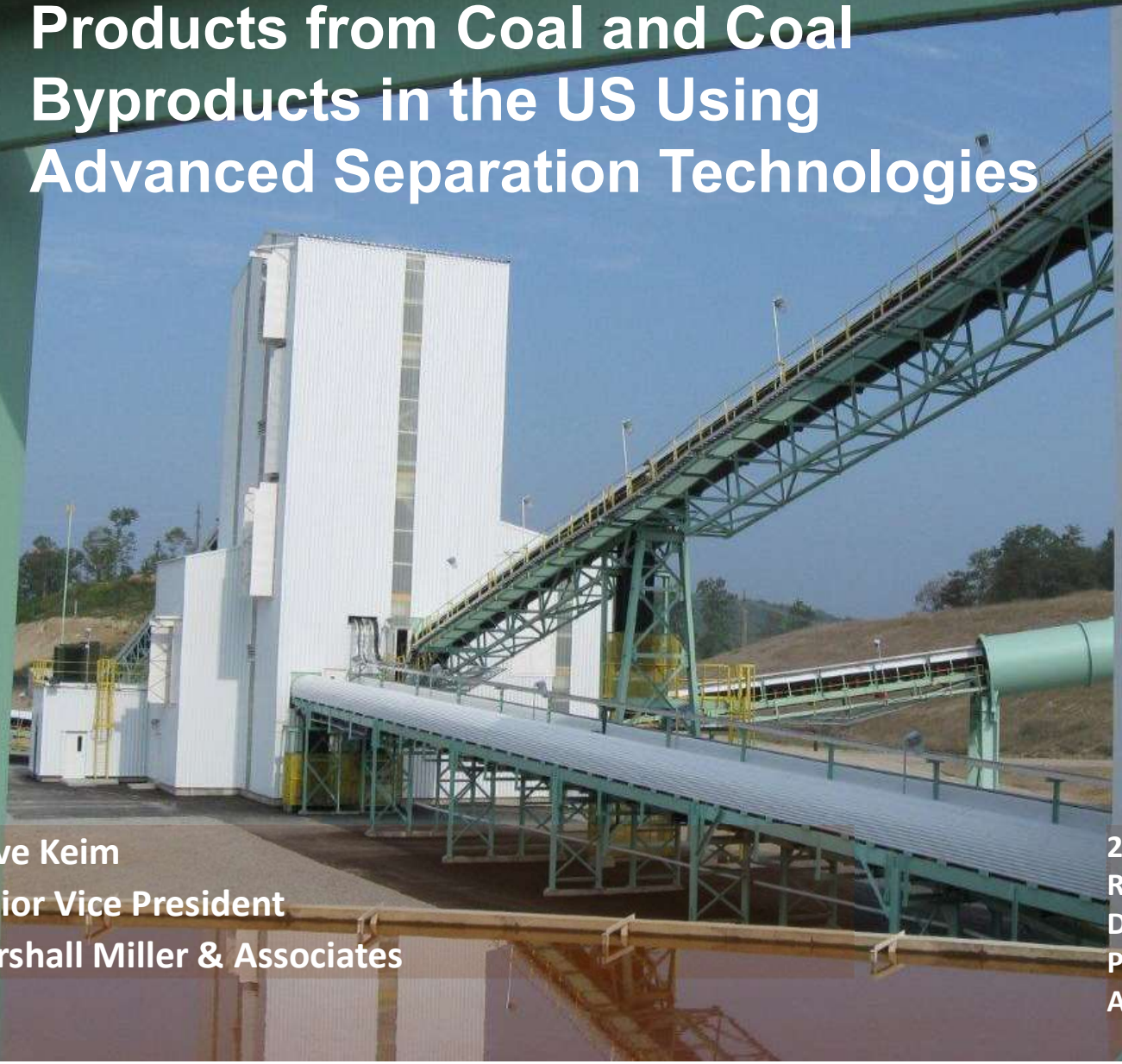
Production of Saleable Rare Earth Products from Coal and Coal Byproducts in the US Using Advanced Separation Technologies



Steve Keim
Senior Vice President
Marshall Miller & Associates

2018 Annual Review Meeting
Rare Earth Elements Program
DOE/NETL
Pittsburgh, PA
April 10, 2018

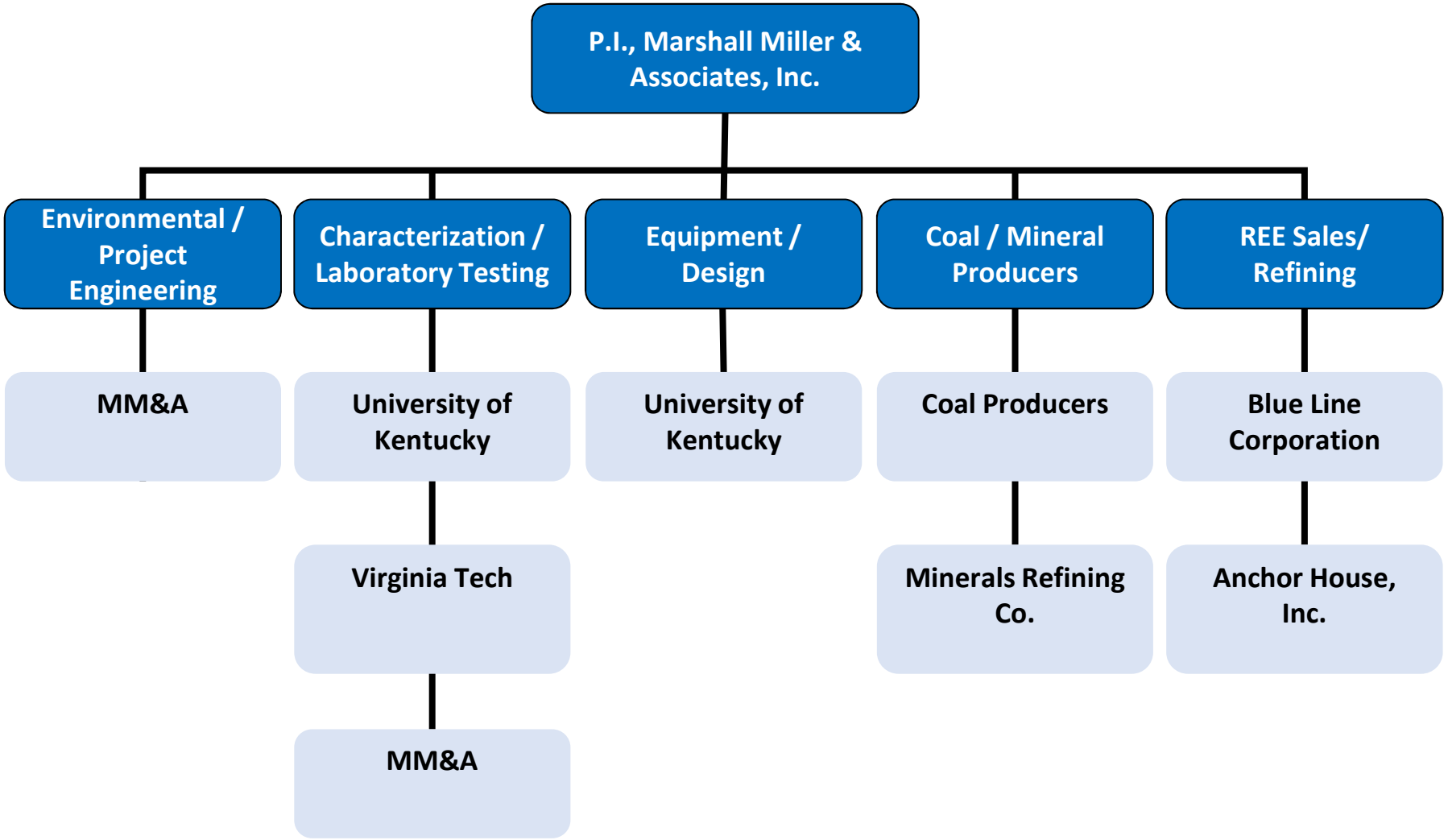
High-Level Project Summary

- Past research has shown that REE's are present in coal and coal byproducts, particularly the non-carbon bearing portions of coal deposits which are not economical to sell as a coal product. These are commonly referred to as "partings" or "high ash" material. Such material is included in run-of-mine coal and is removed in processing plants and discarded in refuse impoundments.

- High-ash partings (and subsequently relatively high REE bearing material) is discarded in large volumes on a daily basis. Additionally, refuse impoundments contain significant volumes of material which contain REE's.

- **This project aims to assess the feasibility of recovering REE's from high ash, discarded material.**

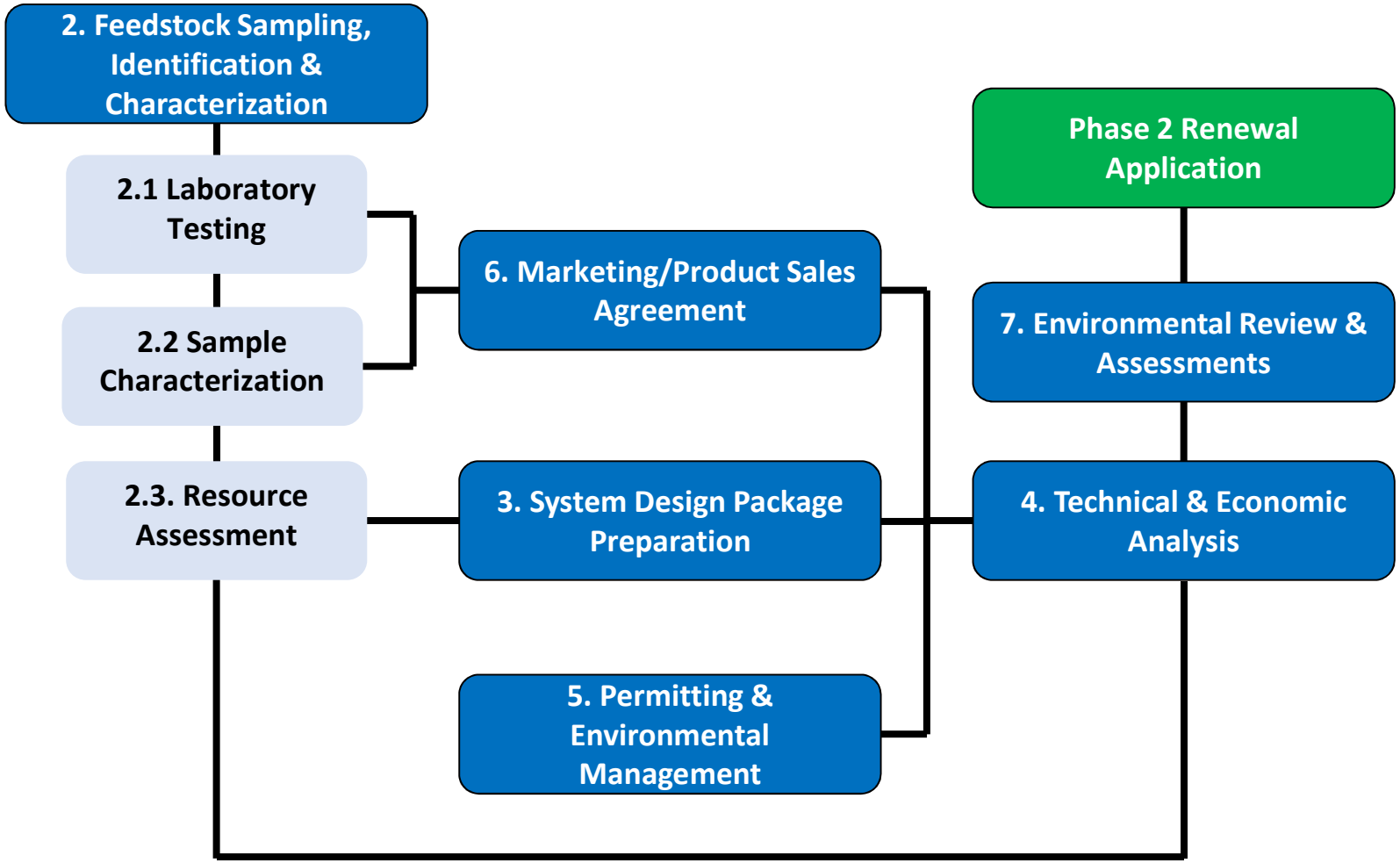
Overview of Project Team



Project Schedule

	2017							2018											2019											
	Phase I - Engineering Development																													
	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Phase I - Engineering Development																														
Task 1.0 Project Management				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■												
Task 2.0 Sampling, Identification & Characterization																														
Subtask 2.1 Sample Collection & Characterization					■	■	■																							
Subtask 2.2 Resource & Reserve Estimate						■	■	■	■																					
Subtask 2.3 Laboratory Testing					■	■	■	■	■	■	■	■	■	■	■	■	■													
Subtask 2.4 Phase I Sample Analysis					■	■	■	■	■	■	■	■	■	■	■	■	■	■												
Task 3.0 Systems Design Package Preparation																														
Subtask 3.1 Flowsheet Development							■	■	■	■	■	■																		
Subtask 3.2 Flowsheet Design									■	■	■	■	■	■	■	■	■	■												
Subtask 3.3 Design Review/Fatal Flaw Analysis													■					■												
Task 4.0 Techno-Economic Analysis																														
Subtask 4.1 Technical Evaluation												■	■	■	■	■	■													
Subtask 4.2 Economic Evaluation													■	■	■	■	■	■												
Task 5.0 Permitting & Environmental Management																														
Subtask 5.1 Site Permitting Plan									■	■	■	■	■	■	■	■	■	■												
Subtask 5.2 Environmental Management Plan									■	■	■	■	■	■	■	■	■	■												
Task 6.0 Production Sales Agreement Dvelopment																														
Subtask 6.1 Market Assessment					■	■	■	■	■	■																				
Subtask 6.2 Sales Agreement Development											■	■	■	■	■	■														
Task 7.0 Envioronmental Review/Assessment																														
Subtask 7.1 Data/Information Collection					■	■	■	■	■	■																				
Subtask 7.2 EA/EIS Response/Mitigation									■	■	■	■	■	■	■	■	■	■												
Task 8.0 Benchmark Process Audits						■	■	■	■	■																				
Task 9.0 Phase I Project Reporting				■			■			■			■			■	■	■												

Project Flow Chart



Where are REE's in coal?

High Level Coal Mining & Processing Flowchart

Low-Ash (High Coal Purity) Product

Coal Processing Plant

Coarse Refuse

Coarse Refuse Impoundment

Middling (Moderate Coal Purity) Product

Fine Refuse

Fine Refuse Impoundment

Where can we target REE Recovery from Coal?

Low-Ash (High Coal Purity) Product

Coal Processing Plant

Coarse Refuse

Coarse Refuse Impoundment

Middling (Moderate Coal Purity) Product

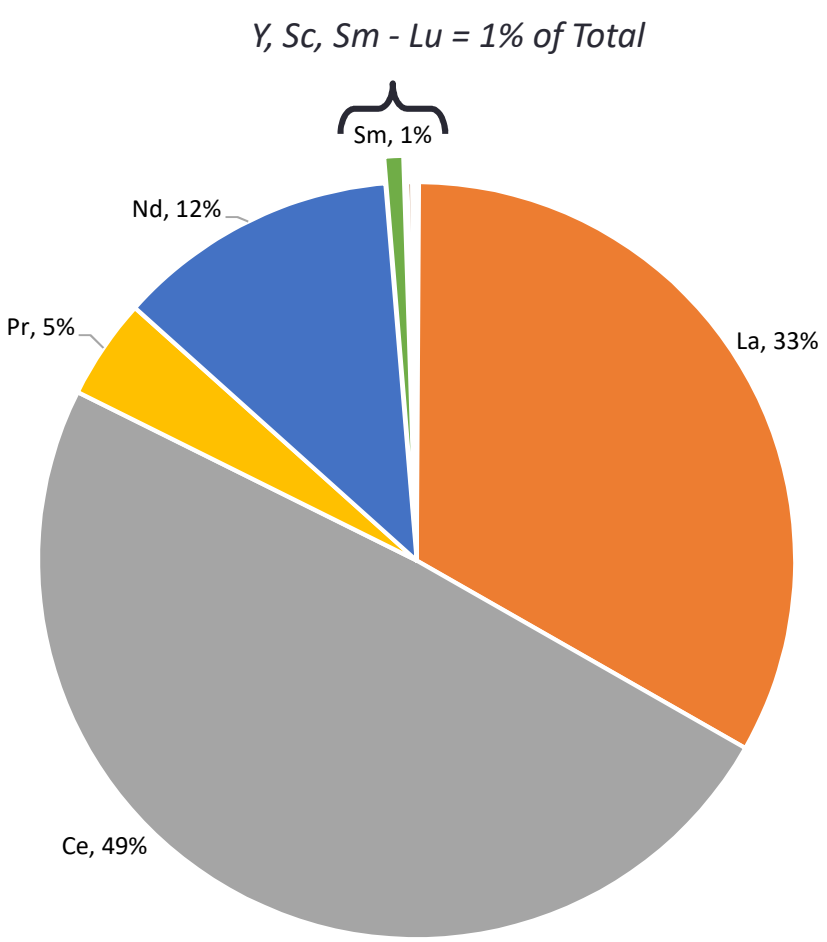
Fine Refuse

Fine Refuse Impoundment

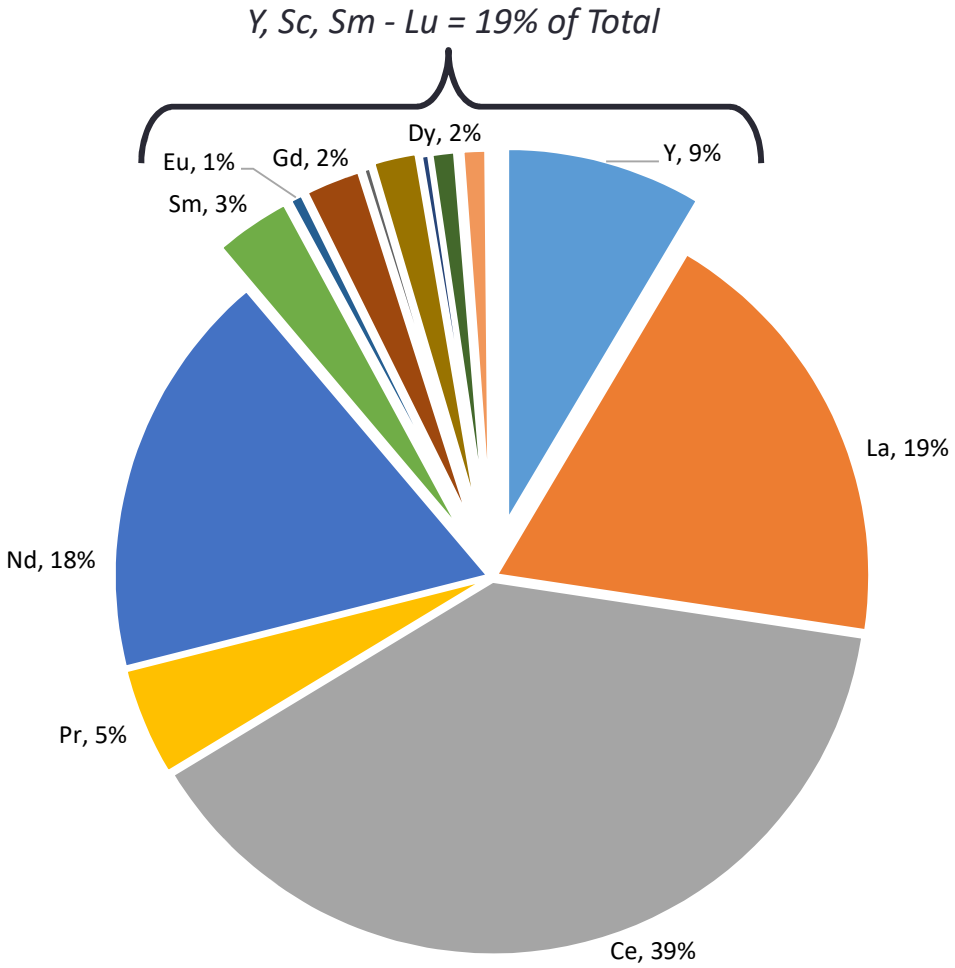
Project Specifics

- **What are we doing?** Conducting upfront engineering work associated with the design and permitting of a facility to produce 10 pounds per day of 90% pure rare earth oxides from coal/coal waste.
- **Where is the projected located?** We are focused on Central Appalachian coal based feedstocks, including various product/refuse streams from preparation plants
- **How are going about this?** We will assessing the technical feasibility of the project through feedstock sampling, general site layouts/logistics and economics to determine the best site for Phase II, the construction/installation of the facility

3. REE Distribution



Mountain Pass



Reject Coal, CAPP

Likely Cost Profile of CAPP Met Coal Operation

	per Foot	per Raw Ton	per Clean Ton	$/Per Year
Direct Cash Mining Cost				
Labor - Mine	$ 56.31	$ 10.34	$ 19.53	$ 22,540,000
Supplies - Excluding Roof Control	$ 10.00	$ 1.84	$ 3.47	$ 4,002,929
Supplies - Roof Control	$ 13.41	$ 2.46	$ 4.65	$ 5,368,735
Maintenance and Repair	$ 19.06	$ 3.50	$ 6.61	$ 7,628,413
Power	$ 5.44	$ 1.00	$ 1.89	$ 2,179,547
Other	$ 2.88	$ 0.53	$ 1.00	$ 1,154,196
Total - Direct Cash Mining Cost	**$107.11**	**$ 19.67**	**$ 37.15**	**$ 42,873,820**
Other Direct Cost				
Enviromental	$ 5.77	$ 1.06	$ 2.00	$2,308,392
G&A	$ 5.77	$ 1.06	$ 2.00	$2,308,392
Total - Other Direct Cost	**$ 11.53**	**$ 2.12**	**$ 4.00**	**$4,616,785**
Coal Preparation and Handling				
Coal Preparation Allocation	$ 19.06	$ 3.50	$ 6.61	$7,628,413
Material Handling	$ 13.61	$ 2.50	$ 4.72	$5,448,867
Total Coal Prep. And Handling	**$ 32.67**	**$ 6.00**	**$ 11.33**	**$13,077,280**
Indirect Cash Cost				
Total - Indirect Cash Mining Cost	**$ 33.04**	**$ 6.07**	**$ 11.46**	**$13,227,088**
Capitalization				
Depreciation of Major Mining Equipment	$ 17.30	$ 3.18	$ 6.00	$6,925,177
Amortization of Development Capital	$ 0.36	$ 0.07	$ 0.12	$143,239
Depreciation of Sustaining Capital	$ 8.65	$ 1.59	$ 3.00	$3,462,588
Depletion	$ -	$ -	$ -	$0
Total - Capitalization	**$ 26.31**	**$ 4.83**	**$ 9.12**	**$10,531,004**
Sale Price (Excluding Rare Earth)	$ 216.25	$ 39.72	$ 75.00	$ 86,564,711.28
Total Cash Mining Cost	$ 184.35	$ 33.86	$ 63.94	$ 73,794,973
Total Mining Cost Fully Loaded	$ 210.66	$ 38.69	$ 73.06	$ 84,325,977
EBITDA	$ 31.90	$ 5.86	$ 11.06	$ 12,769,738
Operating Margin (P/L) before Income Tax	**$ 5.59**	**$ 1.03**	**$ 1.94**	**$ 2,238,734**

Task 2. Update

2. Feedstock Sampling, Identification & Characterization

2.1 Laboratory Testing

2.2 Sample Characterization

2.3. Resource Assessment

6. Marketing/Product Sales Agreement

3. System Design Package Preparation

5. Permitting & Environmental Management

4. Technical & Economic Analysis

7. Environmental Review & Assessments

Phase 2 Renewal Application

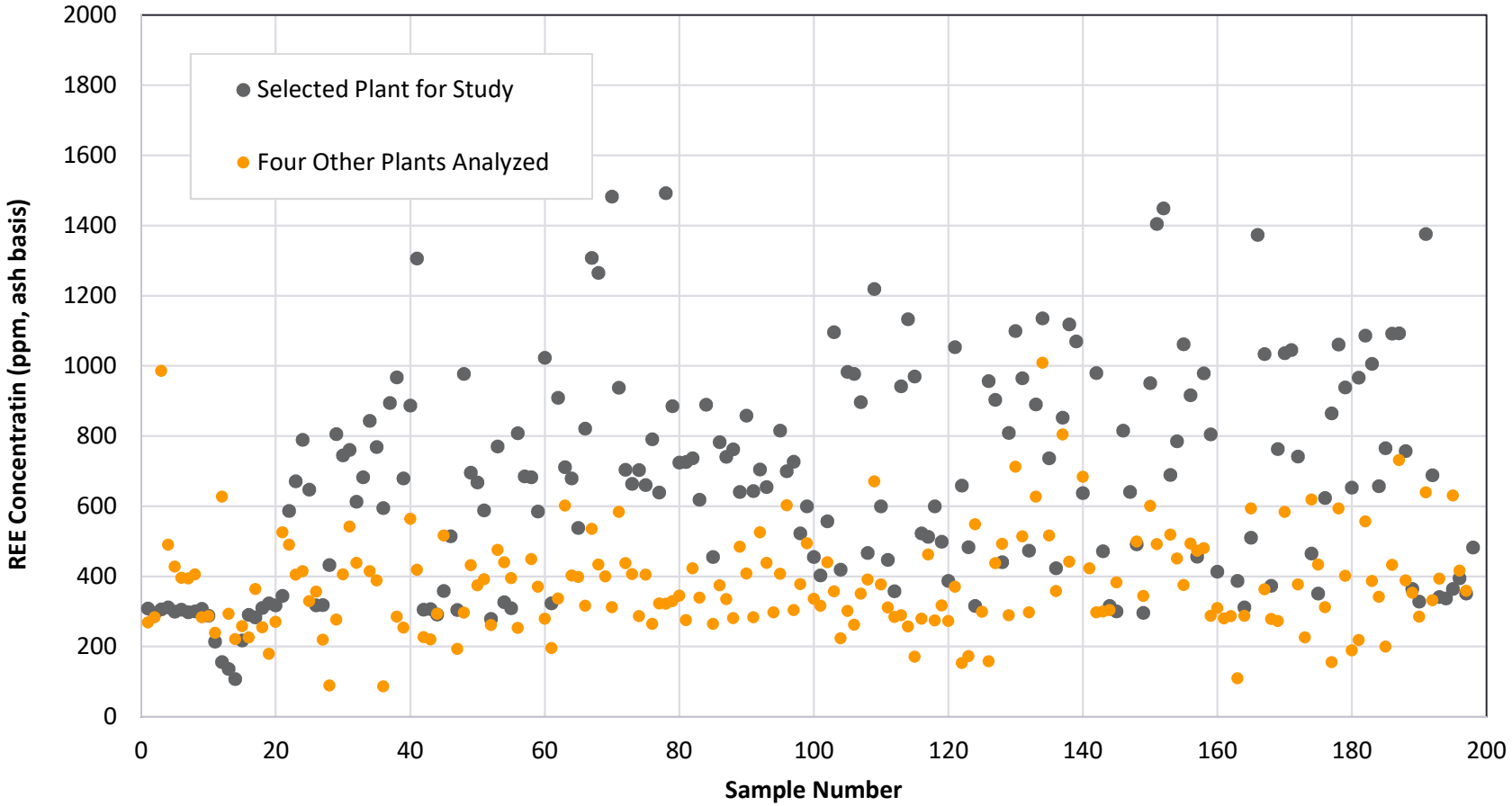
Characterization of the Resource

- **Sample coal processing plant to determine potential product/refuse circuits containing REE's.** Our team completed sampling at multiple CAPP plants which process coal from multiple coal beds ranging in depositional setting, age and coal rank.

- **After determining if "hot" REE's exist in the plant, evaluate geological data to determine potential depositional sources and the long term forecast for potential REE production.** Our team is nearing the completion of a resource/reserve evaluation to determine the long term potential of REE production.

- **Determine recovery factors to assess how much of the resource can feasibility be recovered with novel separation technologies.** Our team is running continuous tests on multiple coal/waste samples (multiple barrels of sample) to determine recovery factors for individual element constituents.

Results, Sampling of Processing Plants



Supplemental Channel Samples

Slide 15

SK1 Steve Keim, 2/5/2018

Channel Sample 1 - Bulk Properties

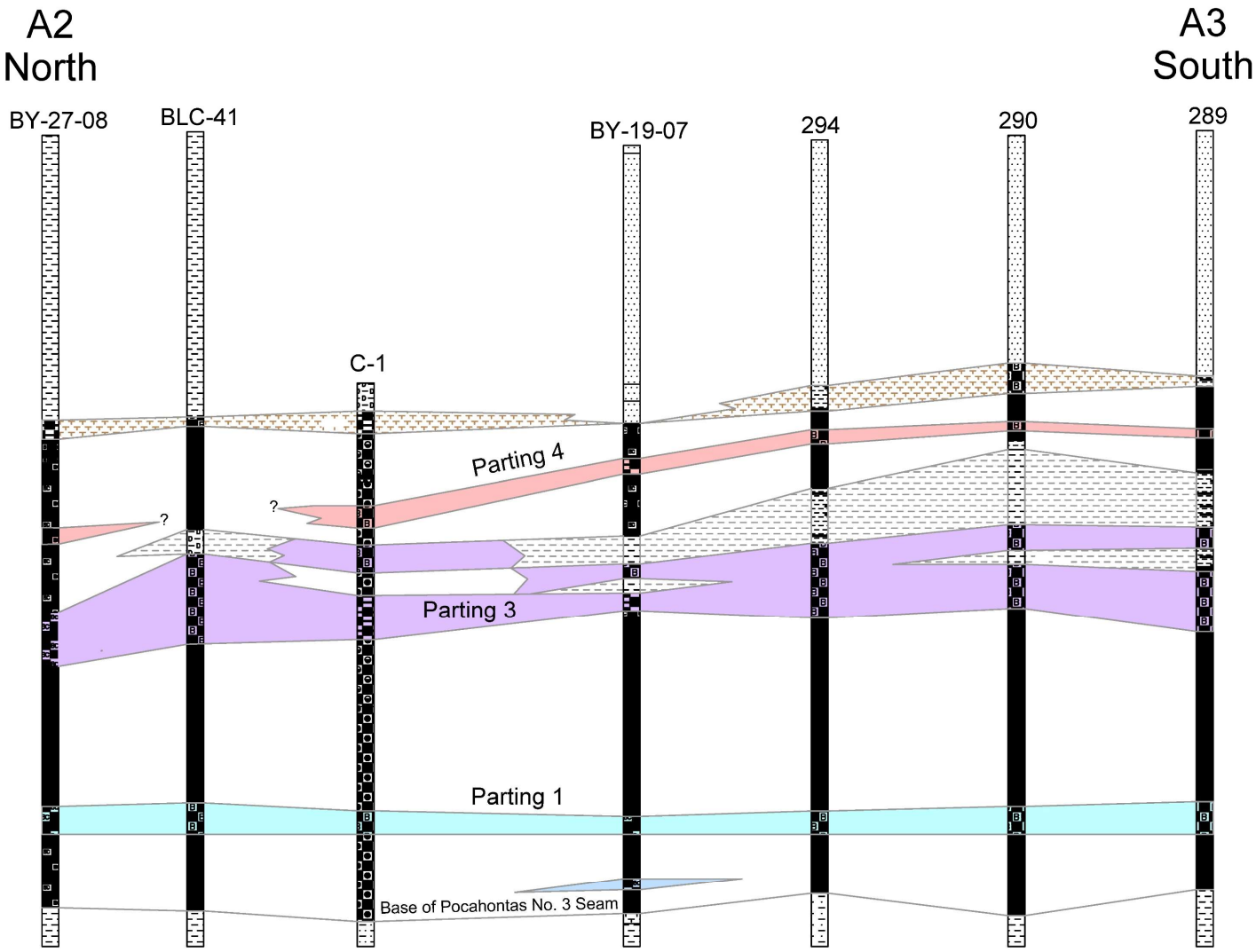
			Thickness			Bulk Properties			Mass (%, dry)			
Sample ID	Lithology Description	CDMS Litho Code	Indiv. (ft)	Cum. (ft)	Sample (ft)	Density (SG)	Density (lb/ft3)	Mass (lb/ft2)	All Splits	In-Seam Only	Relative Thickness	Relative Mass
Roof	Shale/Drk Gray/Hard	SHDK	0.25	0.25	0.25	2.18	136.2	34.0	5.2	--	IIII	IIII
1	Bone w/ Coal Streaks	BOWCOK	0.20	0.45	0.20	1.81	112.8	22.6	3.5	5.3	III	III
2	Clarain w/ Vitrain Layers	COCLAR	0.37	0.82	0.37	1.40	87.6	32.4	5.0	7.6	IIIII	IIII
3	Coal w/Thick Pyrite Layer	COWPY	0.06	0.88	0.27	1.35	84.4	22.8	3.5	5.4	IIII	III
	Vitrain w/ Fusain Streaks	COBRT	0.21	1.09								
4	Bone w/ Coal Streaks	BO	0.20	1.29	0.80	1.56	97.5	78.0	12.0	18.4	IIIIIIIIIII	IIIIIIIII
	Vitrain	COBRT	0.15	1.44								
	Bone	BO	0.25	1.69								
	Vitrain w/ Bone Streaks	COBRT	0.20	1.89								
5	Bone w/ Coal Streaks	BOWCOK	0.40	2.29	1.93	1.52	94.9	183.2	28.1	43.1	IIIIIIIIIIIIIIIIIIIIIIIIIIIIII	IIIIIIIIIIIIIIIIIIIIIIII
	Clarain w/ Vitrain Streaks	COCLAR	0.60	2.89								
	Vitrain w/ Fusain Streaks	COBRT	0.93	3.82								
6	Bone	BO	0.21	4.03	0.21	1.61	100.2	21.0	3.2	5.0	III	II
7	Vitrain	COBRT	0.78	4.81	0.78	1.33	83.1	64.8	9.9	15.3	IIIIIIIIII	IIIIIII
Floor	Siltstone/Very Hard	SI	1.50	6.31	1.50	2.07	128.9	193.3	29.6	--	IIIIIIIIIIIIIIIIIIIII	IIIIIIIIIIIIIIIIIIIIII
Sample	All Strata	--	6.31	--	6.31	--	--	652.2	100.0	100.0		
Coal	Coal (No Roof & Floor)	--	4.56	--	4.56	--	--	424.8	65.1	100.0		
Rock	Rock (Roof & Floor)	--	1.75	--	1.75	--	--	227.4	34.9	0.0		

Channel Sample 1 - Bulk Properties

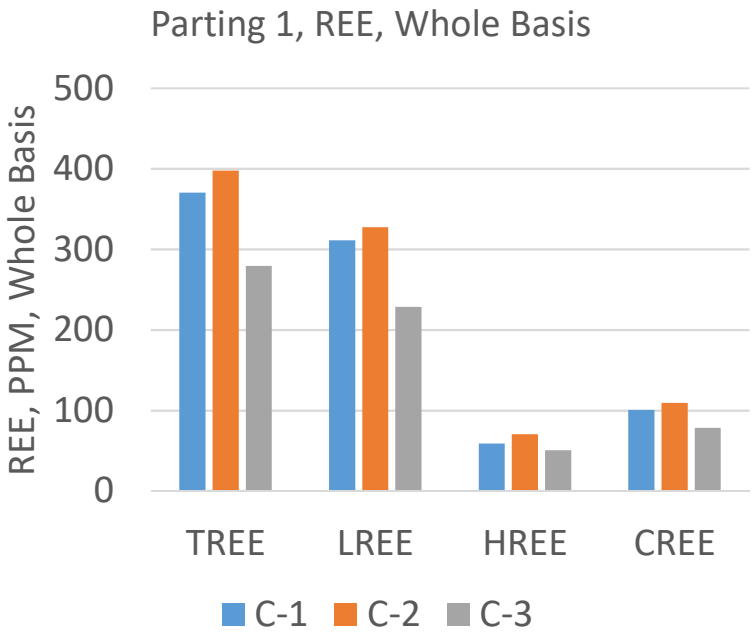
Sample	Lithology	Mass	Ash	Concentration (ppm, whole-basis)				Concentration (ppm, ash-basis)				Concentration Ratios			
ID	Description	(%, dry)	(%, dry)	TREE	LREE	HREE	CREE	TREE	LREE	HREE	CREE	L/T	H/T	C/T	H/L
Roof	Shale/Drk Gray/Hard	5.2	80.86	166.8	126.1	40.7	53.4	206.3	155.9	50.4	66.0	0.76	0.24	0.32	0.32
1	Bone w/ Coal Streaks	3.5	48.27	218.4	184.4	34.0	57.9	452.4	382.0	70.4	120.0	0.84	0.16	0.27	0.18
2	Clarain w/ Vitrain Layers	5.0	13.20	75.6	60.8	14.7	21.5	572.5	460.9	111.6	162.5	0.81	0.19	0.28	0.24
3	Coal w/Thick Pyrite Layer Vitrain w/ Fusain Streaks	3.5	8.82	62.8	48.7	14.1	19.3	712.2	552.0	160.2	219.3	0.78	0.22	0.31	0.29
4	Bone w/ Coal Streaks Vitrain Bone Vitrain w/ Bone Streaks	12.0	26.95	151.0	125.9	25.0	41.5	560.2	467.3	92.9	154.0	0.83	0.17	0.27	0.20
5	Bone w/ Coal Streaks Clarain w/ Vitrain Streaks Vitrain w/ Fusain Streaks	28.1	23.38	157.9	130.9	27.0	44.1	675.2	559.8	115.4	188.5	0.83	0.17	0.28	0.21
6	Bone	3.2	30.75	370.4	311.2	59.2	100.5	1204.5	1012.1	192.4	326.9	0.84	0.16	0.27	0.19
7	Vitrain	9.9	6.93	69.4	46.0	23.4	27.9	1001.0	663.6	337.4	403.1	0.66	0.34	0.40	0.51
Floor	Siltstone/Very Hard	29.6	70.68	287.0	243.7	43.3	82.7	406.1	344.8	61.3	117.1	0.85	0.15	0.29	0.18
Sample	All Strata	100.0	39.28	188.5	156.4	32.2	54.4	480.0	398.1	81.9	138.6	0.83	0.17	0.29	0.21
Coal	Coal (No Roof & Floor)	65.1	21.65	145.5	119.0	26.4	41.6	671.8	549.7	122.0	192.2	0.82	0.18	0.29	0.22
Rock	Rock (Roof & Floor)	34.9	72.20	269.0	226.1	42.9	78.3	372.6	313.1	59.5	108.5	0.84	0.16	0.29	0.19

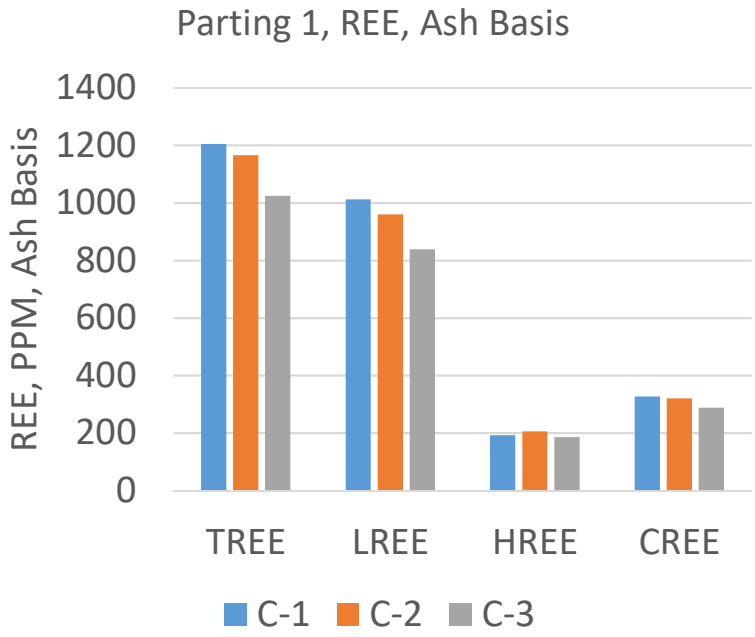
LREE = La, Ce, Pr, Nd, Pn
HREE = Gd, Tb, Dy, Ho, E
CREE = Y, Nd, Eu, Tb, Dy

Resource Study Cross Section Example

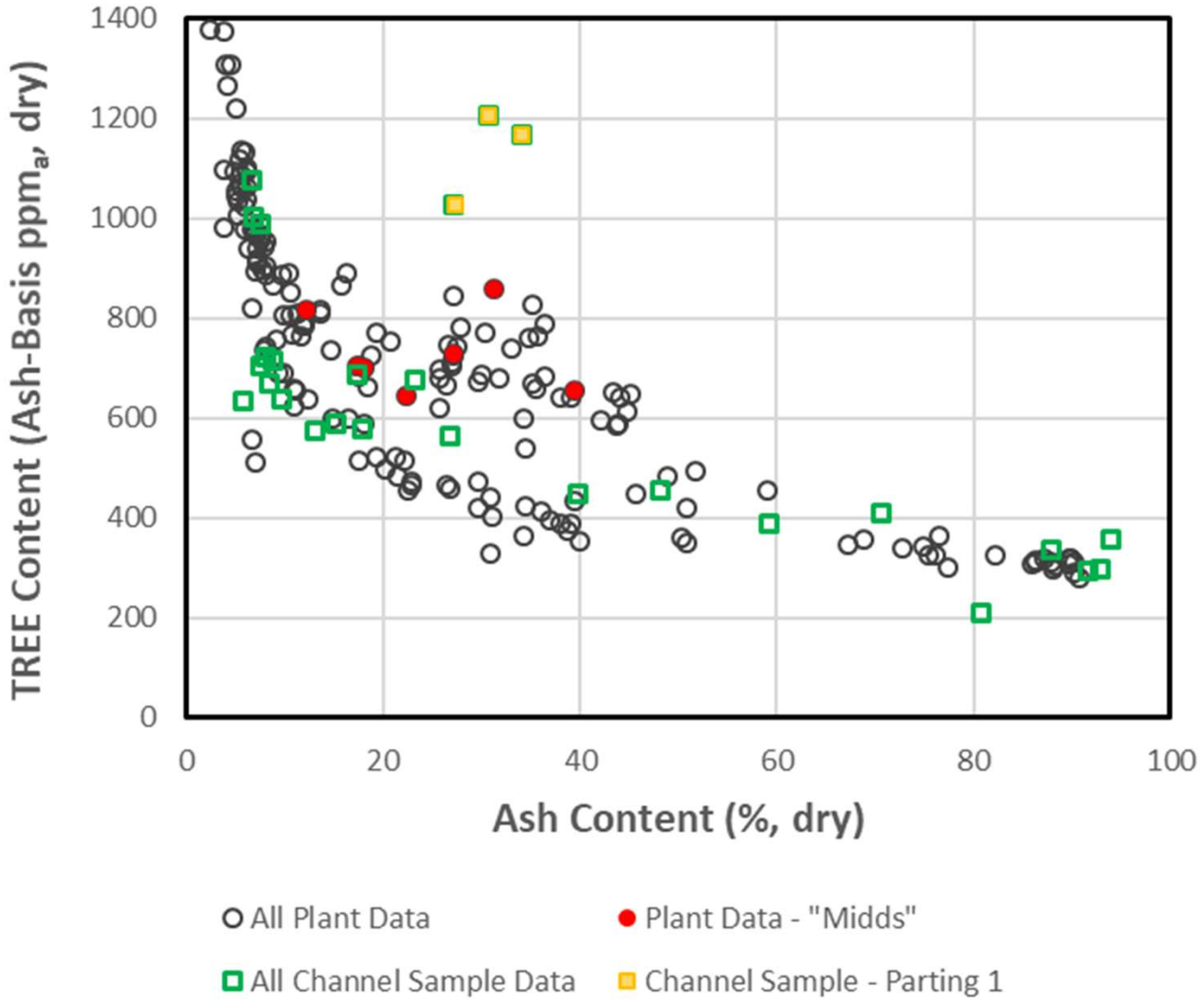


Channel Sample Comparison—Parting 1





Channel Samples & Plant Samples



Where are we focusing our efforts?

Low-Ash (High Coal Purity) Product

Coal Processing Plant

Coarse Refuse

Coarse Refuse Impoundment

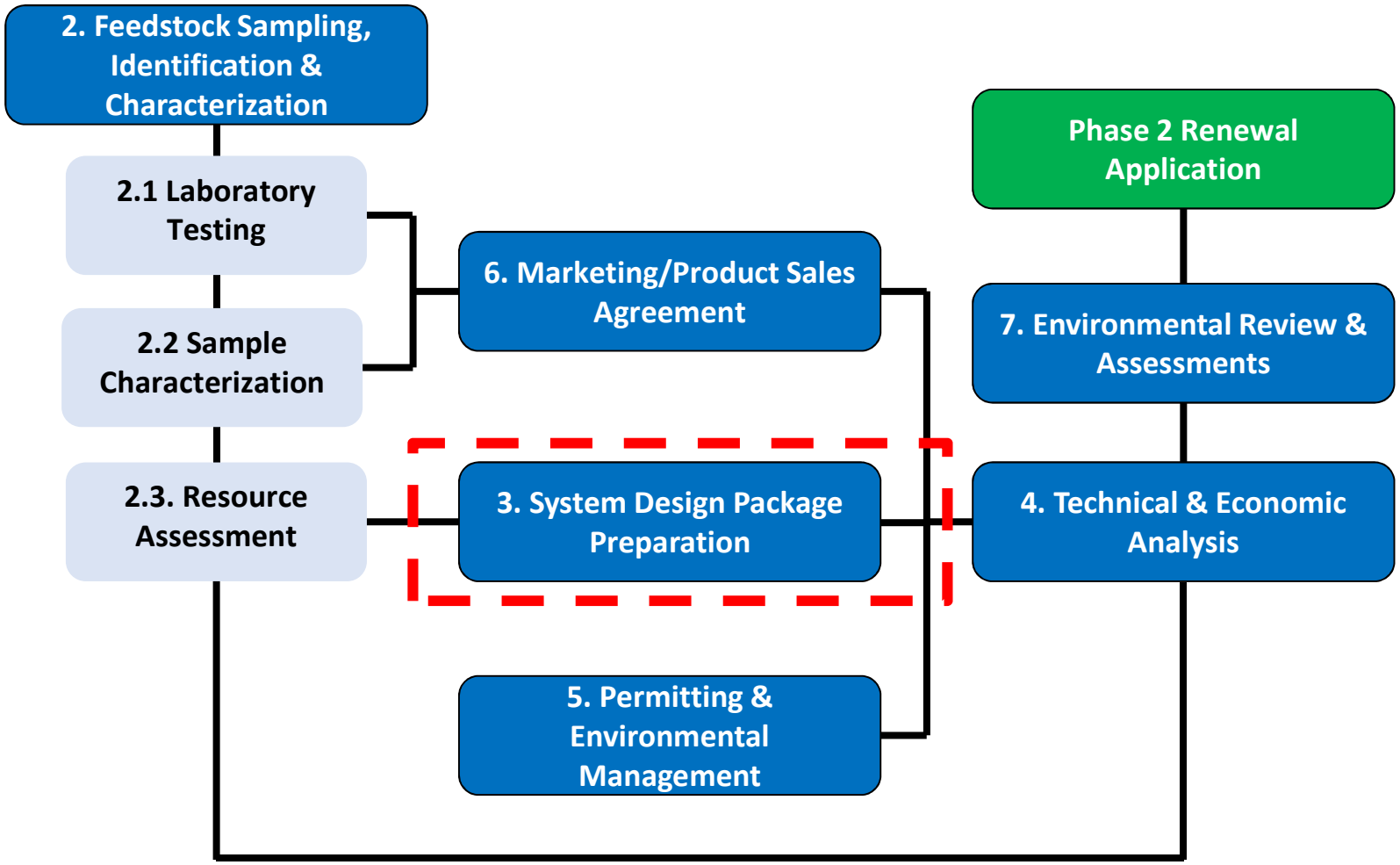
Fine Refuse

Fine Refuse Impoundment

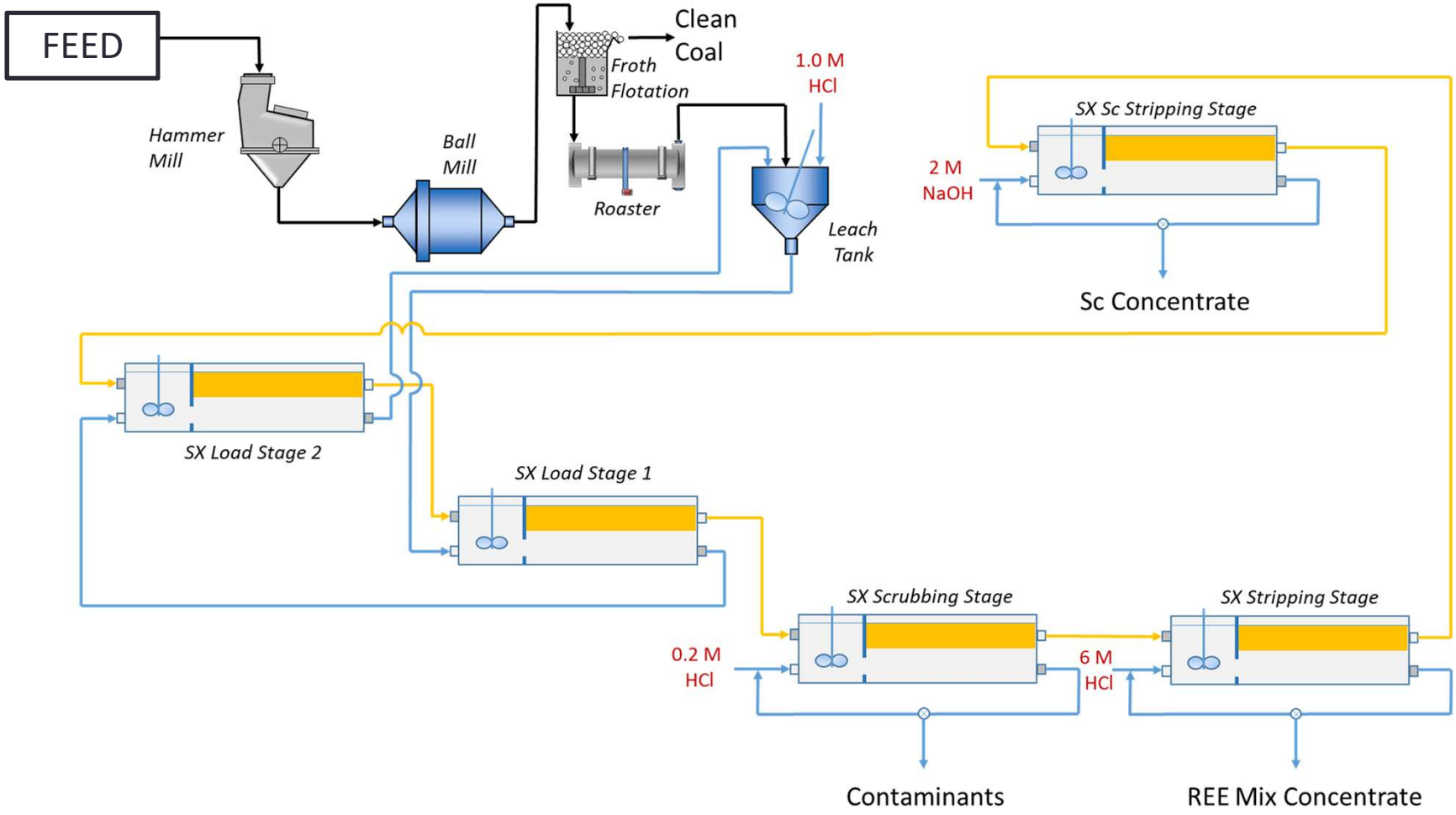
Middling (Moderate Coal Purity) Product

Middling Product—Reduce Size and Subdivide into High Purity Coal & REE Rich Feedstock

REE Processing Design Update



Flowsheet Development

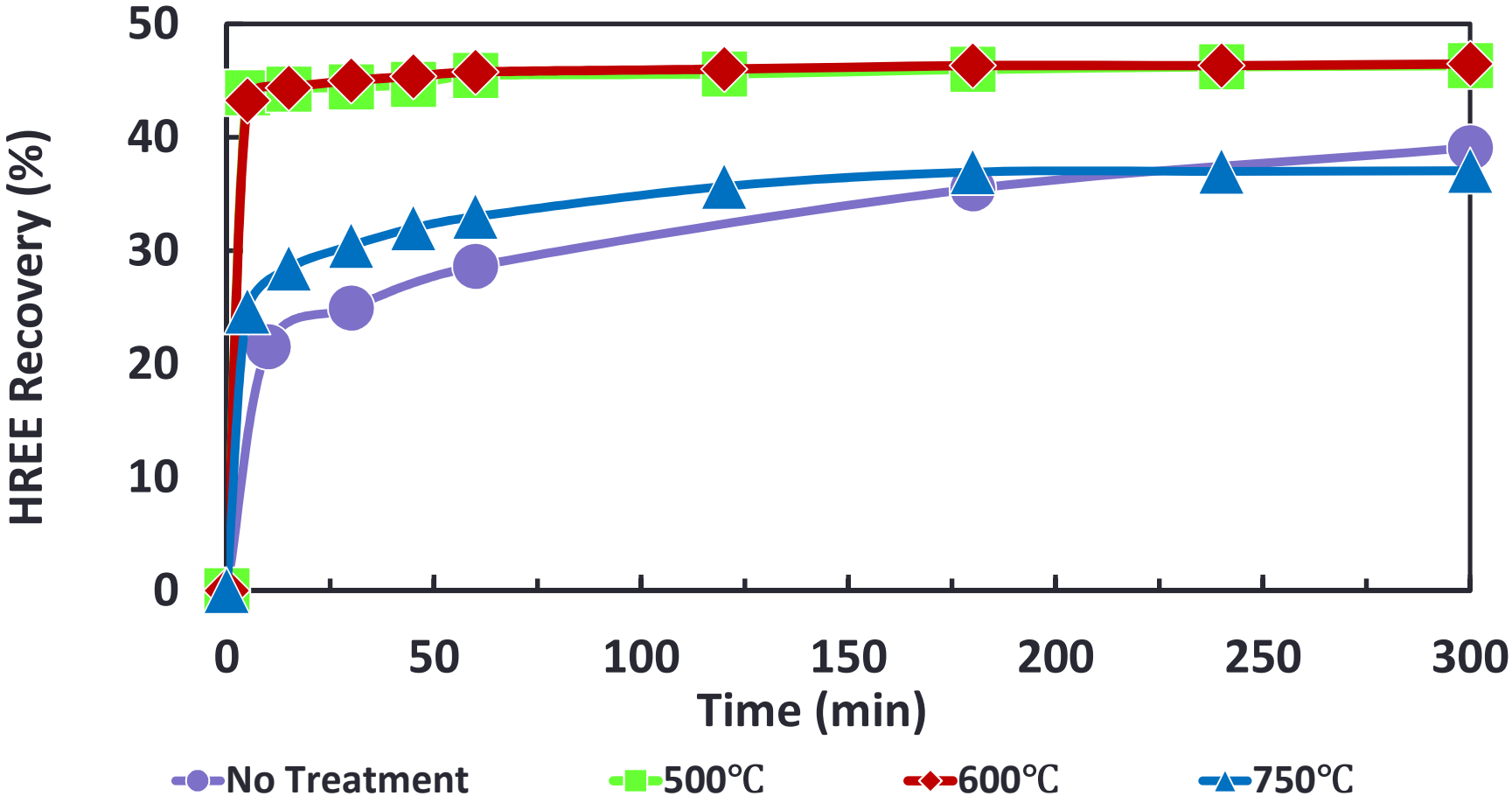


Solvent Extraction Unit – University of Kentucky

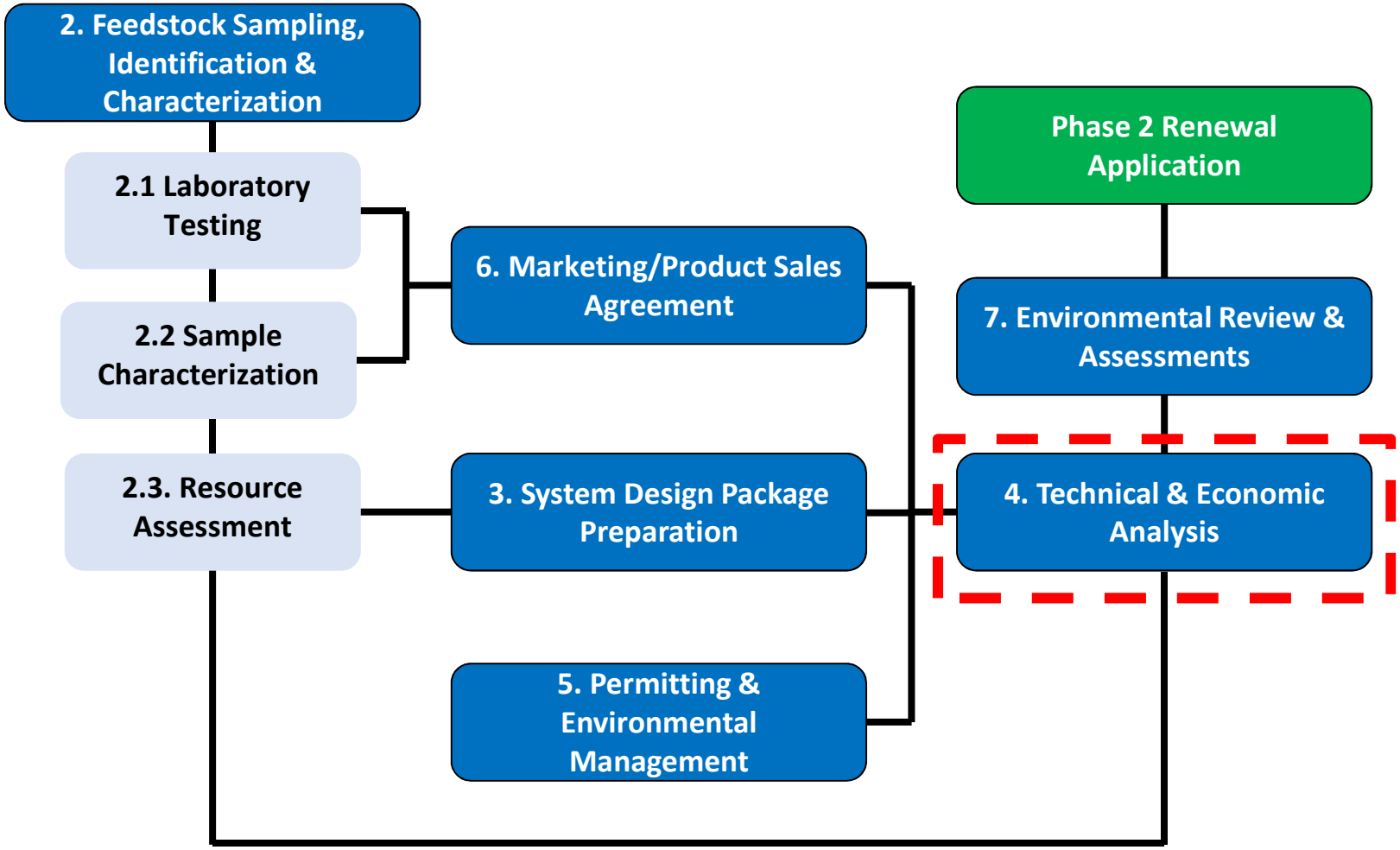
Ongoing Laboratory Tests—REE Extraction

- **Leaching.** Currently evaluating the effectiveness of various acids, strengths, leaching times, leaching temperature.
  - Initial leaching testing suggests difficult leachability for most REE's with recoveries <50%. Additional pre-treatment tests are underway to increase REE leachability
- **Roasting.** Currently evaluating the effectiveness of roasting to oxidize REE's and increase leachability.
  - Initial testing shows that some REE recoveries are significantly increased through roasting. Additional tests are underway.
- **Solvent Extraction.** Solvent extraction tests on leachate material have shown very favorable REE recoveries.
  - Ability to recycle acid has also been proven, significantly decreasing operating costs associated with solvent extraction process.
- **Summary: High recovery leachate production in the current challenge.**

Effect of Roasting Temperature on REE Leachate Recovery



Task 2. Update



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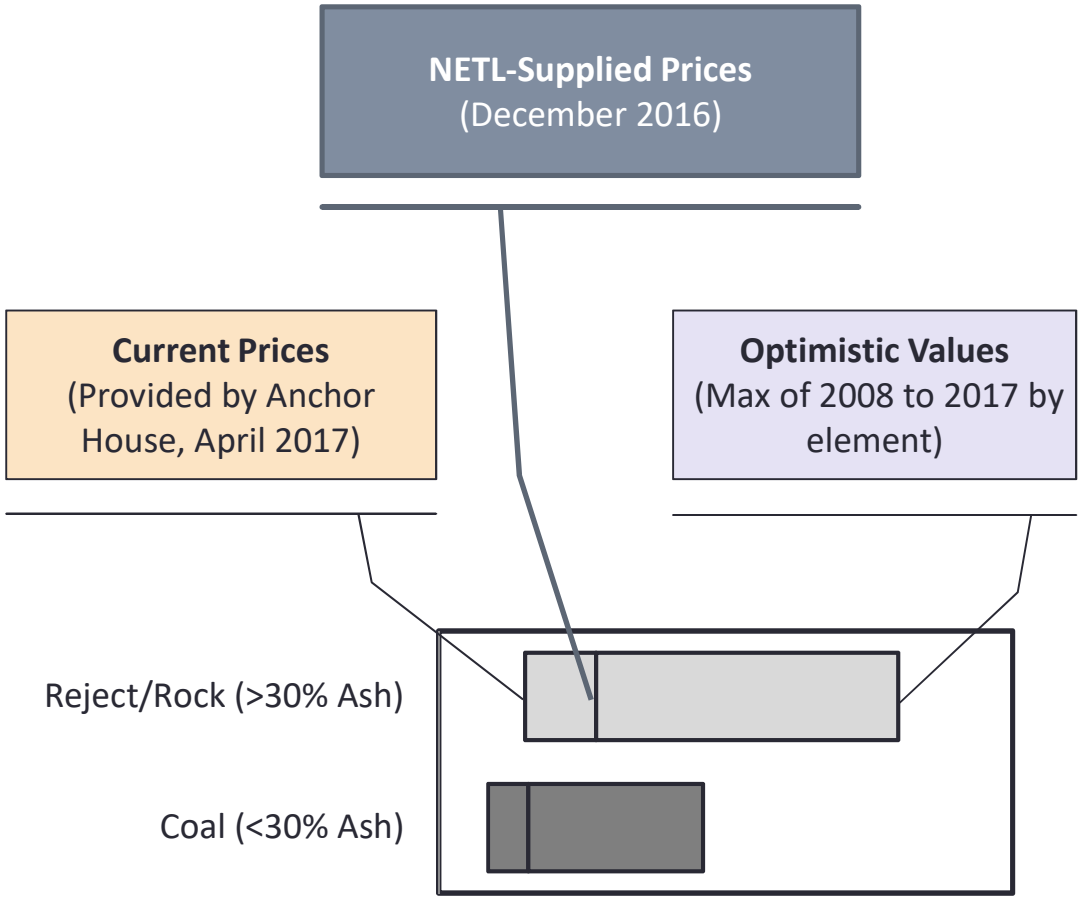
MINERALS REFINING COMPANY

Virginia Tech 1872

University of Kentucky



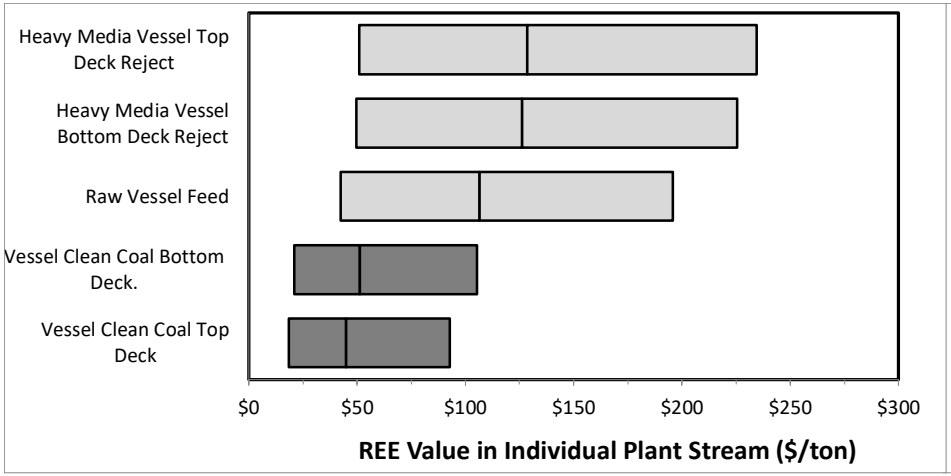
REE Value in Individual Stream ($/ton)

REE Prices ($/kg oxide)

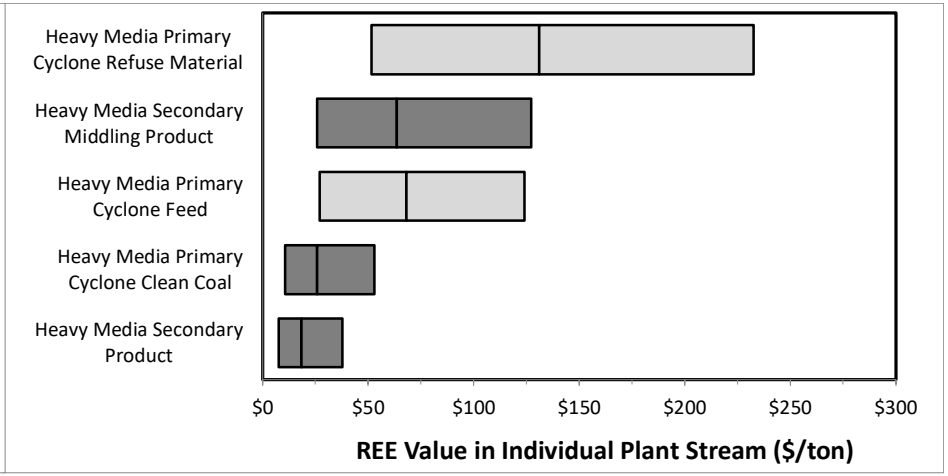
Element	Current Prices	NETL-Supplied Prices	Opt. Prices
Sc	$1,500	$4,200	$5,400
Y	$4.60	$6.00	$165
La	$2.25	$2.00	$100
Ce	$2.20	$2.00	$100
Pr	$70.00	$52.00	$225
Nd	$56.00	$42.00	$270
Sm	$2.2.	$5.74	$200
Eu	$55.00	$150	$3,300
Gd	$17.46	$32.00	$239
Tb	$505	$400	$2750
Dy	$188	$230	$1,600
Ho	--	--	$750
Er	$26.30	$34.00	$255
Tm	--	--	$2,500
Yb	--	--	$450
Lu	--	--	$4,000

Contained Value of REEs in Plant Products

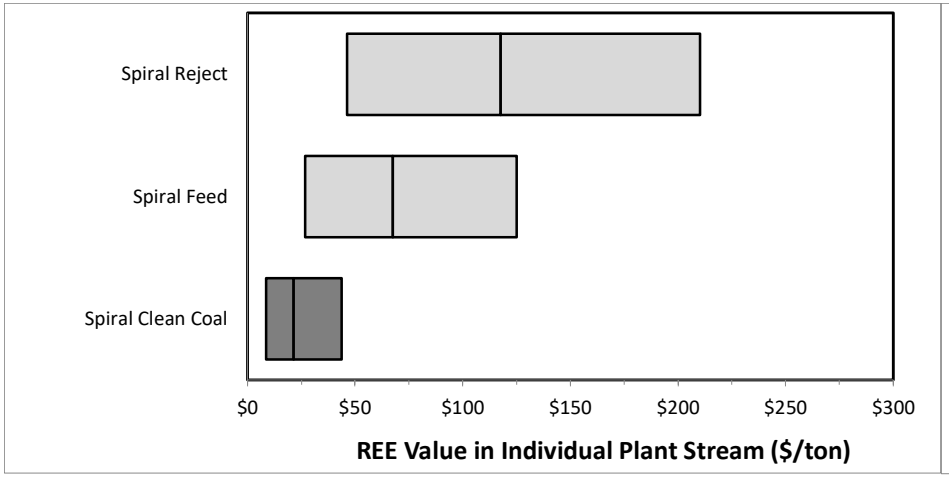
Vessel Circuit



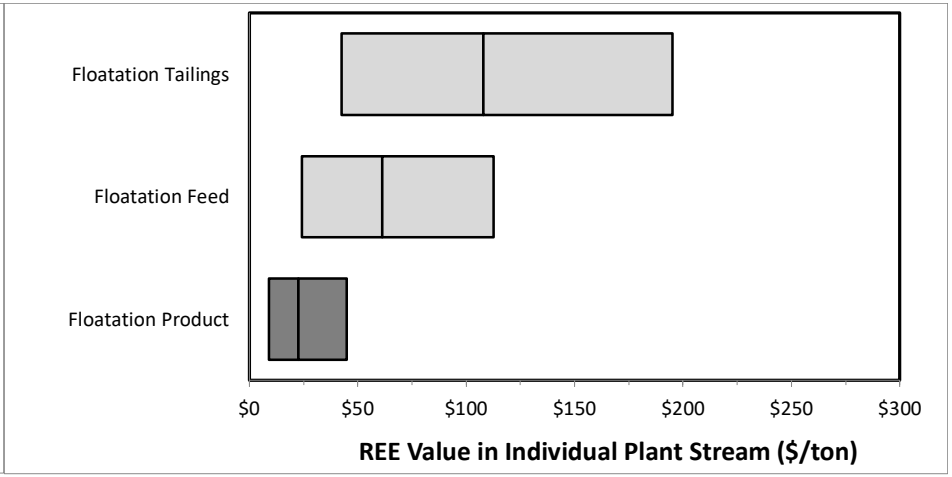
Cyclone Circuit



Spiral Circuit



Flotation Circuit



High-Level Comments on Economics

- **Scandium represents ~90% of the value of the resource**
- Estimated value per ton of high REE parting is in the range of ~$20-$30. *Note—this is a "contained" value estimate and does not account for recovery & dilution.*
- Assuming that 75% of the high REE parting reports to middling circuit, anticipated contained value in the targeted plant circuit is in the range of ~$15-$23 per ton.
- ***Through decarbonization, the anticipated contained value of the REE feed is in the range of $40-$70/ton.***
  - ***Recovery factors associated with REE processing are still being analyzed for leachate generation and could range from 30% to 90%. As such, the value of a product could range from $12 to $60 per raw ton of feed.***
- **Operating costs associated with REE processing need to be well below the above estimated value of $12 to $60 per raw ton.**
  - Costs will include leachate preparation, leaching, solvent extraction, and refuse disposal.

Summary & Conclusions

- The project team has sampled multiple preparation plants and identified a middling/moderate-ash coal product as a potential feedstock for REE recovery
- Through analysis of exploration drilling data & channel samples, the team has determined that the REE concentrations will maintain a consistent level in the middling product throughout the life of the coal mine
- A project partner can decarbonize the feedstock, and effectively upgrade the coal portion of the product to a higher value and concentrate the REE feedstock
- Regarding processing of the REE's, the team is currently assessing ways to boost recovery during leachate production. Recovery during solvent extraction steps is very strong. High recovery of REE's is crucial to offset operating costs and to allow ample production volumes of REE's.

Questions?