Manufacturing Valuable Coal-Derived Products in Southern Appalachia

FE0032045

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U.S. Department of Energy

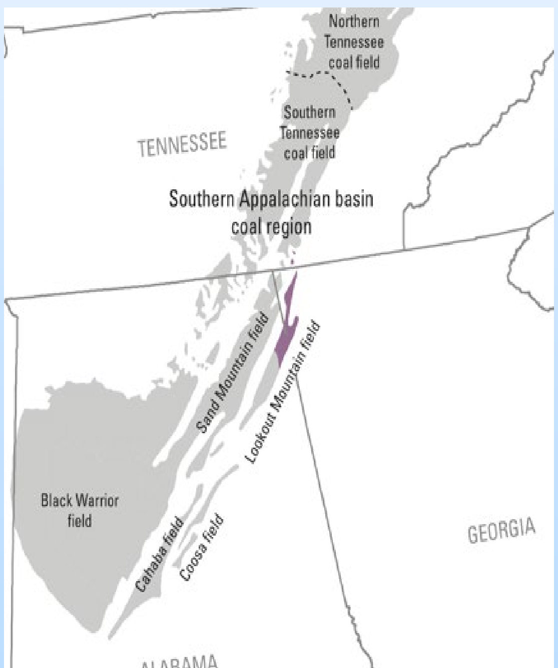
National Energy Technology Laboratory

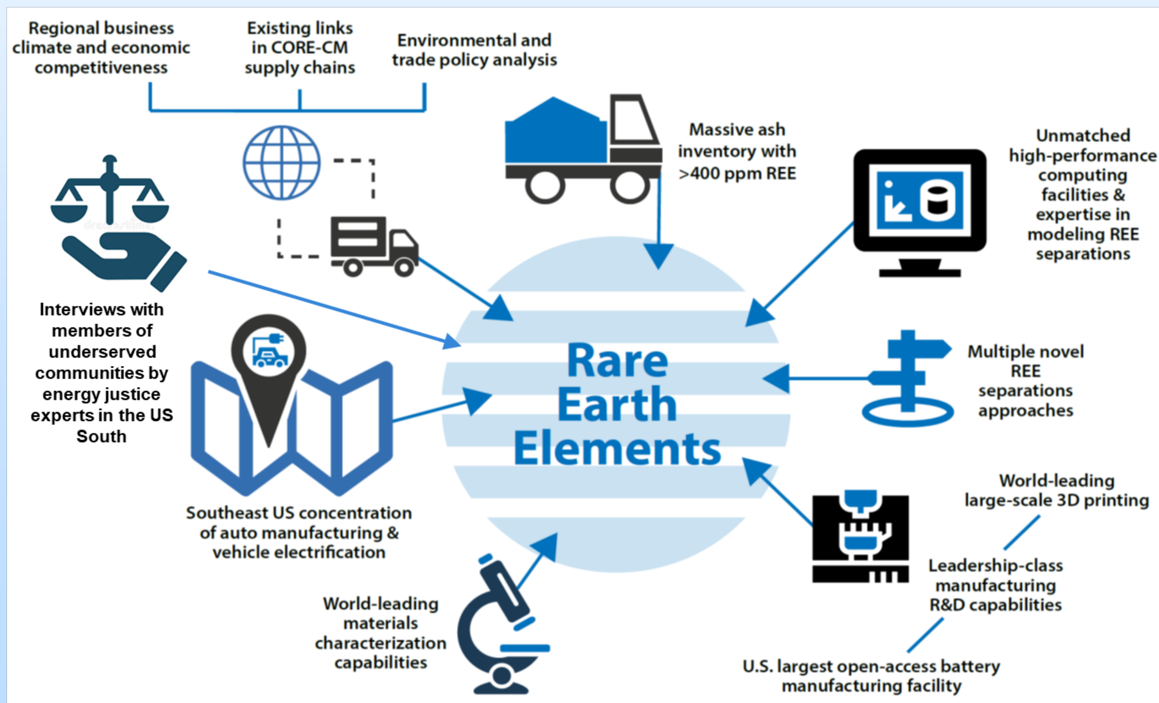
Resource Sustainability Project Review Meeting

April 2 - 4, 2024

Project Overview

Project Participants: IACMI (Applicant – Managed by Collaborative Composites Solutions Corporation), Geological Survey of Alabama (GSA), Oak Ridge National Laboratory (ORNL), Roane State Community College (RSCC), Southern Company (SO), Tennessee Geological Survey (TGS), University of Alabama-Birmingham (UAB), University of Alabama-Tuscaloosa (UA), University of Tennessee-Knoxville (UTK)





Technical Approach/Project Scope

Task 2—Basinal Assessment of CORE-CM Resources

- Milestone 2.1: Coal ash sample plan indicating number of samples, ash sources, and data to be acquired. *(M3)*
- Milestone 2.2: Six-month resource assessment progress report with key findings and existing data. *(M6)*
- Milestone 2.3: GIS maps of coal reserves for AL & TN coalfields *(M24)*
- Milestone 2.4: Samples for mineral characterization and analysis delivered to NETL. *(M20)*

Task 3—Basinal Strategies for Reuse of Waste Streams

- Milestone 3.2: Preliminary assessment of beneficial ash use opportunities *(M9)*
- ***Ash pond valuation tool and regional REE supply curve estimates***
- ***Regional coal-REE supply chain (input-output) modeling framework and gap analysis***

Task 4—Basinal Strategies for Infrastructure, Industries, and Business

- Milestone 4.1 Existing business and industry structure with NAICS codes. *(M6)*
- Milestone 4.2 Taxonomy and REE security cost measures. *(M9)*
- Milestone 4.3 Transportation, electricity, & broadband inf. ability to support CORE-CM businesses *(M12)*
- Milestone 4.4: Four critical aspects of REE security costs. *(M18)*
- Milestone 4.5: Report or article on REE security costs submitted for publication. *(M24)*

Task 5—Technology Assessment, Development, and Field Testing

- Milestone 5.1: Assessment on utilization of high-performance computer modeling of REE separations. *(M15)*
- ***Assessment of optimizing chemical, biological, and electromagnetic separation technologies***

Task 6—Technology Innovation Centers

- Milestone 6.1: List of existing capabilities at planned Technology Innovation Center sites. *(M15)*

Task 7—Stakeholder Outreach and Education

- Milestone 7.1: Key stakeholders identified and a list of stakeholders that are critical outreach targets. (*M3*)
- Milestone 7.2: AL community college partner(s) selected for local delivery of training in coal communities. (*M15*)
- ***Interviews with members of underserved communities near coal ash sites***

Notable Features of our Approach

The 3 Rs: Resource → Remediation → Refining → Resiliency

Technology Innovation

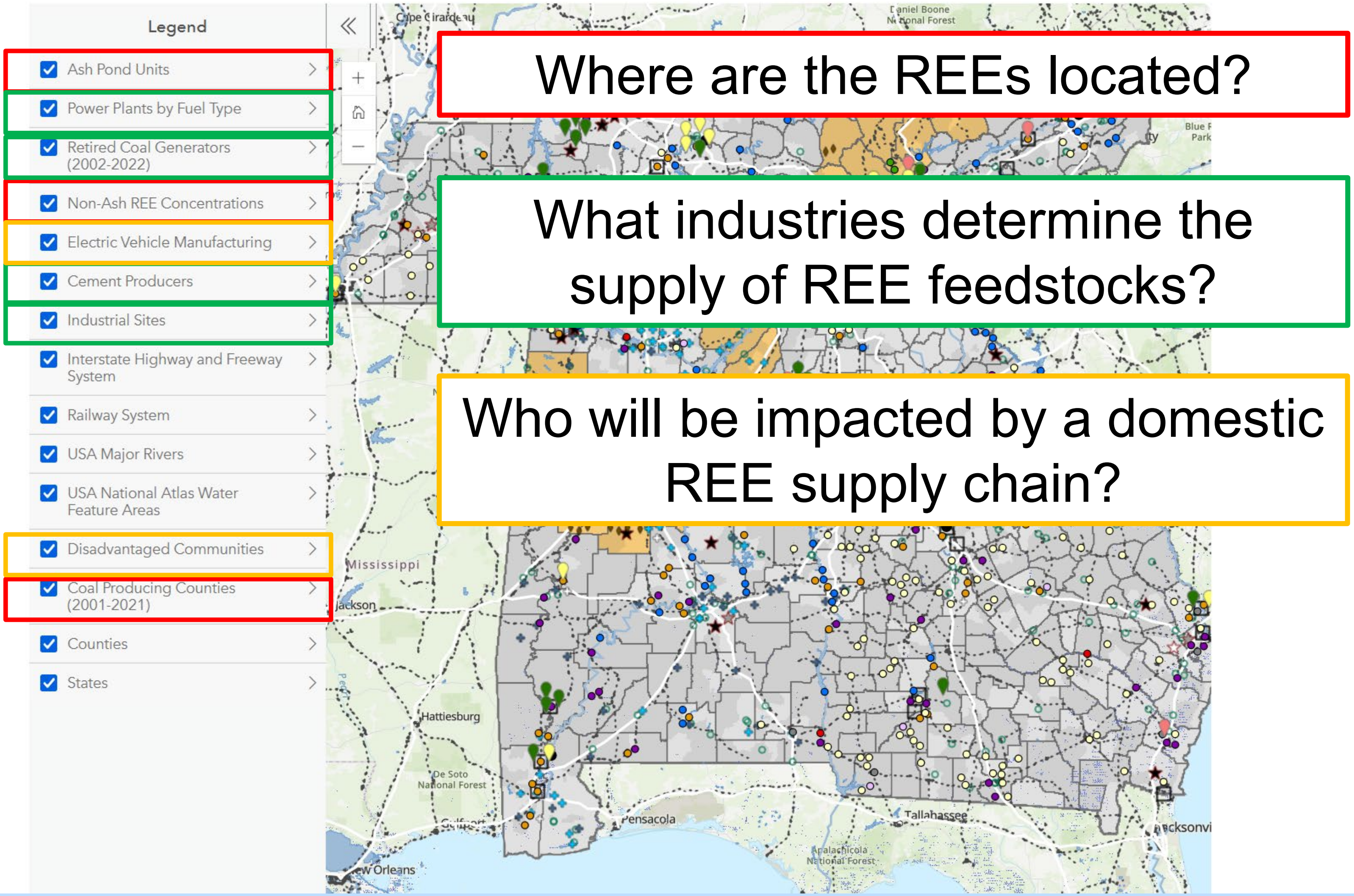
- Resource characterization of waste feedstock
- Ash beneficiation
- REE separations
- Resilient infrastructure

Markets, Policy, and Community

- TEA and LCA
- Supply chain modeling
- REE markets and security premiums
- Zoning and land use regulations
- Public perception
- Workforce development

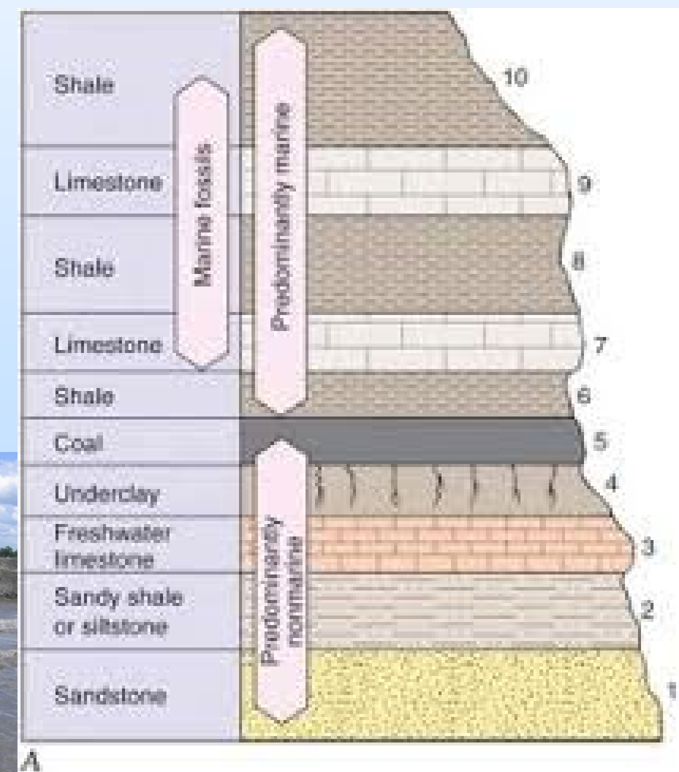
Infographic: Coal-REE Ecosystem

Available at: https://baker.utk.edu/southern-appalachia-rare-earth-element-ecosystem/



Task 2 Accomplishments:
Historical data records reported

- Coal and Coal-Associated Sediment (N = 1,154)
  - Coal Samples
    - Represent 48 different coal seams
  - Coal-Associated Sediments (17)
    - Mostly shales
  - Coal Refuse (5)
- Coal Ash (N = 1,176)



Task 2 Accomplishments: New Materials Collection/Characterization

Non-Ash Samples (N = 88)

Phase I
- Coal Underclay
- Coal Roofrock
- Coal Processing Wastes
- Acid Mine Drainage Sludge

Phase II
- Clay
- Phosphate
- Organic Shales
- Lignite
- Sandstone

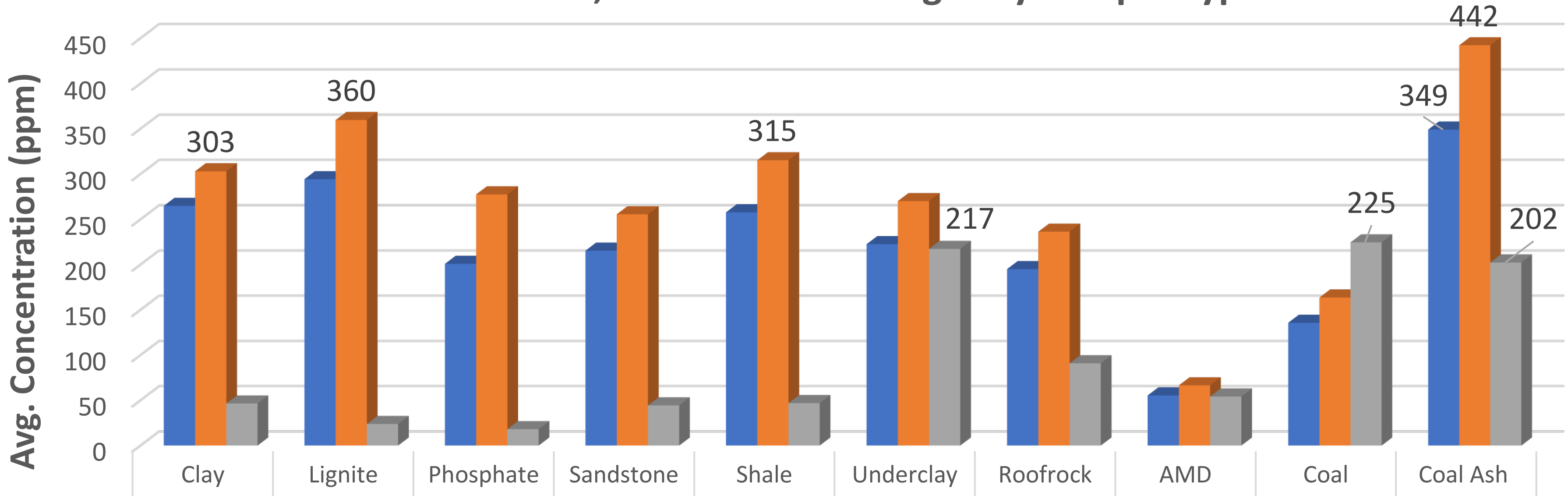
Coal Ash Samples (N = 227)

Alabama Plants
- Barry
- Gaston
- Gorgas
- Greene
- Miller

Georgia Plants
- Arkwright
- Bowen
- Branch
- Hammond
- Wansley

Task 2 Accomplishments: Resource characterization

REE, REE+ and Li Averages by Sample Type

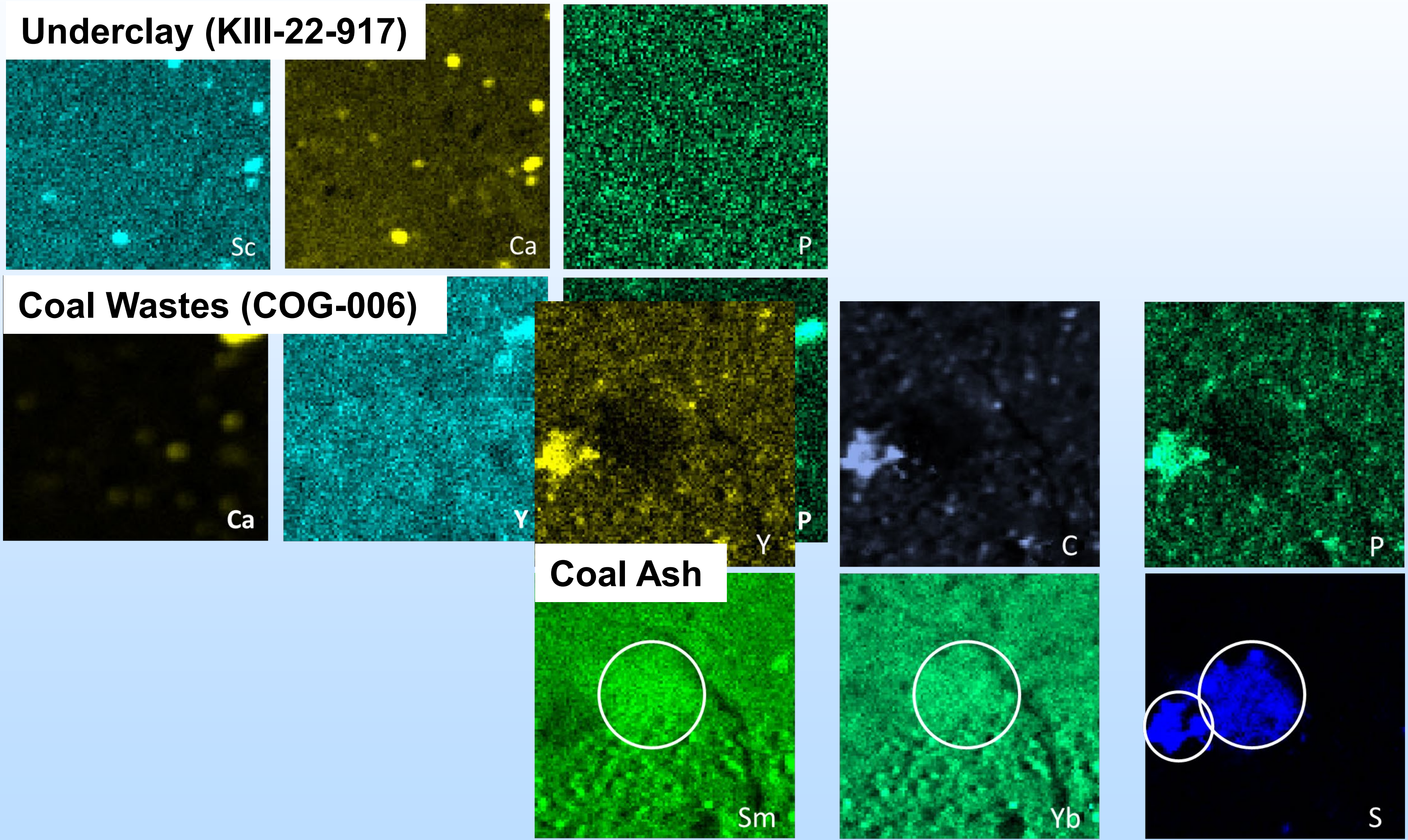


	Clay	Lignite	Phosphate	Sandstone	Shale	Underclay	Roofrock	AMD Sludge	Coal Waste	Coal Ash
REE	264.885	294.300	200.843	215.445	257.776	222.5829	195.0592	55.3867	135.6767	349.097797
REE+	303.022	359.633	277.518	255.570	315.232	270.1114	236.3746	66.5200	163.5767	442.164964
Lithium	46.442	23.767	18.050	44.350	46.869	217.3786	90.8692	54.2000	224.5667	202.362181

Sample Type

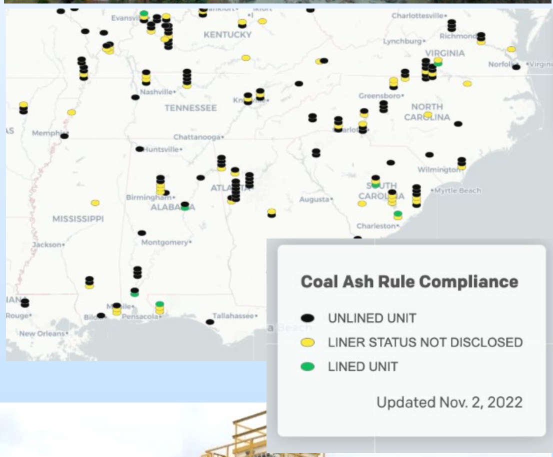
REE REE+ Lithium

Task 2 Accomplishments: Elemental Mapping by Micro-XRF



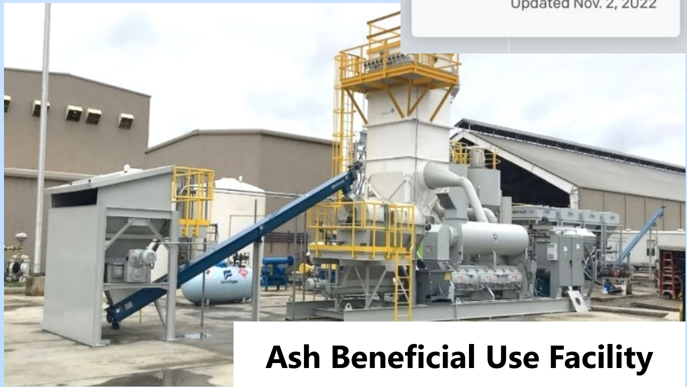
Task 3 Overview:
Ash resource assessment

- 219 million cubic yards of coal ash in AL-GA-TN stored in 58 surface impoundments
  - Vast majority operated by Southern Company and the TVA
  - Ongoing additions to impoundments represent the small amount of fly ash not sold for beneficial uses.



- 32 (~55%) are closed or operator has submitted a formal notice that it will stop dumping coal ash and begin the closure process in the near future.
  - 40 will leave the coal ash where it is and "capping" it with a cover (operator must continue care for at least 30 years)
  - 27 will excavate coal ash and transport it to a different disposal unit for permanent disposal

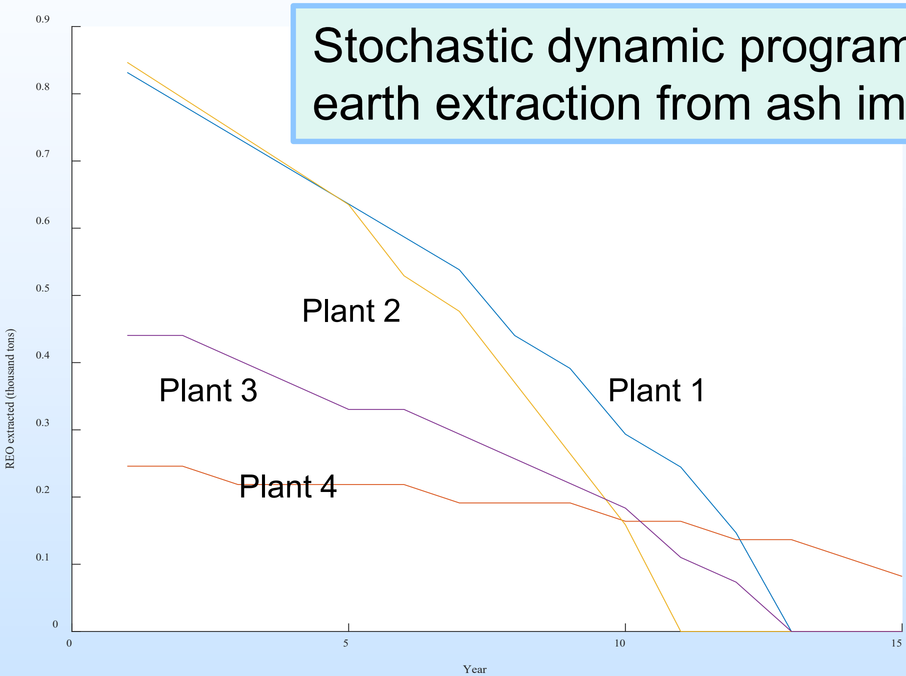
- Active ash beneficiation industry in the region

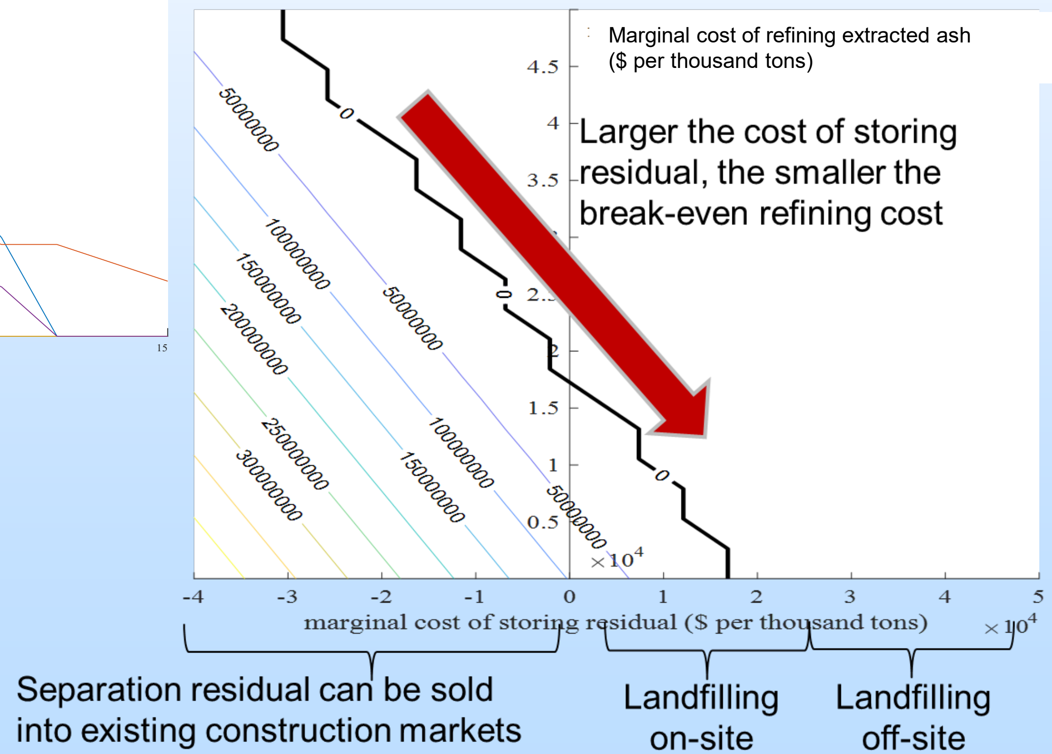

Ash Beneficial Use Facility

Task 3 Accomplishments:

Ash site valuation & cost targets

Stochastic dynamic programming model of profit-maximizing rare earth extraction from ash impoundments (solved via policy iteration)





Quantifies the economic need for novel separations techniques.

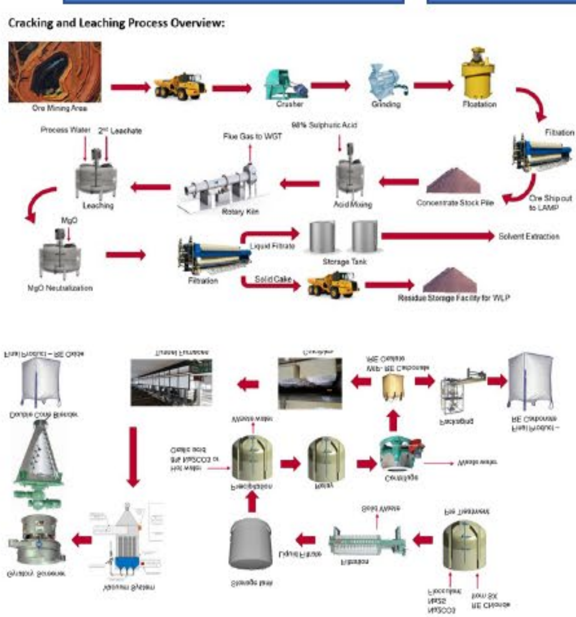
Task 4 Overview:
Integrated REE supply chain

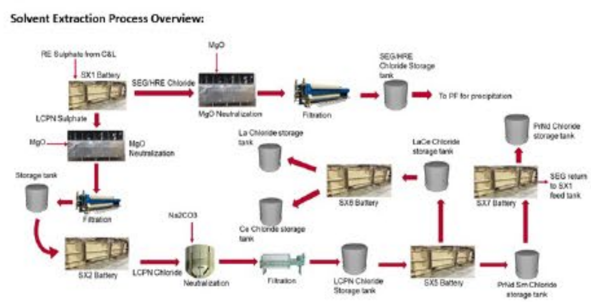
Non-traditional fossil waste feedstocks

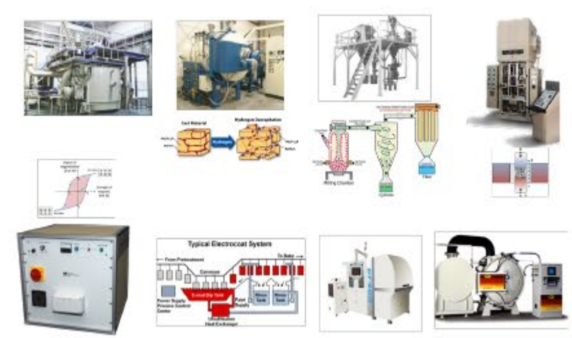
Diversify with US and allied suppliers

Chinese Global %

Mine	Mixed REE Concentrate	Separation	Reduction to metal	Alloying and Magnet Making
60%	60%	85%	75%	>80%





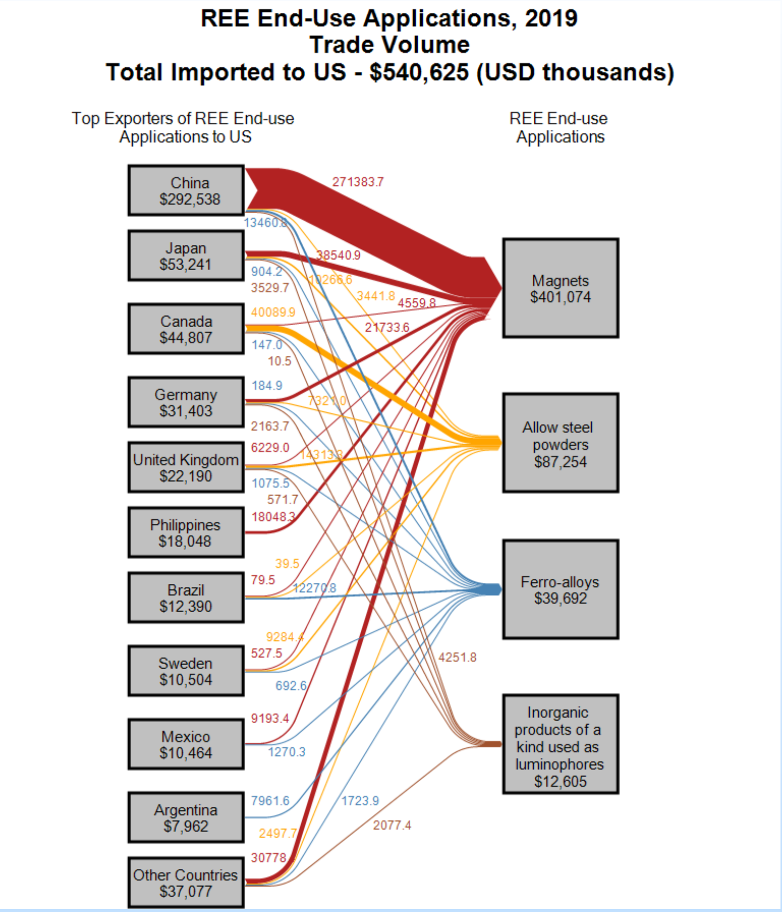


Task 4 Accomplishments:
Coal-REE supply chain modeling

- **Demo framework:** 35-industry U.S. IO accounts that report detail on *magnet-related CM-REE, strongly linked supply-chain industries*, and the rest of the economy
- Key data gaps:
  - output distributions
  - input recipes

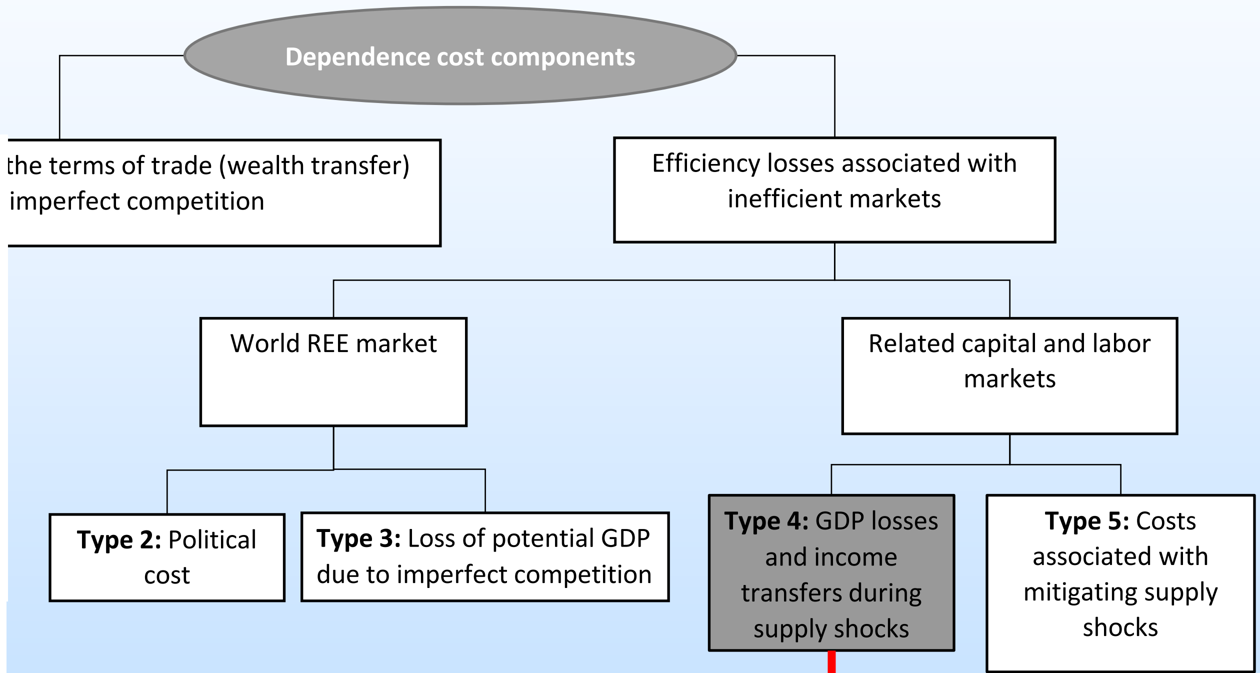
  Solution: CM-REE industry generated synthetically by extracting data from related industries'

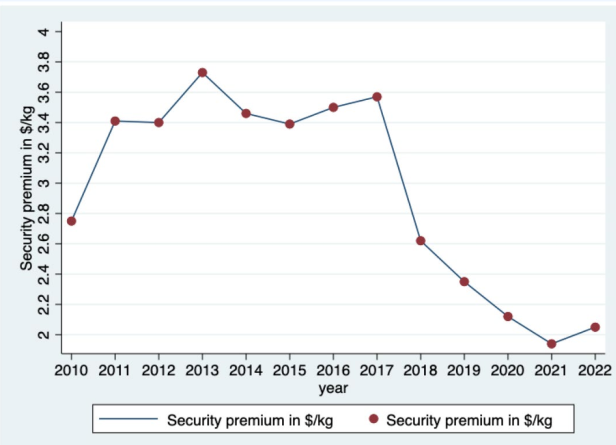
- **Questions we can now answer with refined data from Phase II project:**
  1. How much CM-REE output will be needed to support specified growth scenarios (by industry or economy-wide)?
  2. How much non-CM-REE output would be sacrificed if output is constrained?

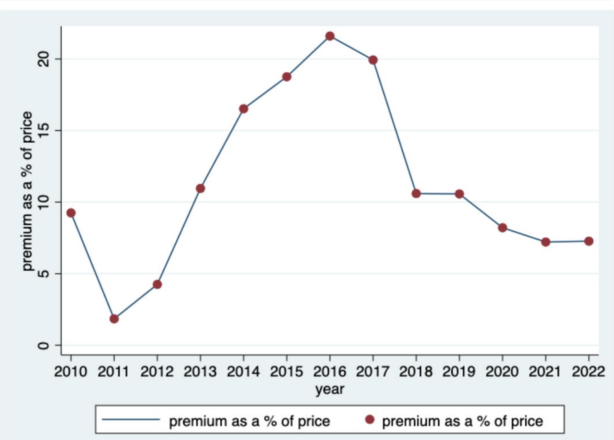


Task 4 Accomplishments:
REE dependence costs

Dependence cost: the loss of economic welfare that may arise from the U.S. consuming too much REE from foreign sources







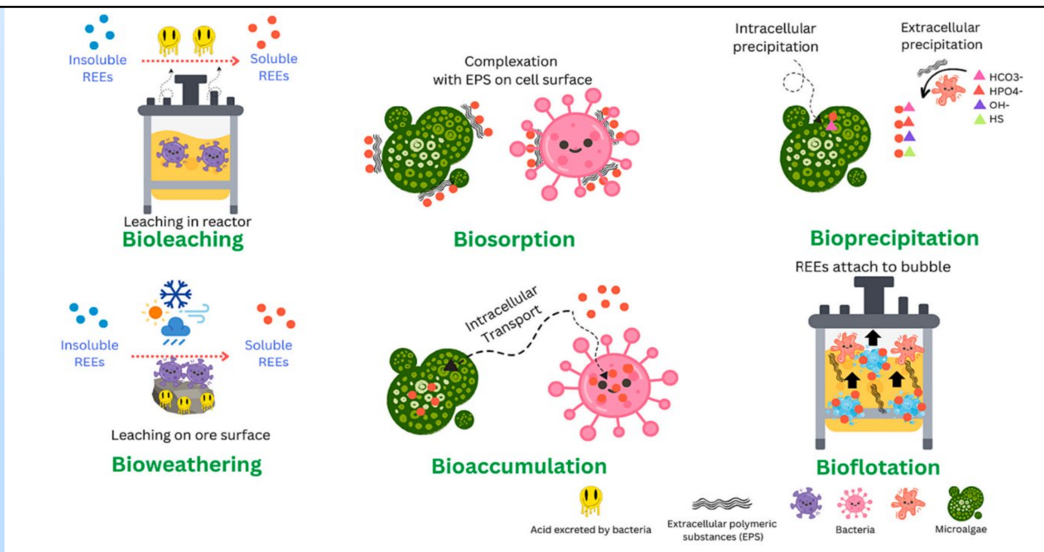
Assessing policy options:
1) Subsidize ROW or domestic supply
2) Impose tariff on Chinese imports equal to security premium
3) Impose quota on Chinese imports

Task 5 Overview:
Optimizing REE separations

Novel Separations Expertise

- Solvent extraction / ion exchange (ORNL)
- Biological processing (ORNL, UT)
- Electromagnetic processing (ORNL)
- Thermochemical (Nth Cycle, American Renewable Metals)
- HPC/AI-driven tools (UT)

Biomining Technology Capabilities: Exploits a microorganisms' biogeochemical processes to recover REEs



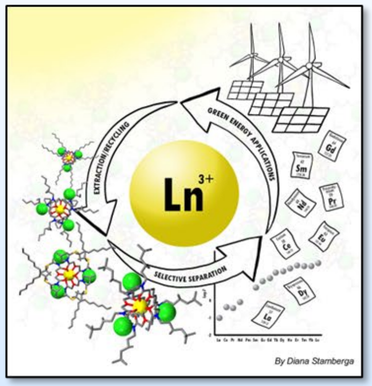
Biomining next steps:

- Fast screening of bacteria, algae and plant resources with several CFA sources
- Genome-wide association studies to identify genotype to REE absorption phenotype, molecular modeling REE absorption
- Genetic engineering to maximize REE recovery
- Process modeling
- TEA and LCA evaluation

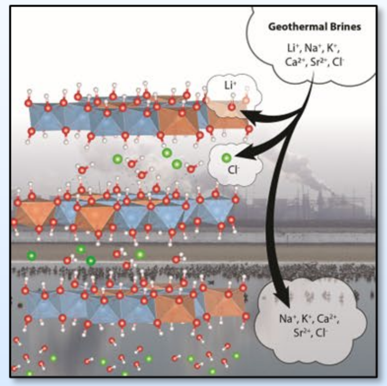
Task 5 Overview:
Chemical separations S&T

Chemical Separations S&T are in ORNL's DNA

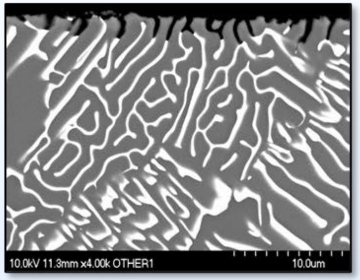
Graphite Reactor and Plutonium Separation (1944)



Diglycolamides to improve rare-earth element separation



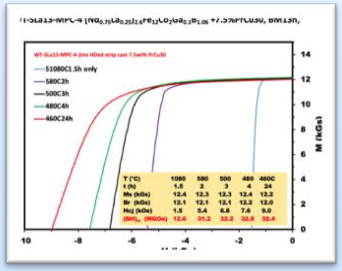
Li Al-layered double hydroxide (LDH) sorbent to recover Li from geothermal brines



Aluminum-Cerium Alloys

3D-printed Magnets

Electrochemical graphitization of coal-derived carbons



New Magnets

Robotic separation of batteries and magnets

From Brines and Mines to Magnets and Batteries

INNOVATION CROSSROADS at Oak Ridge National Laboratory

NTH CYCLE

Electro-extraction technologies for critical metals miners and recyclers

MOMENTUM TECHNOLOGIES

Membrane Solvent Extraction for recovering Co, rare-earths, and other Li-ion battery metals.

ReCell ADVANCED BATTERY RECYCLING

Cost-effective, flexible processes for recycling lithium-ion batteries

CMI

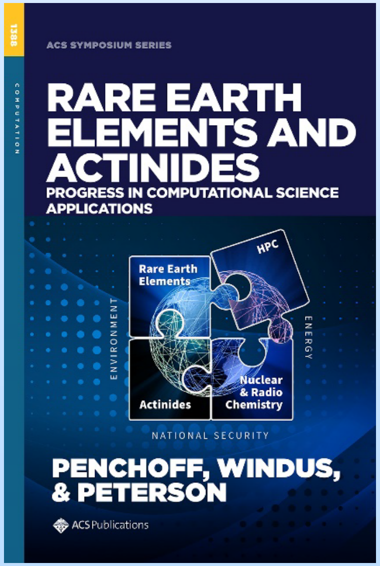
Critical Materials Institute

Task 5 Accomplishments: Optimization of REE Separations HPC/AI-driven Thermochemistry

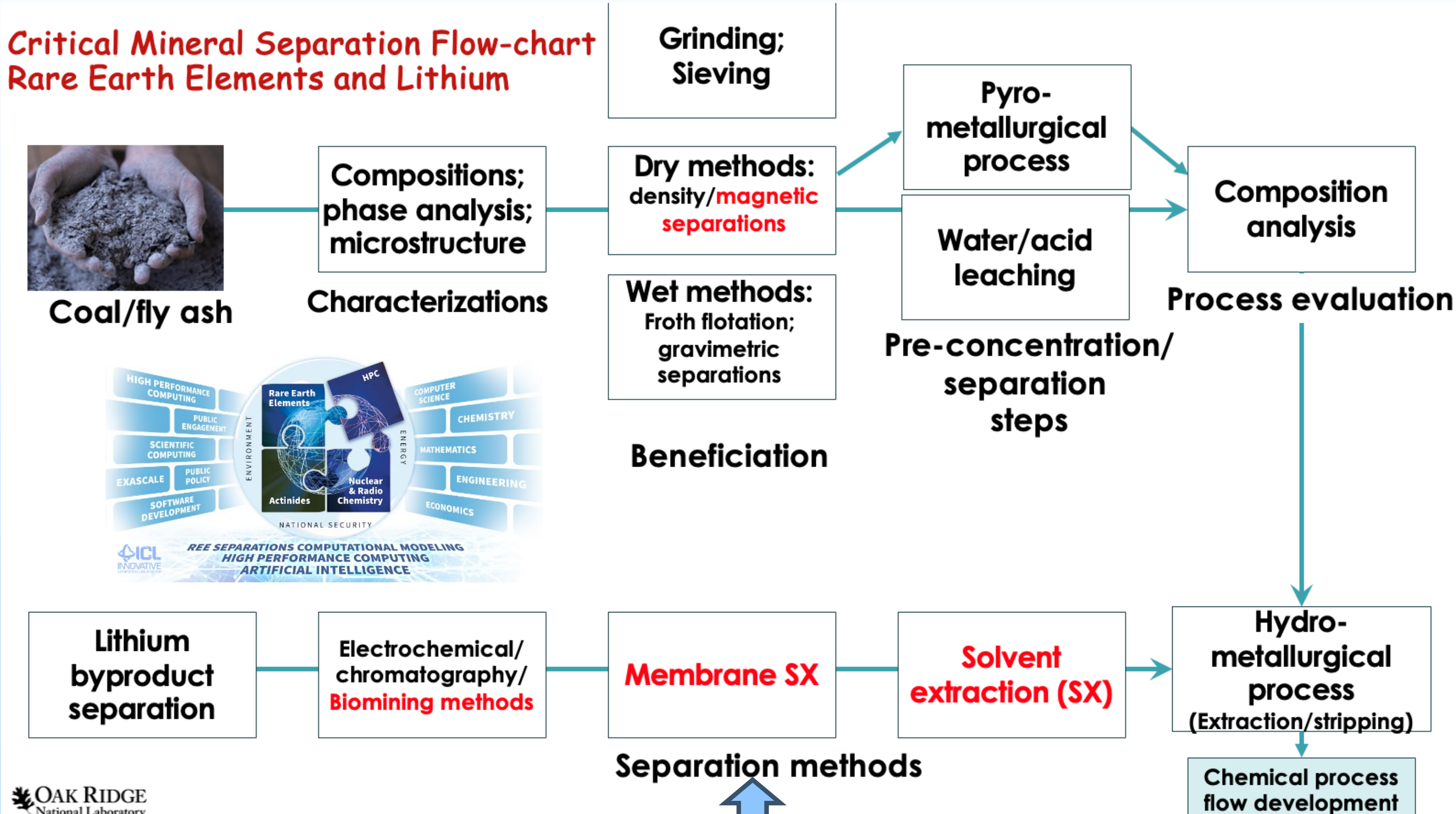
- **Predictive capabilities for binding selectivity**
  - We are utilizing REACKT to predict binding for optimization of separations of REEs
  - REACKT is currently being trained for solvent extraction and ion exchange separations.
    - Training has included 1000+ reactions relevant to REE separations (literature data)
    - Laboratory data from work in the team will be added to enhance the training of the AI algorithms.
  - Additional AI capabilities with REACKT will be evaluated to include separation techniques besides solvent extraction and ion exchange.
- **REACKT is an AI model designed to accurately predict reaction characteristics (such as logK values) involving REEs and actinides.**
  - It also contributes to a deeper understanding of the complex interactions between REEs and extracting agents
- **The HPC/AI efforts provide a synergistic flow in which the laboratory results inform the models, and the predictions from the model inform the optimization of separations.**

Developed by Peterson & Penchoff
https://icl.utk.edu/reackt/

REACKT
Rare Earth Actinides Constants & logK Thermodynamics



Task 5 Overview:
Combining separations techniques



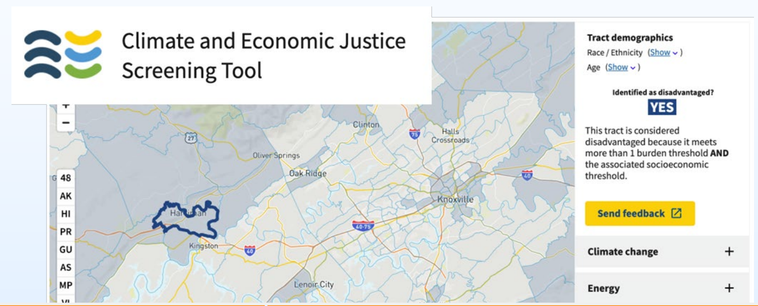
HPC/AI Targets:

- Optimize separations of REEs
- Understand REEs' behavior to find alternatives
- Provide fast predictions for market analysis, societal, and national security needs

Task 7 Accomplishments:
Public perception of CM extraction from CCR

Mixed-method approach to evaluate public perception of critical mineral extraction from coal waste, evaluating both worker and community health and safety.

- Semi-structured interviews with environmental and environmental justice organizations and labor unions representing utility employees.
- Survey of communities adjacent to coal ash impoundments in AL, GA, and TN (N=1,044).



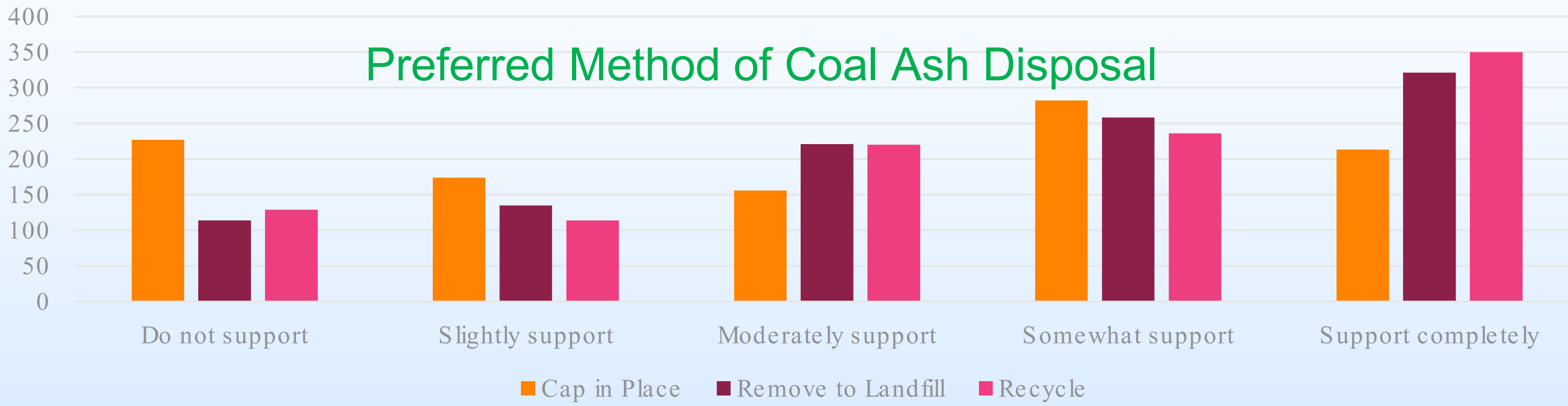
Using Climate and Economic Justice Screening Tool (CJEST) identified communities identified as disadvantaged.

State	Number of Coal Sites	Number in or Adjacent to DAC
AL	8	8
GA	8	3
TN	7	6

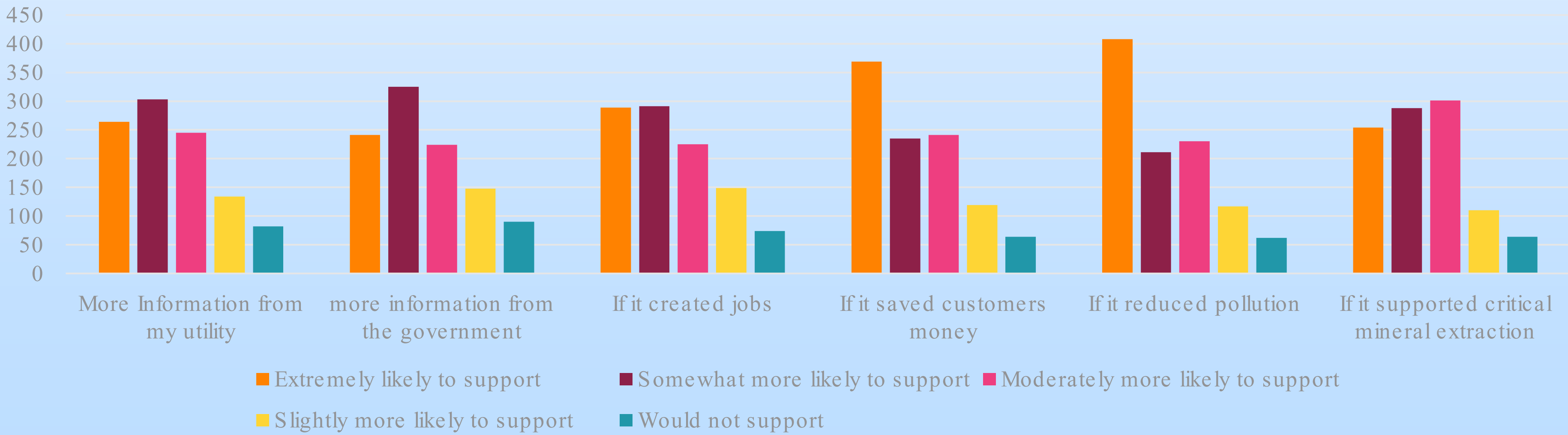
Need to understand how neighboring residents access information

Where respondents are extremely or somewhat likely to seek out about environmental issues in their community.	
Electric utility	44%
Water utility	44%
Local schools	34%
State government office or website	43%
Local government office or website	43%
Social media	48%
Local media (i.e. TV, radio, newspaper)	48%

Task 7 Accomplishments:
Public perception of CM extraction from CCR



Would any of the following make you more likely to support beneficial reuse of coal ash?



The 4 Rs of our Approach

Resource	• Coal ash (UA, Southern Co, TVA) • Acid mine drainage water and sludge (UA) • Underclays (UA) • Roof rock (UA)
Remediation	• Process cost threshold analysis (UTK, TVA, Southern Co) • Community surveys (UTK)
Refining	• Solvent extraction / ion exchange (ORNL) • Biological processing (ORNL, UT) • Electromagnetic processing (ORNL) • Thermochemical (Nth Cycle, American Renewable Metals) • HPC/AI-driven tools (UT)
Resiliency	• Coal-REE supply chain analysis (UTK, Econolyze) • REE security premium modeling (UTK) • Resilient infrastructure (UTK, Southern Company)

BAKER SCHOOL OF PUBLIC POLICY AND PUBLIC AFFAIRS · THE COMPOSITES iacmi INSTITUTE · THE UNIVERSITY OF ALABAMA · OAK RIDGE National Laboratory · Southern Company · TVA · Roane State Community College · UAB

Appendix

– These slides will not be discussed during the presentation but are mandatory.

Organization Chart

IACMI (Applicant – Managed by Collaborative Composites Solutions Corporation)
Geological Survey of Alabama (GSA)
Oak Ridge National Laboratory (ORNL)
Roane State Community College (RSCC)
Southern Company (SO)
Tennessee Geological Survey (TGS)
University of Alabama-Birmingham (UAB)
University of Alabama-Tuscaloosa (UA)
University of Tennessee-Knoxville (UTK)

Prime Recipient:
John Hopkins, CEO
IACMI

Principal Investigator:
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Baker Center for Public Policy
University of Tennessee

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Heather Castleberry, IACMI
Catherine Ross, IACMI

Task 2: Resource Assessment
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Marcella McIntyre-Redden, GSA
Barry W. Miller, TGS
Riley Flowers, SO

Task 3: Waste Stream Reuse
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Charles Sims, UTK
Eric Pierce, ORNL
Manoj Mahapatra, UAB

Task 4: Strategies for Infrastructure, Industries and Business
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Matthew Murray, UTK
Randall Jackson, EconAlyze
Deborah Penchoff, UTK
Jill Welch, UTK
John Hopkins, IACMI

Task 5: Technology Assessment
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Deborah Penchoff, UTK
M. Parans Paranthaman, ORNL
Manoj K. Mahapatra, UAB
Brian Pillay , UAB
Uday Vaidya , UTK

Task 6: Technology Innovation Center
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Charles Sims, UTK
Rona J. Donahoe, UA
Edgar Lara-Curzio, ORNL
Uday Vaidya , UTK
Brian Pillay , UAB

Task 7: Stakeholder Outreach and Education
Joannie Harmon, IACMI
Mark Morrison, IACMI
Kim Harris, RSCC
Teresa Duncan, RSCC
Nikki Luke, UTK

Supporting organizations

Alabama Abandoned Mine Land Reclamation Program	Gadsden State Community College (GSCC)
Alabama Power Company (APCo)	Microbeam Technologies Inc. (MTI)
Alabama Surface Mining Commission (ASMC)	Nth Cycle
American Coal Ash Association (ACAA)	TN Dept of Environment and Conservation (TDEC)
American Renewable Metals (ARM)	Tennessee Valley Authority (TVA)
Drummond Company	University of Utah
East Tennessee Development District (ETDD)	Wallace State Community College (WSCC)
Energy Technologies Inc. (ETI)	