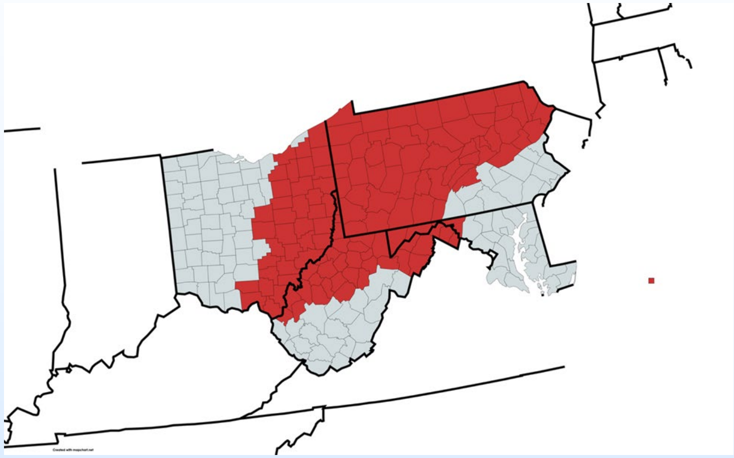
Consortium to Assess Northern Appalachian Resource Yield (CANARY) of CORE-CM for Advanced Materials (DE-FE0032052)



2024 NETL Resource Sustainability Project Review Meeting

Sarma V Pisupati

Professor, Energy and Mineral Engineering

Director Center for Critical Minerals

Barbara Arnold

Chair and Professor of Practice, Mining Engineering

CANARY CORE-CM

Highlights by Task

- Task 1.0 - Project Management and Planning
  - Environmental Justice Targets
  - Economic Revitalization and Job Creation Targets
  - Environmental, Safety, and Health Analysis
- Task 2.0 - Basinal Assessment of CORE-CM Resources
- Task 3.0 - Basinal Strategies for Reuse of Waste Streams
- Task 4.0 - Basinal Strategies for Infrastructure, Industries and Businesses
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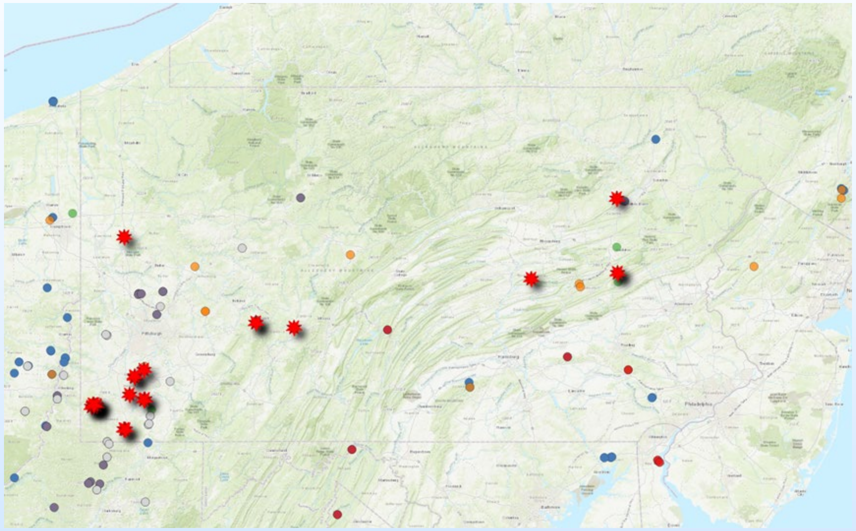
Mine Tailing Health & Safety Implication for Potential CORE-CM Recovery in North Appalachian Basin



By selecting Federal Agency Involvement Regulatory --- MSHA (Mine Safety and Health Administration), High and Significant risk tailing dams have been assigned as red pins

- Tailings are resources with extraction risk in North Appalachian Basin
- MSHA regulated a few high or significant risk tailings in Pennsylvania (12), Ohio (3), West Virginia (40).
- The special tailing sites (High and low risks) are investigated for comparison. High risk ones are large volume tailings.
- Field work will be required
- Very limited geomechanical and geotechnical information in open literature
- Site specific information may need for resource estimation

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Targeted Resources

- Acid mine drainage/sludge—have received samples from some of our top targets
- Tailings impoundments (ash from FBCs, coal, metal mines)
- Metal slags
- Coarse coal preparation plant refuse
- Coal underclays—Mercer and Lower Kittanning
- Coal for carbon ore/graphite
- Produced waters (potential Li source)

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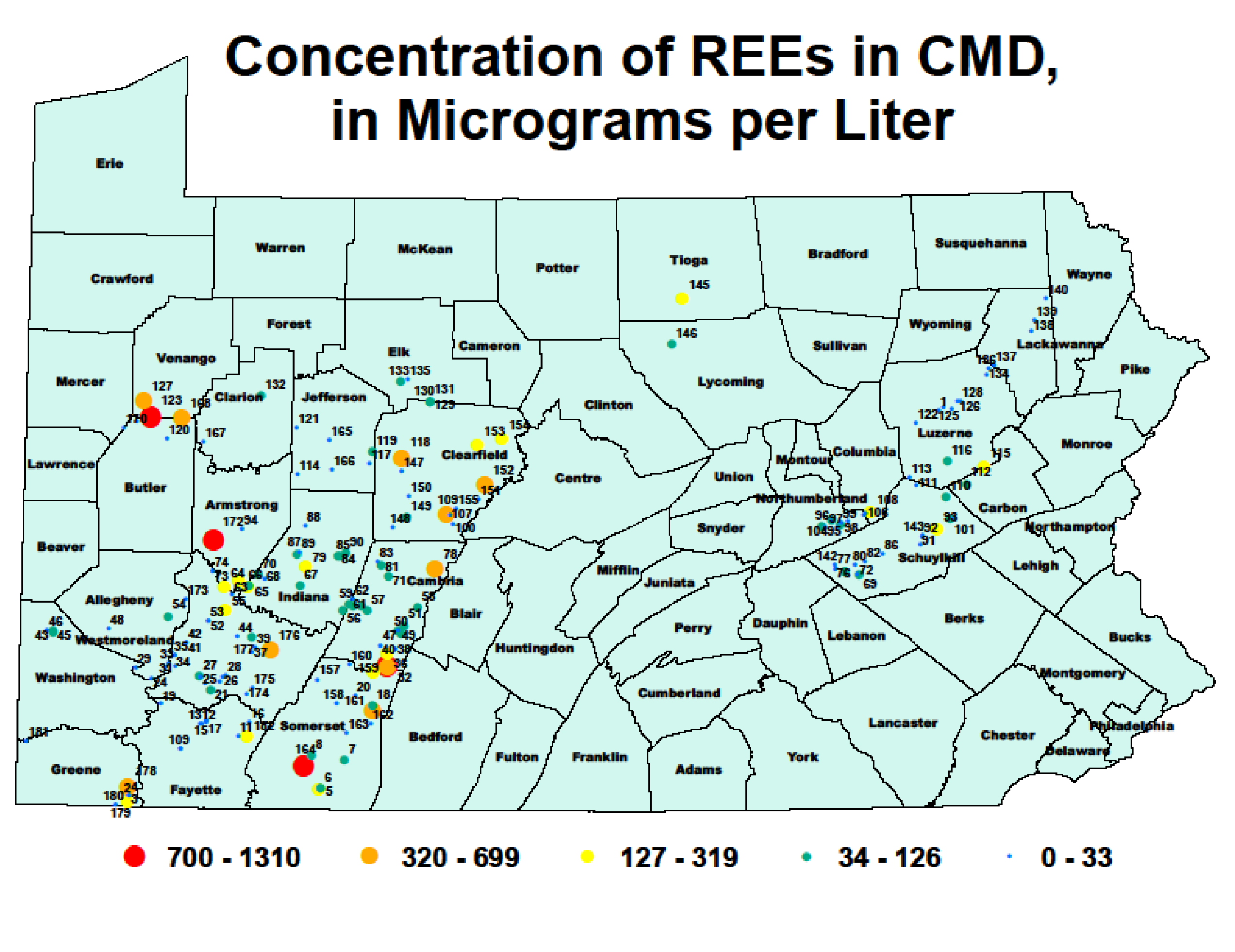
Acid Mine Drainage

Literature Data Cataloged



Compilation by Stakeholder Group member, John Memmi

Acid Mine Drainage

New Samples

Additional new WV and PA samples in progress

	Location	pH	Mg (ppm)	Al (ppm)	Mn (ppm)	Ni (ppm)	Zn (ppm)	TREE (ppb)	HREE (ppb)	LREE (ppb)	H/L
Previous sites	Clearfield 1	3.66	323.74	37.89	41.84	1.65	3.12	545	310	230	1.35
	Clearfield 2	4.00	128.53	14.20	17.15	0.46	0.81	431	180	250	0.72
	Clearfield 3	3.72	176.94	18.75	22.33	0.70	1.14	472	210	260	0.81
Current sites	MD 1	2.77	299.99	54.53	49.67	1.60	5.71	1415	703	712	0.99
	MD 2	5.99	108.34	7.81	12.19	0.35	1.26	207	114	91	1.26
	MD 3	3.11	224.51	33.98	33.39	0.90	3.70	871	438	432	1.01
	MD 4	2.95	166.93	30.52	27.71	0.74	2.90	698	350	348	1.01
	MD 5	3.10	149.25	33.12	27.42	0.89	3.35	832	416	416	1.00

Upper Freeport Seam mined at the MD site

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Pittsburgh Seam Refuse Samples from Lab Tests

	TREE	+Y + Sc	Prim Mag	Sec Mag	LREE	HREE	Ga	Ge
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
B -28+100 Heavy	366	474	98	27	323	30	57	53
B -28+100 Medium	203	266	55	16	179	17	31	28
B -16+28 Heavy	262	320	59	15	240	16	29	7
						UCC	**19**	**1.5**

	TREE	+Y + Sc	Prim Mag	Sec Mag	LREE	HREE	Ga	Ge
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
H -28+100 Heavy	317	413	81	24	279	27	43	45
H -16+28 Heavy	474	616	130	36	418	40	70	57
						UCC	**19**	**1.5**

FBC (Fluidized Bed Combustor) Site 1

Separate fly ash and bottom (bed) ash

Feed coal and coarse refuse reject sample

Coarser fractions, again, generally have higher REEs

A few anomalies for Ge??

UCC for Ge = 1.5 ppm

	TREE+Y+Sc	Ge (ppm)
Bed Ash 1 +3M	574	8
Bed Ash 1 -3+14M	535	7
Bed Ash 1 -14+28M	536	8
Bed Ash 1 -28+100	364	7
Bed Ash 1 -100M	349	4
Bed Ash 2 +3M	489	8
Bed Ash 2 -3+14M	505	8
Bed Ash 2 -14+28M	441	8
Bed Ash 2 -28+100	380	8
Bed Ash 2 -100M	353	4
Bed Ash 3 +3M	482	3
Bed Ash 3 -3+14M	557	9
Bed Ash 3-14+28M	548	9
Bed Ash 3 -28+100M	336	4
Bed Ash 3 -100M	376	3
P3 Reject 1 +3M	367	7
P3 Reject 1 -3+14M	368	8
P3 Reject 1 -28 +100M	322	8
P3 Reject 1 -100M	352	7
P3 Reject 2 +3M	409	9
P3 Reject 2 -3+14M	363	9
P3 Reject 2 -14+28M	362	8
P3 Reject 2 -28+100M	298	7
P3 Reject 2 -100M	360	5
P3 Reject 3 +3M	428	15
P3 Reject 3 -3+14M	409	8
P3 Reject 3 -14+28M	366	7
P3 Reject 3 -28+100M	346	8
P3 Reject 3 -100M	352	6
800 Belt 1 -3+14	354	9
800 Belt 1 -14+28M	349	10
800 Belt 1 -28+100M	234	10
800 Belt 1 -100M	219	5
800 Belt 2 -3+14	480	11
800 Belt 2 -14+28M	312	9
800 Belt 2 -28+100M	273	11
800 Belt 2 -100M	218	5
800 Belt 3 -3+14	482	11
800 Belt 3 -28+100M	197	4
800 Belt 3 -100M	243	5

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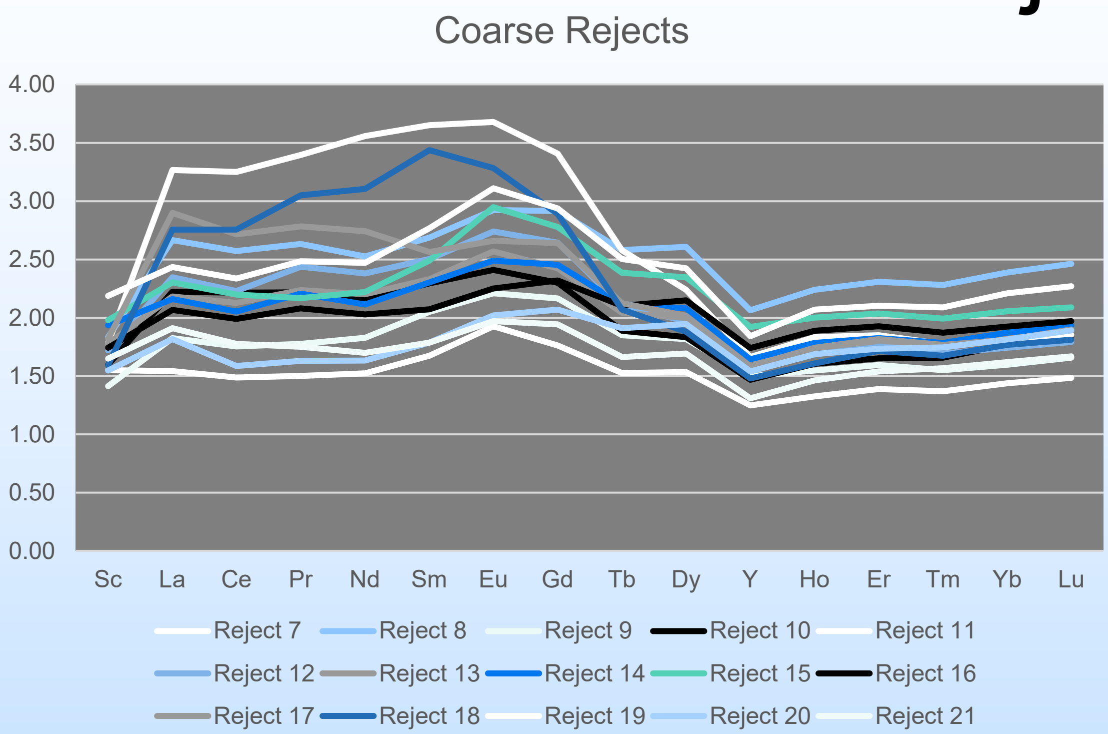
Additional FBC Site 1 Data—Coarse Rejects



Sample	TREE+Y+Sc	Prim Mag	Sec Mag	Ge
Reject 7	271	57	15	12
Reject 8	450	95	25	7
Reject 9	316	68	19	11
Reject 10	373	80	20	6
Reject 11	536	126	31	8
Reject 12	392	87	23	6
Reject 13	376	81	21	7
Reject 14	371	79	21	7
Reject 15	398	83	23	6
Reject 16	359	76	20	8
Reject 17	455	99	23	7
Reject 18	463	110	28	8
Reject 19	424	92	25	7
Reject 20	301	62	17	7
Reject 21	312	64	17	14

UCC for Ge = 1.5 ppm

Variation from June through December sampling period

What is the coarse preparation plant reject?

Possibly Lower Kittanning seam roof

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FBC Site 2

Combined fly ash and bottom (bed) ash

Coarser fractions higher in REEs

Samples	TREE + Y + Sc	Prim Mag	Sec Mag
Ash 6/11	501	100	25
Ash 6/11 +3M	505	101	25
Ash 6/11 -3+14M	605	132	29
Ash 6/11 -14+28M	520	107	26
Ash 6/11 -28+100M	366	73	19
Ash 06/11 -100M	355	75	21
Coal 6/11	330	71	16
Coal 6/11 +3M	513	114	26
Coal 6/11-3+14M	477	106	24
Coal 6/11 -14+28M	332	70	16
Coal 6/11 -28+100M	276	59	14
Coal 6/11 -100M	204	42	13
Coal 6/10	367	81	18
Coal 6/10 +3M	453	94	24
Coal 6/10 -3+14M	486	105	24
Coal 6/10 -14+28M	333	89	21
Coal 6/10 -28+100M	253	88	21
Coal 06/10 -100M	180	87	21
Ash 6/10	479	84	20
Ash 6/10 +3M	629	83	20
Ash 6/10 -3+14M	704	83	20
Ash 6/10 -14+28M	509	84	20
Ash 6/10 -28+100M	388	85	20
Ash 06/10 -100M	364	83	20

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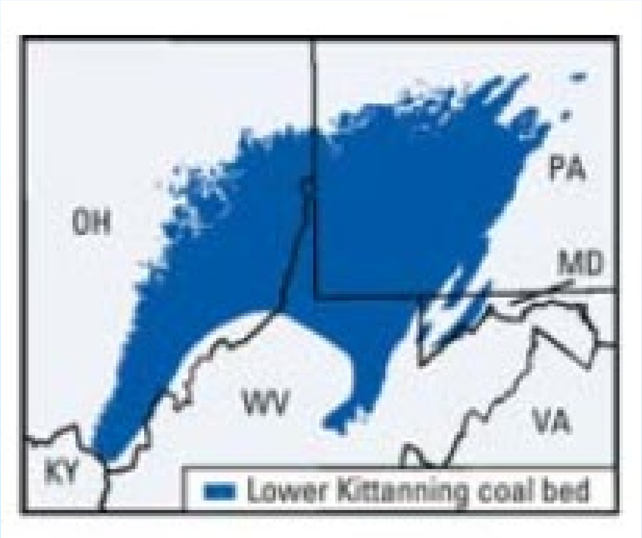
Lower Kittanning Seam

- Mining company core samples collected around the basin (PA and WV)



https://pubs.usgs.gov/fs/fs004-02/fs004-02.html

- “Underburden” quite variable across the basin based on core descriptions and ICP data, though general trend for high REEs just under the coal
- Literature suggests very finely disseminated minerals (micron size) interspersed in the clay—would require leaching for recovery
- More samples underway including cores from the “roof”

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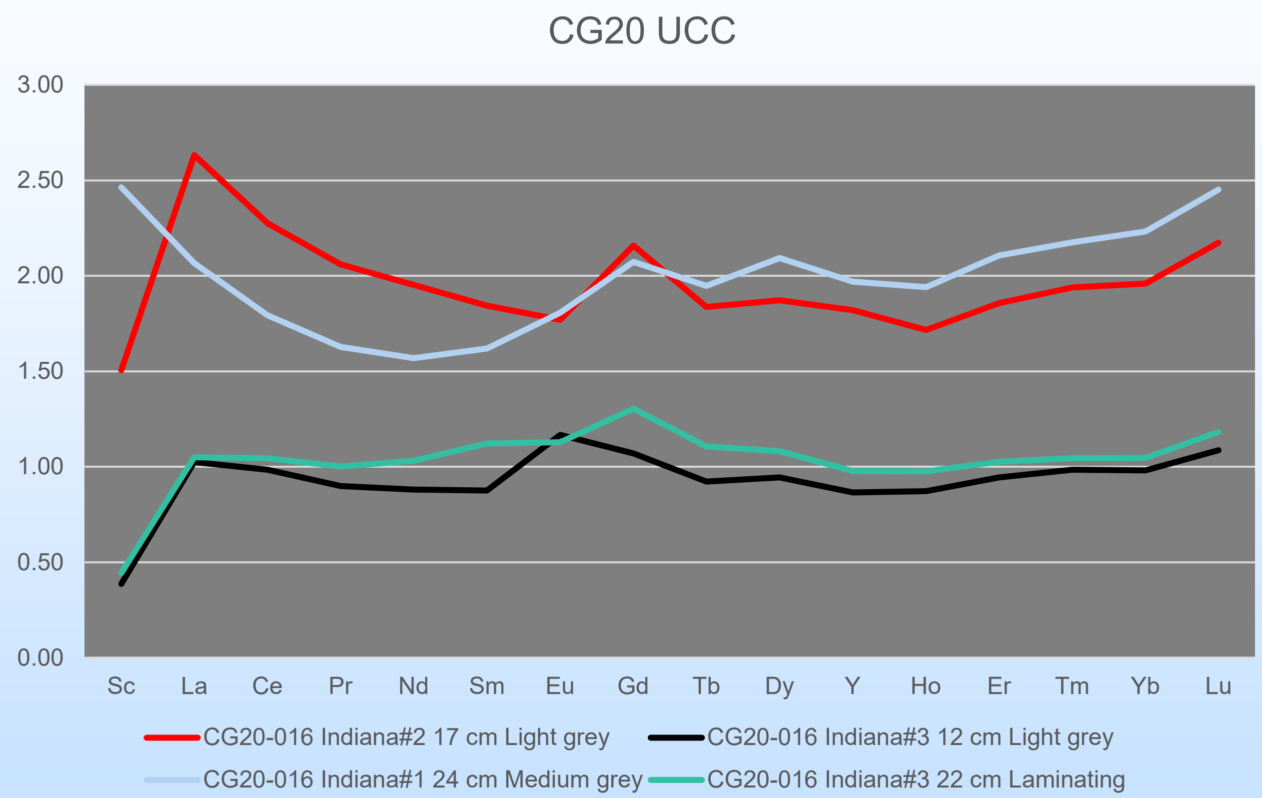
UCC Curves for Some Lower Kittanning Underclays



	TREE+Y+Sc	Primary Mag	Sec Mag
CG20-016 Indiana#3 12 cm Light grey	388	73	18
CG20-016 Indiana#1 24 cm Medium grey	166	33	9
CG20-016 Indiana#3 22 cm Laminating	344	61	17
CG20-016 Indiana#2 17 cm Light grey	182	38	11

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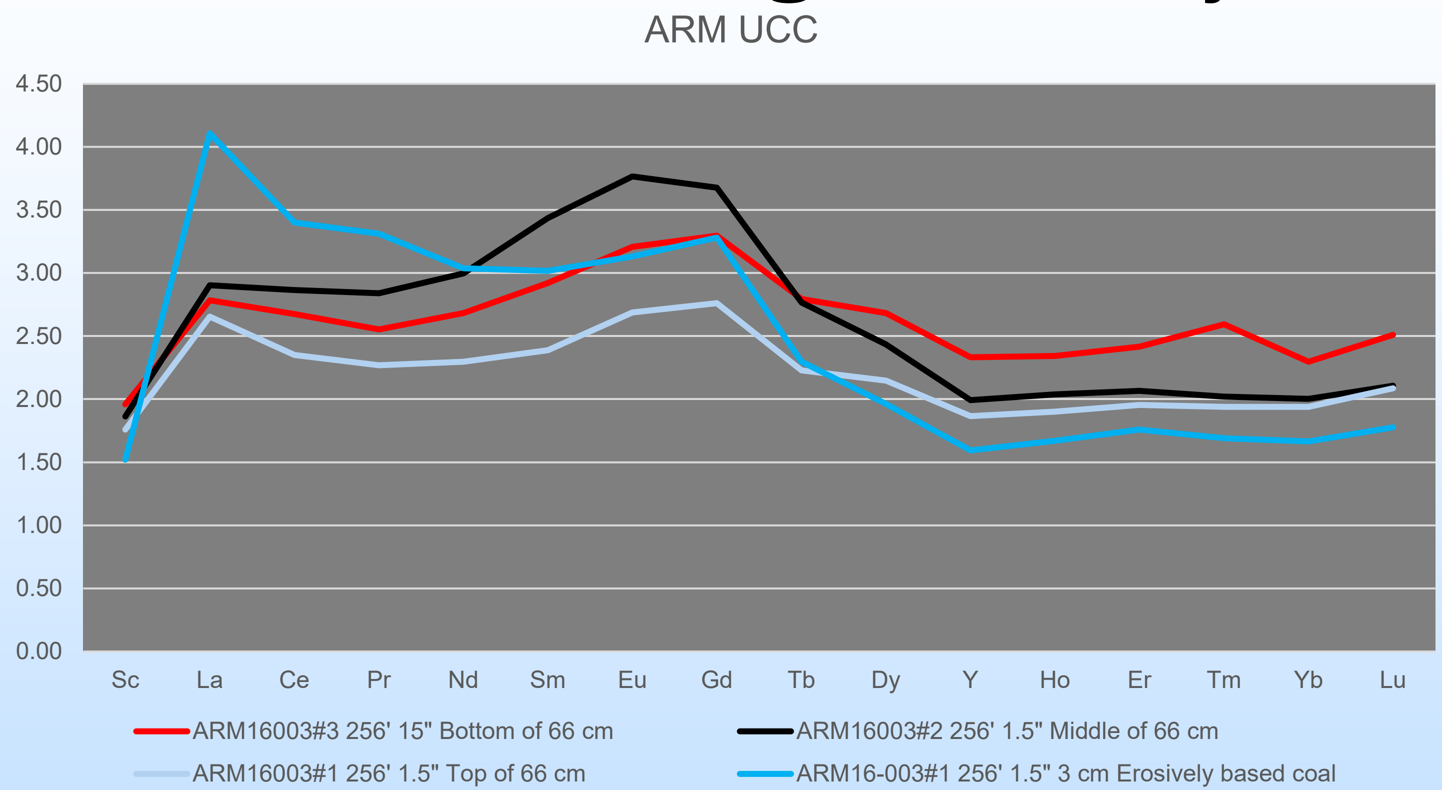
UCC Curves for Some Lower Kittanning Underclays



	TREE+Y+Sc	Primary Mag	Sec Mag
ARM16003#3 256' 15" Bottom of 66 cm	474	99	28
ARM16003#2 256' 1.5" Middle of 66 cm	493	108	31
ARM16003#1 256' 1.5" Top of 66 cm	415	85	23
ARM16-003#1 256' 1.5" 3 cm Erosively based coal	546	111	27

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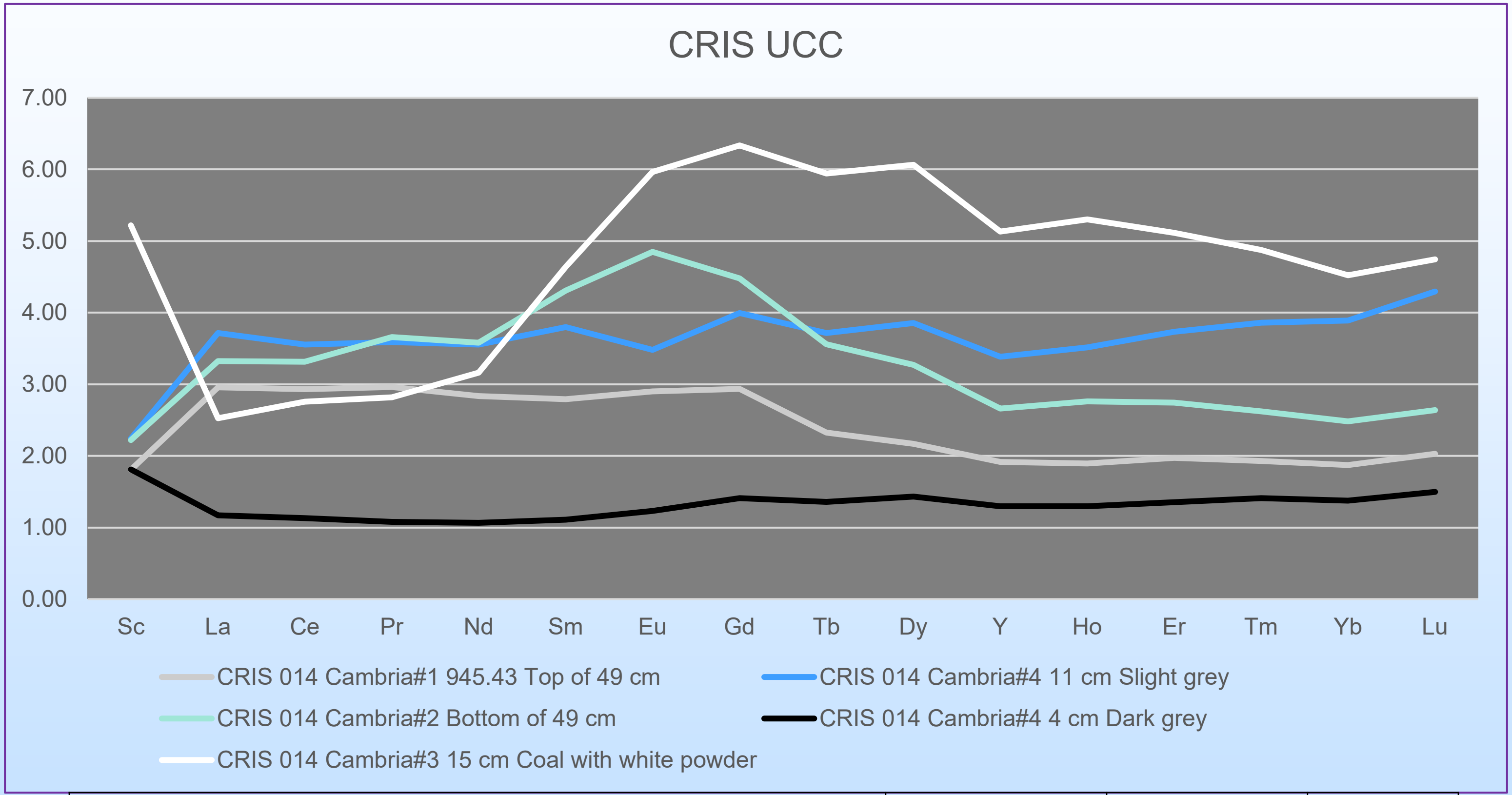
UCC Curves for Some Lower Kittanning Underclays



	TREE+Y+Sc	Primary Mag	Sec Mag
CRIS 014 Cambria#1 945.43 Top of 49 cm	485	104	25
CRIS 014 Cambria#4 11 cm Slight grey	636	134	35
CRIS 014 Cambria#2 Bottom of 49 cm	590	133	39
CRIS 014 Cambria#4 4 cm Dark grey	222	41	11
CRIS 014 Cambria#3 15 cm Coal with white powder	643	127	49

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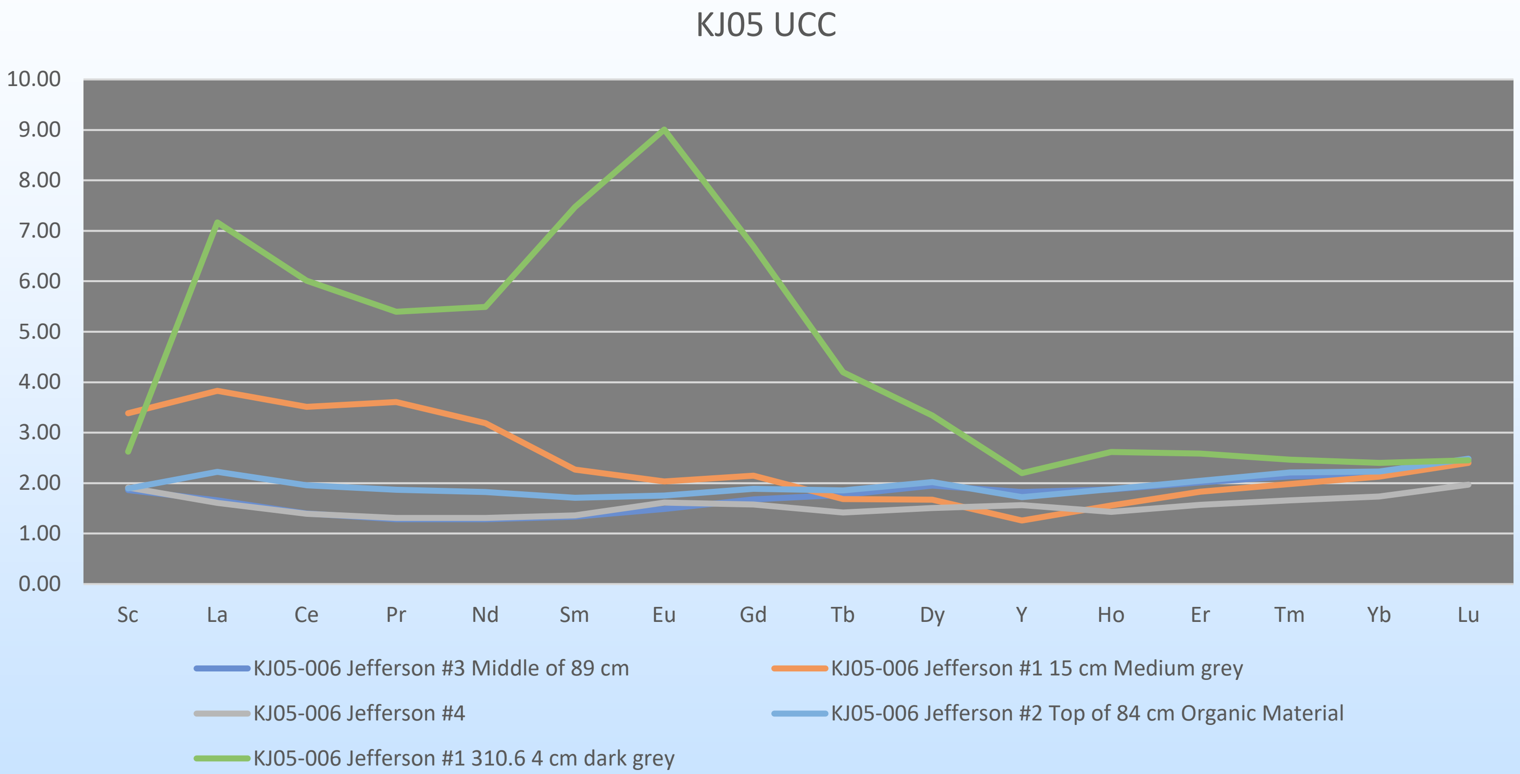
UCC Curves for Some Lower Kittanning Underclays



	TREE+Y+Sc	Primary Mag	Sec Mag
KJ05-006 Jefferson #3 Middle of 89 cm	282	51	14
KJ05-006 Jefferson #1 15 cm Medium grey	561	116	20
KJ05-006 Jefferson #4	271	49	13
KJ05-006 Jefferson #2 Top of 84 cm Organic Material	354	69	16
KJ05-006 Jefferson #1 310.6 4 cm dark grey	961	195	61

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HISTORIC METAL MINES

- Review of Northern Appalachian metal mines that produced battery metals/other critical minerals
- Also documenting uranium, rare earth elements, graphite (historic production in PA and NY), and titanium mines/occurrences

Ohio (eastern) Metal Mine Summary for Battery Elements (also for PA, NWV, MD)

Location (County)	Commodity	Following Commodities	Critical Mineral(s)	Plant Name	Opened	Closed	Tonnage Produced Est.	Prod. Size	Current Land Use
Ashtabula	Titanium	None	Ti	Ashtabula Processing Plant	1967	1992	239,700 tonnes (1967-1992). 99.3% sponge rate	Significant	Factory
Ashtabula	Aluminium	None	Al	Therm-X Company Aluminum Site				Small	Native restoration, vegetation
Gallia	Aluminium	Iron, Titanium	Al, Ti	Clarion Fire Clay Silica Occurrence	Est. 1959	Est. 1973		Significant	Still there
Guernsey	Aluminium	Iron	Al	Lower Kittanning Under Clay Iron Occurrence	1850			Significant	Vegetation
Guernsey									
Lawrence									
Mahoning	Aluminium	None	Al	Oakwood Billets Processing Plant				Small	Houses
Monroe	Aluminium	None	Al	Hannibal Reduction Plant	1958			Small	Houses
Muskingum	Aluminium	Iron, Titanium	Al, Ti	Brookville Underclay Aluminum Occurrence	1850	ESt. 1975		Significant	Vegetation
Scioto	Aluminium	Iron, Titanium	Al, Ti	Sciotoville Fire Clay Silica Occurrence	1861	Est. 1978		Significant	Vegetation
Jefferson	Chromium	Iron	Cr	Steubenville Smelter				Significant	Houses
Trumbull	Titanium	None	Ti	Niles Steel Plant	1950		21,515 tonnes (1991-1992)	Significant	Houses
Cuyahoga	Zirconium	None	Zr	Harshaw Chemicals Processing Plant				Small	Houses
Cuyahoga	Zirconium	None	Zr	Zircoa Refractories Processing Plant				Small	Houses
Cuyahoga	Zirconium	None	Zr	Sherwood Refractory Cleveland Plant				Small	Houses
Cuyahoga	Beryllium	None	Be	Brush Wellman Processing Plant				Small	Houses
Cuyahoga	Aluminium	Iron	Al	Metallurgical Incorporated Processing Plant				Small	Houses
Cuyahoga	Nickel	None	Ni	Hanna Nickel Smelter				Small	Houses
Cuyahoga	Zirconium	None	Zr	Lincoln Electric Processing Plant				Small	Houses

Houses, vegetation, factory, only one site still there.

15 sites in NWV, 2 in MD panhandle, 22 in PA
most are reclaimed or developed sites

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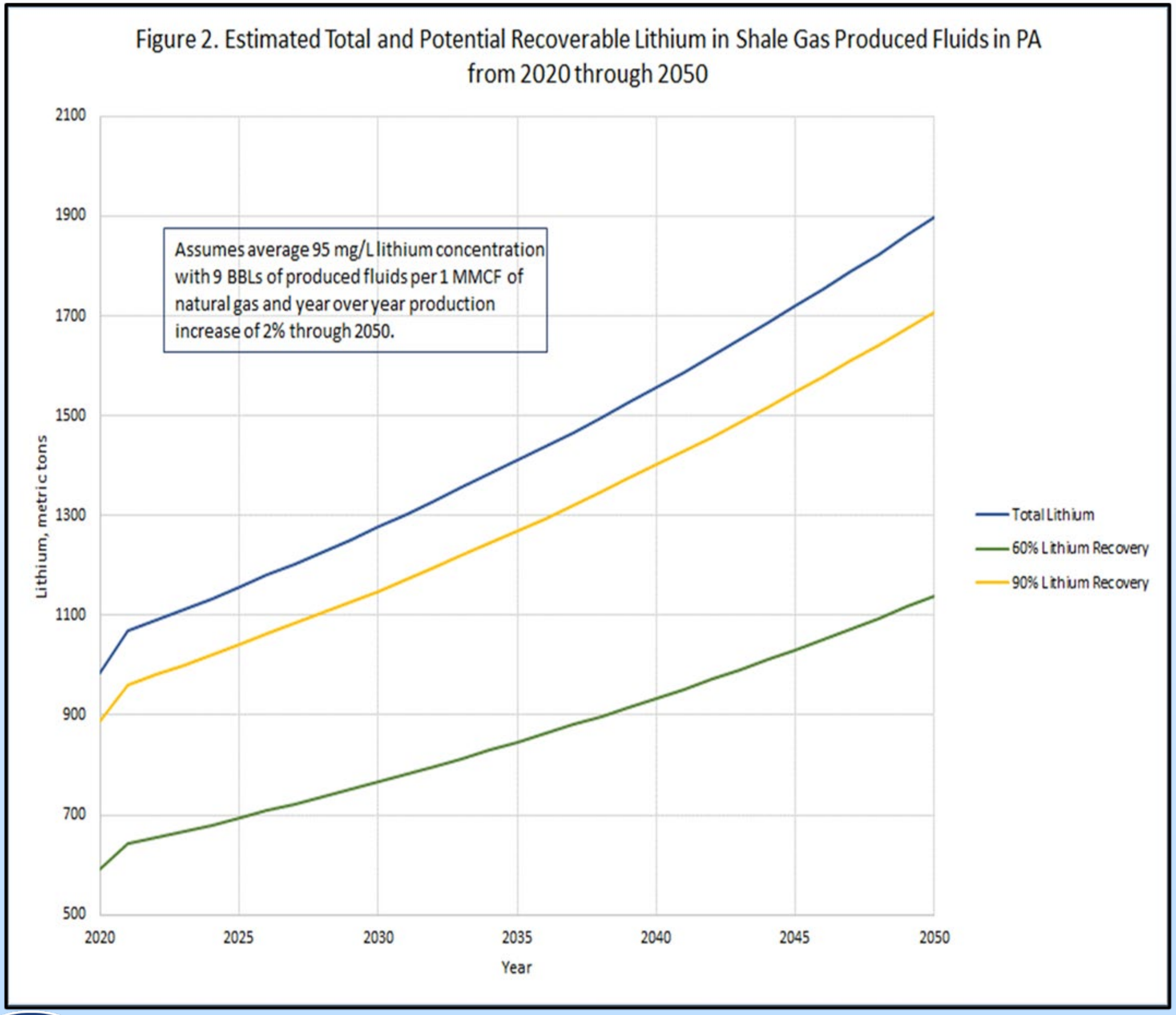
Historic Metal Mines

Also evaluating slag

- Historic mines throughout PA, MD, NWV, OH
- Last metal mine in PA closed in the 1980s
- PAGS samples from wastes at the sites

Mine Tailings	Total REEs	+ Y + Sc	Co
Boyertown	445	464	125
French Creek (also 2.7% Cu)	4002	4117	768
Grace	43	56	694
Jones	11	16	445

Estimation of lithium resources in Pennsylvania's shale energy produced fluids



- This analysis estimates that in years 2021 and 2022 approximately 1,200 and 1,300 metric tons of lithium were contained in shale gas produced fluids from PA alone.
- Dependent on the extraction technology It is predicted that lithium recovery efficiencies of 60-90% can be achieved.
- In 2022 between ~800 to 1200 metric tons of lithium could be recovered from shale gas produced fluids in Pennsylvania alone, which is similar to current annual national lithium production.
- Year 2050 nearly doubles the potential lithium resource to 1,900 metric tons/year based on EIA shale gas production projections

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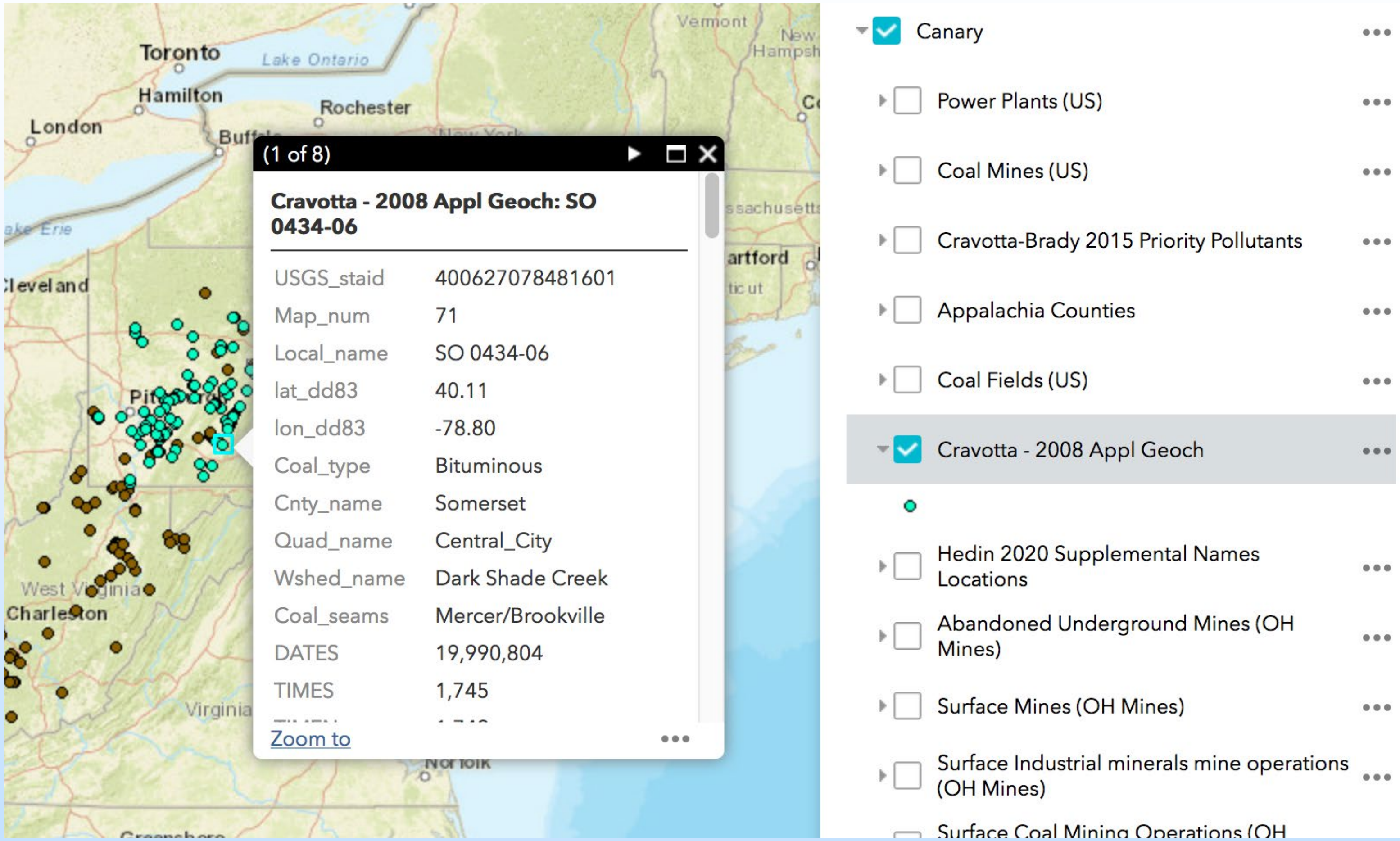
Mapping



Working on querying capability

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Carbon Ore

- Lots of "carbon ore" (coal) available in NAPP covering most bituminous ranks (including coking coals) and anthracite
- Documented anthracite graphitization studies
- "Coking" coals source for carbon fibers and graphite

Opportunities (per J. Mathews)

Multiple opportunities exist:	*Bituminous*	*Anthracite*
• Carbon fibers	V. High	-
• Graphite	V. High	V. High
• Graphene + associated	V. High	V. High
• *Electrically Conductive ink*	Low	High
• *Foams*	V. High	-
• Additives	Med	Med
• Specialty materials	?	?
• Rare earth elements (others)	?	?
• Coal* in construction materials	V. High	V. High

**Not ash-related*

Carbon Ore Companies in NAPP, for example:

- Calgon Carbon Corporation, along with its European operation, Chemviron Carbon, is a worldwide manufacturer and supplier of granular activated carbon treatment systems and value-added technologies. Moon Township, PA.
- Weaver Industries specializes in custom machined graphite, molding urethane, blown glass art, and electrodes. Denver, PA.
- Anthracite Industries supplies carbon and graphite products used in various industrial applications, including friction materials, lubricants, fuel cells, and cast metals. Sunbury, PA.
- CFOAM LLC produces coal-based carbon foam materials (high strength and heat/chemical resistant), including a graphitzed foam. Triadelphia, WV.

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Other Critical Minerals

- Titanium, for example
  - Perryman Company
    - Melting facility, Coal Center, PA
    - Hot rolling mill and finishing and dedicated bar finishing facility, Houston, PA
    - Intermediate titanium processing facility, Frackville, PA
  - International Titanium Corp.
    - Grinding a variety of ingots, billets, blooms slabs, and forgings in all shapes and sizes, just outside of Pittsburgh, PA
  - TSI Titanium
    - Rolled and forged titanium round bar products, Derry, PA

- Tin, for example
  - Tin Technology & Refining LLC
    - Nonferrous metal recycler specializing in the refining of tin-based byproducts and residues, West Chester, PA
  - Nathan Trotter & Company
    - Largest manufacturer of tin and tin alloys in North America, Coatesville, PA

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Biological Recovery of Critical Minerals from Secondary Sources

Ecological benefits

Fruit and leaves are important for birds, and flowers are important for pollinators

(Nafici, 2014; Webmaster, 2018; Sanchez, 2019; Lester, 2023)

- Pokeweed grew well in up to 70% of AMD soil.
- The accumulation of REEs in current set was low, potentially due to the low REE in the soil sources, pH or high P in the soil.
- Pokeweed significantly reduced the manganese content in the soil.
- Most REEs in pokeweed: Root> Mature leaves> Stem> Fruit
- Most REEs in dandelion: Mature leaves> Root

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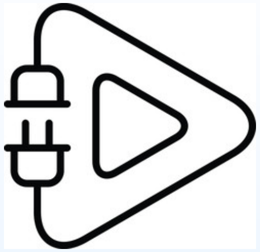
Technology Innovation Center(s)

- Many ideas discussed with our Technical Operations Committees and Stakeholders
  - goal was to develop advanced technologies and make industry more competitive, take feedstocks with different characteristics, write a guideline in cookbook form, but OK to work on current technologies to minimize water use and make waste benign
  - data bank funded with state and federal money
  - development money needed; price matters; tariffs change the global markets/supply chains—look at macroeconomics
  - virtual center, a co-op with membership and coordination with some facilities
  - a center should be plug and play, a modular system
  - suggested a hub and spoke arrangement, a national pilot facility owned by the federal government and operated by a contractor, perhaps like the National Carbon Capture Center in Wilsonville AL. Can address proprietary tech and cost; possible need for regional centers



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Stakeholder Outreach and Education

- Mineral resources workforce development needed across all commodity supply chains—exploration, mining, processing, materials, etc. Unskilled, skilled, and professional.
- Reach out to community colleges, retooling programs for other engineering graduates to enter the mineral resource industry
- Need support from many sources

- CANARY stakeholders' group has met ~quarterly
- Many meetings with industry (PA conventional oil & gas, for example), government (local, state, and federal officials), unions (meeting with UMWA), environmental groups (Sierra Club)

United Mine Workers of America UMWA

PIOGA Pennsylvania Independent Oil & Gas Association

Sierra Club

Ask Me Questions!

Acknowledgement
US DOE CORE-CM Program

DE-FE0032052

Colorado School of Mines, University of KY
Virginia Tech, Tetra Tech