



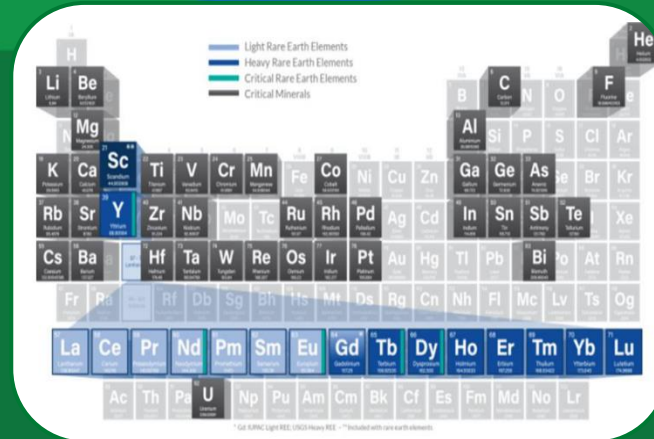
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Fossil Energy and  
Carbon Management

# 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



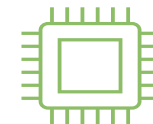
**Batteries** for electric vehicles &  
grid storage

Iridium & Platinum



**Electrolyzers** for green hydrogen  
production & **fuel cells** used energy  
storage

Gallium & Silicon Carbide\*



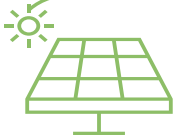
**Semiconductors** enable high voltage  
power & efficient lighting

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



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# Significant vulnerability across many supply chains

Graphite 100% →

Manganese 100% →

Rare Earths >95% →

Platinum 83% →

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

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

Magnesium 52% →

*Maximum US  
 Reliance on  
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 Was 30% in 2005*

Commodity	Net import reliance as a percentage of apparent consumption in 2023
ARSENIC, all forms	100
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FLUORSPAR	100
GALLIUM	100
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, <sup>4</sup> 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

# 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
<p>Battery Manufacturing and Processing Section 40207(b)(c)</p> <p>\$6 Billion</p> <p>Battery Recycling Sections 40207 and 40208</p> <p>\$335 Million</p>	<p>Advanced Manufacturing Production Credit Sec 13502 (45X)</p> <p>Clean Vehicle [Tax] Credit Sec 13401 (48C) \$10 Billion</p> <p>Conversion Grants Sec 50143 \$2 Billion</p>	<p>Advanced Vehicle Technology Manufacturing Loans</p> <p>Loan Guarantees</p> <p>\$15-20 Billion to date</p>	<p>Critical Minerals</p> <p>\$500 Million (Ukraine Stimulus)</p> <p>\$250 Million (IRA 30001)</p>	<p><i>Industrial Base Analysis and Sustainment Program \$2 Billion</i></p> <p><i>Invest in 6 priority industrial capability development areas:</i></p> <p><i>Shipbuilding</i> <i>Workforce</i> <i>Weapons</i> <i>Electronics</i> <i>Chemical</i> <i>Batteries</i></p>	<p>CHIPS ACT: \$52.7 billion in federal funding to revitalize the U.S. semiconductor industry</p> <p>ITAC on Critical Minerals and Metal (Trade Policy)</p> <p>Select USA (FDI)</p> <p>USEACs</p> <p>FCS</p> <p>New Supply Chain Office</p>	<p>Make More in America Initiative: Direct loans, loan guarantees, and insurance</p> <p>Projects over \$50 million</p> <p>Securing Importation of Processing Equipment and Modular Parts</p>	<p>Targeted Investments in Mining and Minerals Projects Abroad to Support Global Clean Energy</p> <p>Example: DFC equity investment in Mali, Brazil, and Mozambique</p>	<p>\$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</p>	<p>Mining Law Reform: Interagency Working Group providing whole-of-government effort to reform the General Mining Law</p> <p>(non-financial)</p>



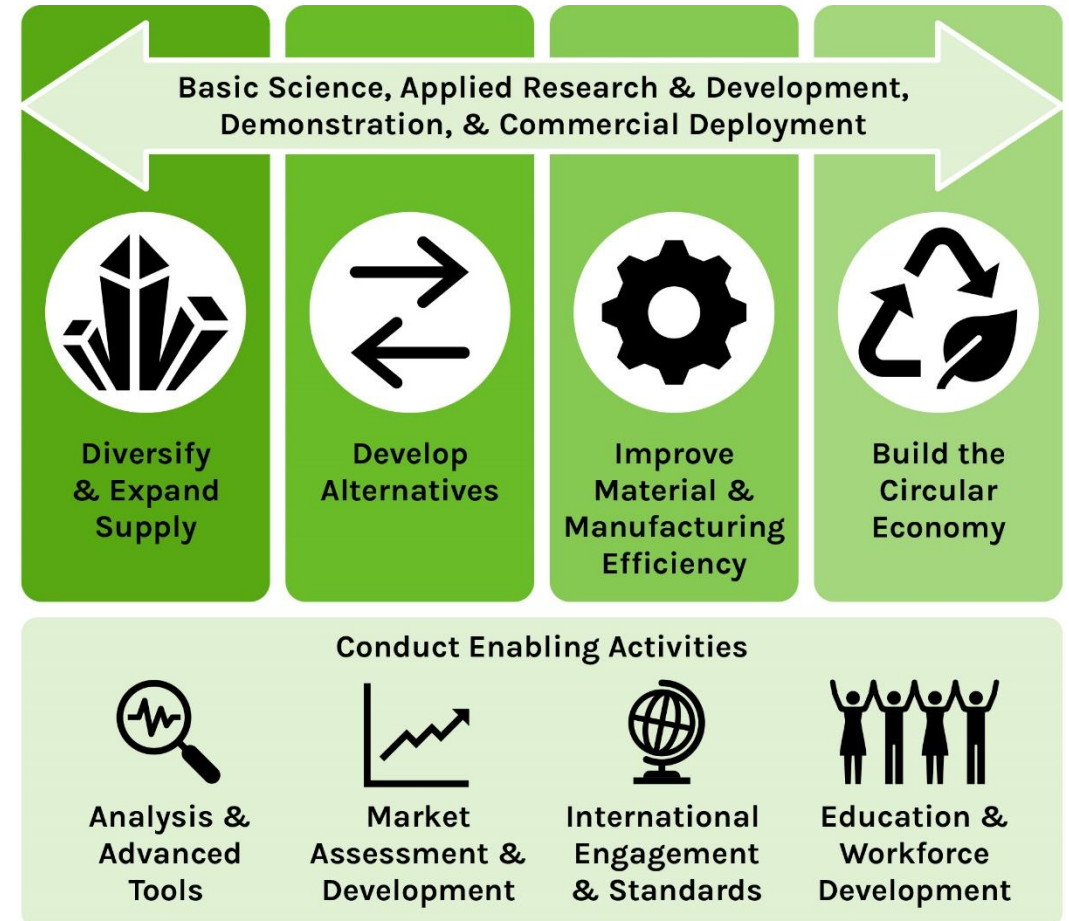
**MESC**  
OFFICE OF MANUFACTURING AND ENERGY SUPPLY CHAINS

# 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>



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**DOE is an integral part of an All-of-Government Strategy**

# CORE-CM: Developing National Prospectus by Assessing Regional Opportunities

[AOI 7 – University of Wyoming; Laramie, WY](#)

[AOI 9 – University of Wyoming; Laramie, WY](#)

[AOI 11 – University of Alaska Fairbanks](#)



[AOI 8 – Univ. of Utah Salt Lake City, UT](#)

[AOI 6 – UND Grand Forks, ND](#)

[AOI 4 – NMIMT Socorro, NM](#)

[AOI 12 – University of Kansas Center for Research; Lawrence, KS](#)

[AOI 5 – University of Illinois Champaign, IL](#)

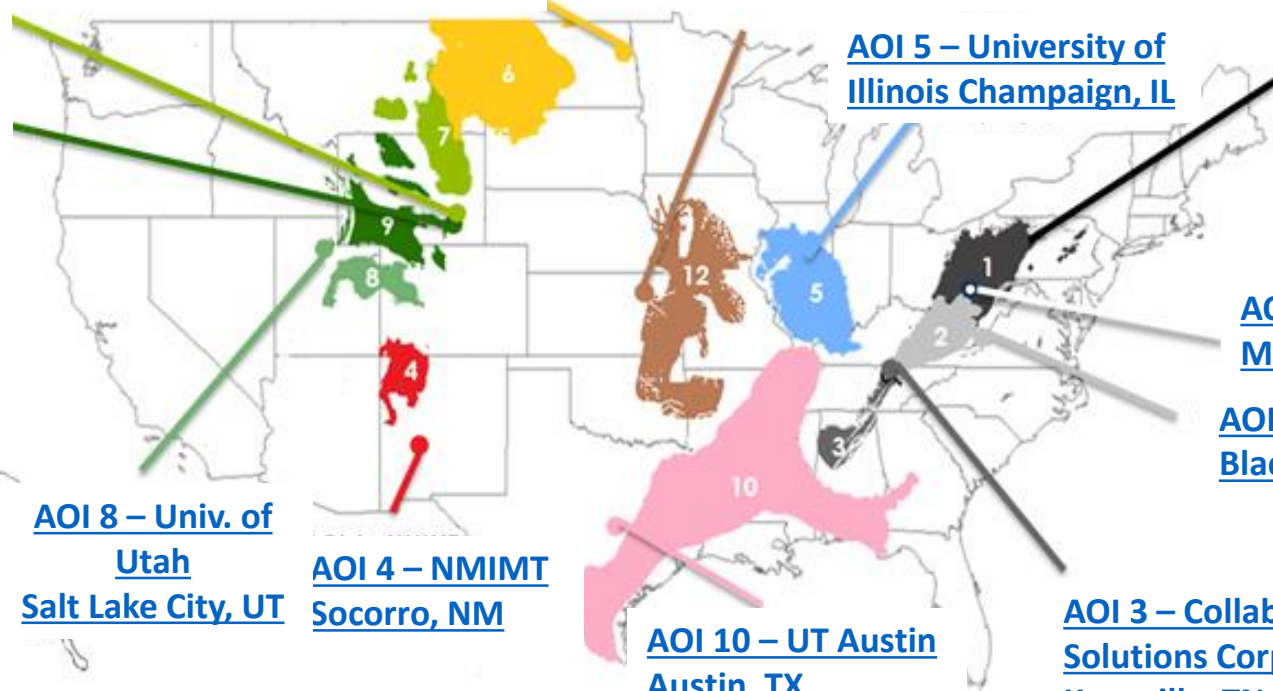
[AOI 10 – UT Austin Austin, TX](#)

[AOI-1 PSU University Park, PA](#)

[AOI 13 – WVU RC Morgantown](#)

[AOI 2 – Virginia Tech Blacksburg, VA](#)

[AOI 3 – Collaborative Composite Solutions Corporation Knoxville, TN](#)



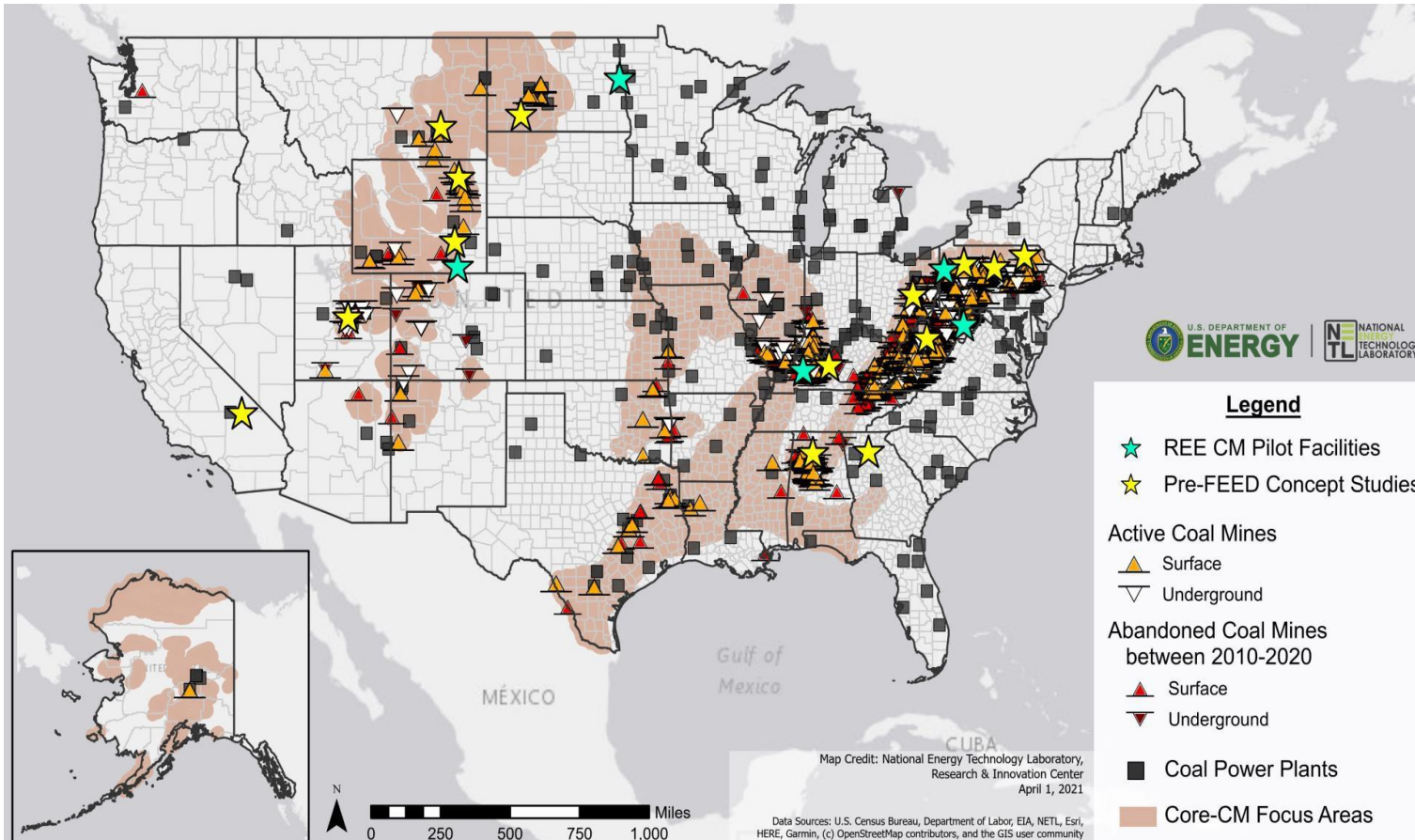
- Build broad-based regional coalition teams, including Tribal Nations, local communities
- Investigate regional resources (materials, facilities, infrastructure, workforce), opportunities, and challenges
- Catalyze regional economic growth and job creation, while addressing legacy waste and environmental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



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# A Taste of the Potential from Coal-Based Sources



From USGS. COALQUAL database

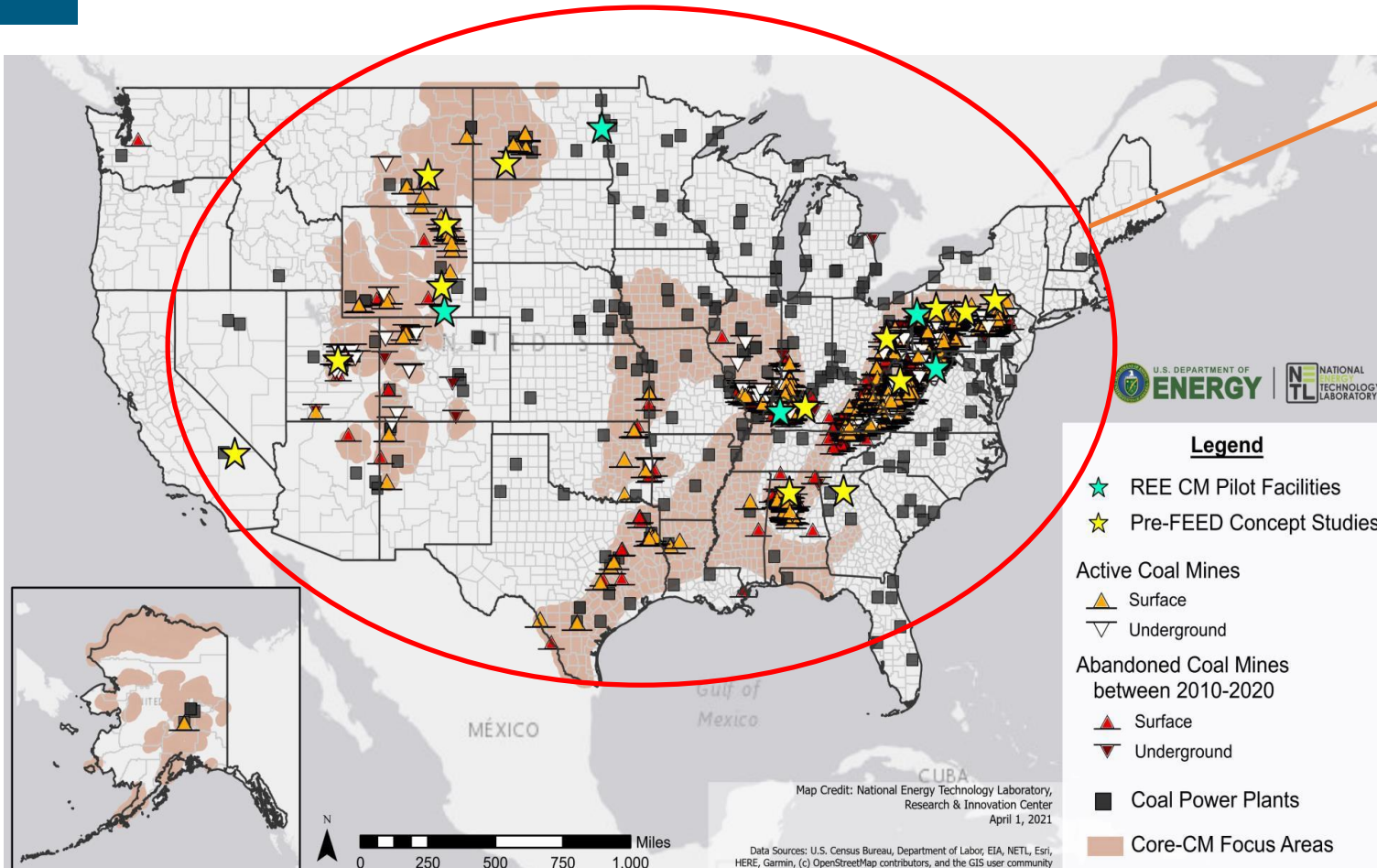
## Potential In-Place Volume in U.S. Legacy Coal Ash

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

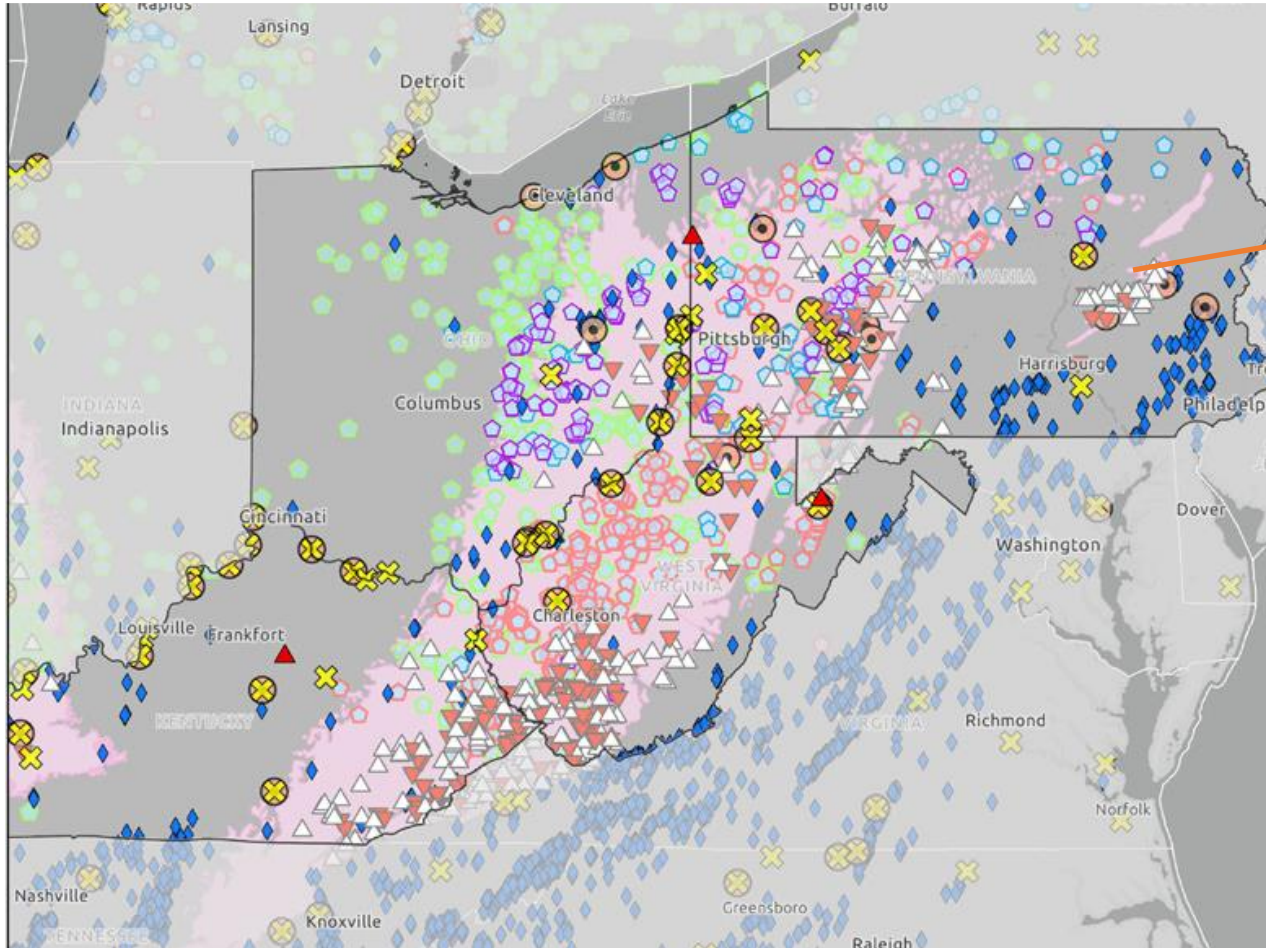
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- ~30,000t/yr in current production



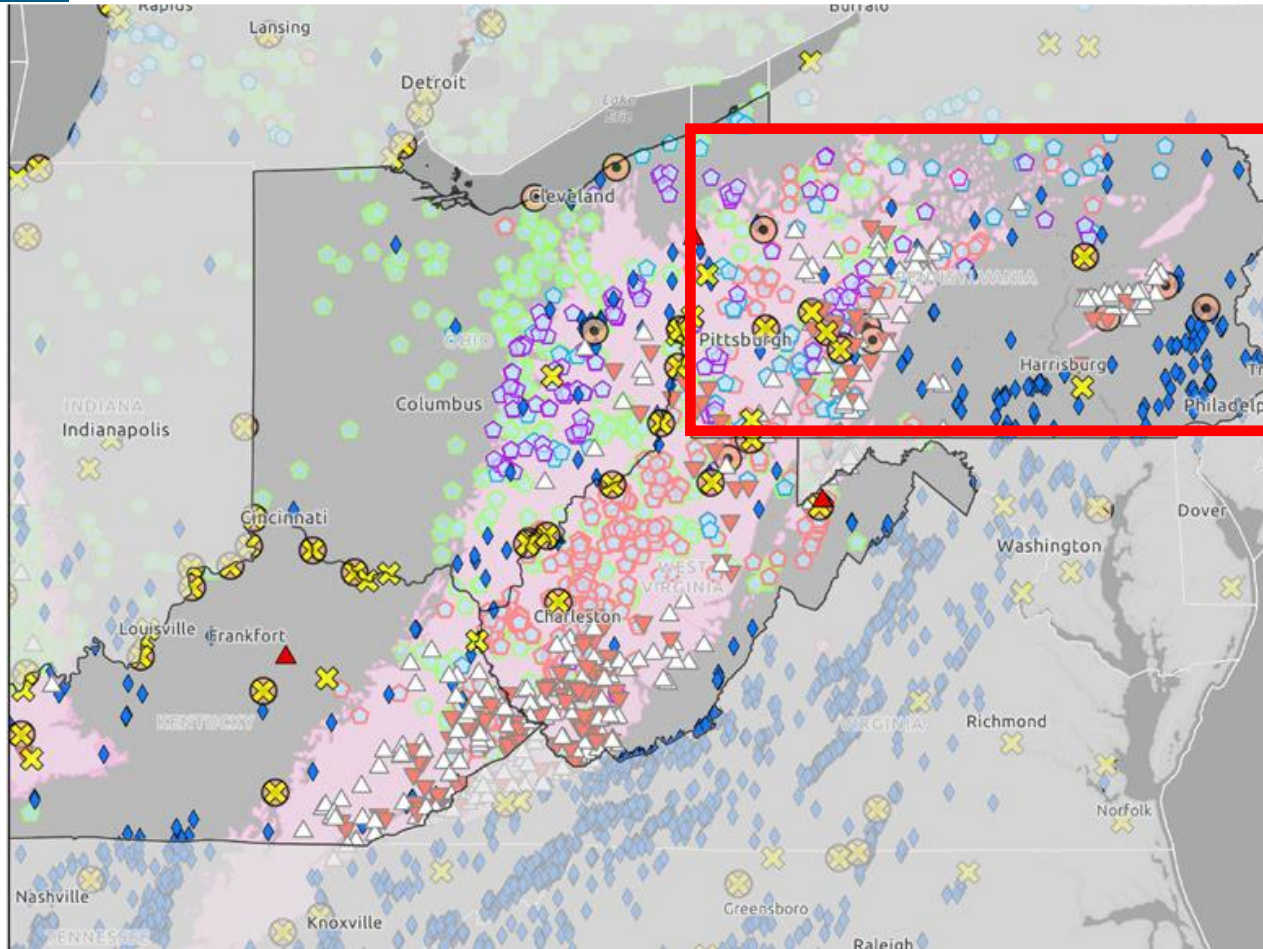


# A Taste of the Potential from Coal-Based Sources



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

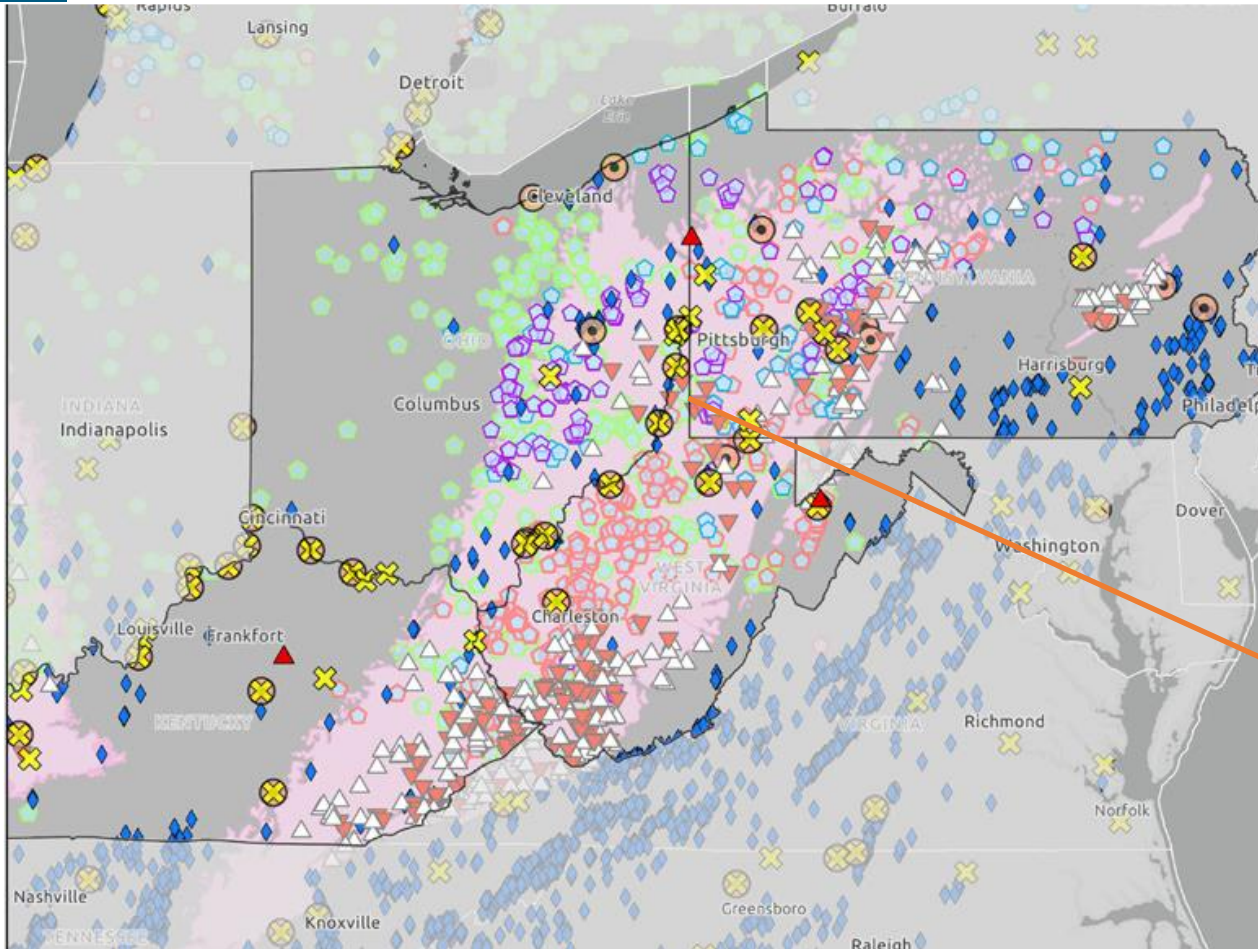
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- 331,000 t from PA ash impoundments.
  - Over 10,000 t/yr REE (2018\*; 50% recovery), active ash

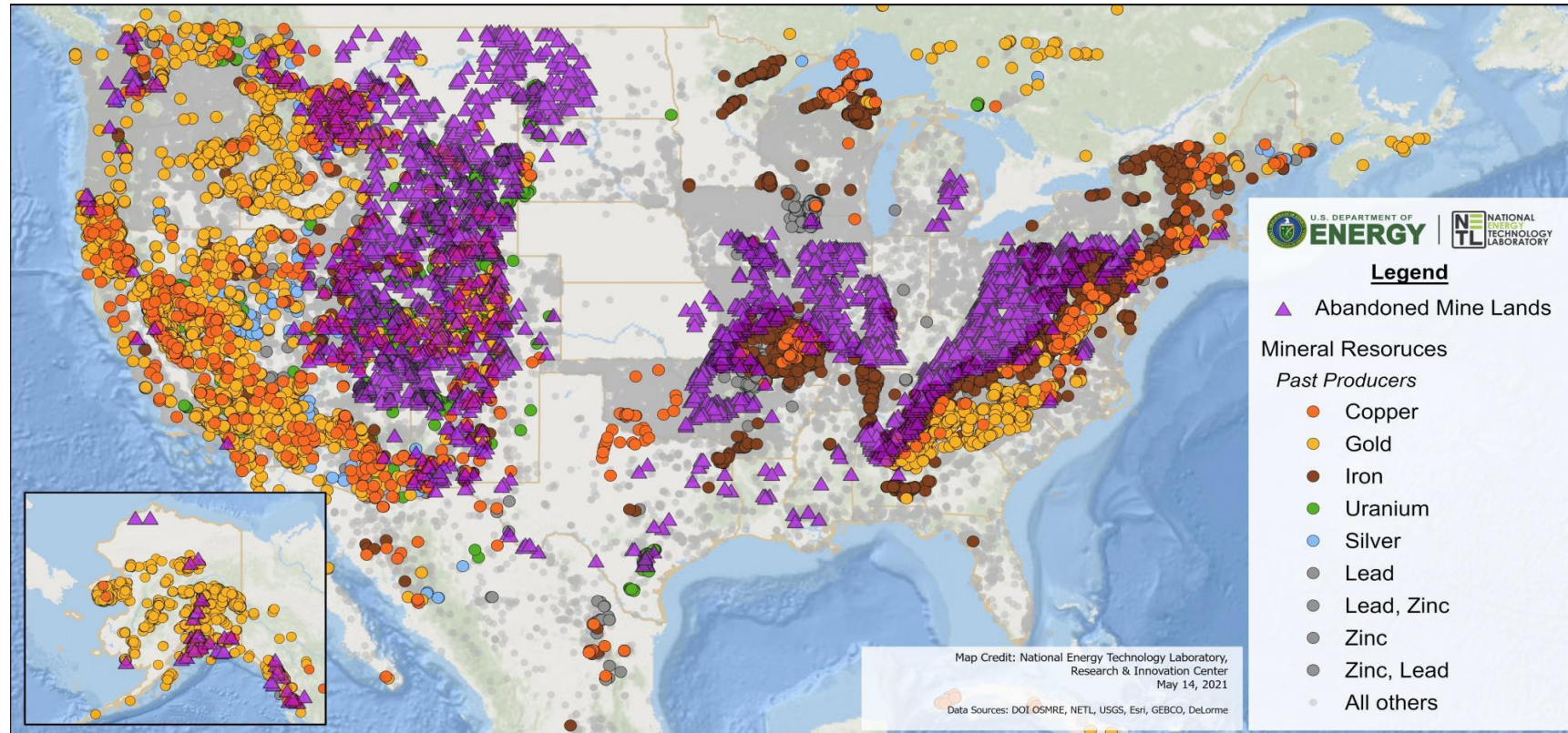


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  - Over 10,000 t/yr REE (2018\*; 50% recovery), active ash
- Between 400-1700 tons/yr REE (50% recovery), Appalachia AMD (HREE enriched)

# 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

PRODUCTION

PROCESSING

PROSPECTING

Coal Refuse



2020 & 2021: RFP  
Concept & Feasibility

TRL  
5-7

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



Fly Ash



AMD

TRL  
5-7

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

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

2017: FOA-1718  
Transformational Separation

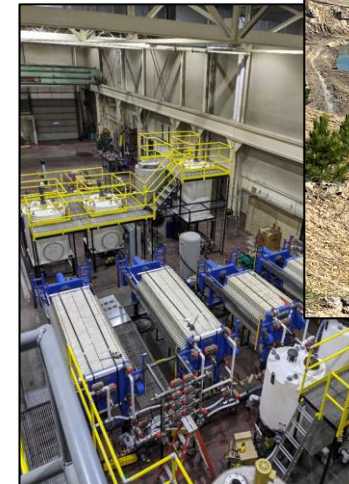
TRL  
3-5

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

2016: RFP 9067 & 2017: RFP 10982  
Field Prospecting

2015

2020



Lignite



AMD

2025

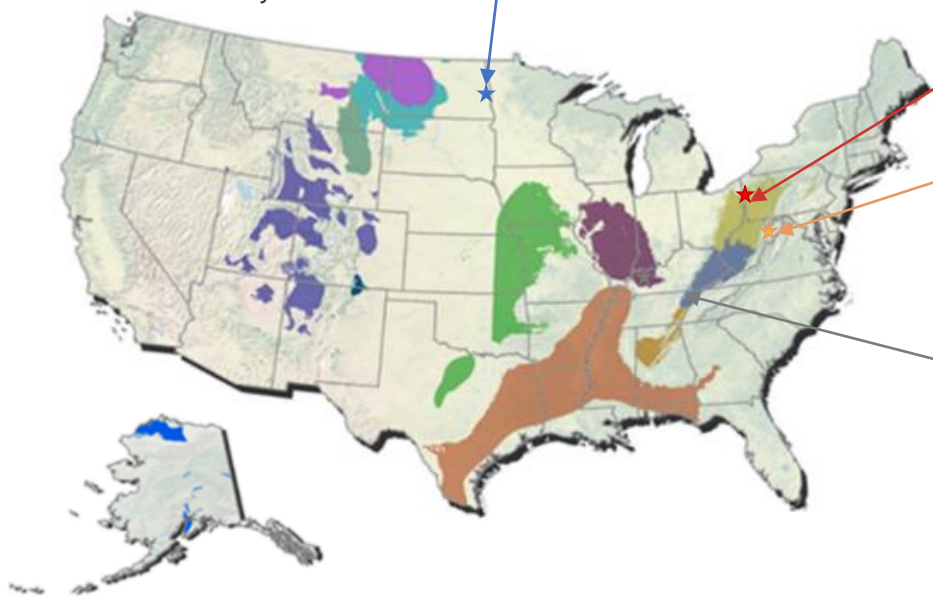
# Small-Scale Pilot Facilities

## 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



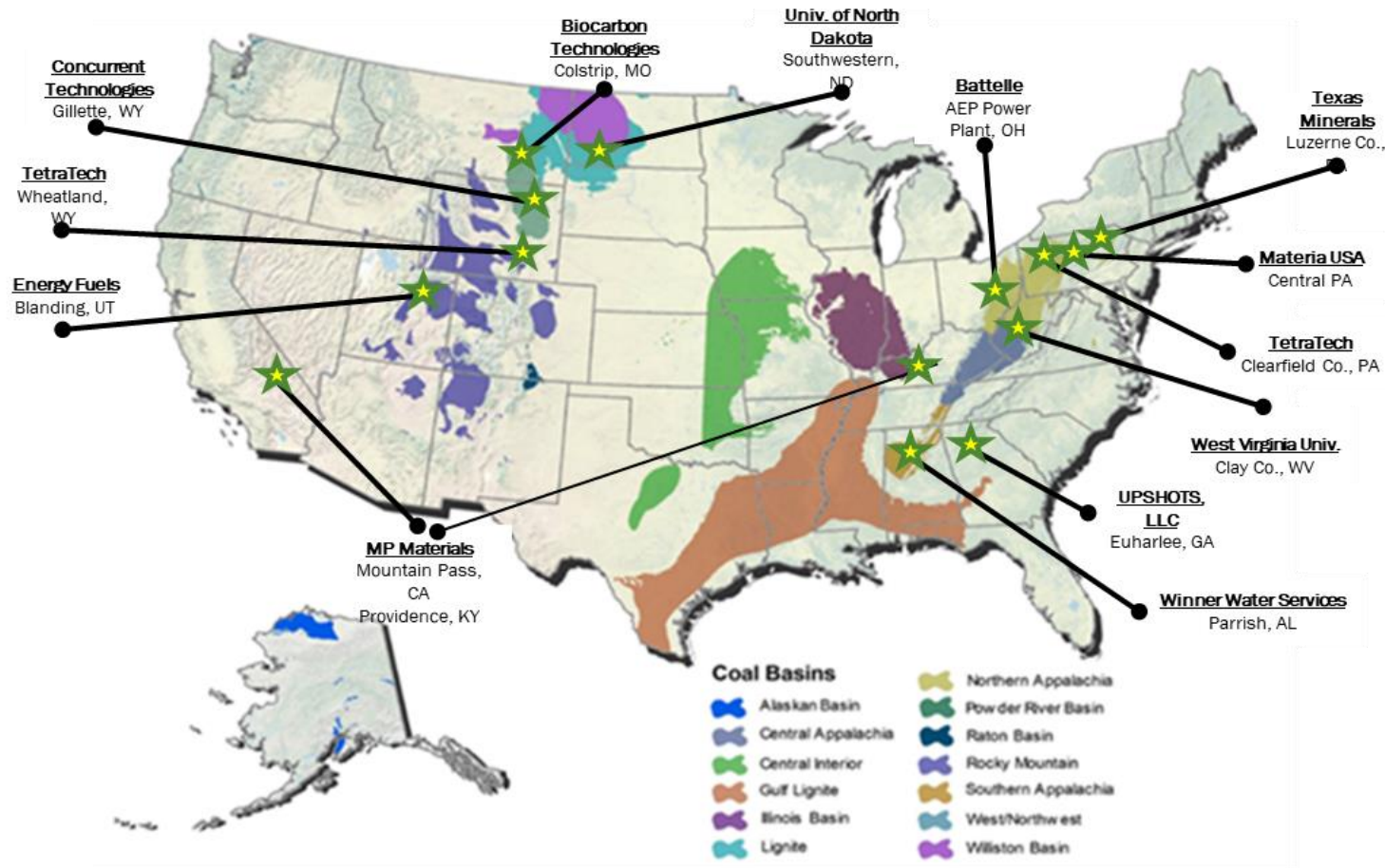
- Location: Webster County, KY
- Feedstock: Course Refuse and Lignite
- Operation Period: July 2021 – July 2022
- Production of highest grade/purity: 0.72 kg >80% REO (with coal refuse)
- Separation Beyond MREO/MRES: N/A
- CMM Produced: 0.3 kg (8% Co, 30% Ni); 0.27 kg (22% Mn)

# 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



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# Opportunity: Waste Minimization and Circularity

Reclaiming, recycling waste materials

Maximizing use of feedstock materials



Can change the risk profile of a project



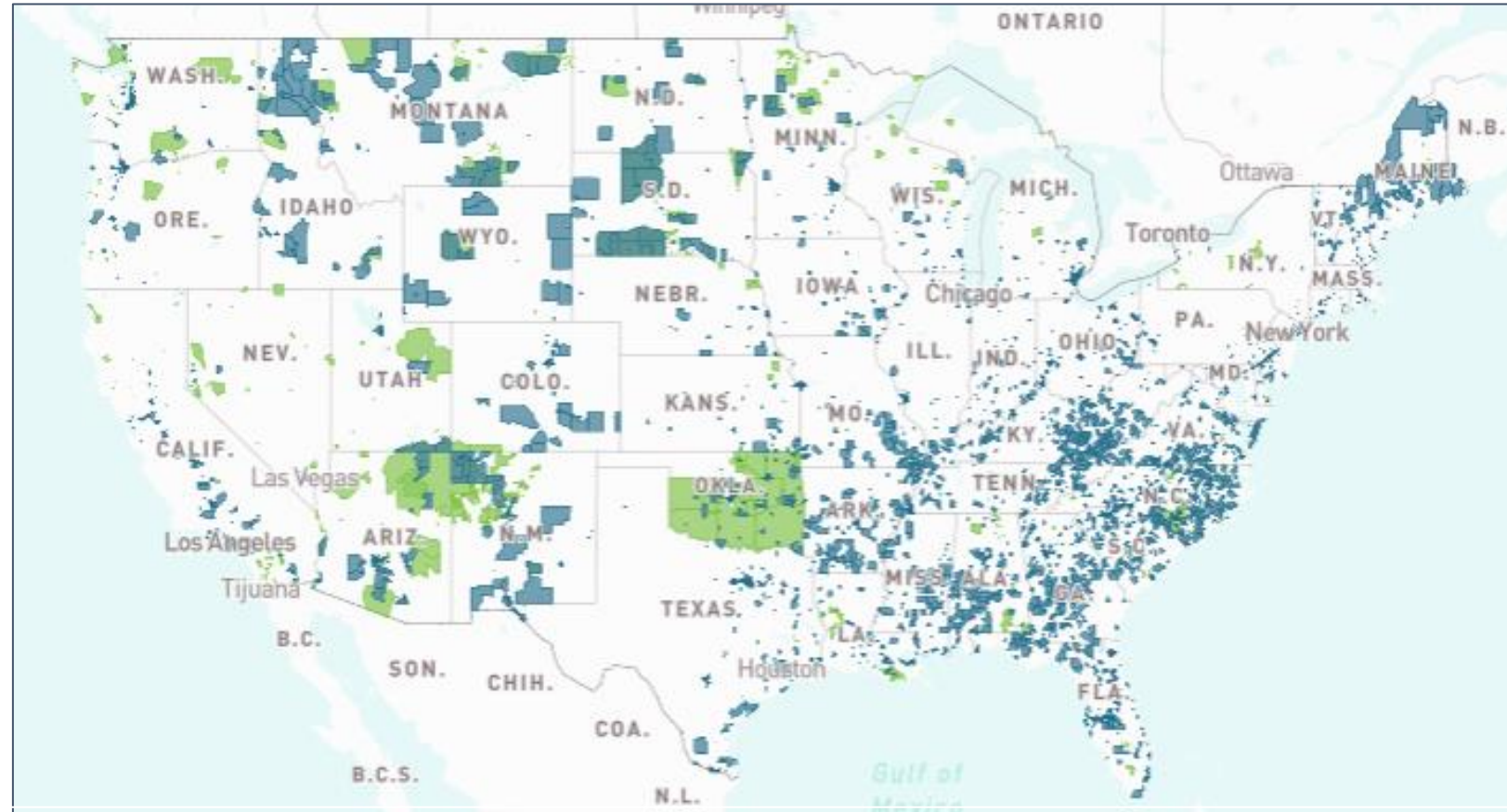
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# Community Engagement is Critical

## Community Benefits Plans



*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*



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# 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?



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# Questions?



Legend:

- Light Rare Earth Elements
- Heavy Rare Earth Elements
- Critical Rare Earth Elements
- Critical Minerals

H																	He	
Li	Be											B	C	N	O	F	Ne	
Mg												Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og	
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		

\* Ga, K, Rb, Cs, Fr, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr are not included with rare earth elements.

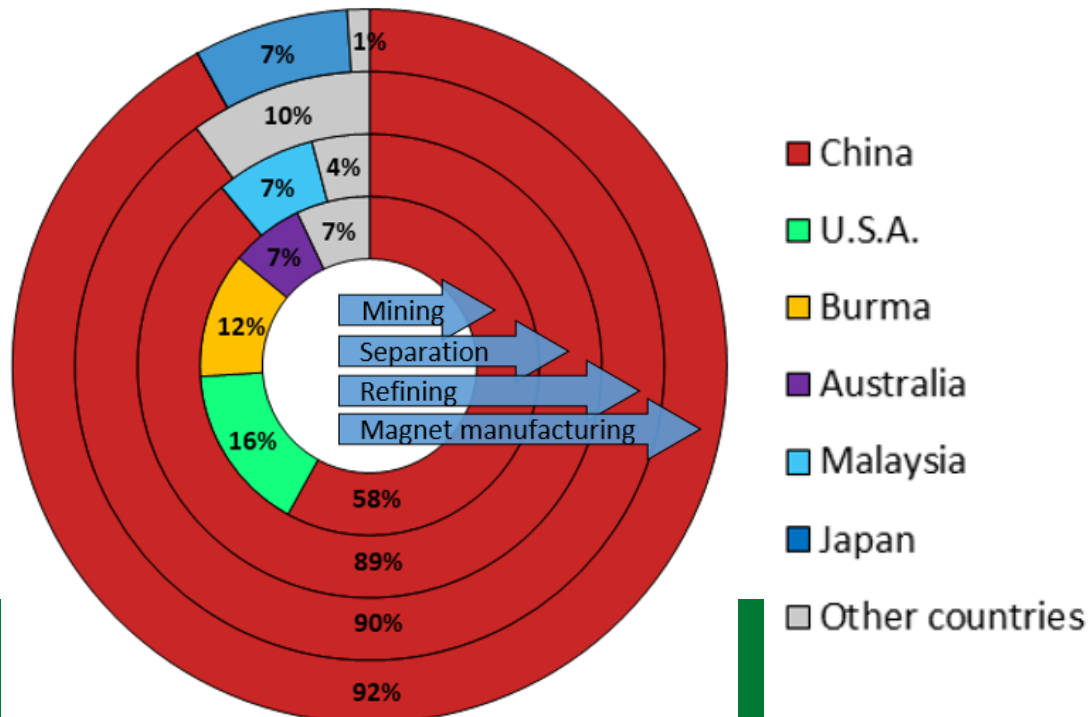


# Critical Mineral and Material Supply Chain Vulnerabilities

## 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

# Four Main Sources for Supply Diversification



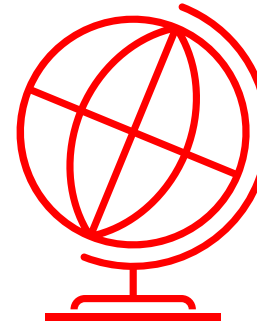
Recycling



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



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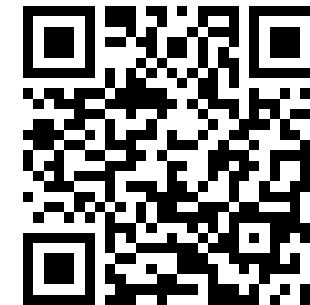


# Thank you

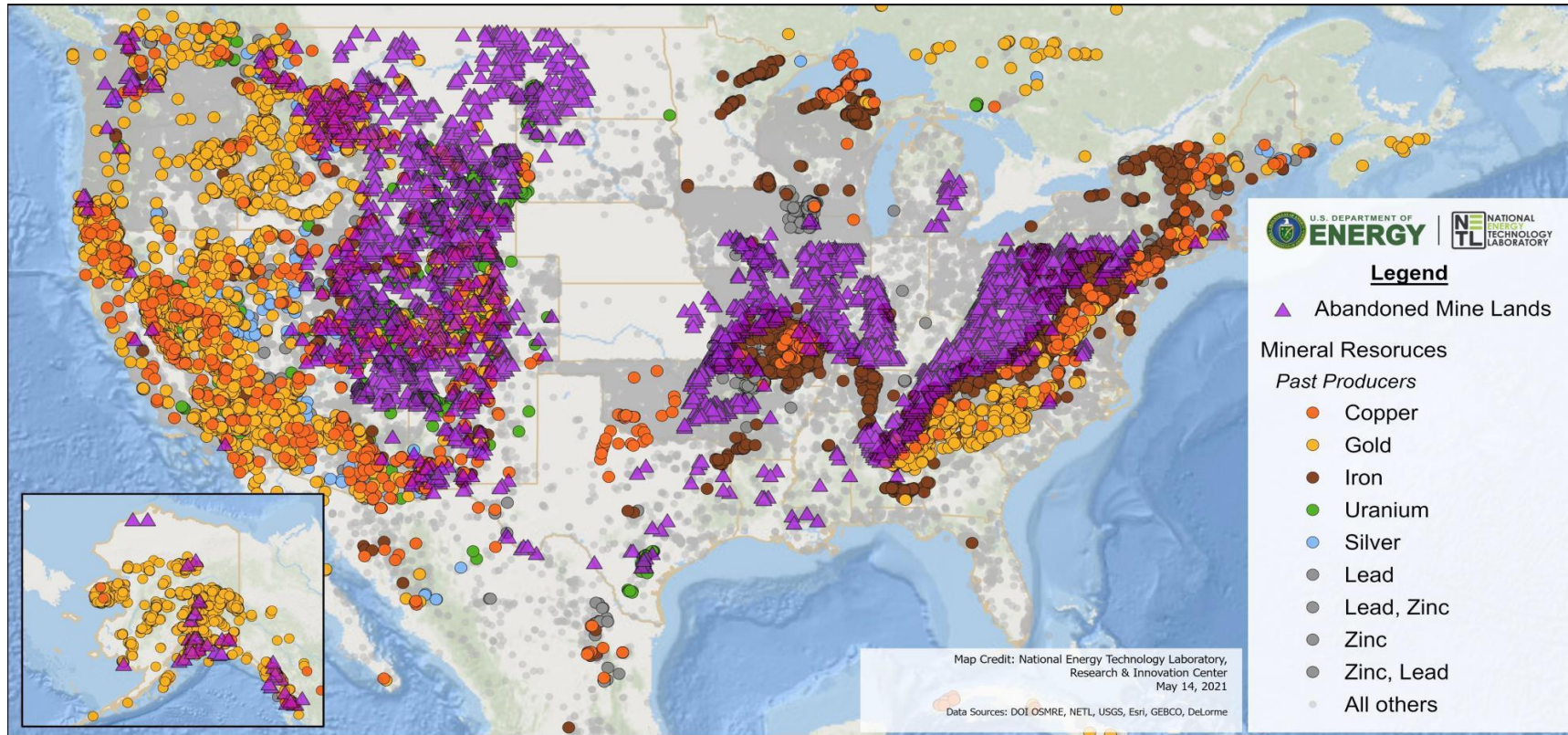
**Grant Bromhal: [grant.bromhal@hq.doe.gov](mailto:grant.bromhal@hq.doe.gov)**

Learn more about CMM at DOE: [energy.gov/criticalmaterials](https://energy.gov/criticalmaterials)

Questions?



# Potential from Other Secondary & Unconventional Sources



From USGS, Abandoned non-coal Mines

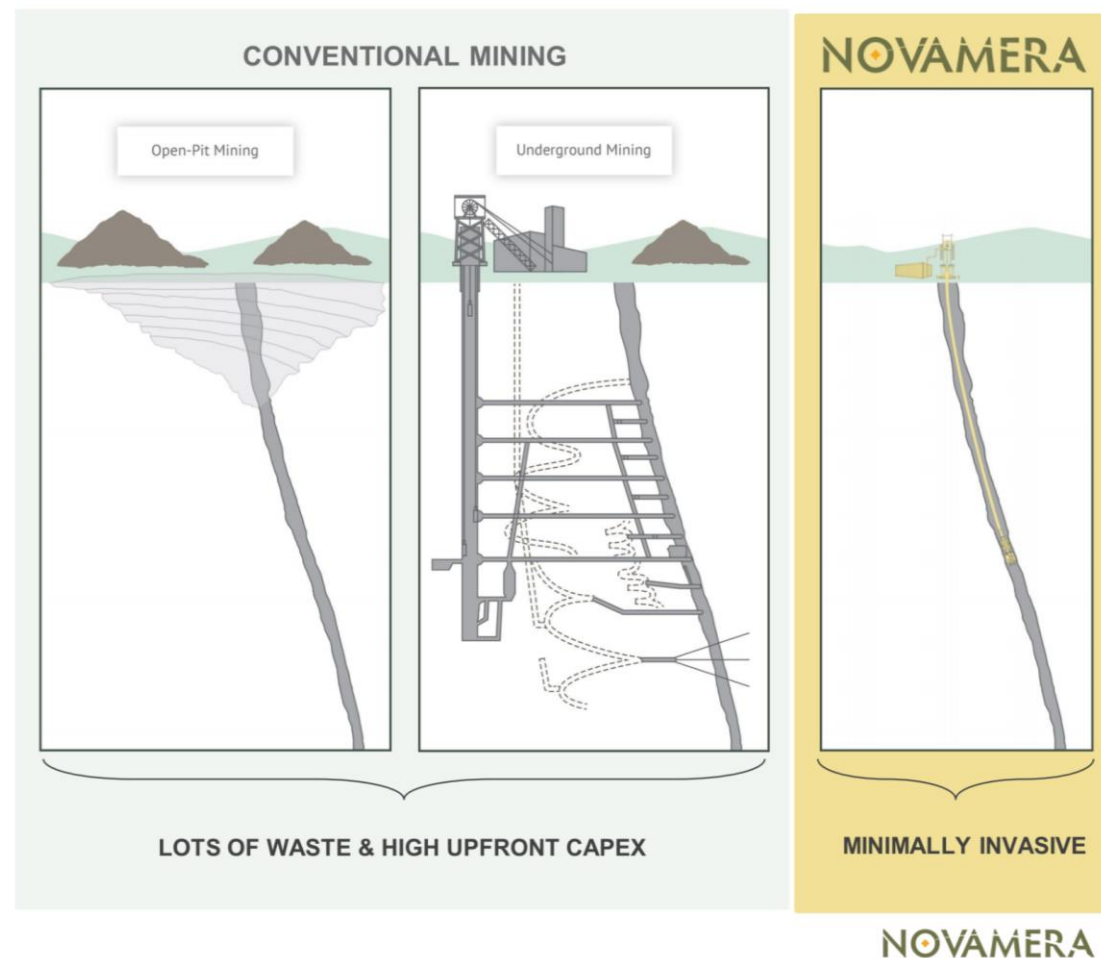
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# Future of Mining RDD&D for precision extraction

*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



# 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

DOE applied R&D offices:  
EERE, NE, and FECM

Office of Science

Early-Stage R&D

Applied R&D and  
Engineering  
Design Studies

Establish technical  
concept

ARPA-E

Office of Electricity

Pilot  
Demonstrations

Develop enabling  
technology and  
demonstrate  
technical feasibility

Large-Scale  
Demonstrations

Establish value and  
commercial benefits

MESC

At-Scale  
Deployment

Transition  
to the market

LPO

ARPA-E: Advanced Research Projects Agency – Energy  
EERE: Energy Efficiency & Renewable Energy  
NE: Nuclear Energy  
FECM: Fossil Energy & Carbon Management  
LPO: Loan Programs Office  
MESC: Manufacturing & Energy Supply Chains

Technology Transfer, Commercialization, & Research Investments: Office of Technology Transitions  
Advance U.S. Energy Policy, Support U.S. Competitiveness, & Enhance Global Energy Security: Office of International Affairs

Emerging Technologies

Established Technologies

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