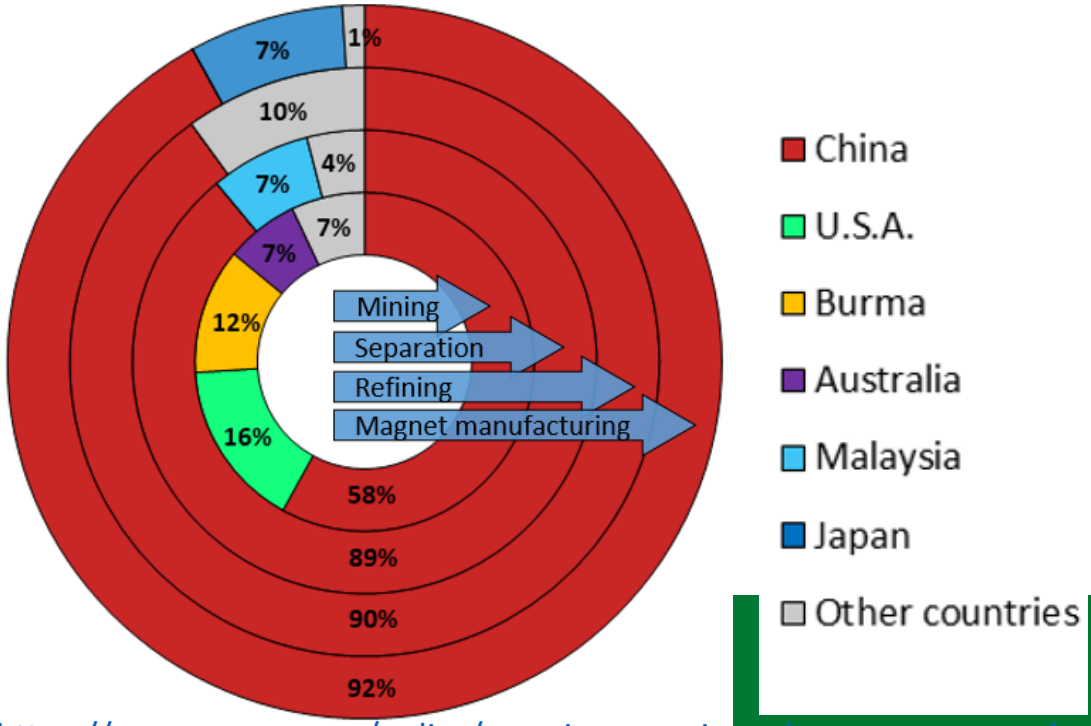
Critical Mineral and Material Supply Chain Vulnerabilities

Supply Chain Vulnerabilities

→ *Up-to-mid stream capabilities **are concentrated in 1-3 countries***

→ ***Lack of midstream capabilities are a gap** that limit growth of upstream supply and downstream value-add manufacturing*

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



Upstream

Mining, Extraction & Concentration

Midstream

Refining & Component Manufacturing

Downstream

Manufacturing

Reuse/Recycle

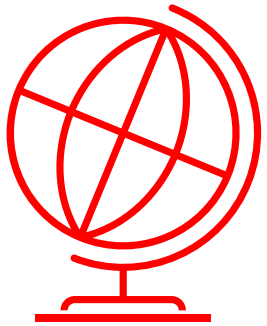
Source: https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain

Four Main Sources for Supply Diversification

Recycling

Secondary & Unconventional Feedstocks

New Domestic Mining



International Sources

Standards Development/Engagement

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

FECM/MSD engages in ISO efforts to improve sustainability in global CM 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

Working with EPA on certification standards for federal procurement

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

Thank you

Grant Bromhal: grant.bromhal@hq.doe.gov

Learn more about CMM at DOE: energy.gov/criticalmaterials

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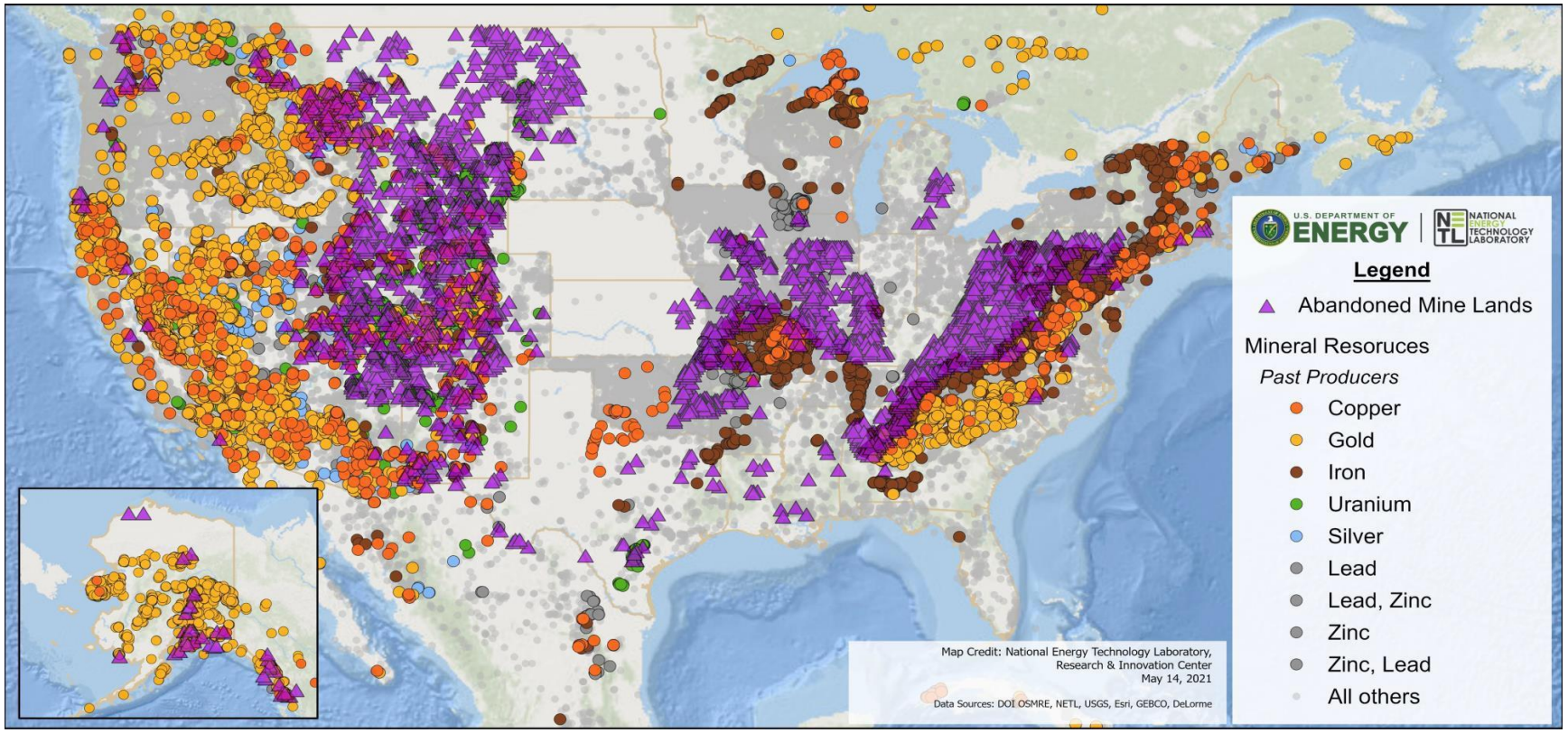
Potential from Other Secondary & Unconventional Sources



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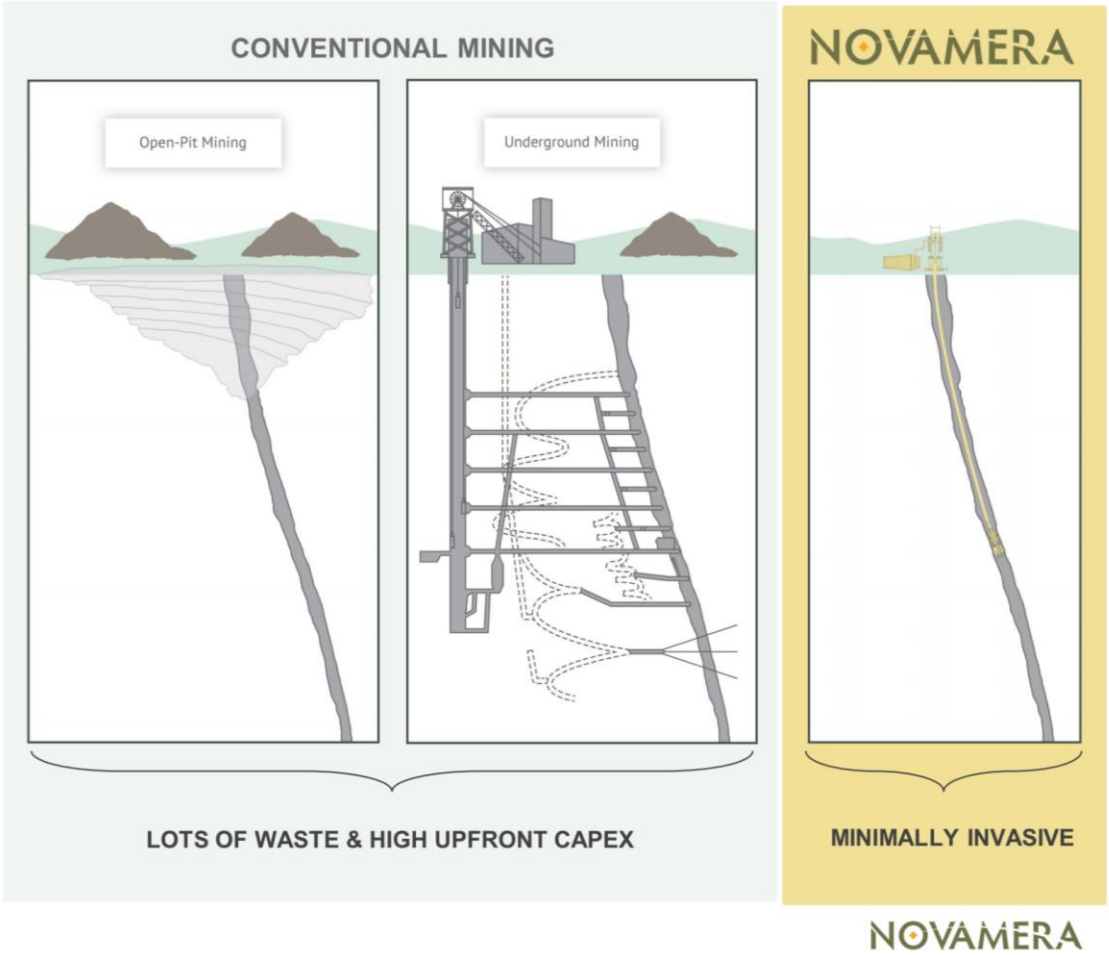
Future of Mining RDD&D for precision extraction

Opportunity to capitalize on recent efforts to revolutionize mining technology

- RDD&D areas needed
  - Advanced drilling technologies
  - Novel geophysics
  - Digital subsurface applications (autonomous ops, robotics, real-time extraction)
  - In-situ mineral extraction (e.g., bio)
  - Novel processing
  - Tailings management
  - Marine mineral production
  - Mineral traceability



Novamera is a gold mining/drilling company that is applying a similar approach now

Future Mining Expected Outcomes

- Acceleration of exploration-to-production timeline – cutting target time in half
- Achieving the "Mine of the Future" vision
  - Low to zero emission mining technologies and practices
  - New technologies for getting "everything" out of a mineral deposit
  - Small "footprint" mining
  - A low-impact national strategy for tailings management, re-use and extraction
- Ensuring a trained workforce concurrent with activity increase
- Improved image of sector – combination of clean technologies and public engagement
- Key support to regulatory agencies – ensuring regulatory adoption of innovation and tested new approaches

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CMM Technology Development