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

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Project Overview

Funding (DOE and Cost Share): $1,982,746 (DOE $1,584,997; Cost share $397,749)

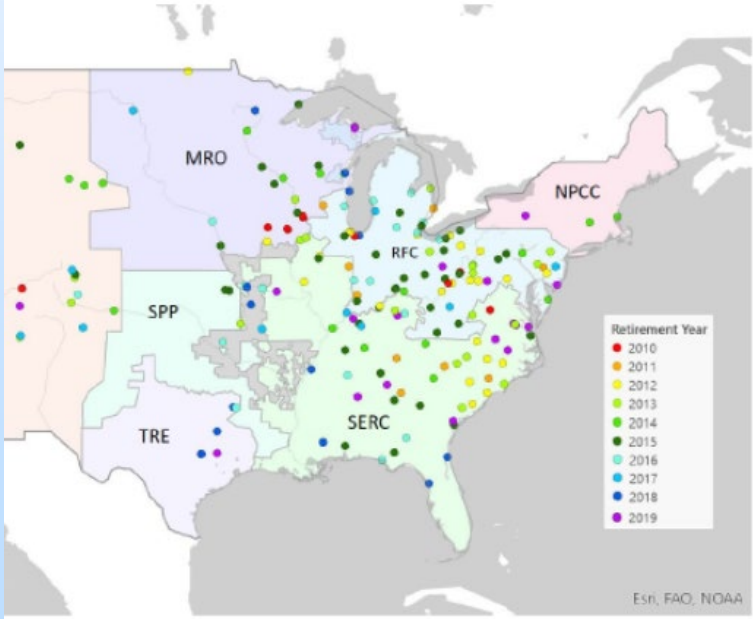
Overall Project Performance Dates: 9/15/2021 - 9/14/2023

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)

Overall Project Objectives: Develop and deploy new technologies for manufacturing rare earth elements (REE), critical minerals (CM), and valuable non-fuel, carbon-based products (CBP) from coal and/or coal waste in the SoApp Basin

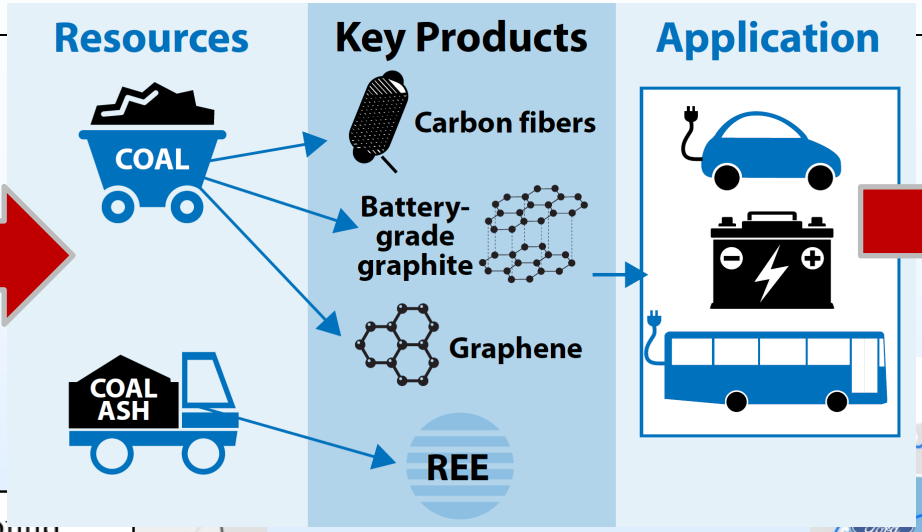
Broader Impacts:

- Revitalizing distressed SoApp coal communities
- Reducing reliance on foreign imports of REE and CM

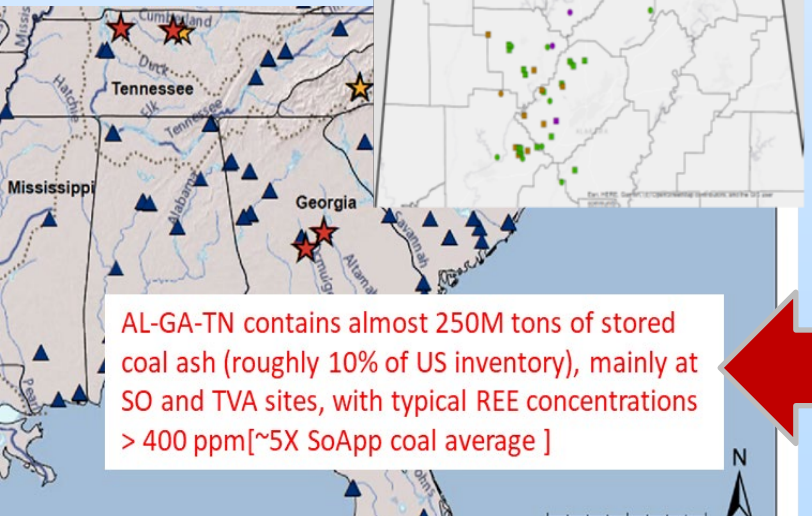


Coal-Fired Generator Retirements 2010-2020

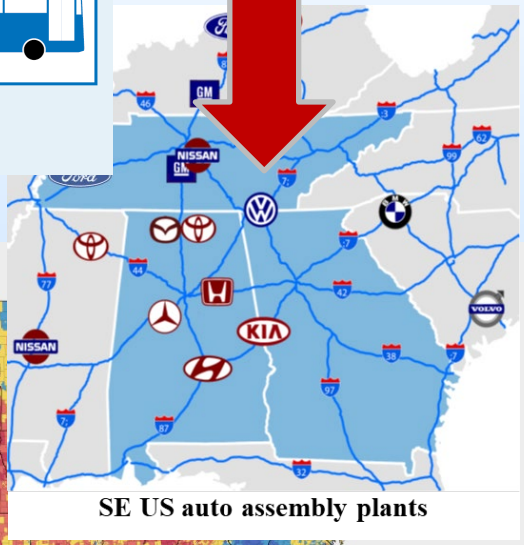
Unique Resource-to-application Ecosystem



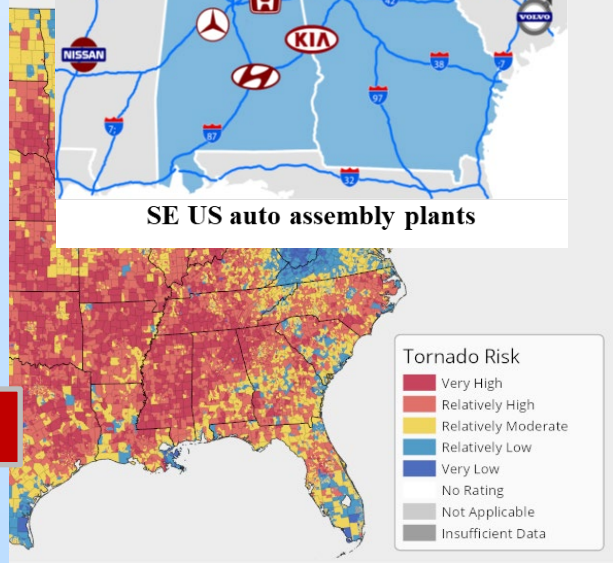
Coal surface and underground mines, coal preparation plants



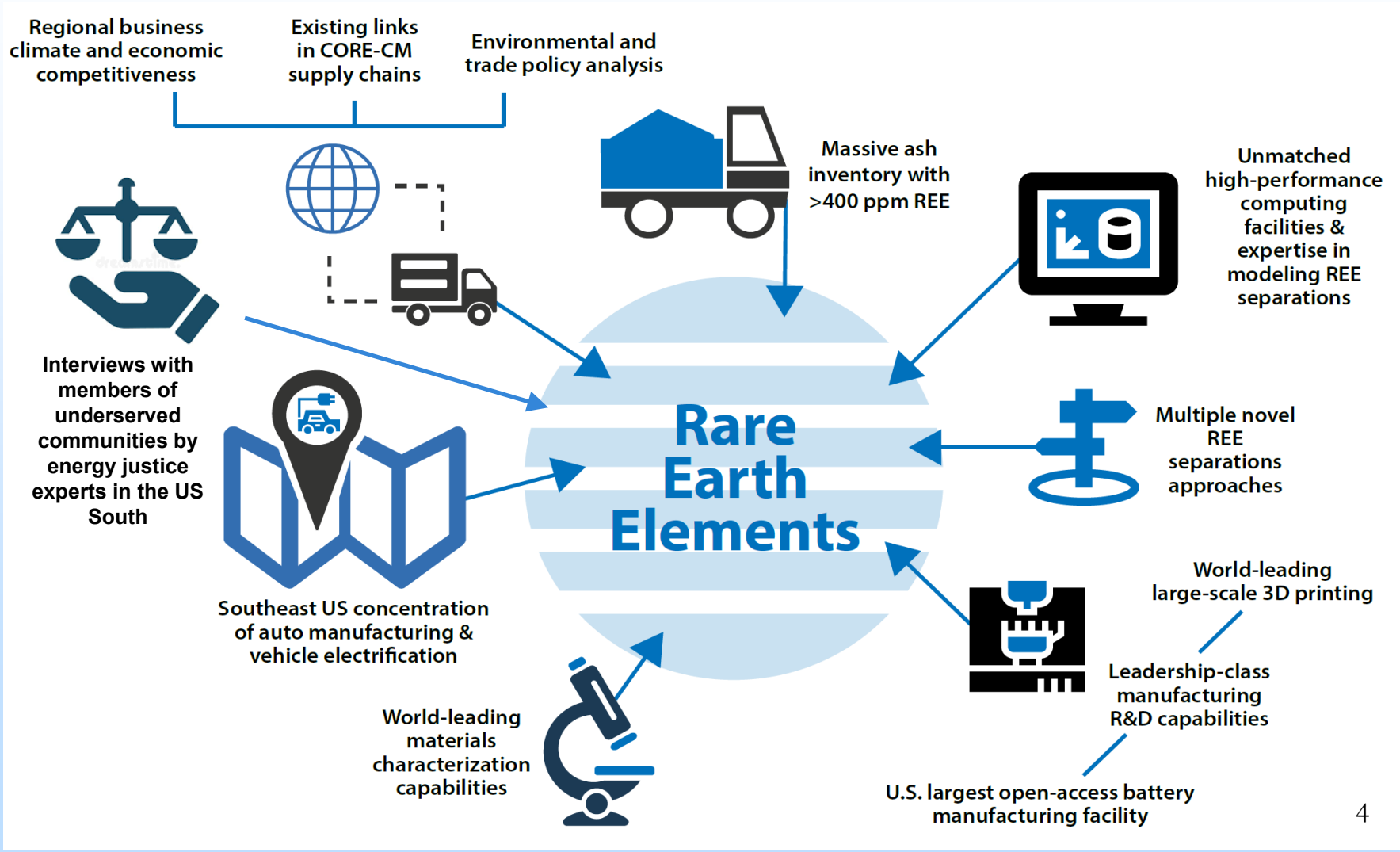
AL-GA-TN contains almost 250M tons of stored coal ash (roughly 10% of US inventory), mainly at SO and TVA sites, with typical REE concentrations > 400 ppm[~5X SoApp coal average]



SE US auto assembly plants



Notable Features of our Approach



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 TN coalfields including acid mine water discharge locations, coal mine refuse locations, and geologic and geochemical data. *(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)*

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)*

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*)

Progress: Resource Knowledge Gaps

- For Alabama, Georgia and Tennessee; 1045, 44 and 20 REE data records were retrieved, respectively, for coal and its associated sediments or wastes

- Evaluation of the compiled data revealed the following:
  - Georgia and Tennessee recorded a very low number of sampled materials
  - bituminous coal is the primary characterized sample type
  - only limited CM-REE data are available for coal-associated sediments and waste materials

Material	Number of Records
Coal	1086
Roof Rock	2
Seat Rock	4
Parting Rock	2
Shale	8
Top Bench	1
Bottom Bench	1
Refuse	5
Underclay	0
AMD (water and sludges)	0
TOTAL	1109

Progress: Resource Characterization

Underclay Samples

- only 4 of the 14 samples qualify as 'ore grade' REE materials (Total REE+Y+Sc ≥300 ppm)
- 4 samples have Li concentrations >300 ppm

Roof rock, AMD water and sludge sample analysis ongoing

Coal ash samples (NR = Not Reported; NA = Not Applicable)

ALABAMA CCP FACILITIES				
Plant Barry (N=6)	**REE (ppm)**	**REE+Y+Sc (ppm)**	**Li (ppm)**	**Co (ppm)**
AVG	206.5	290.2	NR	NR
STDEV	42.97	52.24	NA	NA
Plant Greene (N=16)				
AVG	392.8	499.7	234.6	48.01
STDEV	43.32	57.40	48.24	7.49
Plant Gorgas (N=65)				
AVG	411.6	535.2	NR	NR
STDEV	69.75	90.02	NA	NA
Plant Miller (N=13)				
AVG	385.1	466.0	235.6	32.70
STDEV	68.07	77.46	128.0	12.34
GEORGIA CCP FACILITIES				
Plant Bowen (N=21)	**REE (ppm)**	**REE+Y+Sc (ppm)**	**Li (ppm)**	**Co (ppm)**
AVG	510.4	631.8	201.8	52.64
STDEV	117.7	139.4	48.16	12.98
Plant Hammond (N=10)				
AVG	232.7	314.5	152.8	40.85
STDEV	65.07	81.93	58.68	9.656
Plant McDonnough (N=46)				
AVG	94.43	131.0	128.8	33.18
STDEV	46.92	58.37	30.52	7.210
Plant Wansley (N=10)				
AVG	335.1	426.7	114.8	43.01
STDEV	150.0	185.5	62.1	16.41

Progress: Ash Resource Assessment

- 219 million cubic yards of coal ash in AL-GA-TN stored in 58 surface impoundments (mostly FA with smaller amounts BA mixed in)
  - 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 the operator has submitted a formal notice that it will stop dumping coal ash into the unit and begin the closure process in the near future ("Notice of Intent to Close").
  - 40 will close the impoundment by leaving the coal ash where it is and "capping" it with a cover (operator must continue post-closure care for at least 30 years)
  - 27 will close the impoundment by excavating the coal ash and transporting it to a different disposal unit for permanent disposal

Progress: Ash Beneficial Use

- **Near term:** Primary current fly ash markets include cement production, concrete production (block, precast, and ready-mix), mine reclamation, and structural and roadway fills.
  - 92 concrete producers in AL-TN; mostly in Alabama.
  - 95 ready mix concrete producers in AL-TN.
  - Concrete/cement producers on average 70 to 115 miles from ash impoundment
- **Long term:**

Table 3. Long-term bottom ash applications

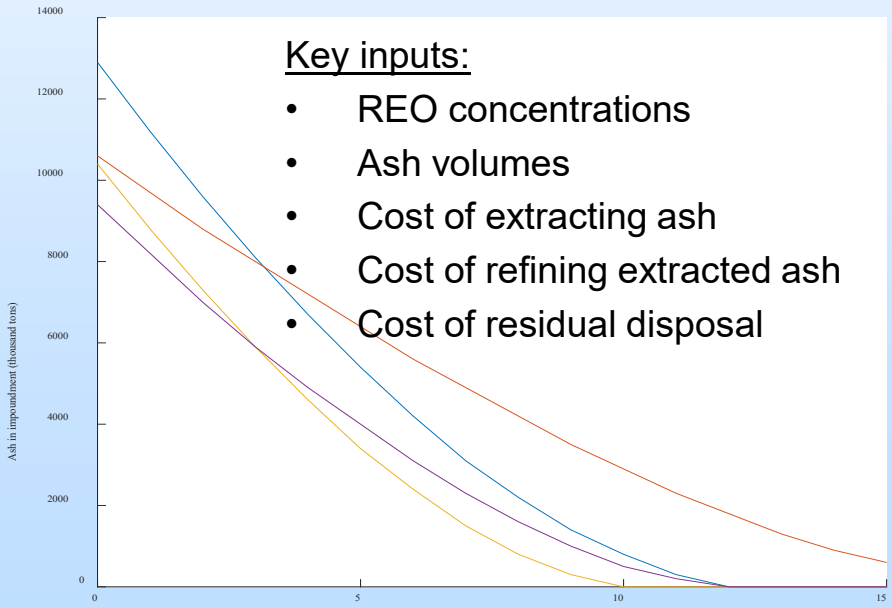
Application	Technology Status	Market Status*	Key Barrier(s)
REE	Developing	None	Technology readiness, needs co-products, imported REO & mined REE cost less
Asphalt		Limited	
Geopolymers (alternative concrete w/o cement)	Mature	Limited in US, used elsewhere esp Australia	Infrastructure, lack of stds, cautious construction industry
Masonry units (bricks, cinder blocks, pavers etc.)	Mature	Limited in US, used elsewhere esp India	Not well understood, merits investigation
Ceramic tiles	Mature	Limited in US, used elsewhere esp China	Not well understood, merits investigation
Furnace/kiln refractory liner	Mature	Limited	Not well understood, merits investigation
Fracking proppants	Promising	In development	Shipping cost, low-cost competing options, oil & gas market volatility
Zeolites (H2O treatment)	Developing	None	Technology readiness
Catalysts (alumina, silica)	Developing	None	Technology readiness
Polymer fillers	Developing	None	Technology readiness

*For products derived from coal ash; all of these markets are mature for products derived from other sources

Progress: Ash Pond Valuation Tool

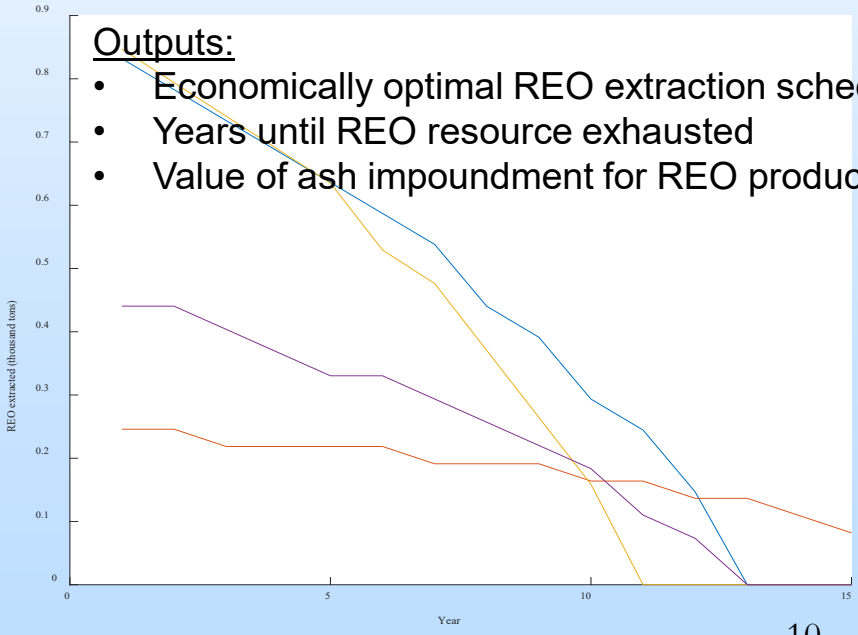
What are the economic feasibility goalposts?

- Dynamic programming model of profit-maximizing REO extraction from ash impoundments (solved via policy iteration)
- Implemented for all sampled impoundments in GA and AL



Key inputs:

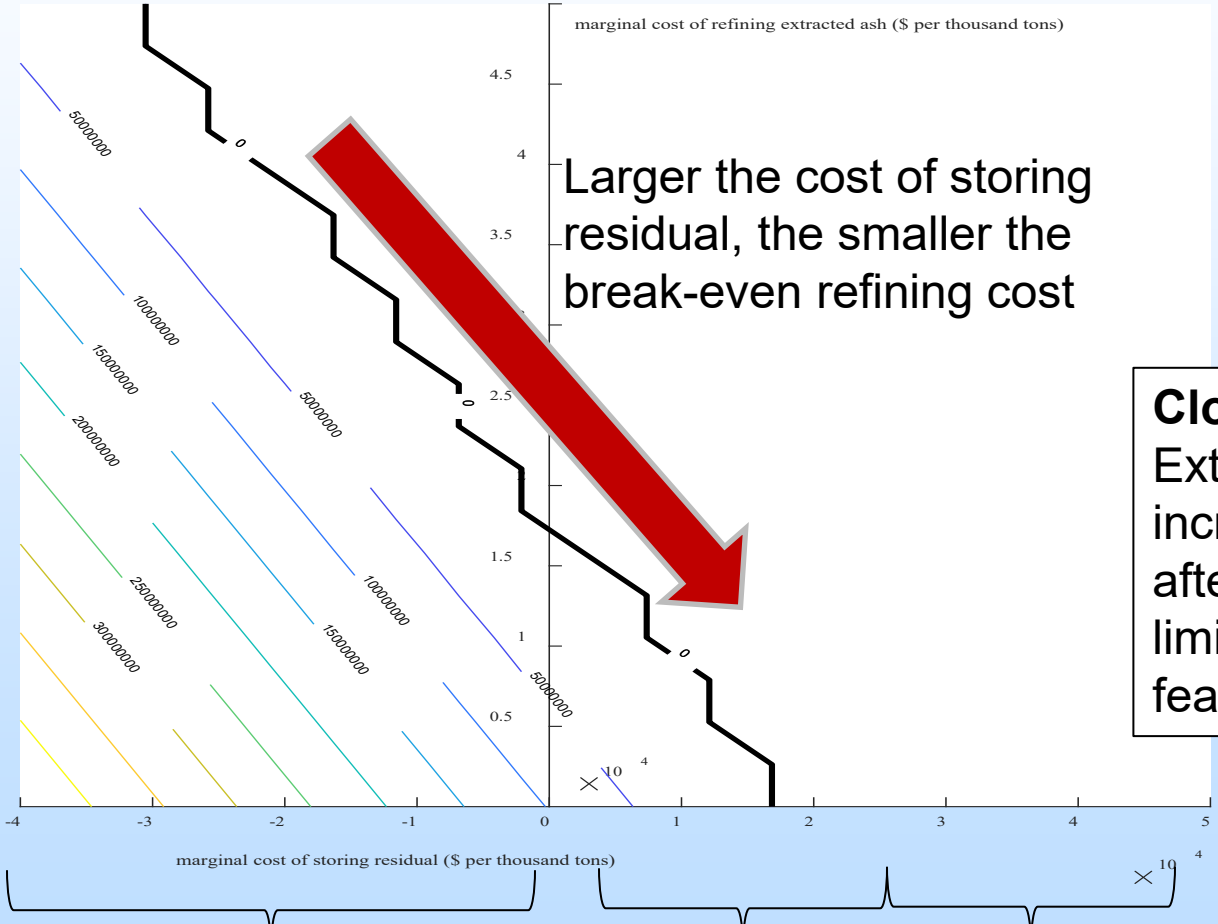
- REO concentrations
- Ash volumes
- Cost of extracting ash
- Cost of refining extracted ash
- Cost of residual disposal



Outputs:

- Economically optimal REO extraction schedule
- Years until REO resource exhausted
- Value of ash impoundment for REO production

Progress: Ash Pond Valuation Tool



Larger the cost of storing residual, the smaller the break-even refining cost

Clock ticking: Extraction costs increase drastically after CCR closure limiting economic feasibility

Separation residual can be sold into existing construction markets

Landfilling on-site

Landfilling off-site

Progress: Evaluations of Exascale enabling capabilities for prediction of REEs and actinides properties

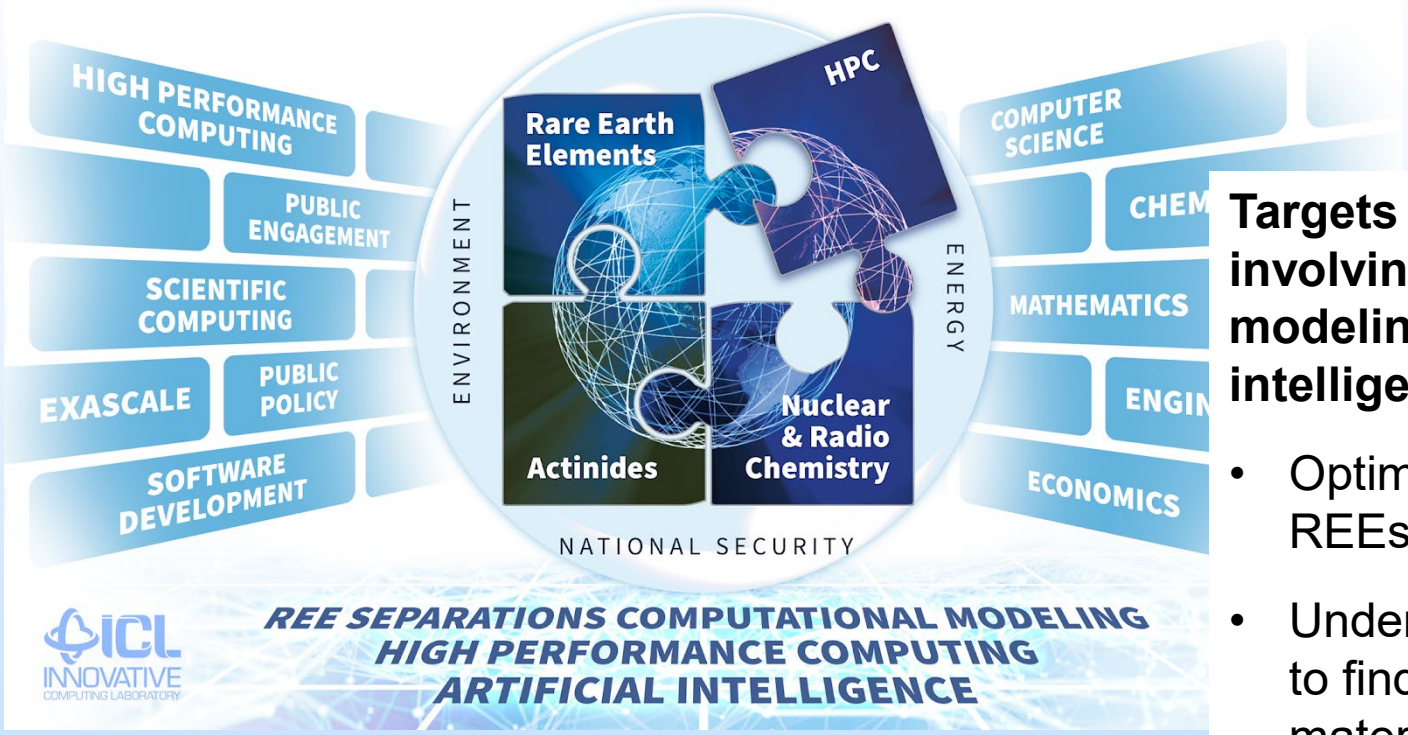


Figure adapted from Penchoff, et. al. *Rare Earth Elements and Actinides: Progress in Computational Science Applications.* Vol. 1388, Chapter 1, 2021. Graphics designed by David Rogers.

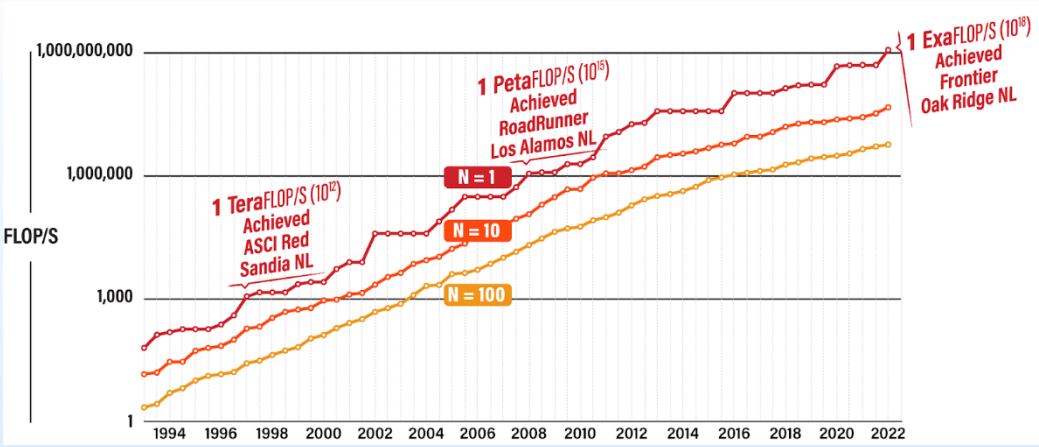
Targets and applications involving molecular modeling and artificial intelligence (AI) to:

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

Progress: Evaluations of Exascale enabling capabilities for prediction of REEs and actinides properties

High Performance Computing

- Out-of-balance hardware-software ecosystem.
- Limitations in modeling REEs and actinides.



Exascale-enabled applications

- Artificial intelligence
  - Algorithmic design and methods development.
  - Data set building, design, and bias analysis.
- Multi-disciplinary co-design of software products for Exascale-enabling capabilities.
- Molecular modeling software development to enable high performance and utilization of latest HPC resources.

Modeling targets

- Predictions of binding preferences for selective separations of REEs and actinides.
- Properties analysis and critical materials redesign.

Progress: Existing Business and Industry Structure

Sectors/products using one or more REE, CM and CBP

Product	NAICS Code
Catalysts	3251
Geopolymers (alumina, silica)	3271, 3273
Ceramic tiles	3271
Furnace/kiln liners	3271
Fracking poppants	3271, 3279
Zeolites (alumina, silica)	3271, 3251
Glass	3272
Nuclear reactor components	3324
Lasers	3335, 3345
Computer hard drives	3341
Xrays/MRIs/CT scan	3345
Lighting	3351
Electric motors	3352, 3363
Batteries	3359
Magnets	3359
Carbon fiber, fiber optics	3359
Graphite	3359, 3369, 3362, 3311
Graphene	3359

2020 Employment by NAICS and state

NAICS	NAICS Description	Alabama Employment	Alabama Percent of Total	Georgia Employment	Georgia Percent of Total	Tennessee Employment	Tennessee Percent of Total	AL-GA-TN Region Employment	AL-GA-TN Region Percent of Total	U.S. Employment	U.S. Percent of Total
2121	Coal mining	2,663	0.139	0	0.000	55	0.002	2,718	0.030	40,109	0.029
32											
32											
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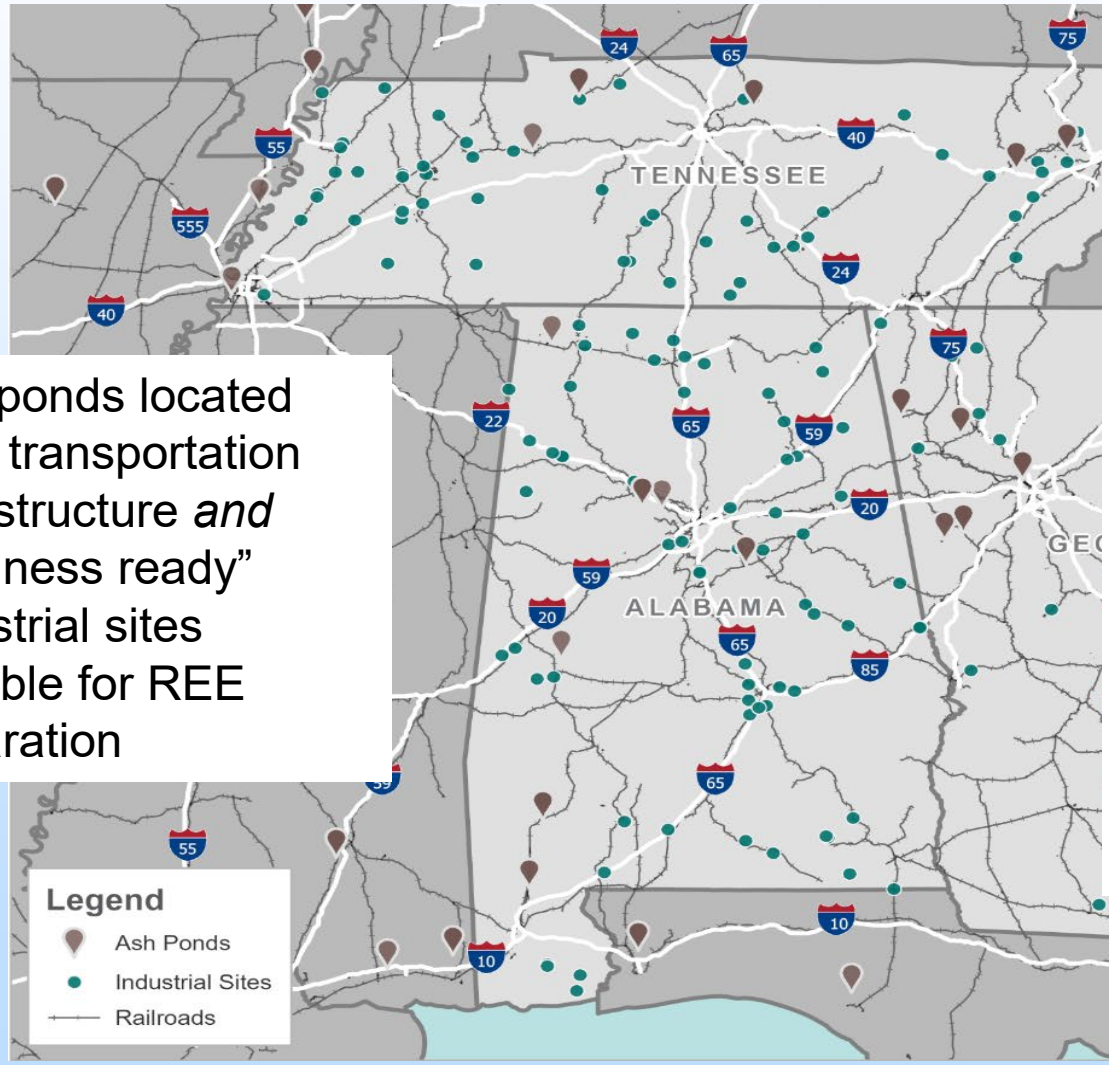
2020 Establishments by NAICS and state

NAICS	NAICS Description	Alabama Establishments	Alabama Percent of Total	Georgia Establishments	Georgia Percent of Total	Tennessee Establishments	Tennessee Percent of Total	AL-GA-TN Region Establishments	AL-GA-TN Region Percent of Total	U.S. Establishments	U.S. Percent of Total
2121	Coal mining	49	0.037	0	0.000	7	0.004	56	0.009	820	0.008
3251	Basic chemical manufacturing	78	0.059	92	0.030	94	0.055	264	0.043	3,384	0.032
3271	Clay product and refractory manufacturing	34	0.026	57	0.018	45	0.026	136	0.022	1,399	0.013
3272	Glass and glass product manufacturing	19	0.014	51	0.016	48	0.028	118	0.019	1,895	0.018
3273	Concrete and concrete product manufacturing	227	0.172	290	0.094	187	0.108	704	0.115	9,053	0.086
3279	Other nonmetallic mineral product manufacturing	91	0.069	217	0.070	122	0.071	430	0.070	4,010	0.038
3311	Iron and steel mills and ferroalloy manufacturing	27	0.020	26	0.008	31	0.018	84	0.014	903	0.009
3312	Steel works, blast furnaces and rolling mills	32	0.024	18	0.006	35	0.020	85	0.014	1,194	0.011
3324	Boiler, tank, and shipping container manufacturing	46	0.035	55	0.018	44	0.026	145	0.024	1,985	0.019
3335	Machine tool manufacturing	64	0.048	124	0.040	199	0.115	387	0.063	8,022	0.076
3336	Engine, turbine and power equipment manufacturing	27	0.020	34	0.011	22	0.013	83	0.014	1,292	0.012
3341	Computer and peripheral equipment manufacturing	25	0.019	63	0.020	20	0.012	108	0.018	1,890	0.018
3342	Telephone apparatus manufacturing (not cell phones)	36	0.027	69	0.022	35	0.020	140	0.023	2,443	0.023
3344	Semiconductor and other electronic component mfg	60	0.045	88	0.028	55	0.032	203	0.033	5,991	0.057
3345	Electromedical and electrotherapeutic apparatus mfg	95	0.072	208	0.067	171	0.099	474	0.077	9,120	0.087
3351	Electric lighting equipment manufacturing	12	0.009	55	0.018	33	0.019	100	0.016	1,695	0.016
3352	Household appliance manufacturing	7	0.005	20	0.006	40	0.023	67	0.011	576	0.005
3353	Electrical equipment manufacturing	45	0.034	116	0.037	76	0.044	237	0.039	2,884	0.027
3359	Other electrical equipment and component mfg	36	0.027	70	0.023	62	0.036	168	0.027	3,289	0.031
3362	Motor vehicle body and trailer manufacturing	55	0.042	83	0.027	62	0.036	200	0.033	2,264	0.022
3363	Motor vehicle parts manufacturing	203	0.154	154	0.050	273	0.158	630	0.103	5,765	0.055
3364	Aerospace product and parts manufacturing	87	0.066	109	0.035	38	0.022	234	0.038	3,510	0.033
3369	Other transportation equipment manufacturing	13	0.010	39	0.013	26.000	0.015	78	0.013	1,095	0.010
	Total for Selected NAICS	**1,368**	**1.035**	**2,038**	**0.658**	**1,725**	**1.000**	**5,131**	**0.835**	**74,479**	**0.710**

- AL, GA, and TN has a greater relative presence of industry sectors using or potentially using rare inputs than the nation.
- Region has the opportunity to be a major user of rare inputs, supporting industrial production and job creation and reducing dependence on rare input imports

Progress: Essential Infrastructure



Ash ponds located near transportation infrastructure *and* "business ready" industrial sites suitable for REE separation

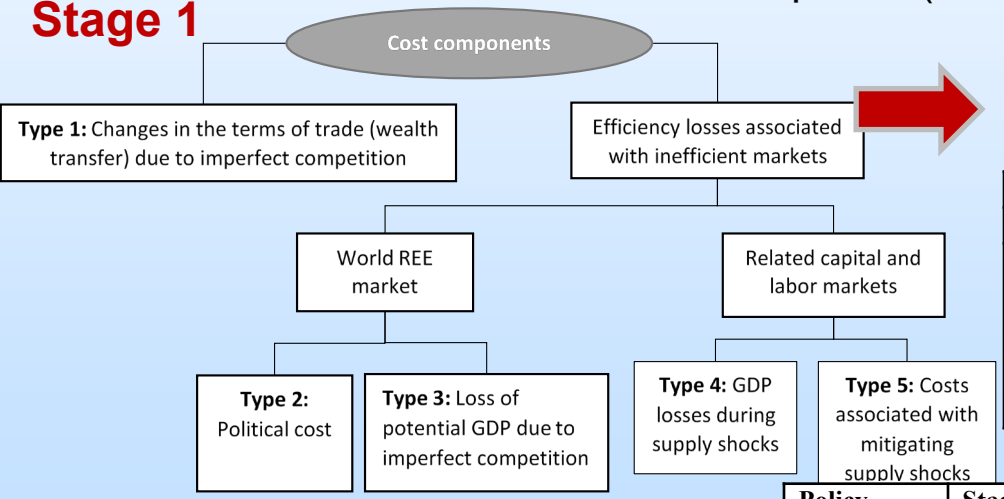
Models

1. *hub and spoke model:* move encapsulated ash from individual ponds or other storage sites to a central hub processing facility
2. *on-site processing and separation facility:* a mobile technology that could move from site to site on rail or truck beds

Progress: REE Security Costs

- Costs (>expenditures) that arise when prices are an imperfect signal of the true cost of imported REE *(cost savings from policies that diversify supply)*
  1. Price sensitivity of demand in the short and long run
  2. Supply responsiveness of non-Chinese producers who do not actively coordinate to exert market power (Brazil, Vietnam, India, Australia)

Stage 1



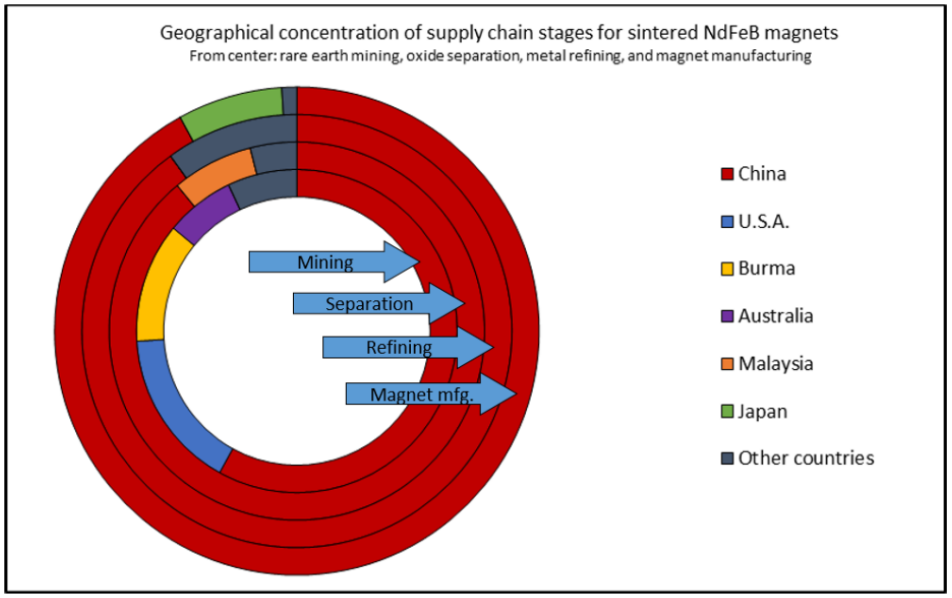
Stage 2

		Approach	
		Premium	Total Cost
Benchmark	Current state-of-the-world	Type A	Type B
	Hypothetical market absent all market failures	Type C	Type D

Policy	Stage 1	Context	Stage 2
REE import tariff	1,3	Motivate need for REE import tariff	C
		Set REE import tariff ($/ton)	A
		Evaluate impact of REE import tariff	B
Domestic REE production subsidy	1,3,4,5	Motivate need to increase domestic production	C
		Set subsidy for domestic oil production (capital expenditure credits, payroll tax reductions, below cost royalty payments)	A

Progress: Global REE Market Analysis

- Create market power index from dominant firm-competitive fringe model
- Bilateral trade flow data (UN Com Trade; Rare earth metals: HS 280530) and USGS REO production data



	Oil[1]	Rare earth metals[2]	Rare earth oxides[3]
Market power index (=1 monopoly; =0 perfect competition)	0.66	0.85	0

1 based on oil prices between 1986-2016
2 UN Com Trade data 2006-2019; Rare earth metals; HS 280530
3 USGS country-level production data 1994-2021

Outreach and Workforce Development Efforts or Achievements

- EJ Screening tools used to identify disadvantaged communities proximate to coal ash impoundments - John Sevier, Kingston, Widow's Creek (TVA); Gadsden, Gaston, Miller, Gorgas (Alabama Power); Bowen (Georgia Power)
  - On-site interviews with these communities ongoing
  - Initial reaction: genuinely excited about this possibility of coal ash reuse both for rare earth and cement but with concerns
- Op-Eds in regional newspapers on REE Global Markets and U.S. Import Reliance
- Public speaker series on REE markets and separations technologies at the Baker Center for Public Policy
- Private ash beneficial use workshop with regional utilities
- Workforce Development (IACMI) –
  - Advanced Composites Career Pathways Program (ACCP) for technician training
  - SkillCrafters STEM program
  - ACE CNC Machining Tool program AR/VR integration
  - Online learning modules

Summary from Southern Appalachia

Resource characterization

limited CM-REE data are available for coal-associated sediments and waste materials

'ore grade' REE materials (Total REE+Y+Sc $\geq$300 ppm) in 6 out of 8 ash impoundments sampled

Markets and Economics

Refining and residual storage cost goalposts for economic viability of ash impoundments as REO source

Analysis of global markets to reveal cost savings to US economy from domestic supply chains

Infrastructure and separations

Mobile separation technologies promising due to cost of transporting ash

Limitations in modeling REEs and actinides due to out-of-balance hardware-software ecosystem

Energy Justice and Stakeholder Outreach

On-site interviews at under-served communities near legacy sites

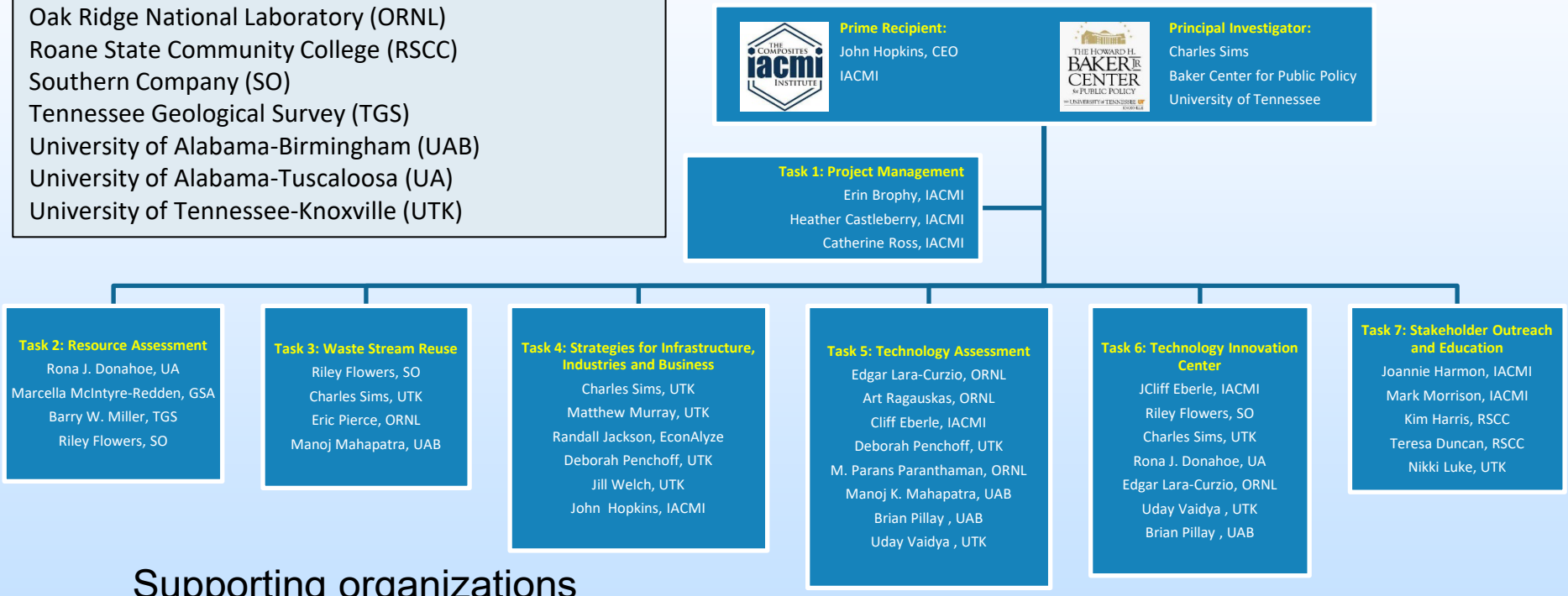
Initial excitement about possibilities

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)



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)	

Gantt Chart

Start date October 1, 2021