Mid-APPalachian Carbon Ore, Rare Earth and Critical Minerals (MAPP-CORE) Initiative

DE-FE-0032054

Dr. Paul Ziemkiewicz
WVU Energy Institute

U.S. Department of Energy
National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
October 25 - 27, 2022

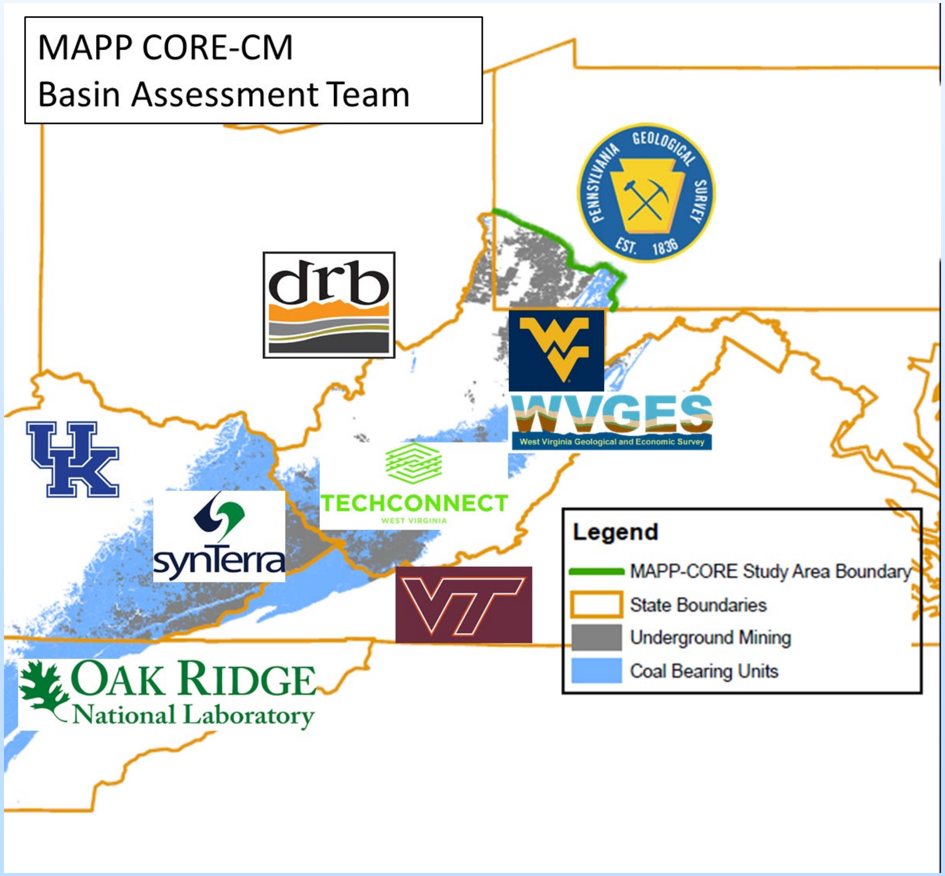
Mid-APPalachian Carbon Ore, Rare Earth and Critical Minerals (MAPP-CORE) Initiative

DE-FE032054

Period Of Performance: 10/01/2021 through 09/30/2023

Funding:

Govt. Share: *$1,585,000.00* Cost Share: *$617,128.00* Total: *$2,202,128.00*



Project Participants

- West Virginia University
- University of Kentucky
- Virginia Tech
- West Virginia Geological and Economic Survey
- Pennsylvania Geological Survey
- Kentucky Geological Survey (through UKY)
- DRB Geological Consulting
- Oak Ridge National Laboratory
- SynTerra Corporation
- TechConnect WV

Overall Project Objectives

Long-Term (Strategic)

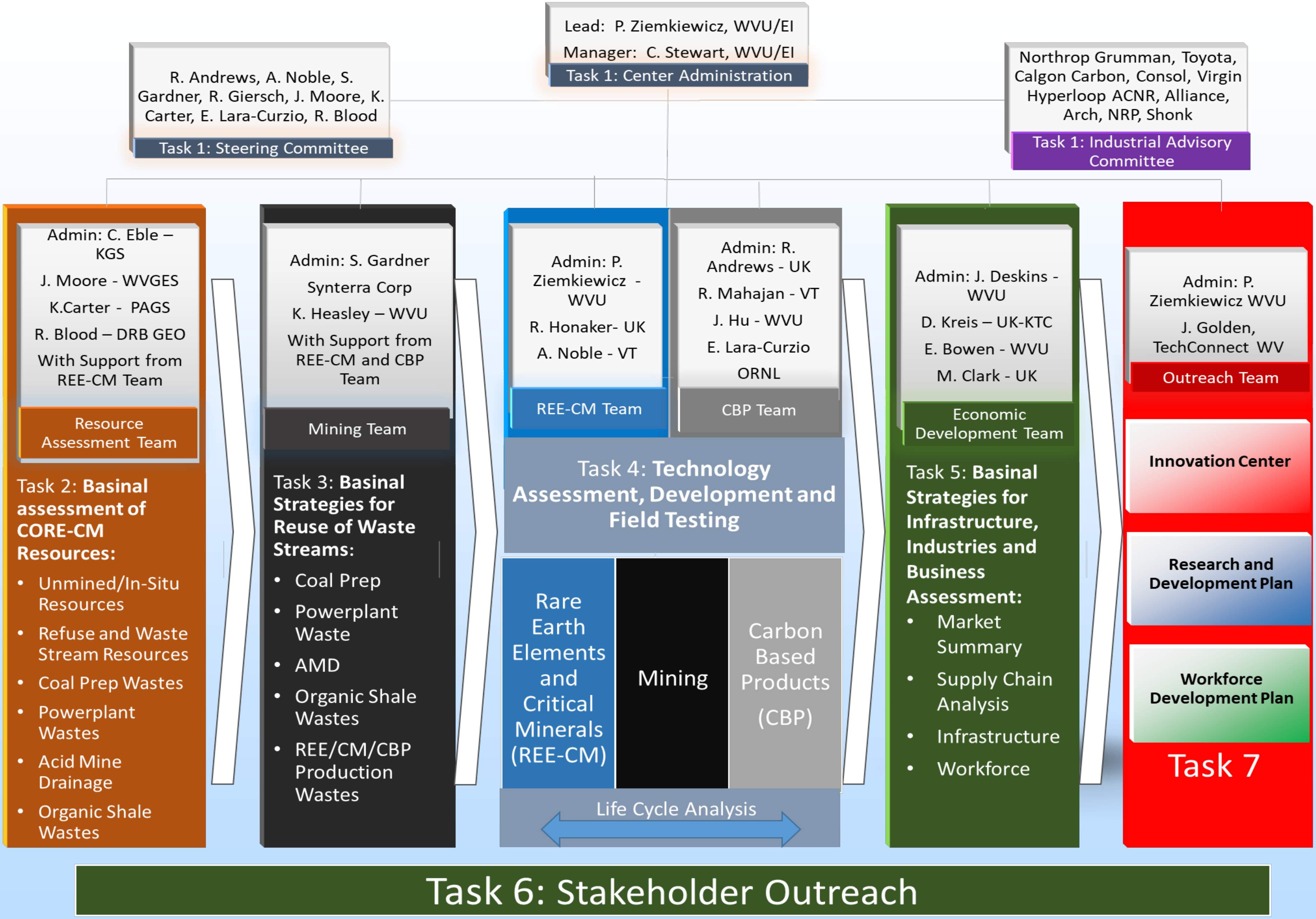
- development of commercial supply chains
- Identify “value-added” technologies
- Identify domestic supply chain gaps
- technology transfer, commercialization and deployment

Near-Term (Tactical)

- resource assessments
- Identify resource production technologies
- Identify key infrastructure resources and gaps
- Engage in-basin industrial/commercial partners

MAPP CORE Organizational Chart

CORE-CM Initiative for U.S. Basins DE-FOA-0002364



Lead: P. Ziemkiewicz, WVU/EI

Manager: C. Stewart, WVU/EI

Task 1: Center Administration

R. Andrews, A. Noble, S. Gardner, R. Giersch, J. Moore, K. Carter, E. Lara-Curzio, R. Blood

Task 1: Steering Committee

Northrop Grumman, Toyota, Calgon Carbon, Consol, Virgin Hyperloop ACNR, Alliance, Arch, NRP, Shonk

Task 1: Industrial Advisory Committee

Admin: C. Eble – KGS

J. Moore - WVGES

K.Carter - PAGS

R. Blood – DRB GEO

With Support from REE-CM Team

Resource Assessment Team

Task 2: **Basinal assessment of CORE-CM Resources:**

- Unmined/In-Situ Resources
- Refuse and Waste Stream Resources
- Coal Prep Wastes
- Powerplant Wastes
- Acid Mine Drainage
- Organic Shale Wastes

Admin: S. Gardner

Synterra Corp

K. Heasley – WVU

With Support from REE-CM and CBP Team

Mining Team

Task 3: **Basinal Strategies for Reuse of Waste Streams:**

- Coal Prep
- Powerplant Waste
- AMD
- Organic Shale Wastes
- REE/CM/CBP Production Wastes

Admin: P. Ziemkiewicz - WVU

R. Honaker- UK

A. Noble - VT

REE-CM Team

Admin: R. Andrews - UK

R. Mahajan - VT

J. Hu - WVU

E. Lara-Curzio ORNL

CBP Team

Task 4: **Technology Assessment, Development and Field Testing**

Rare Earth Elements and Critical Minerals (REE-CM)

Mining

Carbon Based Products (CBP)

Life Cycle Analysis

Admin: J. Deskins - WVU

D. Kreis – UK-KTC

E. Bowen - WVU

M. Clark - UK

Economic Development Team

Task 5: **Basinal Strategies for Infrastructure, Industries and Business Assessment:**

- Market Summary
- Supply Chain Analysis
- Infrastructure
- Workforce

Admin: P. Ziemkiewicz WVU

J. Golden, TechConnect WV

Outreach Team

Innovation Center

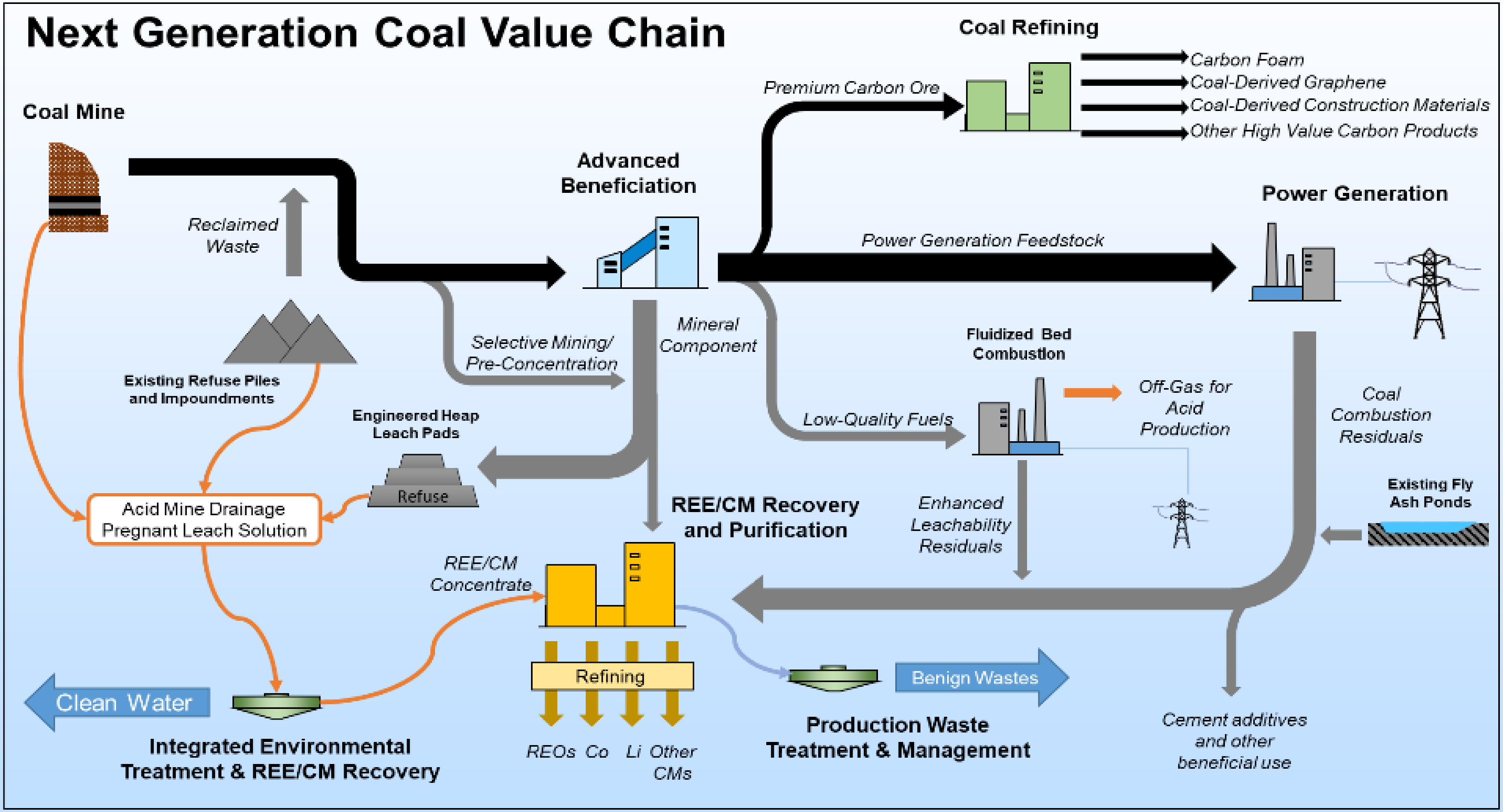
Research and Development Plan

Workforce Development Plan

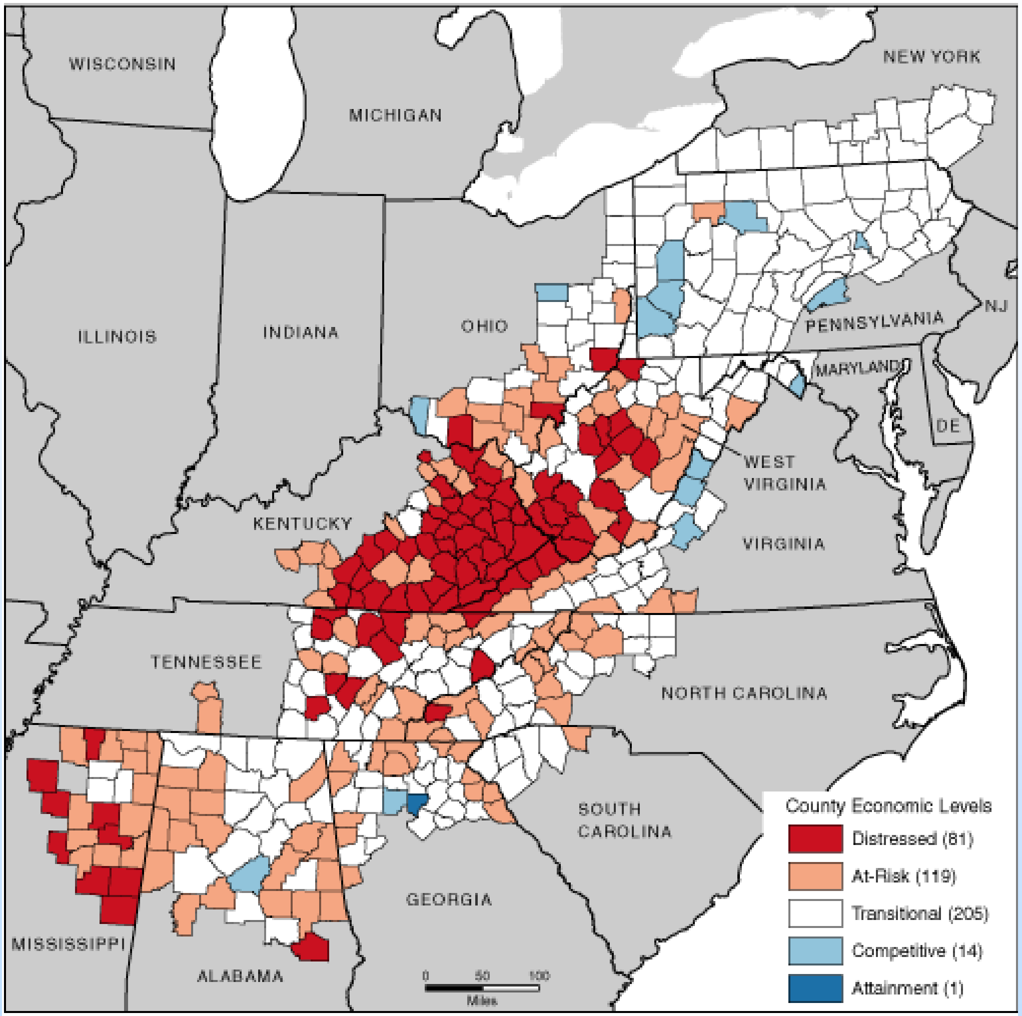
Task 7

Task 6: Stakeholder Outreach

Next Generation Coal Value Chain



MAPP-CORE Vision



Created by the Appalachian Regional Commission, August 2018
Data Sources:
Unemployment data: U.S. Bureau of Labor Statistics, LAUS, 2014–2016
Income data: U.S. Bureau of Economic Analysis, REIS, 2016
Poverty data: U.S. Census Bureau, American Community Survey, 2012–2016

Effective October 1, 2018
through September 30, 2019

- MAPP-CORE addresses
  - upstream production
  - midstream refining and processing
  - downstream manufacturing of high value products
- MAPP-CORE will identify
  - key barriers and opportunities in connecting raw materials and resources to end users and manufacturers
  - technical, workforce and economic considerations.
  - Directly addresses social justice through economic development
  - Directly addresses environmental justice concerns through focus on mine waste cleanup and site reclamation opportunities.
  - Specific projects will require additional analysis (outside the scope of this project)

Success Criteria

- Quantify resource base
  - Refuse
  - Coal ash
  - Acid mine drainage
  - Drill cuttings, shale
- Technology options
  - Handling, sorting
  - Remining, reprocessing
  - AMD treatment options
- Assess processing strategies
  - REE/CM enrichment
  - Carbon products upgrading
- Economic development
  - Workforce
  - Markets
  - Supply chain
  - Infrastructure

Resource Assessment

Focused on Economically Significant Coal Beds

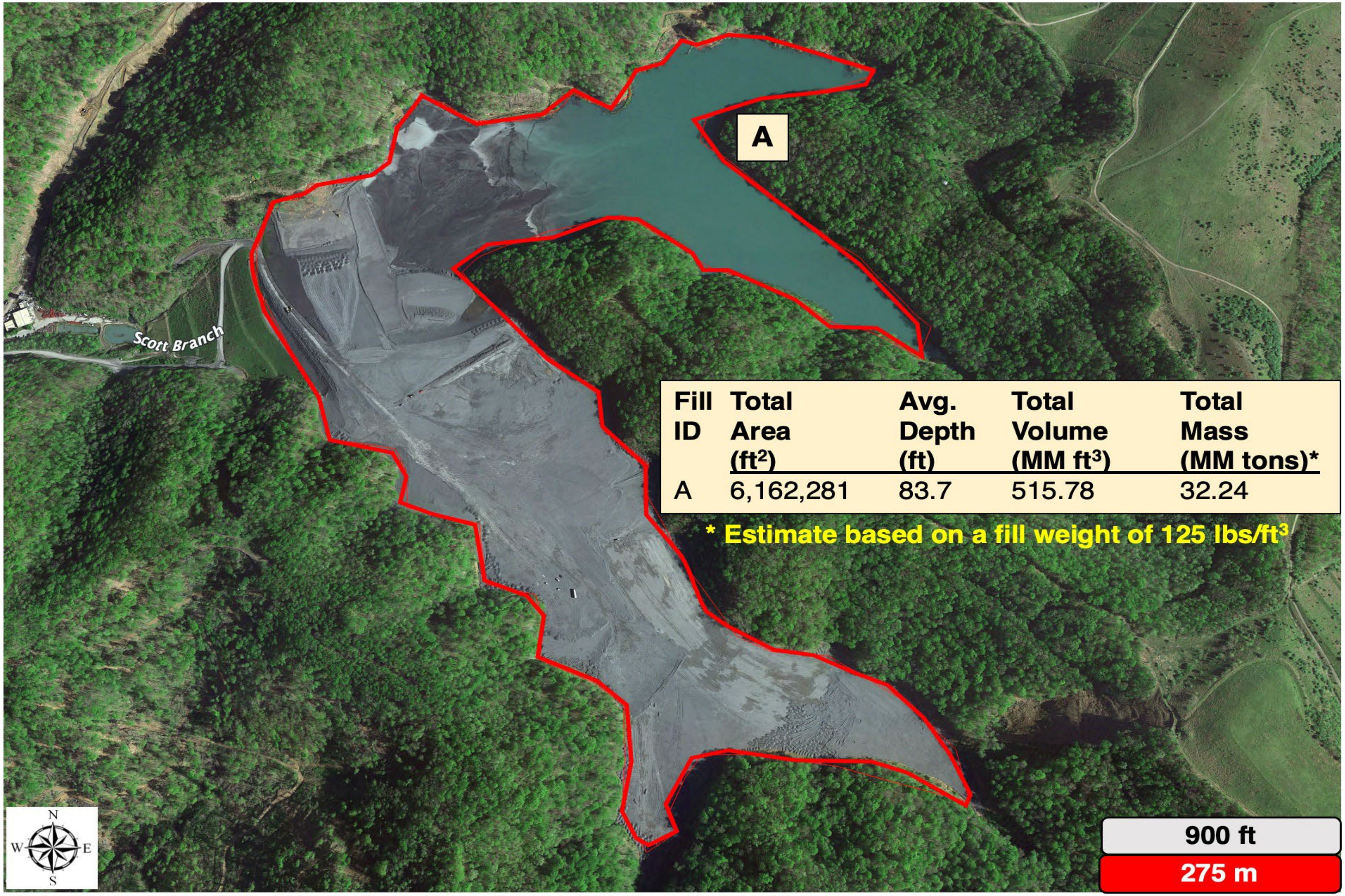
  - Current resource volumes for major coal seams
  - REE/CM Ratios are similar across the basin.
  - Total Waste Volumes can be estimated using consistent loadings and historic waste fractions.

- Significant Differences in Mineral Content and Loading Between Waste Streams
  - Coal Refuse – Gob/Overburden vs. Prep Plant Wastes

		Group / Formation			Eastern Kentucky Coal Beds	West Virginia Coal Beds	Western Pennsylvania Coal Beds
		WV	KY	PA			
Pennsylvanian	**Upper**	**Monongahela**	**Monongahela**	**Monongahela**	*Conemaugh + Monongahela strata present in NE Kentucky with no mineable coal*	Waynesburg	Waynesburg
						Sewickley	Sewickley
						Redstone	Redstone
						***Pittsburgh**	***Pittsburgh**
		Conemaugh	**Conemaugh**	**Conemaugh**		Little Pittsburgh	Little Pittsburgh
						Little Clarksburg	Little Clarksburg
					Harlem	Harlem	Harlem
					Bakerstown	Bakerstown	Bakerstown
					Brush Creek	Brush Creek	Brush Creek
	Middle	**Allegheny**	**Breathitt**	**Allegheny**	Princess No.9	Mahoning	Mahoning
					Princess No. 8	***Lower / Upper Freeport**	***Lower / Upper Freeport**
					Princess No. 7	Middle Kittanning	Middle Kittanning
					Princess No. 6	***Lower Kittanning / No. 6 Block**	***Lower Kittanning**
					Princess No. 5 a,b	Clarion / No. 5 Block	Clarion
					Princess No. 5	Little No. 5 Block	Brookville
		Kanawha		**Pottsville**	Hazard No. 9	***Stockton**	Upper Mercer
					Hazard No.8	***Coalburg**	Lower Mercer
					***Hazard No. 7**	Winifrede	
					Taylor	Chilton	Tionesta
					***Fire Clay**	Fire Clay	
					U. Whitesburg	Cedar Grove	
					L. Whitesburg	Alma	
					***Upper Elkhorn No. 3**	***No. 2 Gas**	Quakertown
					Upper Elkhorn No. 1,2	Powellton	
					***Lower Elkhorn**	***Eagle**	Sharon
	Lower				Manchester	Matewan	
		New River			Tunnel	Iaeger	*base of Pennsylvanian section in western Pennsylvania*
					Cumberland Gap	***Sewell**	
						Fire Creek	
		Pocahontas			*base of Pennsylvanian section in Kentucky*	Pocahontas No. 8	
						Pocahontas No. 7	
						Pocahontas No. 6	
						Pocahontas No. 5	
						Pocahontas No. 4	
						Pocahontas No. 3	
						Pocahontas No. 2	

***Economically significant coal beds**

MC Mining Preparation Facility Fill Area – Pike County, KY



Fill ID	Total Area (ft²)	Avg. Depth (ft)	Total Volume (MM ft³)	Total Mass (MM tons)*
A	6,162,281	83.7	515.78	32.24

* Estimate based on a fill weight of 125 lbs/ft³

Resource Assessment

Powerplant Wastes

- Estimates for mass are critical
- Heavy dependence on GIS techniques to estimate volumes/mass

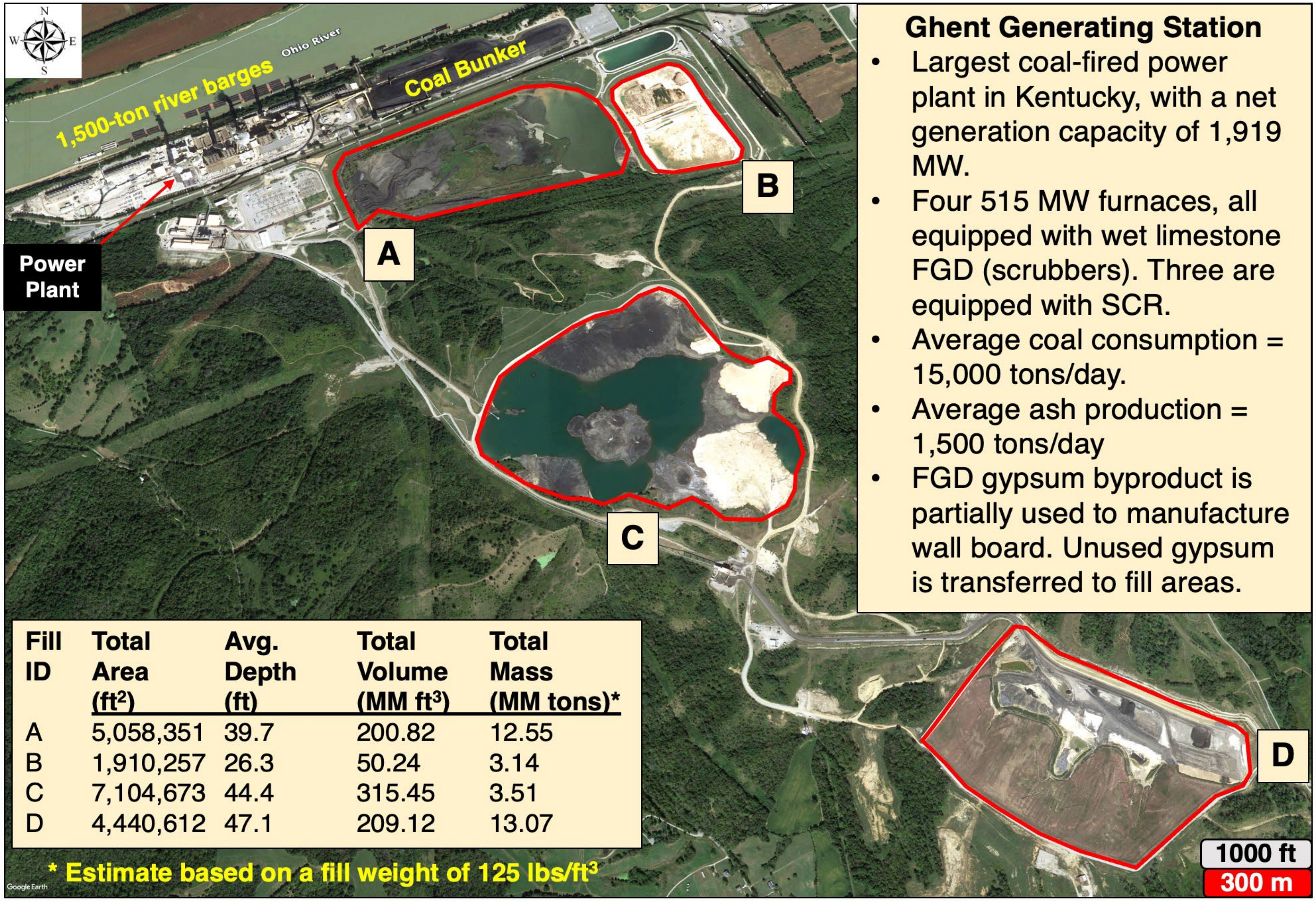
Acid Mine Drainage

- Major sources have been identified and in many cases quantified
- Perhaps the most “mature” resource assessment

Shale Wastes

- Shale waste discussion is likely to be dominated by new production.
- Black shales also have similar loadings across the basin
- “Production” will be a function of future gas development (hydrogen?)

Electric Power Generation - Ghent Generating Station, Ghent, KY



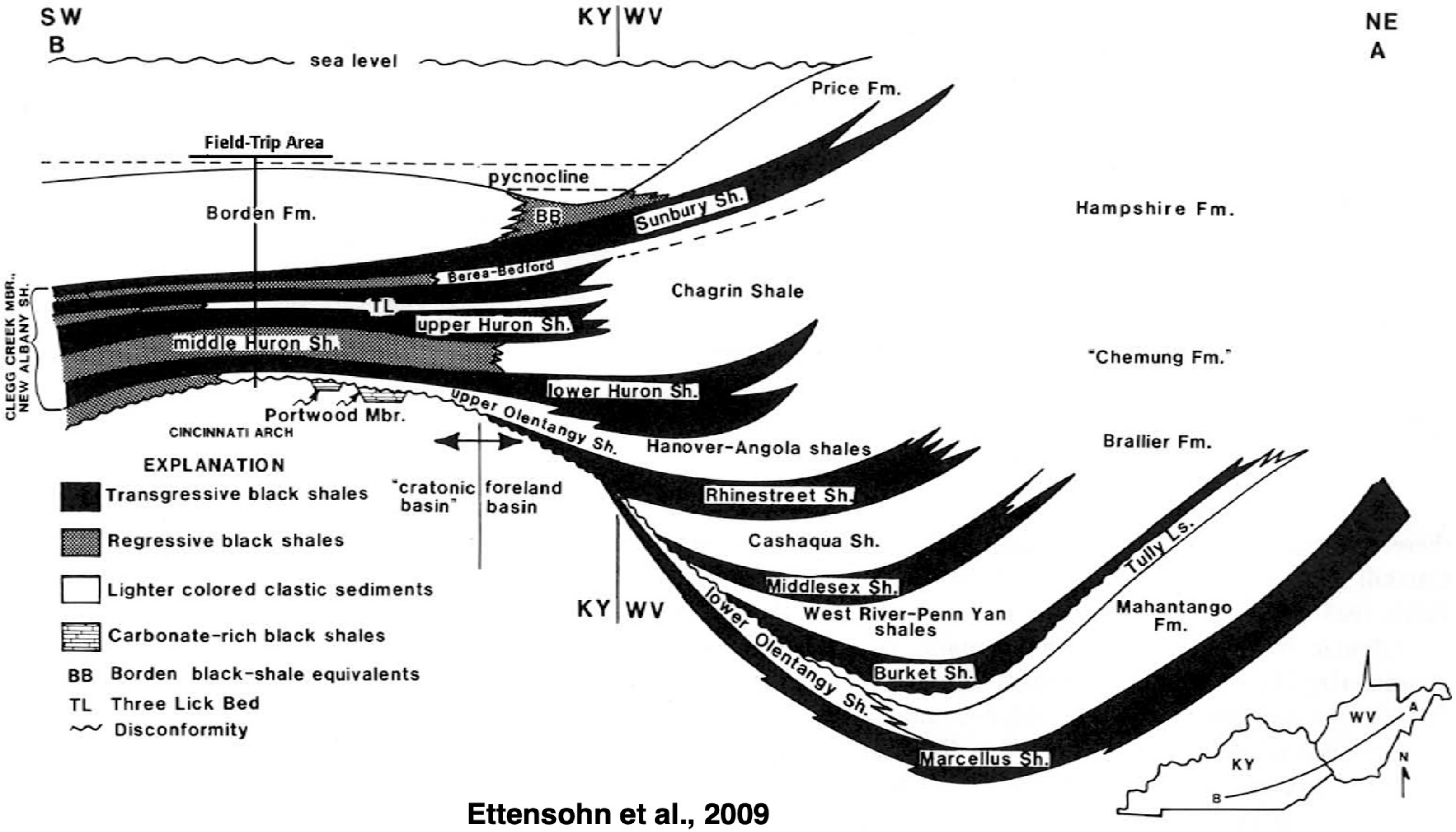
Ghent Generating Station

- Largest coal-fired power plant in Kentucky, with a net generation capacity of 1,919 MW.
- Four 515 MW furnaces, all equipped with wet limestone FGD (scrubbers). Three are equipped with SCR.
- Average coal consumption = 15,000 tons/day.
- Average ash production = 1,500 tons/day
- FGD gypsum byproduct is partially used to manufacture wall board. Unused gypsum is transferred to fill areas.

Fill ID	Total Area (ft^2)	Avg. Depth (ft)	Total Volume (MM ft^3)	Total Mass (MM tons)*
A	5,058,351	39.7	200.82	12.55
B	1,910,257	26.3	50.24	3.14
C	7,104,673	44.4	315.45	3.51
D	4,440,612	47.1	209.12	13.07

* Estimate based on a fill weight of 125 lbs/ft^3

Organic-Rich Black Shale Units in the Central Appalachian Basin



Ettensohn et al., 2009

Eastern Kentucky

Sunbury Shale

Ohio Shale

- *Cleveland Member*
- *Three Lick Bed*
- *U/M/L Huron Members*

West Virginia - Pennsylvania

Sunbury/Price/Pocono

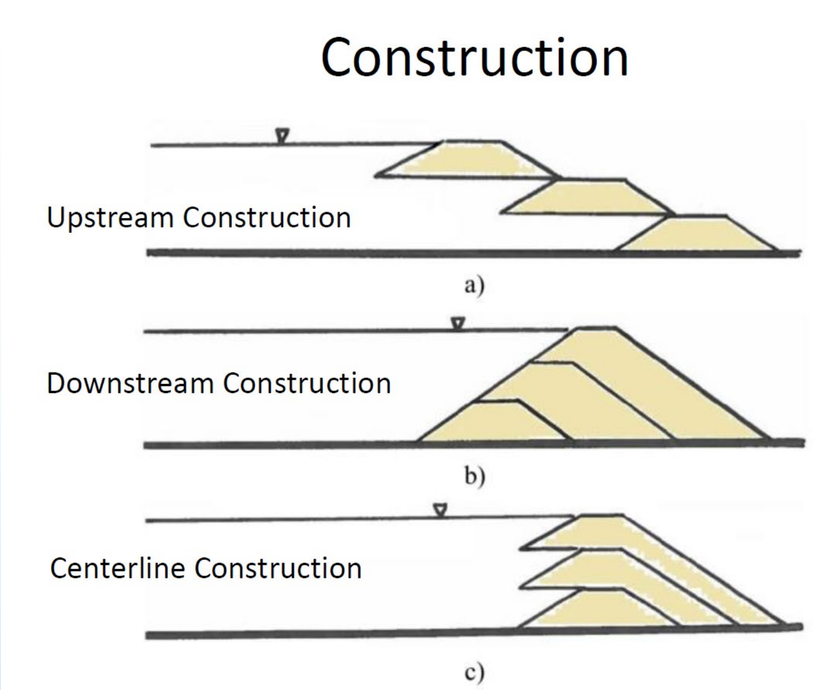
Ohio/Chagrin Shale

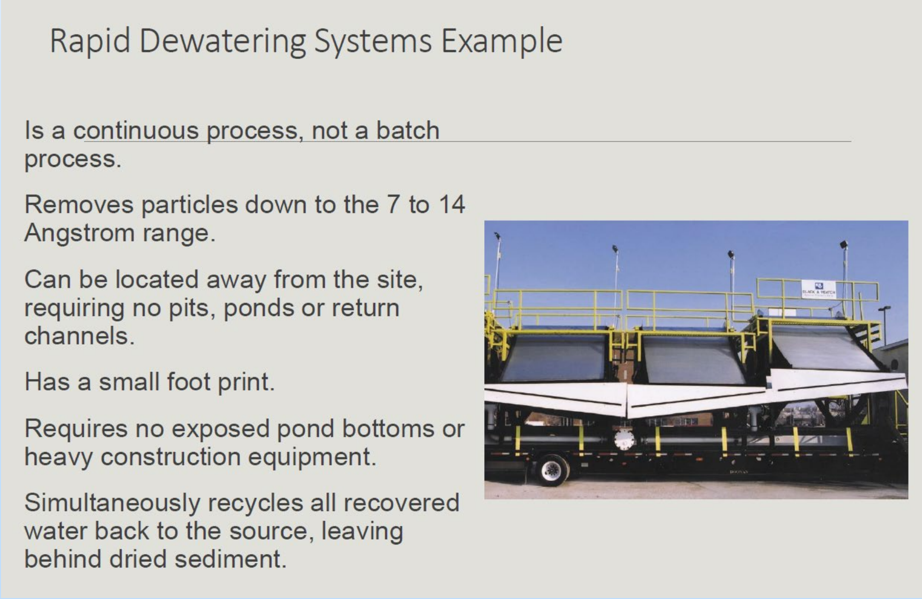
Rhinestreet + U/L Olentangy Shales

Middlesex + Burket Shales

Marcellus Shale

Waste Stream Processing





Rapid Dewatering Systems Example

Is a continuous process, not a batch process.

Removes particles down to the 7 to 14 Angstrom range.

Can be located away from the site, requiring no pits, ponds or return channels.

Has a small foot print.

Requires no exposed pond bottoms or heavy construction equipment.

Simultaneously recycles all recovered water back to the source, leaving behind dried sediment.

Significant Challenges in Waste Stream Processing

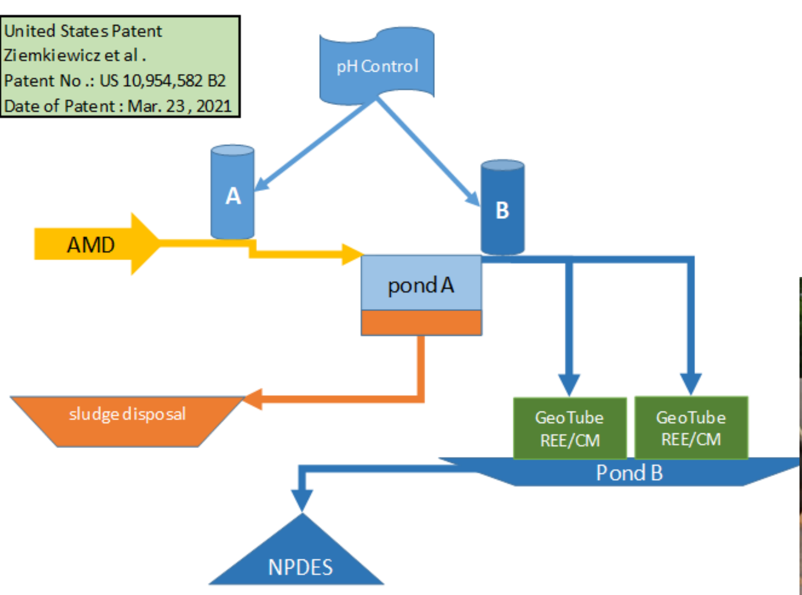
- Deconstruction of Impoundments
  - Prep Plant and Coal Ash Impoundments
  - Significant geotechnical difficulty in deconstructing these structures safely
- Permitting of reprocessing/remining has significant liability considerations

Waste Stream Processing

Significant Challenges in Waste Stream Processing

- Gob Piles Are Often Burned Out
  - Spontaneous combustion
- What is ultimate fate of re-mined/reprocessed wastes?
  - Significant mass/volume remain after REE/CM extraction. Physical space and disposal is a concern
- AMD processing provides bright spot
  - Non-hazardous wastes
  - Benign materials handling

REE/CM Production Technologies


United States Patent
Ziemkiewicz et al.
Patent No.: US 10,954,582 B2
Date of Patent: Mar. 23, 2021

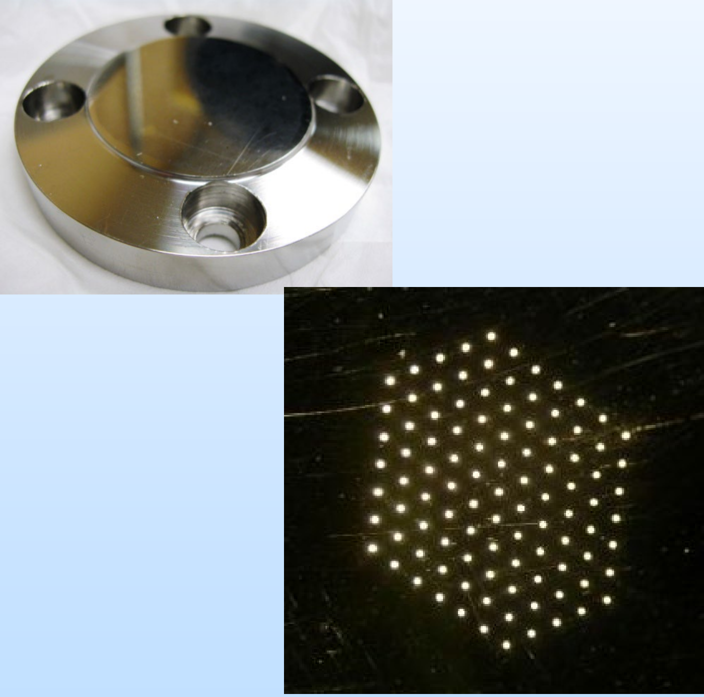
Remote site AMD treatment / REE/CM capture

Summary: Feedstocks/processing

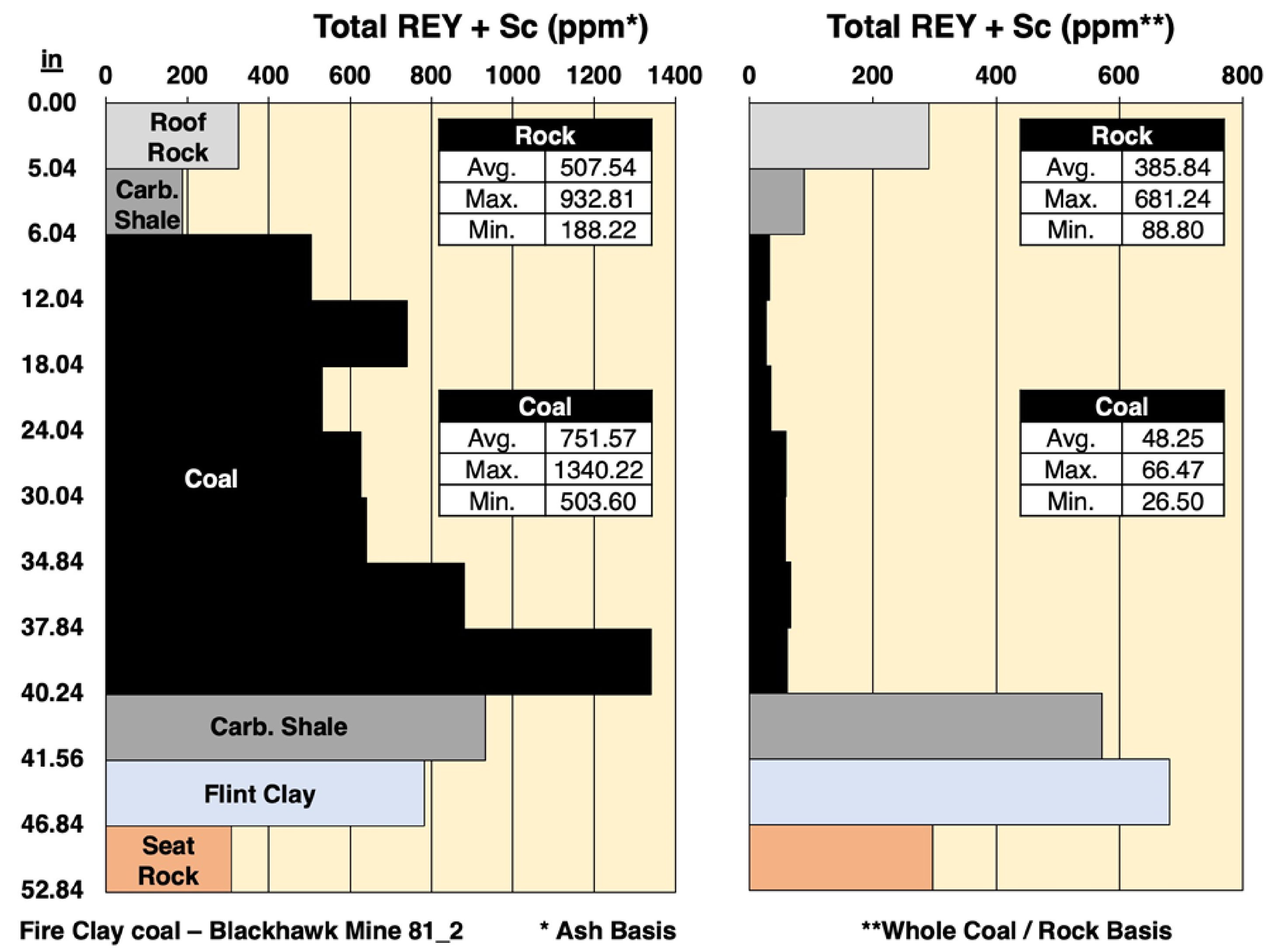
Feedstock	Processing	Economic viability	
Refuse	Physical beneficiation	low	low recovery
	Chemical extraction	Low	high acid consumption
	Pre leach calcination	Higher	higher recovery/kinetics
Fly ash	Physical beneficiation	Low	Low Recovery
	Chemical extraction	Low	High acid consumption multi stage recovery
	Alkaline thermal extraction	Higher	Relative to Physical and Chemical methods
AMD	Multi stage AMD treatment	High	High recovery, low CapX, OpX

Challenges with carbon fiber from coal

- Ash – plug spinnerets, stops mesophase coalescences, results in rough fiber surfaces, and acts as point failure defect
- Sulfur – puffs during oxidation
- Too low or too high softening poin
- Cost of producing synthetic pitch
- Cost of thermal treatments
- Ash
- Ash
- Ash



Most REE/CM is in the mineral fraction



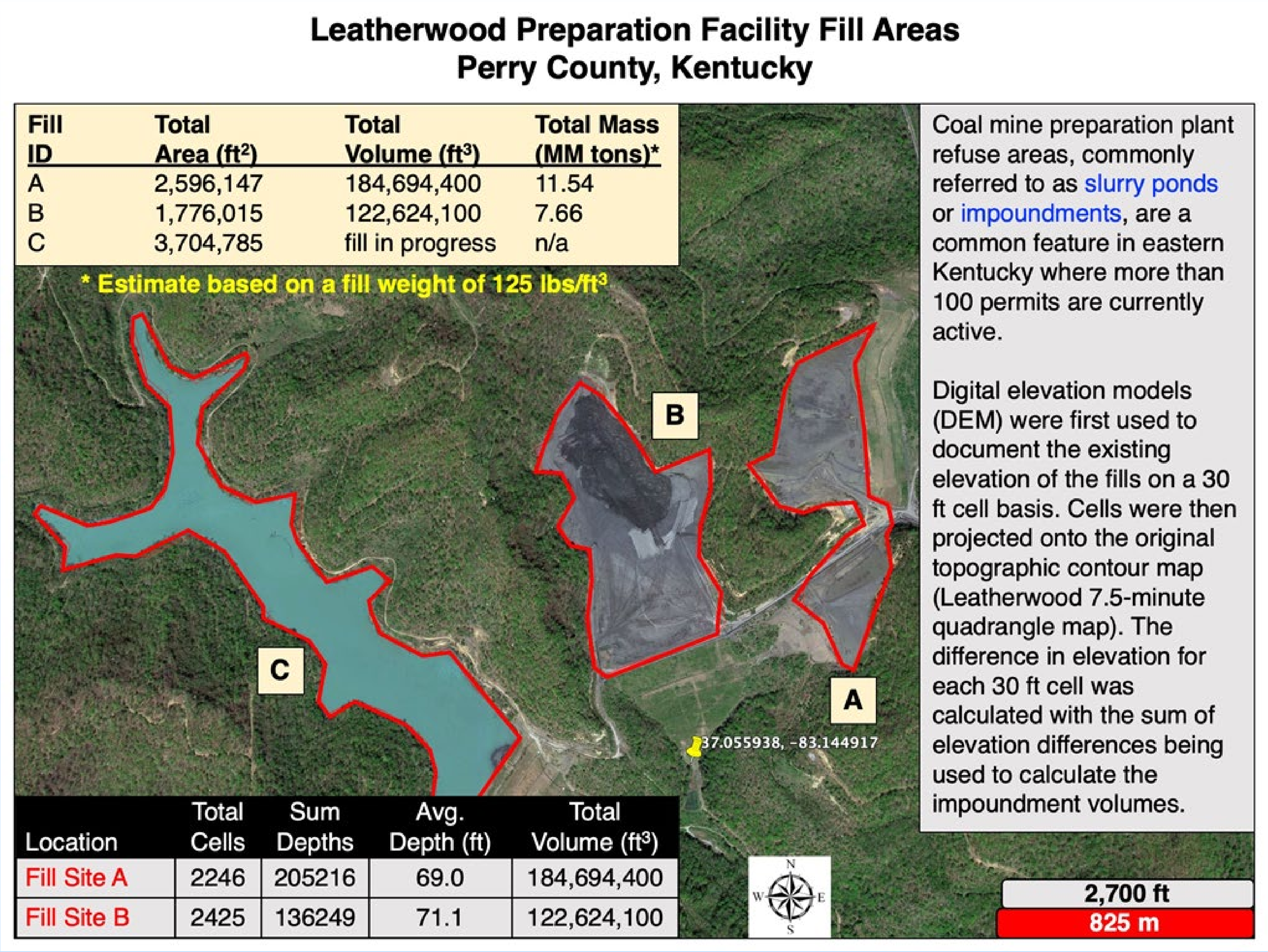
Rock	
Avg.	507.54
Max.	932.81
Min.	188.22

Coal	
Avg.	751.57
Max.	1340.22
Min.	503.60

Rock	
Avg.	385.84
Max.	681.24
Min.	88.80

Coal	
Avg.	48.25
Max.	66.47
Min.	26.50

Refuse piles A+B contain ~6,700 t REE



Leatherwood Preparation Facility Fill Areas
Perry County, Kentucky

Fill ID	Total Area (ft²)	Total Volume (ft³)	Total Mass (MM tons)*
A	2,596,147	184,694,400	11.54
B	1,776,015	122,624,100	7.66
C	3,704,785	fill in progress	n/a

* Estimate based on a fill weight of 125 lbs/ft^3

Coal mine preparation plant refuse areas, commonly referred to as slurry ponds or impoundments, are a common feature in eastern Kentucky where more than 100 permits are currently active.

Digital elevation models (DEM) were first used to document the existing elevation of the fills on a 30 ft cell basis. Cells were then projected onto the original topographic contour map (Leatherwood 7.5-minute quadrangle map). The difference in elevation for each 30 ft cell was calculated with the sum of elevation differences being used to calculate the impoundment volumes.

Location	Total Cells	Sum Depths	Avg. Depth (ft)	Total Volume (ft³)
Fill Site A	2246	205216	69.0	184,694,400
Fill Site B	2425	136249	71.1	122,624,100

Key Early Findings

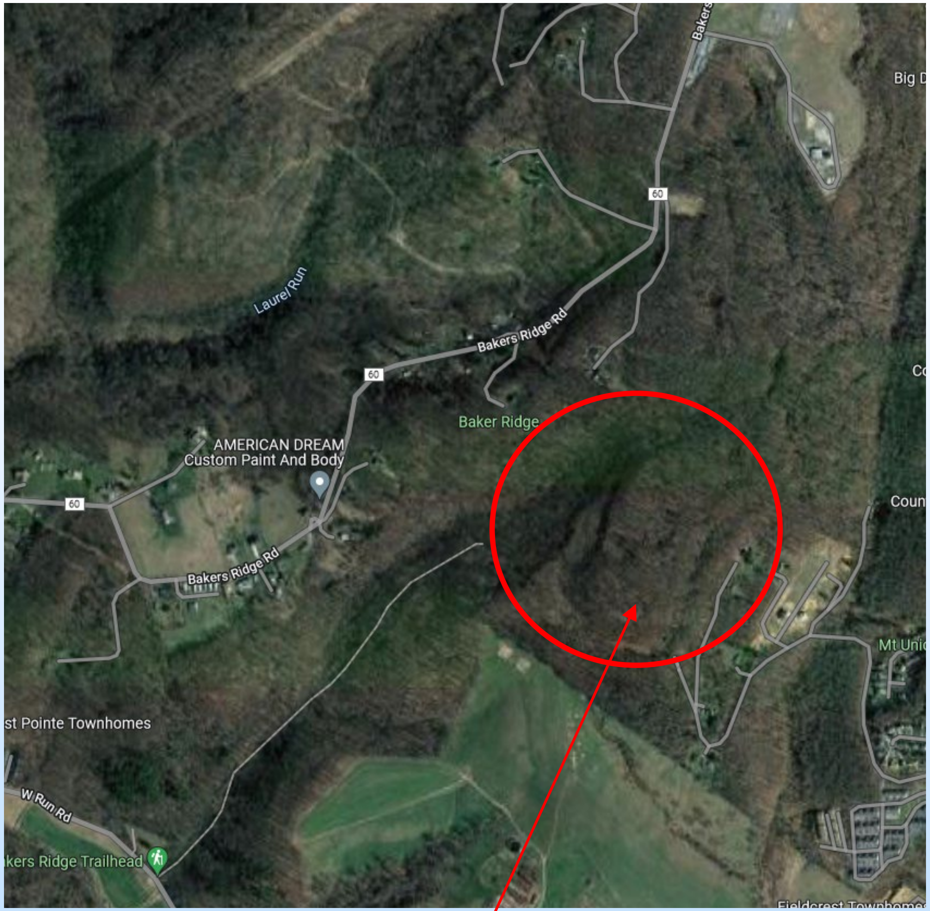
Basin Reuse

- Deconstruction of impoundments(prep waste or powerplant ash) has significant risk
  - Construction type is an early screening tool – if known
  - Permitting of these operations is likely to be challenging
  - Economics will favor largest sources and favorable siting (ARQ is an example – but unclear how many sites have this set of conditions)
- Materials Handling and Sorting Issues
  - Prep Wastes are predominantly carbon (mass).
- Powerplant wastes are extremely challenging
  - Permitting and financing will be difficult due to actual **and perceived difficulties** in handling
- Challenge to processing – what to do with "new" waste from a proposed process

  At 10,000 ppm loading = 99% reject

  Example – Project would need to reject ~31.9MM tons of material (estimate 400+ acres)

Key Early Findings



Pre-Law Site – Note Revegetation

Significant (Potentially Critical) Challenges Exist in Each Technical Area

Fundamental Issues of Ownership and Liability Follow All Of These Sites

Resource Quantification

- Significant data gaps exist to evaluate REE/CM loading in waste impoundments
- Gob/Overburden wastes are likely not a significant source (Burnout)
- Shale Wastes Are Not As “Condensed” as coal wastes
    - Wastes have historically been non-hazardous landfilled
- Pre-law sites can be very difficult to locate (and thus to assess)

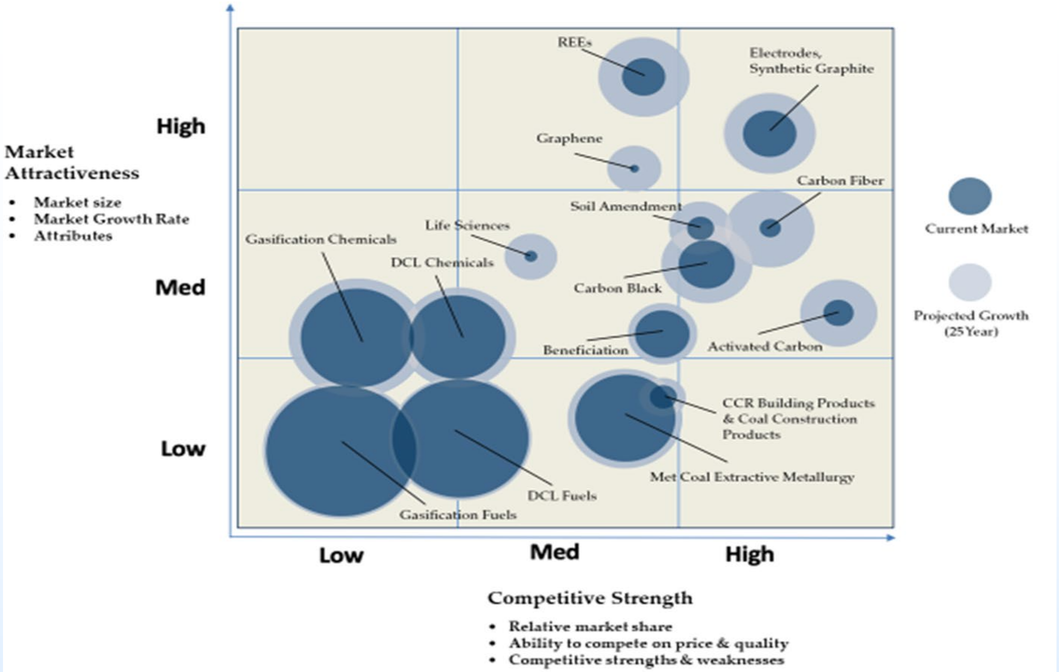
Future Plans

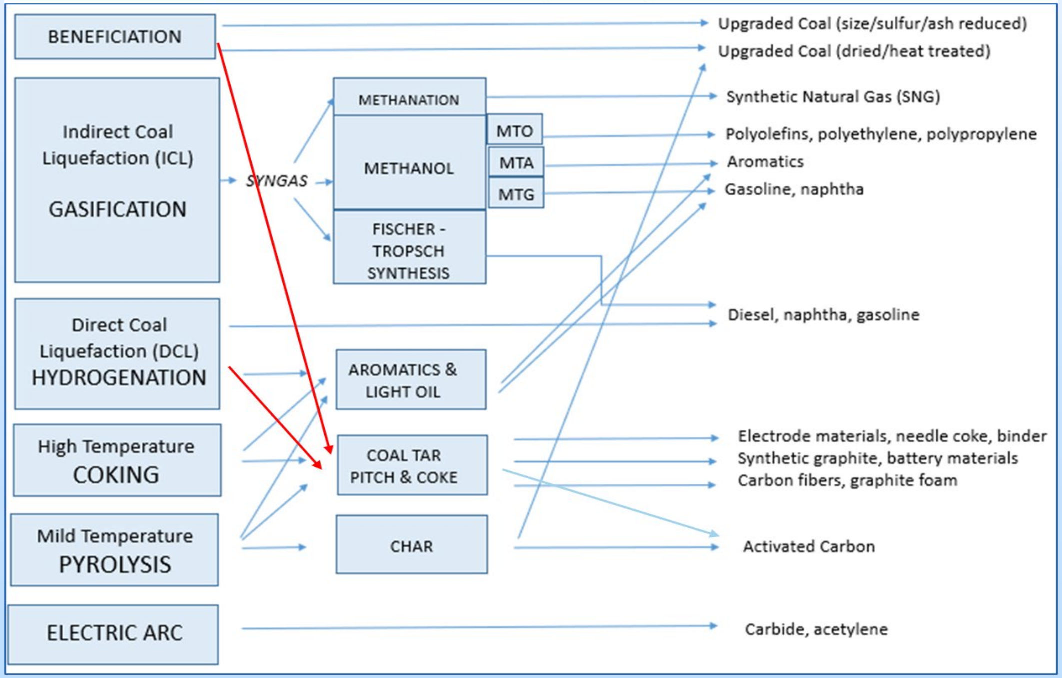
Technology Development

- REE/CM
  - Identify potential technologies to refine waste materials (powerplant ash; coal prep waste) to products

  Future work
  - Identify potential research areas for “hard to manage” sources. (Powerplant Waste)
- Carbon Products
  - Seek to expand feedstock suitability for existing processes/products
  - Impoundments are not uniform in characteristics

  Future Work
  - Identify potential sectors for substitution of carbon materials
  - Volume/Mass mismatch between waste source potentials and products is big – except for combustion.





Summary Slide: Next Steps

1. Resource Classification/Inventory
    1. Refuse
    2. Ash
    3. AMD
2. REE/CM vs. Carbon Products
3. Extraction Technology Evaluation
    1. Practicality, Access, Safety, Regulations
    2. Cost relative to value
4. First Sort: Feasible/non-Feasible
5. For example:

Technology Assessment Worksheet

Technology Short Name: Preconcentration via Staged Precipitation

Date: 9/14/2022

Conducted By: Noble

Applicable Feedstocks: Acid Mine Drainage

Applicable Products: Rare Earths, Co, Mn, Li, Ni, and others

Estimated TRL

Any Application: 9

Core-CM Applications: 6

Brief Explanations (if needed):

Any Application: Staged precipitation is a mature technology in the field of hydrometallugical processing.

Core-CM Applications: Fully integrated process has been testing using realistic feedstock in a 1:20 scale prototype unit.

For TRL definitions, see: Link (pdf)

Technical Description

Raw acid mine drainage (AMD) is treated while simultaneously recovering a high-grade rare earth preconcentrate (nominally 1% to 5% TREE grade) suitable for downstream extraction and recovery. While conventional AMD treatment raises the pH to a suitable endpoint in a single step, this technology prescribes two steps, where the first removes most of the contaminant elements, while the second produces a REE/CM preconcentrate.

Critical Economic, Environmental, Social, and Legal Considerations

Technology has received patent protection [1], and economic assessments have shown favorable outcomes when implementing a regional network sourcing strategy [2]. Technology would incentivize AMD treatment, particularly from abandoned mines, which would support positive environmental and social outcomes. Technology does not create new or additional wastes beyond what is currently produced in conventional AMD treatment.

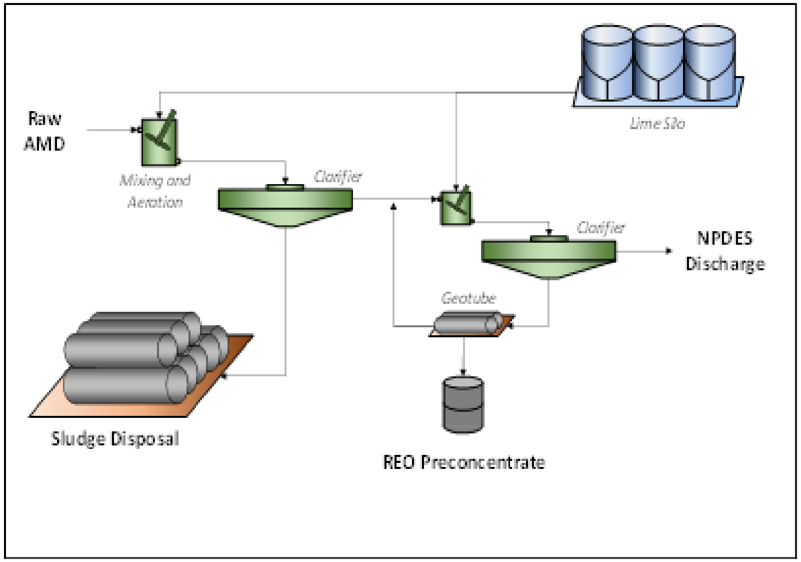
Research, Development, and Demonstration Needs

The first commercial prototype is currently being installed and commissioned under DE-FE0031834. Future RD&D needs include additional onsite demonstrations and broader commercial uptake.

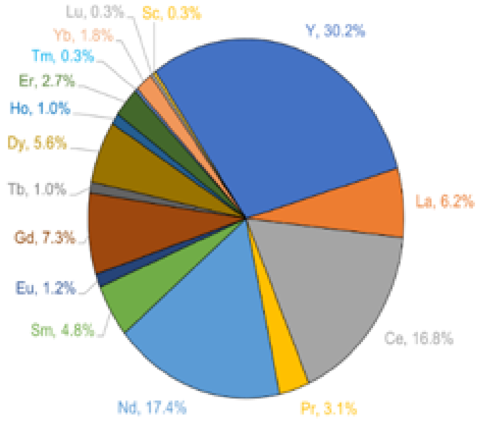
Up to Five Relevant References (if available)

1. Ziemkiewicz, P., Noble, A., & Vass, C. (2021). U.S. Patent No. 10,954,582. Washington, DC: U.S. Patent and Trademark Office.
2. Larochelle, T., Noble, A., Ziemkiewicz, P., Hoffman, D., & Constant, J. (2021). A Fundamental Economic Assessment of Recovering Rare Earth Elements and Critical Minerals from Acid Mine Drainage Using a Network Sourcing Strategy. Minerals, 11(11), 1298.
3. Vass, C. R., Noble, A., & Ziemkiewicz, P. F. (2019). The occurrence and concentration of rare earth elements in acid mine drainage and treatment by-products: Part 1—Initial survey of the Northern Appalachian Coal Basin. Mining, Metallurgy & Exploration, 36(5), 903-916.
4. Vass, C. R., Noble, A., & Ziemkiewicz, P. F. (2019). The occurrence and concentration of rare earth elements in acid mine drainage and treatment byproducts. Part 2: Regional survey of northern and central Appalachian coal basins. Mining, Metallurgy & Exploration, 36(5), 917-929.
5. Ziemkiewicz, P., He, T., Noble, A., & Liu, X. (2016, March). Recovery of rare earth elements (REEs) from coal mine drainage. In West Virginia Mine Drainage Task Force Symposium: Morgantown, WV, USA.

Graphical Abstract, Picture, or Additional Data (if available)



Schematic of staged precipitation process



Typical REE distribution of product

Screening matrix: Reserve/recovery strategies

		REE/CM		
		Refuse	Coal ash	AMD
Reserve	tons			
Grade	%			
Recovery	TRL			
Processing	TRL			

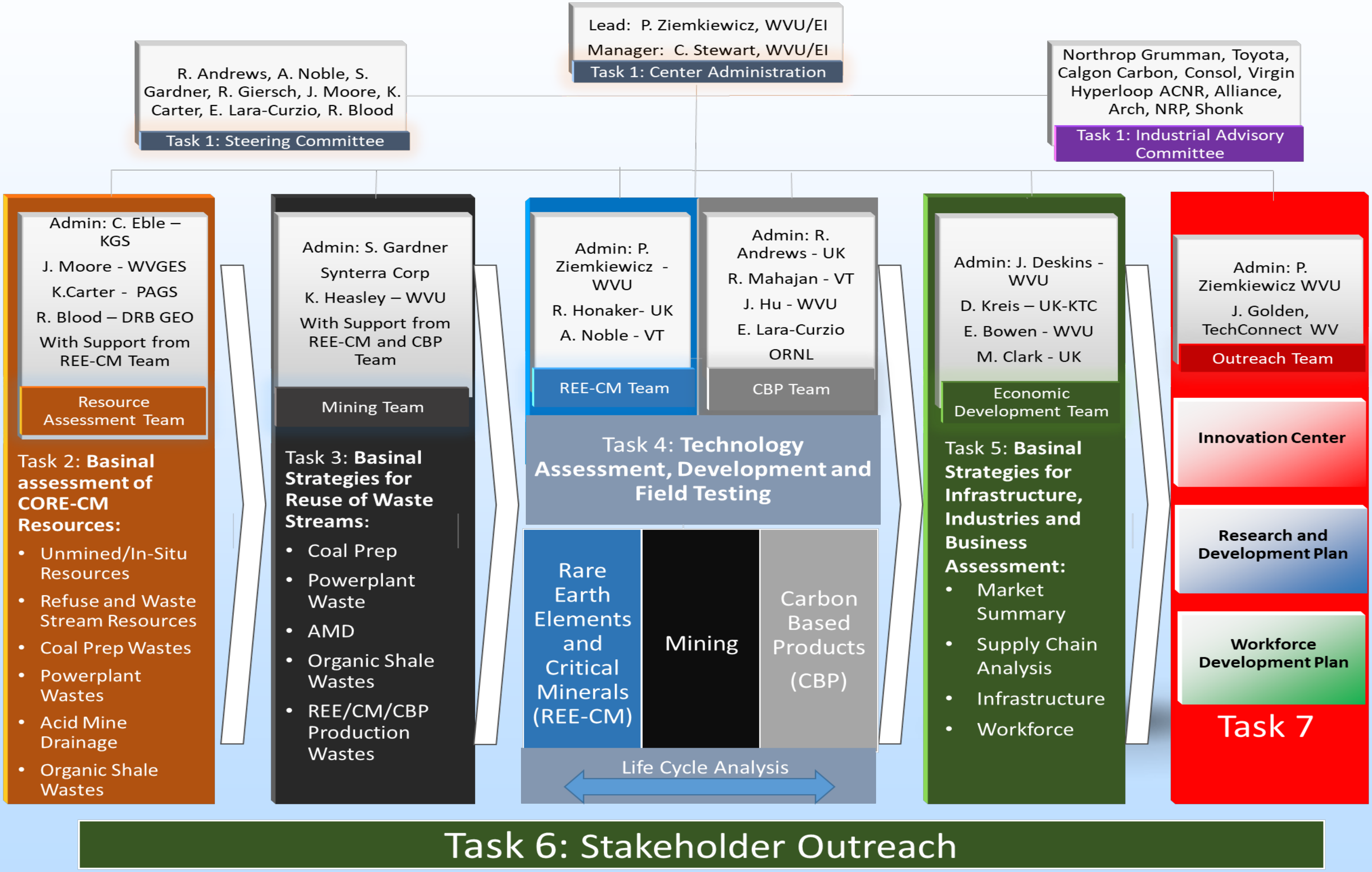
		Carbon Products		
		Refuse	Coal ash	AMD
Reserve	tons			
Grade	%			
Recovery	TRL			
Processing	TRL			

Appendix

Organization Chart

MAPP CORE Organizational Chart

CORE-CM Initiative for U.S. Basins DE-FOA-0002364



Lead: P. Ziemkiewicz, WVU/EI
Manager: C. Stewart, WVU/EI
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Admin: C. Eble – KGS
J. Moore - WVGES
K.Carter - PAGS
R. Blood – DRB GEO
With Support from REE-CM Team
Resource Assessment Team

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- Coal Prep Wastes
- Powerplant Wastes
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ORNL
CBP Team

Task 4: **Technology Assessment, Development and Field Testing**

Rare Earth Elements and Critical Minerals (REE-CM)

Mining

Carbon Based Products (CBP)

Life Cycle Analysis

Admin: J. Deskins - WVU
D. Kreis – UK-KTC
E. Bowen - WVU
M. Clark - UK
Economic Development Team

Task 5: **Basinal Strategies for Infrastructure, Industries and Business Assessment:**

- Market Summary
- Supply Chain Analysis
- Infrastructure
- Workforce

Admin: P. Ziemkiewicz WVU
J. Golden, TechConnect WV
Outreach Team

Innovation Center

Research and Development Plan

Workforce Development Plan

Task 7

Task 6: Stakeholder Outreach

Gantt Chart

WORK BREAKDOWN STRUCTURE	group
Task 1 - Project Management and Planning	WVU
1.1 - Project Management Plan	
Task 2 - Basinal Assessment of CORE-CM resources:	GEO, Mining, REE-CM
2.1 - Unmined/In-Situ Resources (i.e. unmined seams)	
2.2 - Refuse and Waste Stream Resources	
2.2.1 - Coal Prep Wastes	
2.2.2 – Powerplant Wastes	
2.2.3 – Acid Mine Drainage	
2.2.4 – Organic Shale Wastes	
2.3 - Data Check and Report Preparation - Basinal Resource Assessment and Characterization and Data Acquisition Plan	
Task 3 - Basinal Strategies for Reuse of Waste Streams:	Mining, REE-CM, CBP
3.1 Pre-combustion Coal Refuse	
3.2 Low Flow Acid Mine Drainage	
3.3 Selective Mining and Sorting	
3.4 Fluidized Bed Combustion of Waste Coals	
3.5 - REE/CM/CBP Production Wastes	
3.6 - Data Check and Report Preparation - Waste Stream Reuse Plan	
Task 4: Technology Assessment, Development and Field Testing:	Mining, REE/CM, CBP
4.1 Upstream Technology Development	
4.1.1 - Unmined/In-Situ Development Technologies	
4.1.2 - Coal Preparation, Powerplant, and Organic Shale Wastes Technology Development	
4.1.3 - Acid Mine Drainage Development Technologies	
4.2 Downstream Technology Development	
4.2.1 Rare Earth Elements and Critical Minerals	
4.2.2 Carbon Materials and Carbon Based Products	
4.2.3 Coal Conversion for Products Assessment	
4.2.4 Coal conversion to intermediates	
4.2.5 Nanomaterials from Coal	
4.2.6 Market Analysis	
4.3 - Data Check and Report Preparation - Technology Assessment and Field Development Plan	
Task 5: Basinal Economic Assessment:	
5.1 - CORE-CM Market Summary - Industries and Products	
5.2 - Supply Chain Analysis	
5.3 – Infrastructure	
5.4 - Economic Impacts of CORE-CM Products	
5.5 - Data Check and Report Preparation – Basinal Strategies for Infrastructure, Industries and Businesses Assessment	
Task 6 - Stakeholder Outreach	Outreach
6.1 Identify regional stakeholders	
6.2 Convene stakeholder group	
6.3 Develop Plan for Outreach and Education	
6.4 Data Check and Report Preparation – Stakeholder Outreach and Education Plan	
Task 7 - Technology Innovation Center:	Econ, Outreach
7.1 - Technology Innovation Center	
7.2 Data Check and Report Preparation – Technology Innovation Center Plan	

Pathways to products

MAIN PATHWAY

thesize GO from coal

Patent App No. 17/415,445
PCT/US2019/066941
Roop. L. Mahajan and Seul-Yi Lee

VT one-pot synthesis of GO from purified coal

- mild oxidation (only one acid is used without additional oxidant).
- more cost-effective and simpler process than Hummer's method
- preservation and extraction of graphitic domains in the coal

conventional 2-step method of producing graphene oxide

- graphite to graphite oxide
- graphite oxide to graphene oxide

one-pot method

- straight from coal to graphene oxide
- eliminating additional mechanical exfoliation and multiple washing