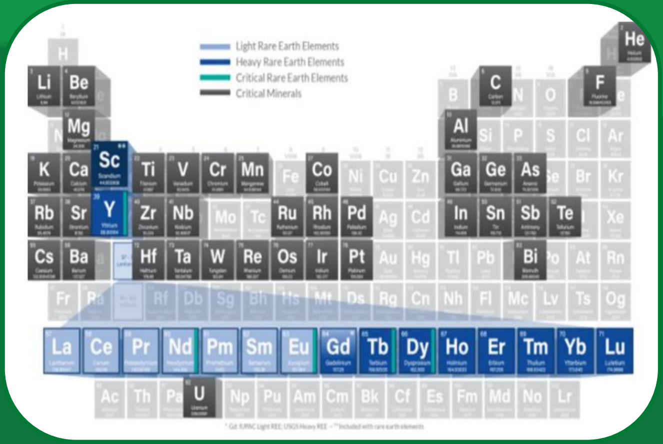
U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

Minerals Sustainability Division Multi-Year Program Plan

US Energy Association (USEA)

October 20, 2021

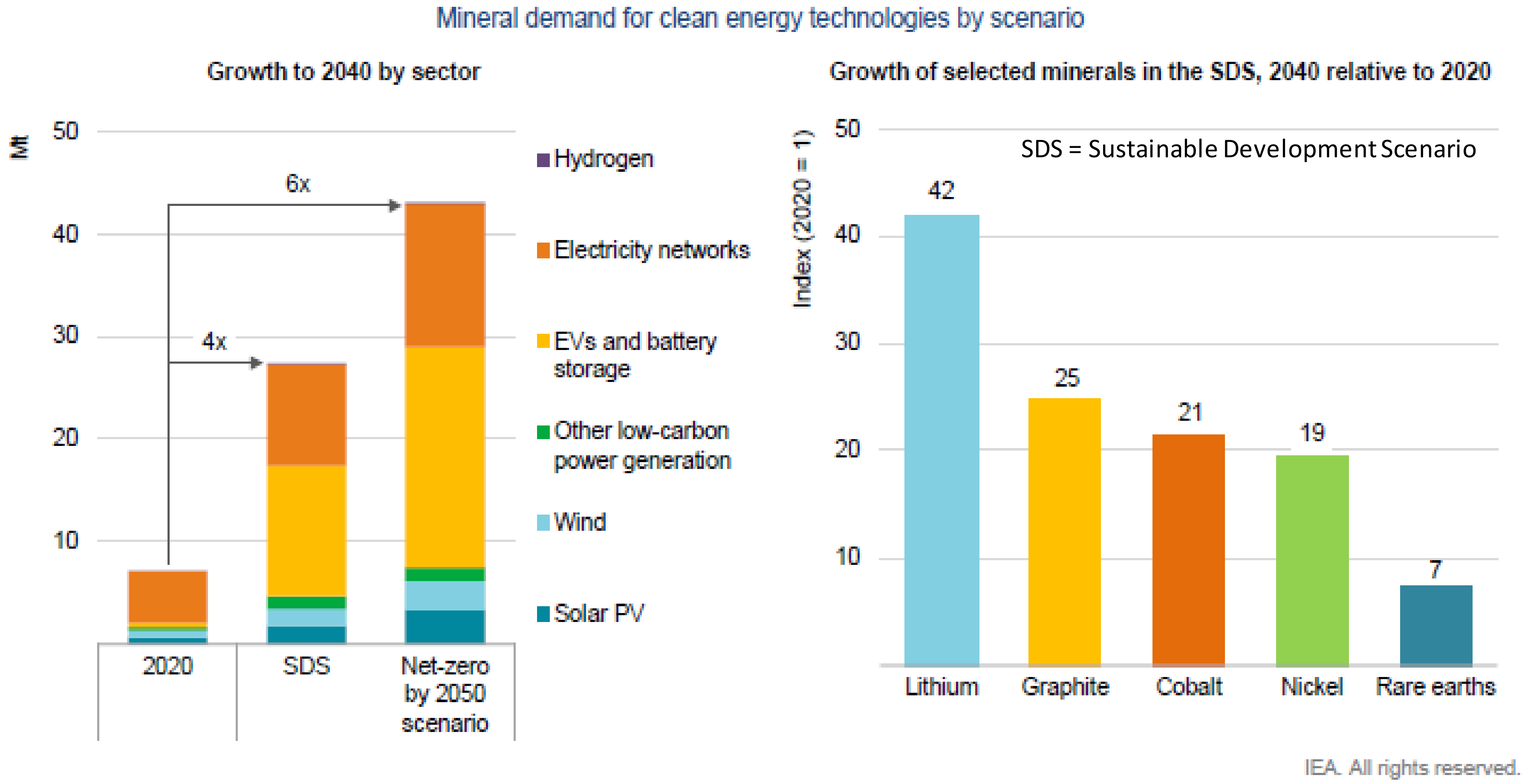




Minerals Sustainability Division Team (HQ)

- Grant Bromhal – Director (Acting)
- Sarah Forbes – Director (on Detail to CEQ)
- Traci Rodosta
- Anna Wendt
- Evan Granite
- Savannah Rice

Challenge: Significant Projected Growth for Clean Energy

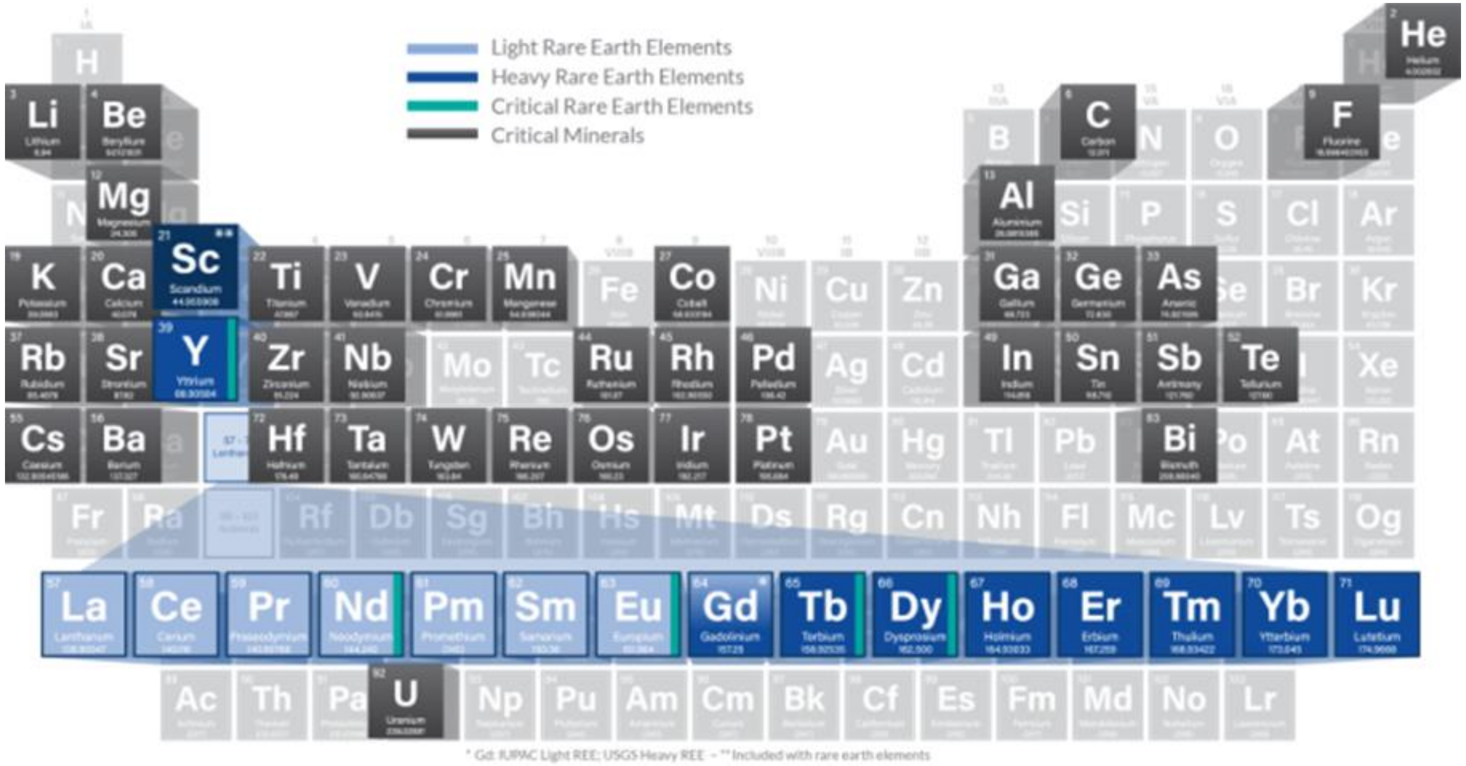


Notes: Mt = million tonnes. Includes all minerals in the scope of this report, but does not include steel and aluminium. See Annex for a full list of minerals.

IEA, 2021

Source: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

Challenge: Lack of Domestic Supply Chains



- Import-dependent (>50% from foreign source) on 32 of 35* critical minerals
- Import-reliant (100% from foreign source) for at least 14 critical minerals

*Source: USGS Minerals Commodity Summaries

DOE Strategy to Address Critical Materials Challenges

Diversify Supply

FECM, SC, EERE, NE, ARPA-E, NNSA

Technologies: Non-traditional sources; mine tailings; uses for co-products; advanced separations/extraction

Long-term goals: Diverse, secure, and resilient domestic sources and supply chains; resource mapping, characterization and fundamental geoscience understanding

Develop Substitutes

SC, EERE, ARPA-E, NNSA

Technologies: New alloys, phosphors, catalysts; new components and systems

Long-term goals: Alternative materials, chemistries, systems, components that provide enhanced functionality for key energy technologies

Recycling & Reuse

FECM, SC, EERE, NE, ARPA-E, NNSA

Technologies: Recovery from products; chemical/ biochemical extraction; additive manufacturing

Long-term goals: Economical and energy efficient recovery from products to enable circular economy for critical materials

Systems Analysis

FECM, SC, EERE, NE, ARPA-E, NNSA

Technologies: Modeling/simulation; systems approach to supply chain; Advanced characterization; techno-economic and life-cycle tools

Long-term goals: Integrated suite of systems, TEA, and LCA tools to assess and mitigate future criticality issues and support domestic supply; multi-scale physics/chemistry models

Demonstrations

FECM, ARPA-E, EERE, NE, NNSA

Technologies: Prototypes and demonstration pilots, including FEED and pre-FEED studies

Long-term goals: Accelerate FEED and demonstrations to support commercial scale production

OTT, IA, LPO

Stakeholder Engagement: Access to foreign markets, foreign partners, and financing. Coordinating policy – international and NSC driven

OTT

Market Analysis: To support decision making

Government-Wide Engagement

- Minerals Sustainability Division (MSD) actively participates in the National Science and Technology Council (NSTC) Subcommittee on Critical Minerals
- Relationships with EPA and DOI (e.g., USGS and OSMRE) are critical to reaching our goals
- International engagements are important both on our technology development front, and in establishing standards for sustainability
- MSD Leadership in the ISO on Lithium and REE standards

NSTC Subcommittee Members

ISO

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.

Principles of Waste Minimization and Circularity

Reclaiming, recycling waste materials

Maximizing use of feedstock materials

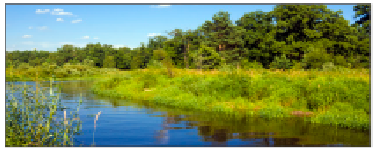
MSD Strategy

Pillar 1

Resource Characterization & Technology Development

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

Pillar 2



Sustainable Resource Extraction Technology Development

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

Pillar 3a

Processing, Refining, & Alloying Technology Development

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

Pillar 3b

Processing and Manufacturing Technology Development

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

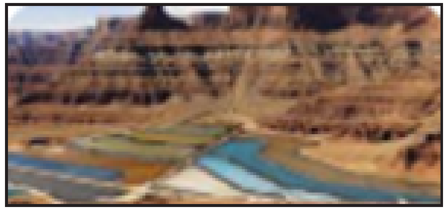
Ni, CO, Cr for Superalloys

- 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

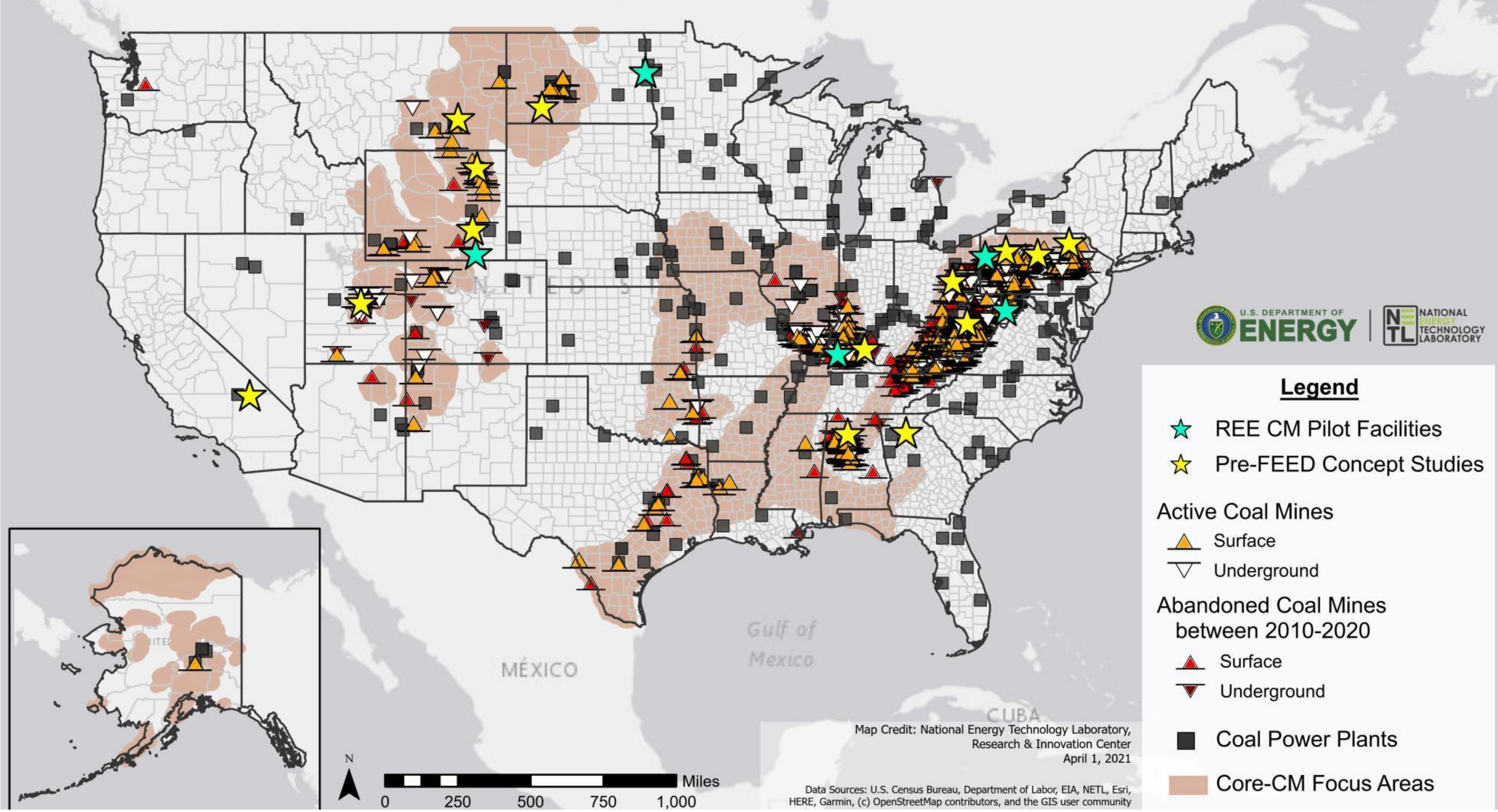
Pillar 1: Resource Characterization & Technology Development



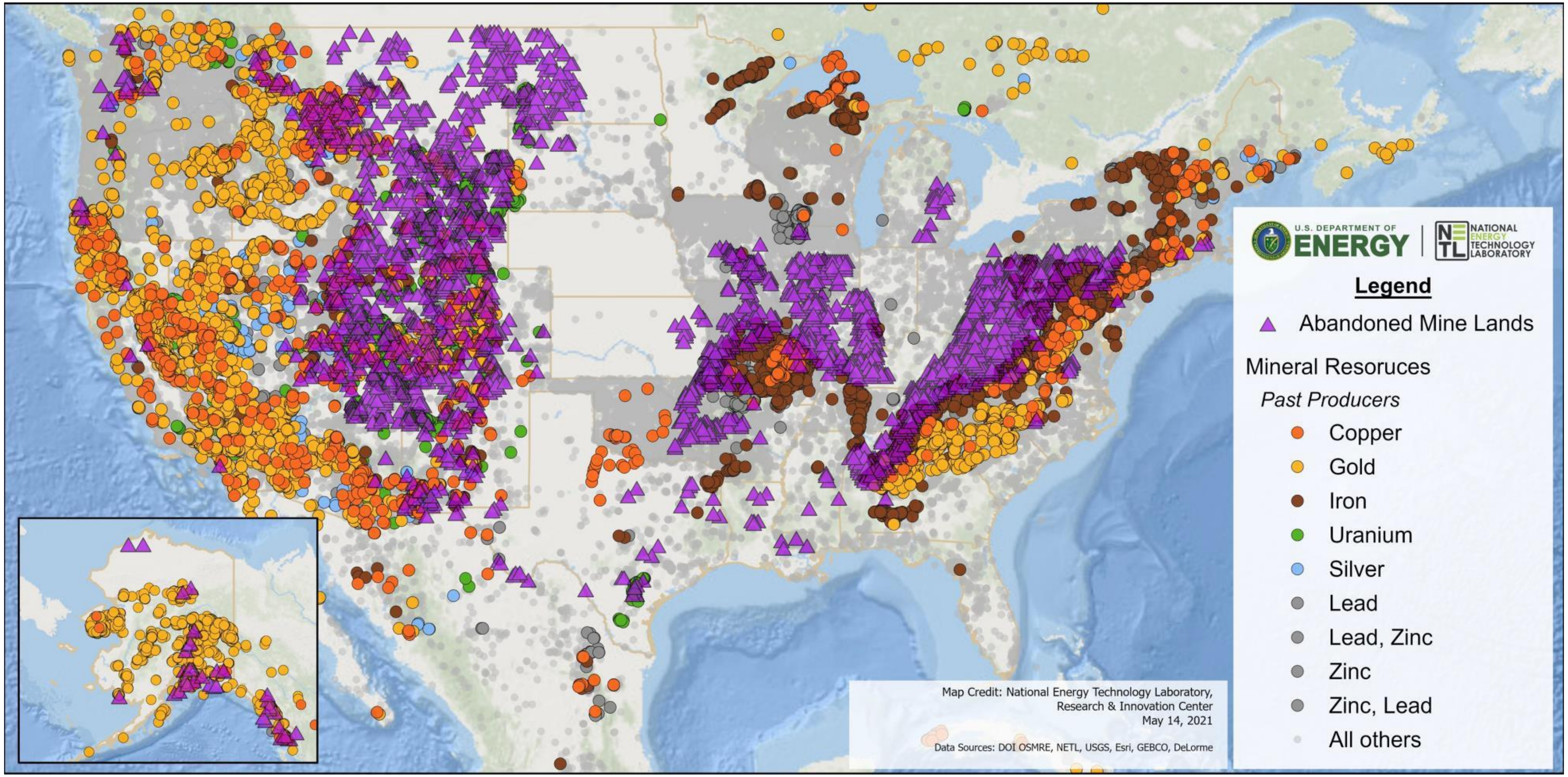
Resource Characterization & Technology Development

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

Unconventional and Secondary Sources Opportunity



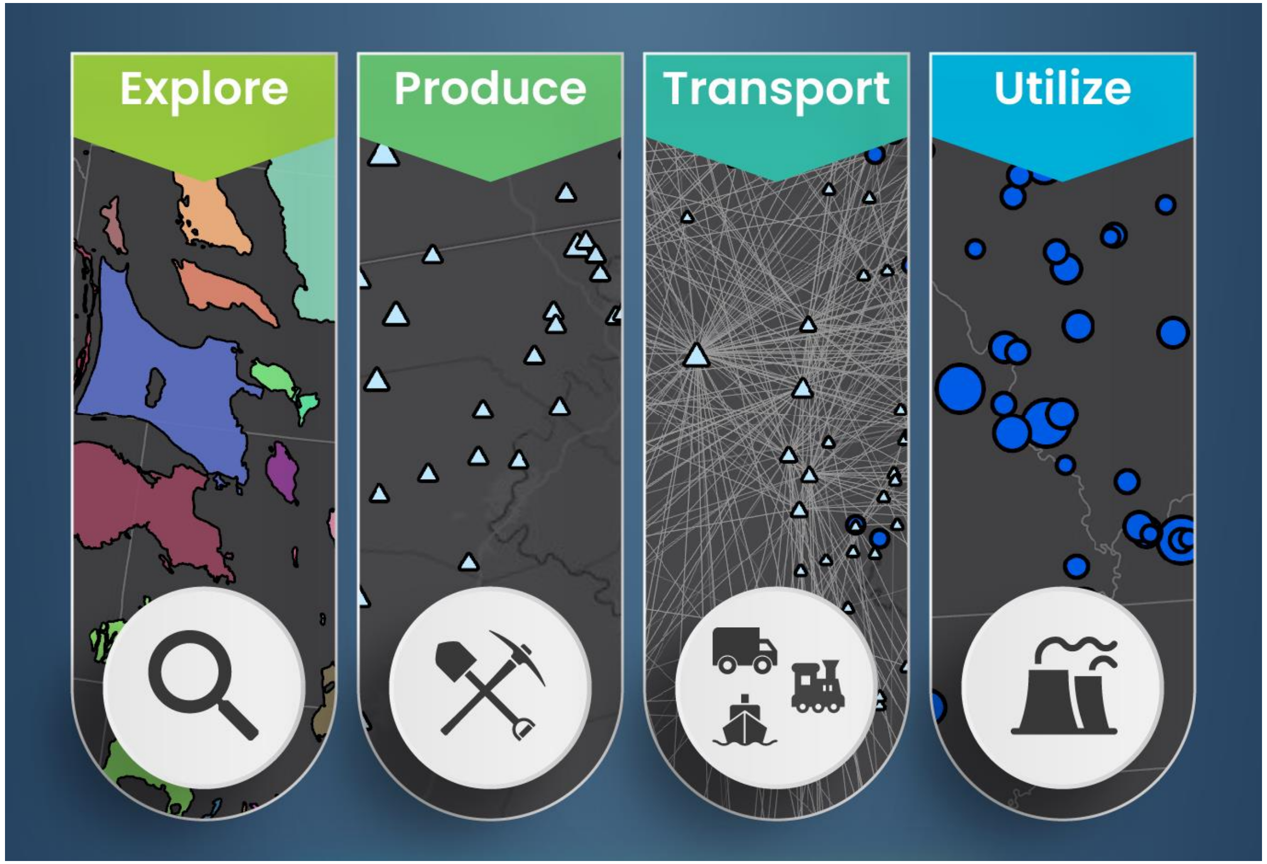
Abandoned Mines Opportunity



USGS MRDS lists 64,883 sites as past producers, inactive metal mines

The Importance of Data

URC Assessment Method: Developing a Geo-data Science Driven Approach to Assess REEs in Coal and Related Feedstocks



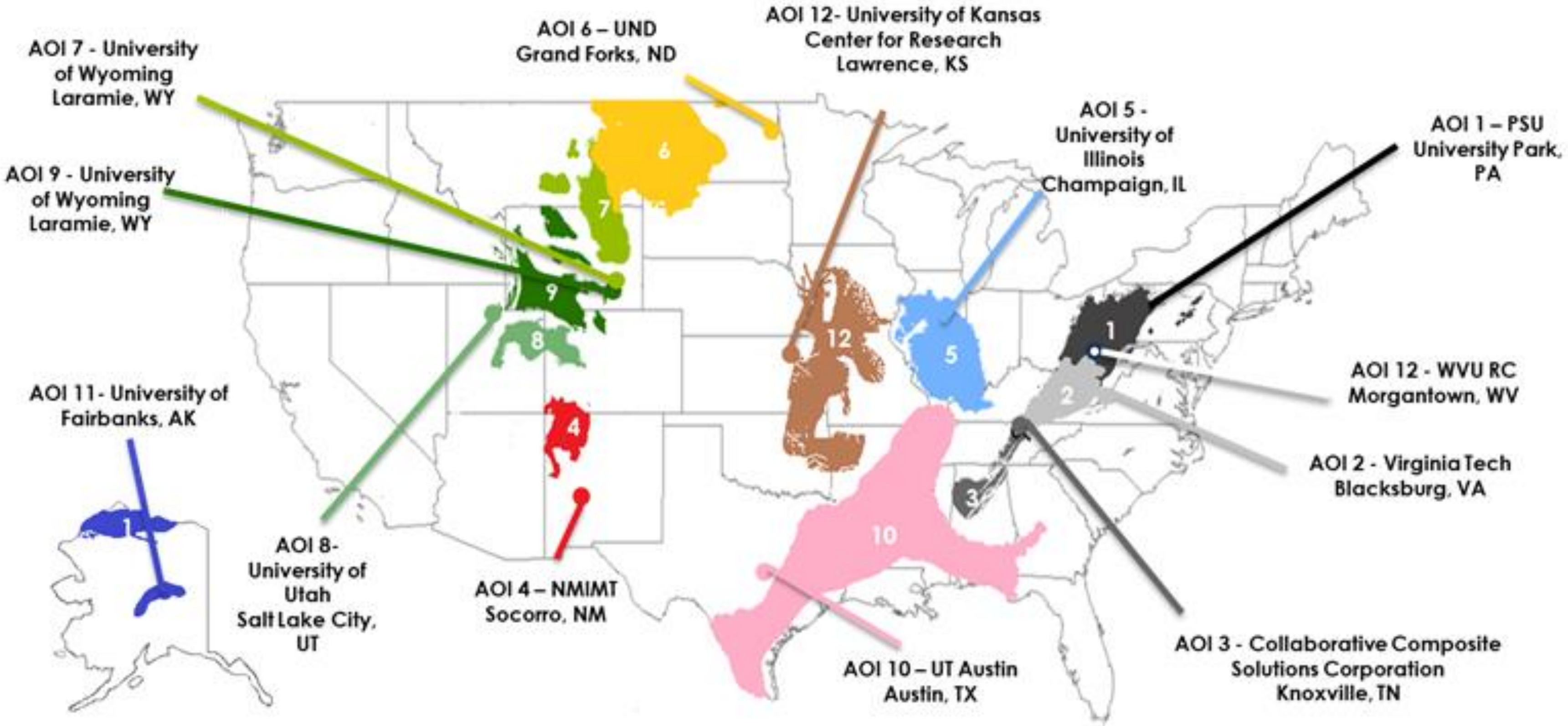
- Systematic data driven approach for identifying REE deposits in sedimentary rocks
  - Identify domestic deposits to unlock the potential for a domestic supply chain
  - Predicting REE Resources from Byproducts

NATIONAL ENERGY TECHNOLOGY LABORATORY

Federate databases across the government

CORE-CM Regional Initiatives

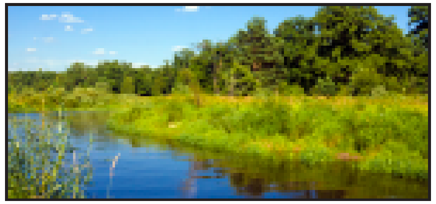
Building coalitions to develop and implement strategies that accelerate and realize the full economic potential of carbon ore and critical minerals across the U.S.



Regional Innovation Centers

- Address the upstream and midstream CM supply chain and downstream manufacturing of high-value, nonfuel, carbon-based products, ores and critical minerals (feedstocks, infrastructure, regulations, workforce)
- Co-located with economically stressed communities in need of clean energy jobs and will provide the foundation for educating next generation technicians, skilled workers, and STEM professionals.

Pillar 2: Sustainable Resource Extraction Technology Development



Sustainable Resource Extraction Technology Development

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

Extracting the Most from a Variety of Feedstocks…

A Daunting Problem

Other Potential Feedstocks

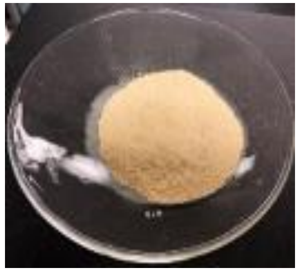
- **Large Number of Possibilities**
- **Relies on Expensive Sampling Data**
- **Addressing Multiple Similar Feedstocks**
- **Predict Location of Best Materials**
- **New Approach – Machine Learning/Artificial Intelligence**

Coal and Coal Byproducts

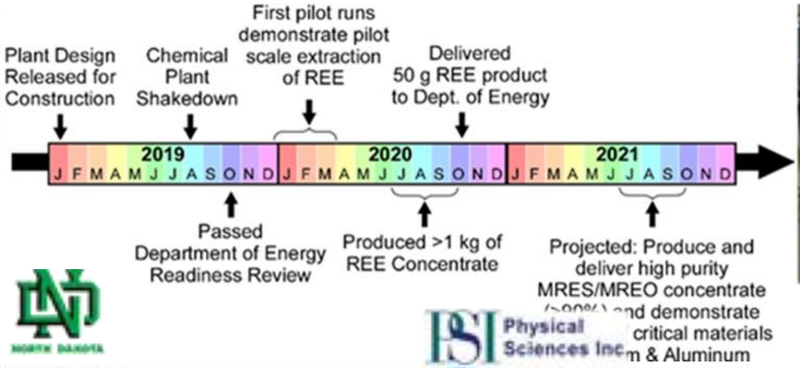
Produced Water

Mine Tailings

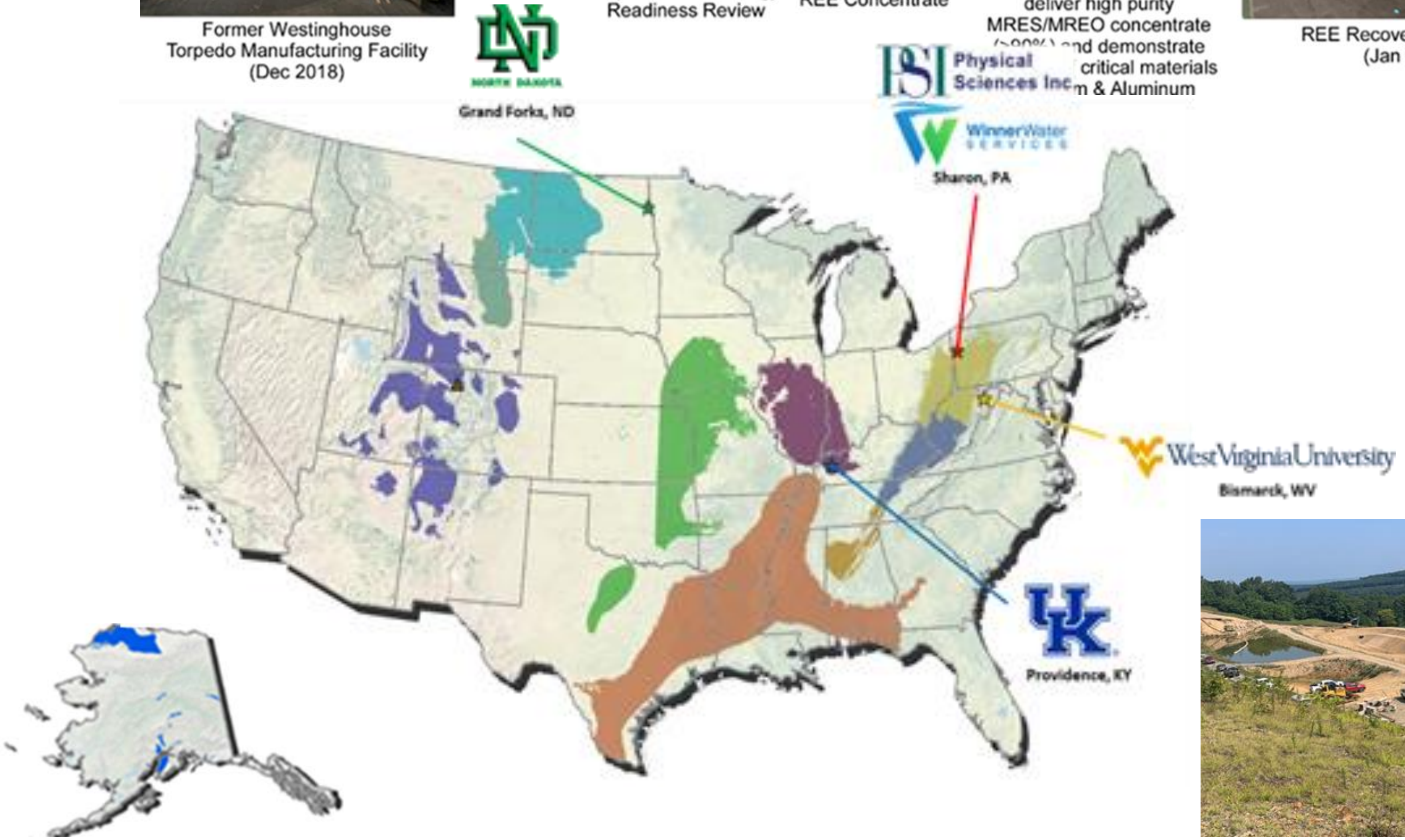
Small Scale Pilots—Proving Technical Feasibility



Former Westinghouse Torpedo Manufacturing Facility (Dec 2018)



REE Recovery Pilot Plant (Jan 2021)



Key Extraction Targets

- **Develop and validate** extraction technologies for unconventional feedstocks
  - Coal and coal byproducts
  - Produced and waste water
  - Other feedstocks
- Catalyzing development of **transformational technologies**
  - Reducing toxic chemicals
  - Targeted extraction (e.g., drilling, in-situ leaching, biomining, agromining)
  - Novel filters/membranes
  - Application of AI/ML technologies
- Combined **remediation** and extraction
  - Critical Minerals
  - Carbon Ore
  - Maximize Value of All Byproducts
- Generate **best practices** to prioritize
  - Risk assessment
  - Resource concentration
  - Sustainability

Source: Lopano, 2021

Pillar 3a: Critical Mineral Processing, Refining, and Alloying Technology Development

Processing, Refining & Alloying Technology Development

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

Significant REE Production Potential Demonstrated

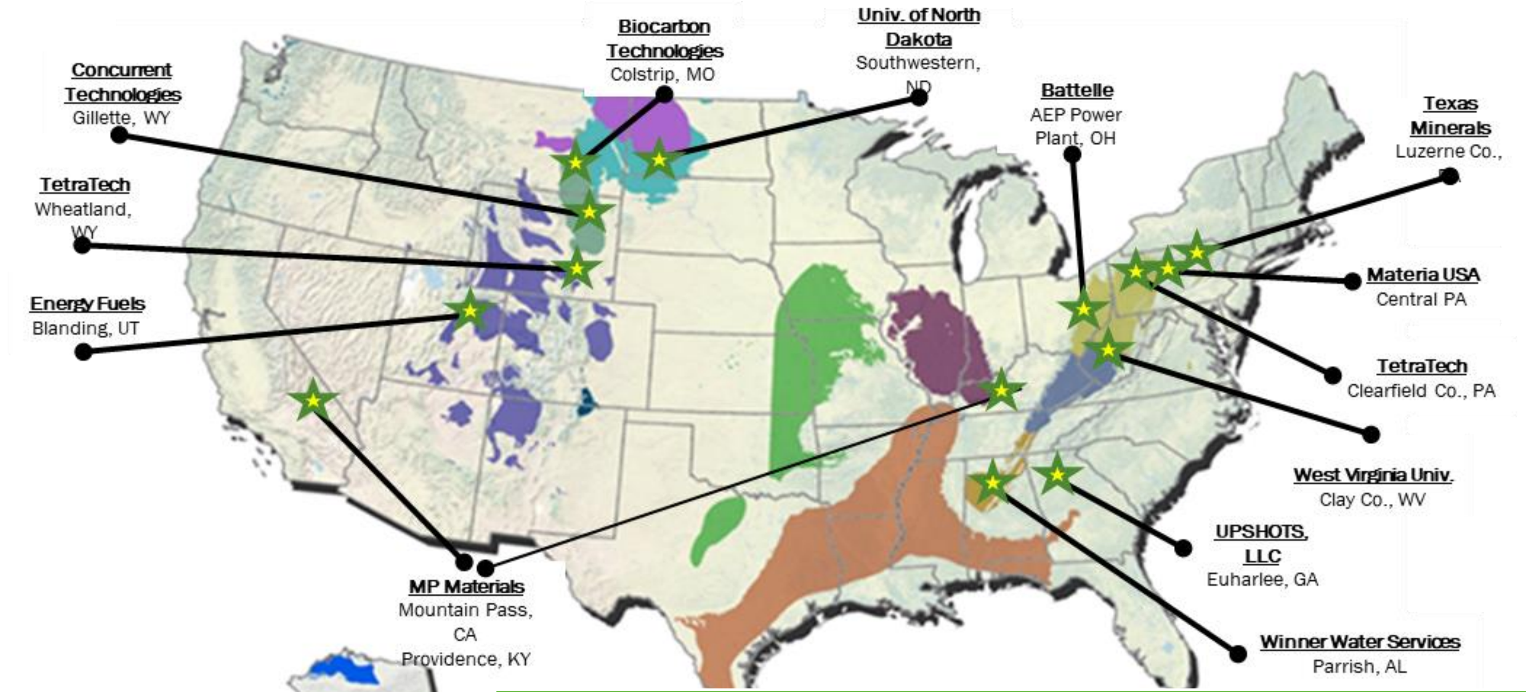
From Small Scale Pilots

	Coal[1]	Coal Refuse[2]		Coal Combustion Ash[3]			Acid Mine Drainage from Appalachian Basin[4]	
	Domestic Production in 2016 (tons)	Actively Produced (Appalachia)	Landfilled	Actively Produced (2016)		Landfilled (Since 1991)	Sludge	Raw AMD
				Flyash (tons)	Bottom Ash (tons)	Coal Combustion Products		
Resource Estimate	728,000,000	~360 million ton	Estimated 2 Billion Tons in PA Alone	37,800,000	10,100,000	~1.5 billion tons	Unknown.	1.5 to 6.6 million gpm
Assumed REE Concentration	at 62 ppm low side[5]	62 - ~700 ppm (Low Estimate 62 ppm)		80 - 1200 ppm (~400 ppm average)[6]			~660 to 750 ppm (708 ppm average)	< 0.5 ppm
Potential REE Produced (tons /year)								
100% Recovery	49,800	24,600	136,700	16,670	4,450	661,000	-	807 - 3560
50% Recovery	24,900	12,300	68,300	8,330	2,230	331,000	-	404 - 1780
20% Recovery	10,000	4,920	27,300	3,330	891	132,000	-	161 - 711
Challenges	Most of the coal is combusted	REE concentrations can vary greatly between layers within a coal seam This variation can translate to variations within the coal.		REE concentrations vary greatly depending on the coal that is combusted within the power plant. The combustion process increases the concentration of REEs in the combustion ash but also makes it more difficult to extract.			Acid mine reclamation sites are distributed throughout a region.	Very low concentrations of REE.

Assessing Economic Feasibility at Larger Scale

Large-Scale Pilots-

Pre-FEED studies for 1-3 tonnes/day MREO for individual separation through metal production



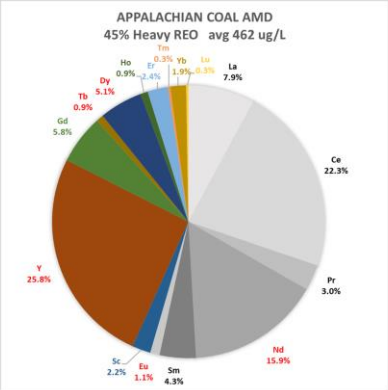
Initial Potential Byproducts or Coproducts
Alumina, Aluminum hydroxide, Cobalt Oxide, Carbon, Cement Substitute, Ferric Chloride, Gallium, Gasifier slag products, Germanium, Halfnium, Iridium, Iron Oxide, Lithium, Magnetite, Niobium, Pig iron, Quartz, Titanium Oxide, Upgraded Lignite, Uranium, Zirconium, and Zeolite

Contractor	Feedstock	Region of Feedstock
West Virginia University	Acid Mine Drainage	Northern/Central Appalachian Coal and Montana Copper Mine
MP Materials	Refuse Heap Leaching	Kentucky Coarse Mine Refuse and AMD Sludge
Energy Fuels	Coal Measures Sediments (Existing Mine)	New Mexico
University of North Dakota	Lignite (Existing Mine)	North Dakota
Winner Water Services	PCC Fly Ash	Georgia - Plant Gorgas
Tetra Tech - PA	Appalachian Underclays	Pennsylvania
Texas Minerals	Appalachian (Anthracite) Underclays	Pennsylvania (Luzeme County) and Jeddo Coal Eckley North
Materia USA	Appalachian Underclays	Pennsylvania (Clearfield County)

Example: CM/REE Integrated AMD Project

Field validation of an integrated AMD treatment and CM/REE plant:

- Continuous process for efficiently treating AMD while producing an enriched CM/REE concentrate
- Planned operation: Late Fall 2021
- Potential production Rate: ~1 tonne/y each -TREE, Co and Ni, ~27 tonne/y Mn--if economic



45% HREE

MREO 99%

Acid Mine Drainage from Appalachian Basin	
	Raw AMD
Resource Estimate	1.5 to 6.6 million gpm
Assumed REE Concentration	<0.5 ppm
Potential REE Produced (tons/year)	
100% Recovery	807-3560
50% Recovery	404-1780
20% Recovery	161-711
Challenges	Very Low Concentrations

Results from field validation pilot-project will inform Pre-FEED Large-scale Project:

- Achieved MREO @ 99% purity using solvent extraction
- Continuous process flowsheet—feedstock agnostic
- Developing reduction module for potential metal production for magnets -- NdPr and SmCo
- NdPr resource could produce (yearly) EV motors for 45K-360K Tesla Model 3 **or** 37K-299K Chevy Bolt

Partners: Rockwell Automation, TenCate Corp., Virginia Polytechnic Institute and State University, Tom Larochelle, and West Virginia Department of Environmental Protection

Key Processing Targets and Opportunities

- Ensure sustainable processing technologies
  - Minimize emissions
  - Reduce chemical use
- Catalyze design, construction, and operation of **First Mover** facilities
  - 1-3 t/day MREO and MRES + CM
  - Other primary products
  - Converting commercial technologies for use
- Novel **transformational technology** development and validation
- **“Dating service”** for companies—bringing industries together throughout the supply chain
- System Optimization—high-power computing/design throughout the supply chain
- Develop **best practices**/lessons learned to accelerate technology dissemination
- Catalyze the deployment of **Next Generation** facilities for high purity refined materials/metals

Pillar 3b: Carbon Ore Processing and Manufacturing Technology Development

Processing and Manufacturing Technology Development

Carbon Ore

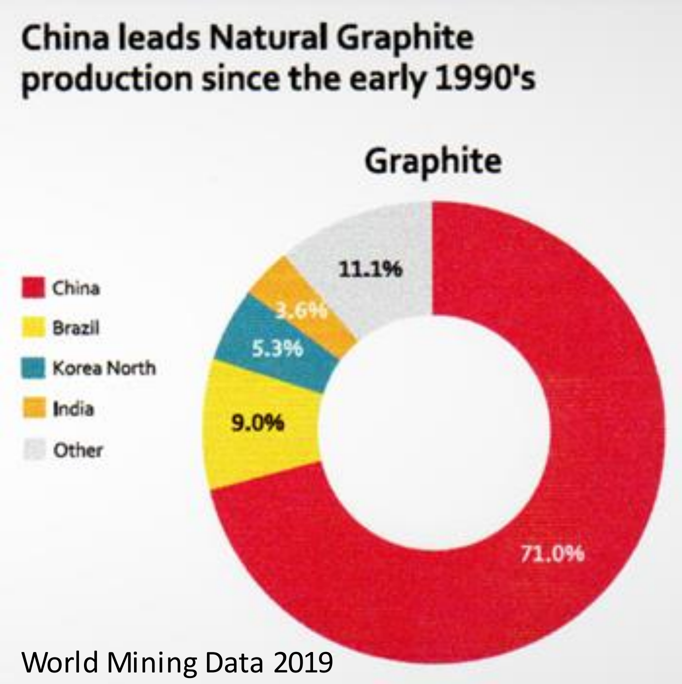
- Housing and infrastructure development
- Advanced carbon material production(carbon fiber, graphene, and nanomaterial)
- Reinvest in critical (graphite and silicon) supply chains

Graphite is critical to 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

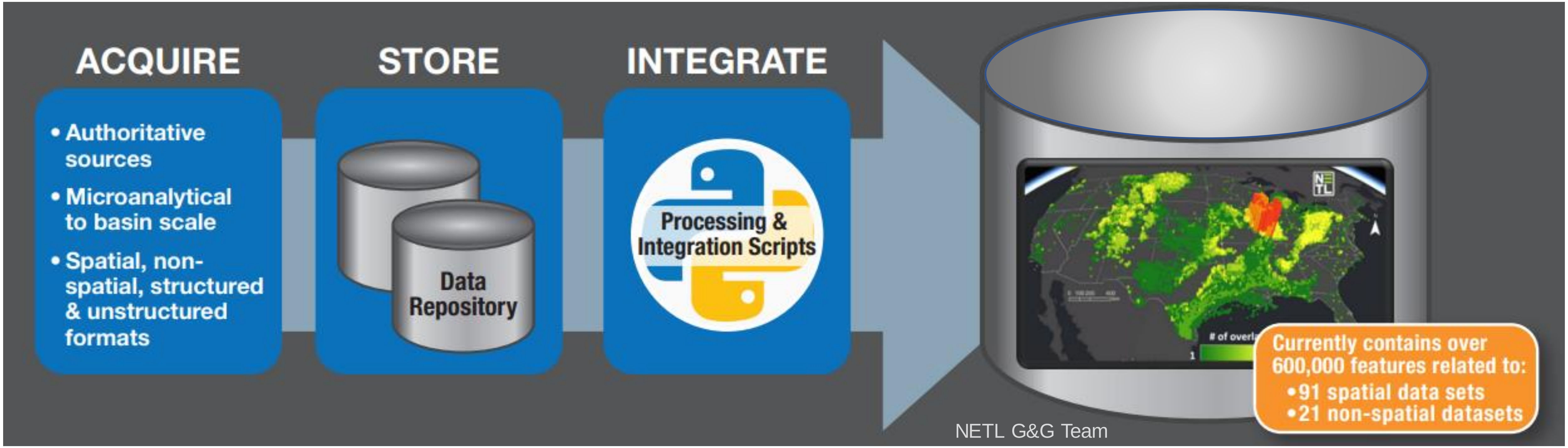


3 billion tons of minerals and metals, including graphite, will be needed to deploy clean energy

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

Carbon Ore Resource Database (CORD)

CORD is designed to optimize coal sources with consumer needs and identify key coal properties for end products



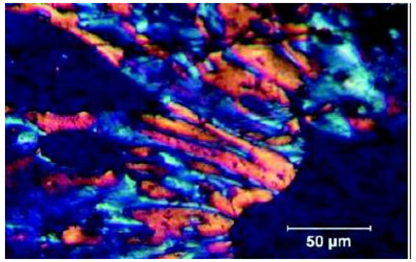
Optimizing coal sources with consumer needs and identifying key coal properties for end products.

Carbon Ore Processing Opportunities

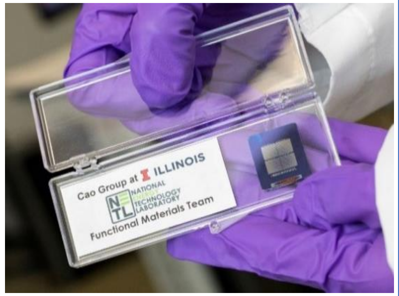
Opportunities toward a clean energy transition -- Advanced processing of carbon ore and associated by-products for the development of everyday and high value carbon products

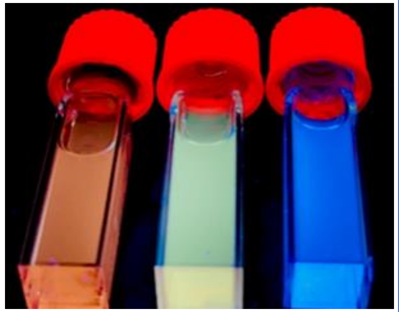
Next-Gen Construction & Infrastructure Materials

Carbon Fibers from Coal Tar Pitch

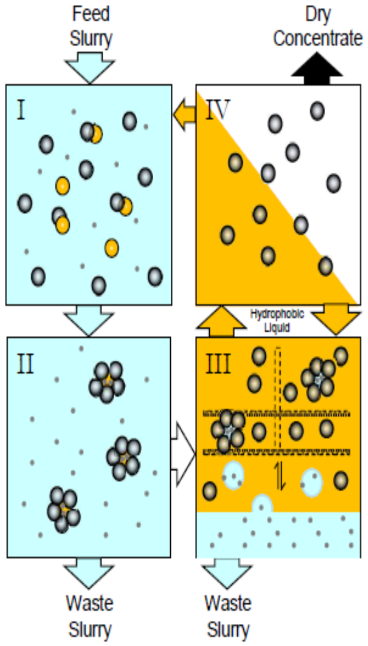


Nanomaterials





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

Crosscutting: International Engagements, Standards, and Supply Chain Development

International Engagements, Standards and Supply Chain Development	
Ni, CO, Cr for Superalloys	**Carbon Ore to Products**
• 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	• Assessment and characterization of coal and waste materials • Environmentally responsible extraction and benefication • Co-production of high purity carbon and critical material products

International Engagement and Standards Development

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

Additional Information

- **MSD Program Plan on USEA website or at:**

  https://www.energy.gov/fecm/division-minerals-sustainability

- **For detailed information on the DOE Rare Earth and Critical Minerals and Carbon Ore Program, go to:**

  https://www.netl.doe.gov/coal/rare-earth-elements

  https://netl.doe.gov/Carbon-Ore-Processing

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

Thank you!

Questions?