Feasibility of Recovering Rare Earth Elements from Thickener Underflows

by

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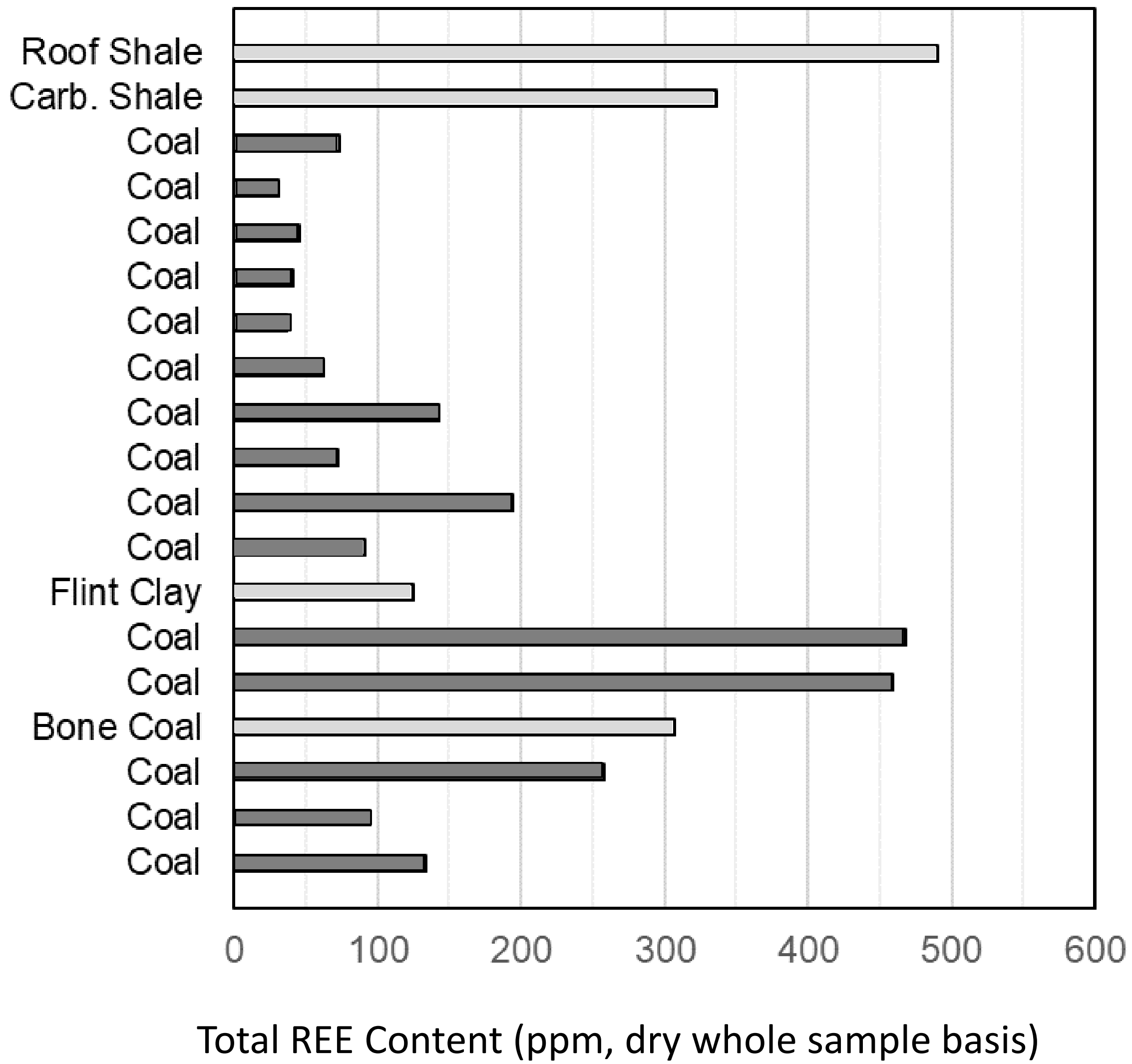
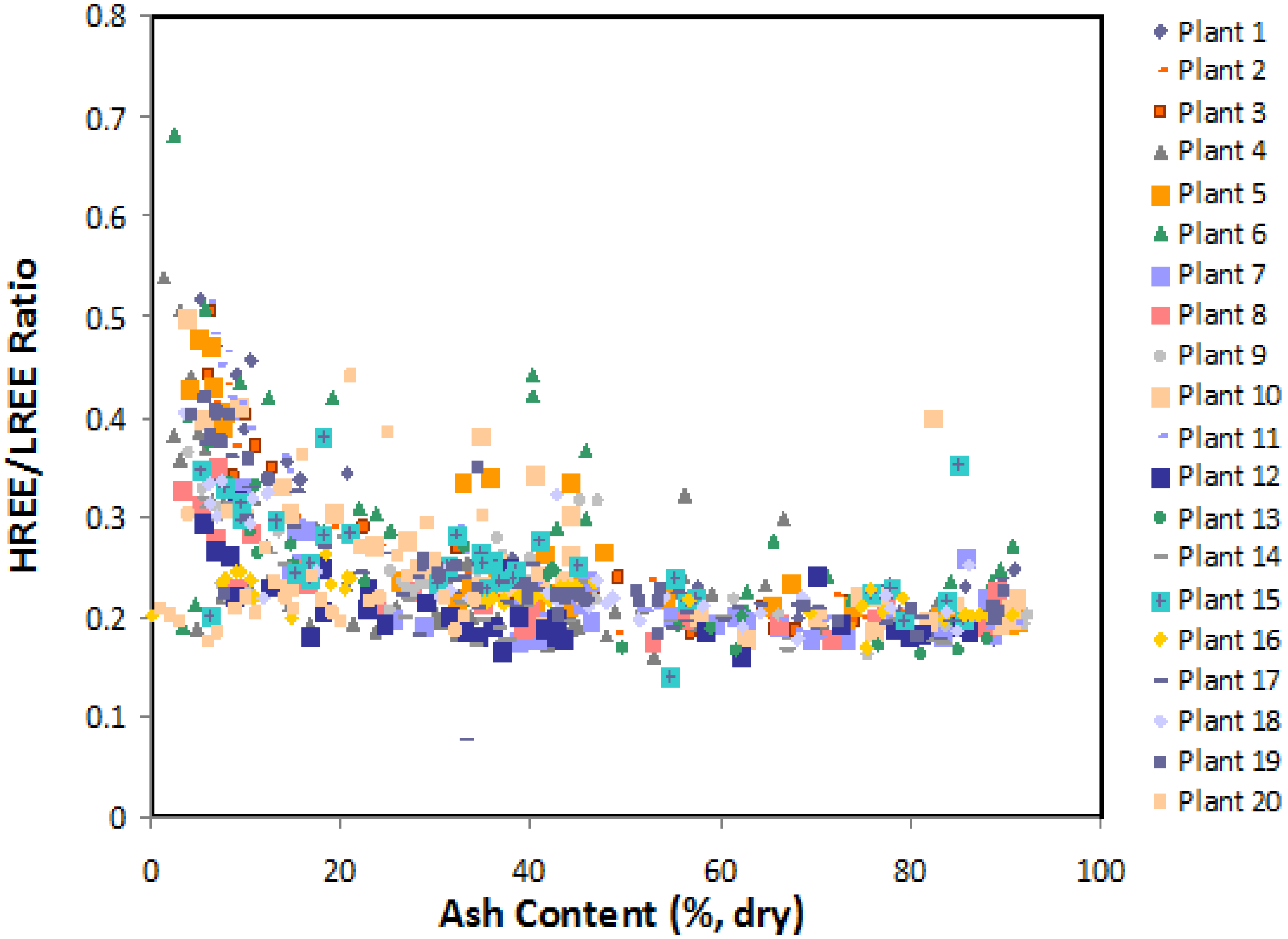
Analysis of Channel Samples

Fire Clay Coal Seam



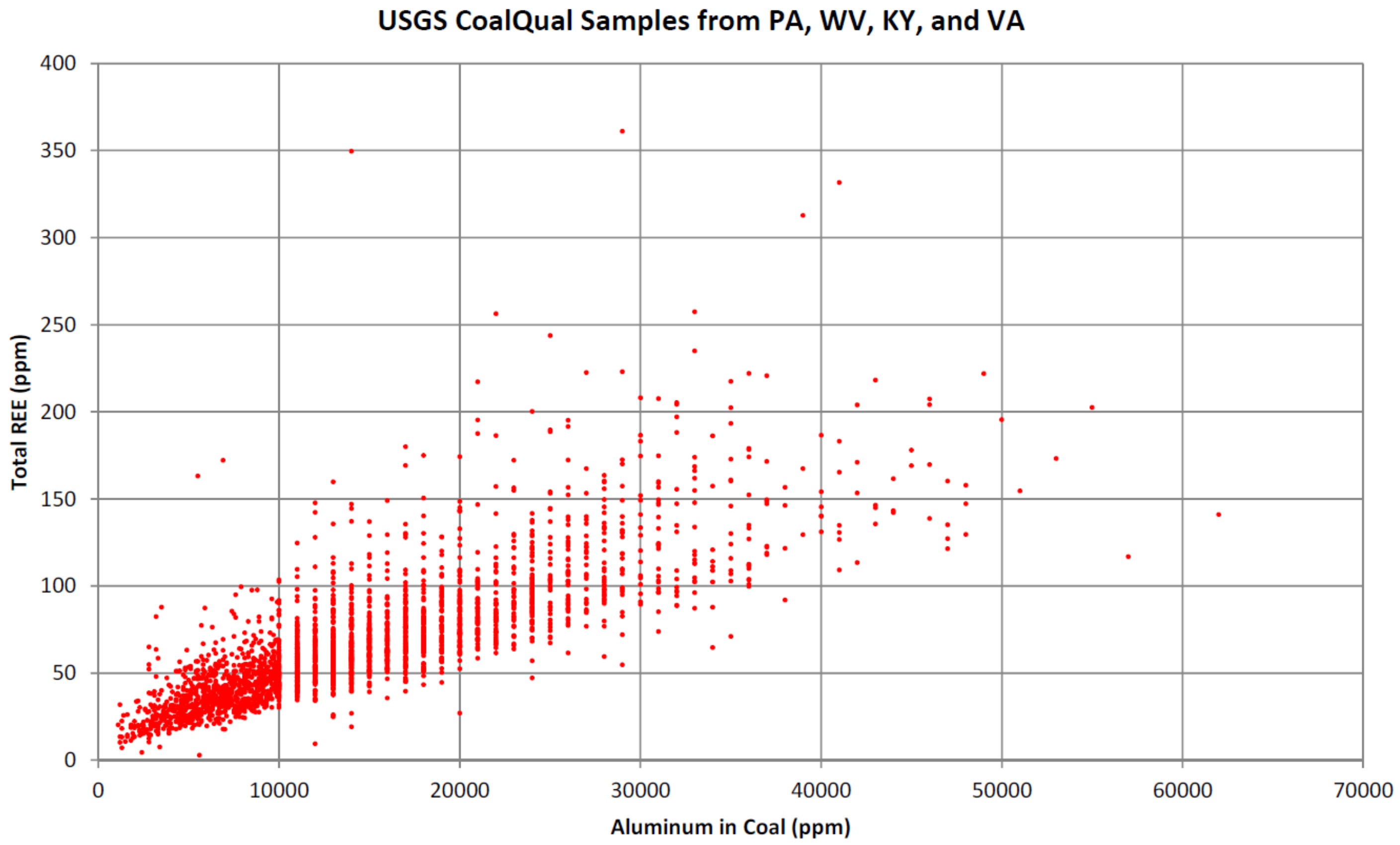
H vs. L REE Ratio



USGS Coal Quality Data Base

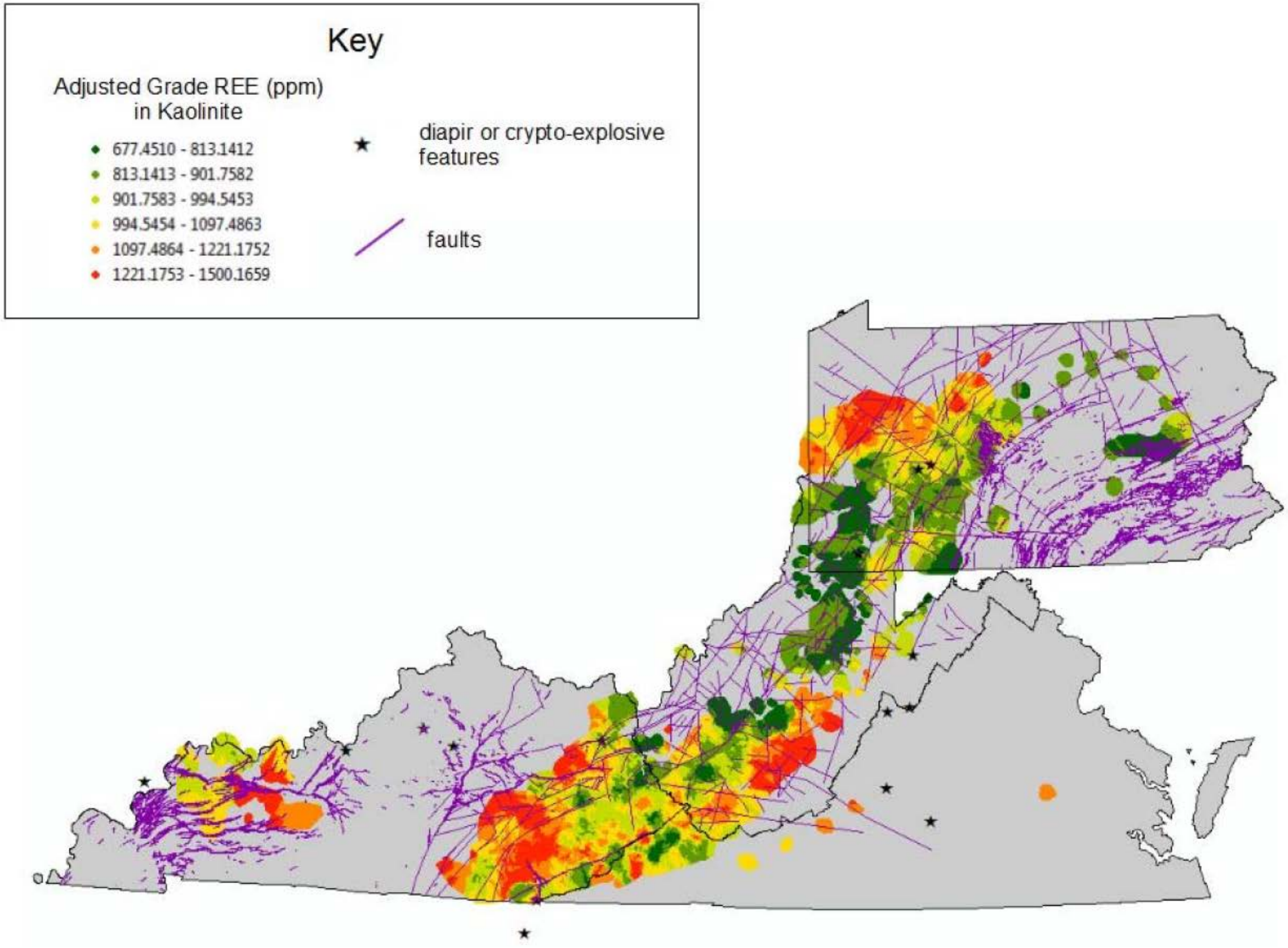
(Bryan et al. 2015)

- REEs are mostly associated with kaolinite



  - 10.9 MM tons at 500 ppm cut-off grade

REE Grades in Kaolinite
(Calculated, Bryan et al. 2015)



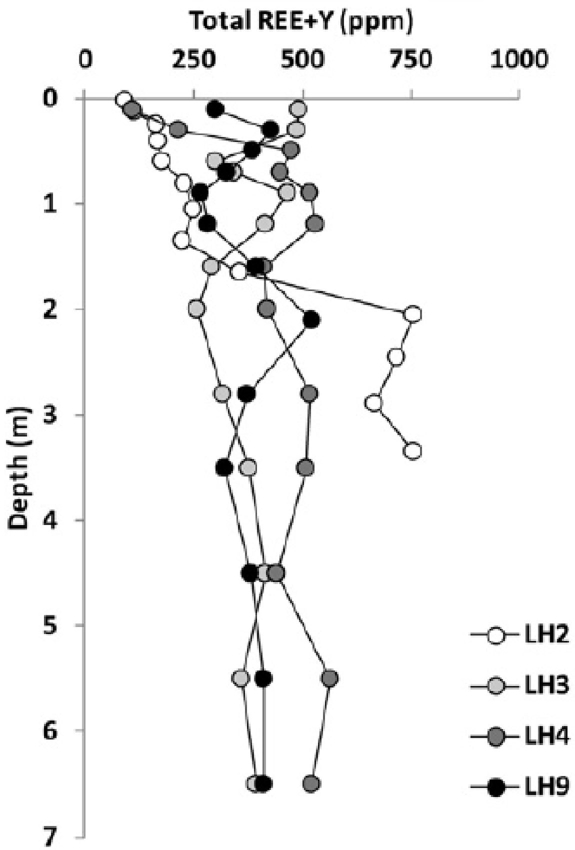
- REE grades on clay are 5-6 times higher than whole coal.

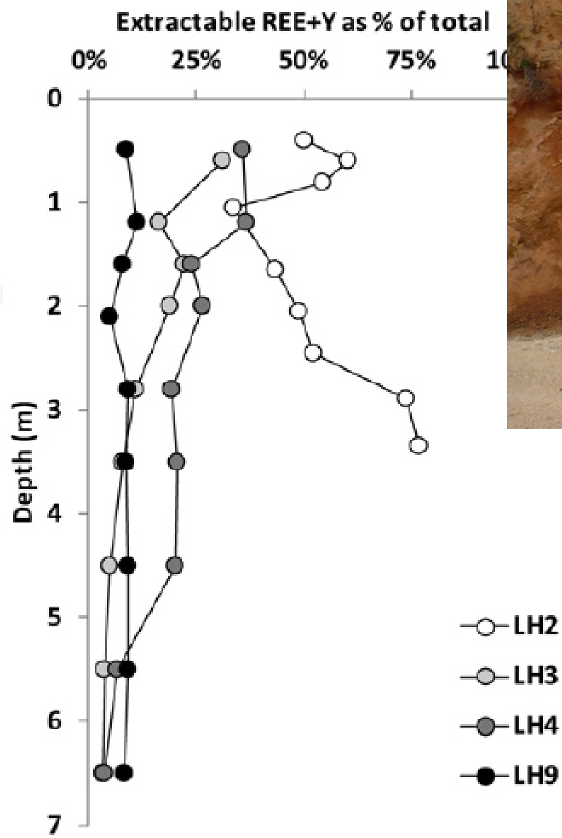
Ion-Adsorption Clay (IAC)

- ❑ South China
  - "Weathered crust elution-deposited rare earth ore"
  - 0.05-0.3% REEs
  - Physisorbed by double-layer force
- ❑ Low-cost extraction process
  - Desorbed by ion-exchange
  - Precipitated by oxalic acid and roasted to REOs.
- ❑ >80% of the world's HREEs
- ❑ >35% of total Chinese REE production

IACs in US?

Bern et al, J. Geochemical Exp. 172, 29 (2017)





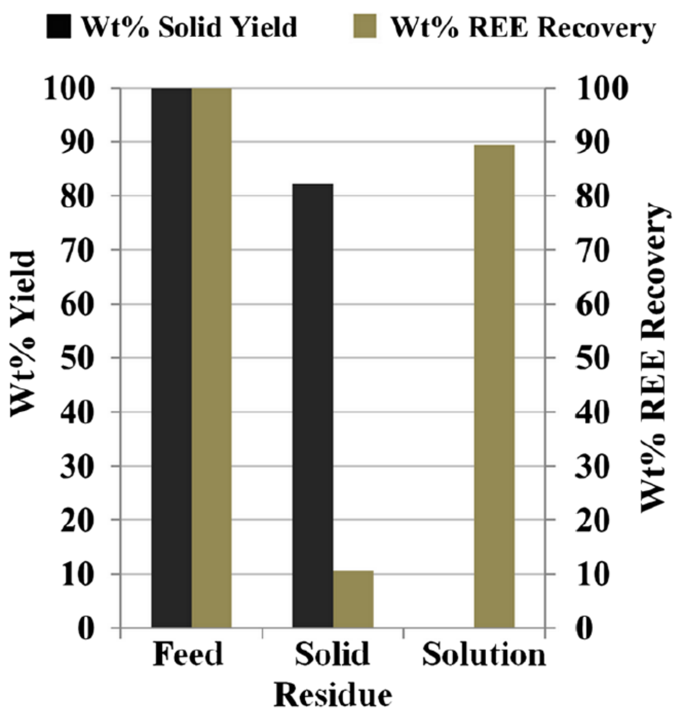
Liberty Hill, South Carolina

Stewartsville, Virginia

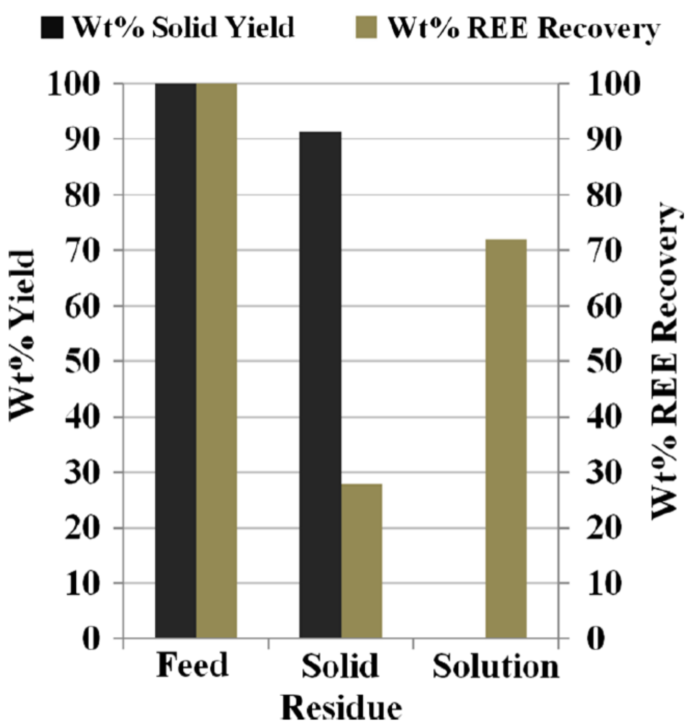
Upper Kittanning Coal, PA

Ion-Exchange Leaching

- Sample A
  - Top of the coal seam

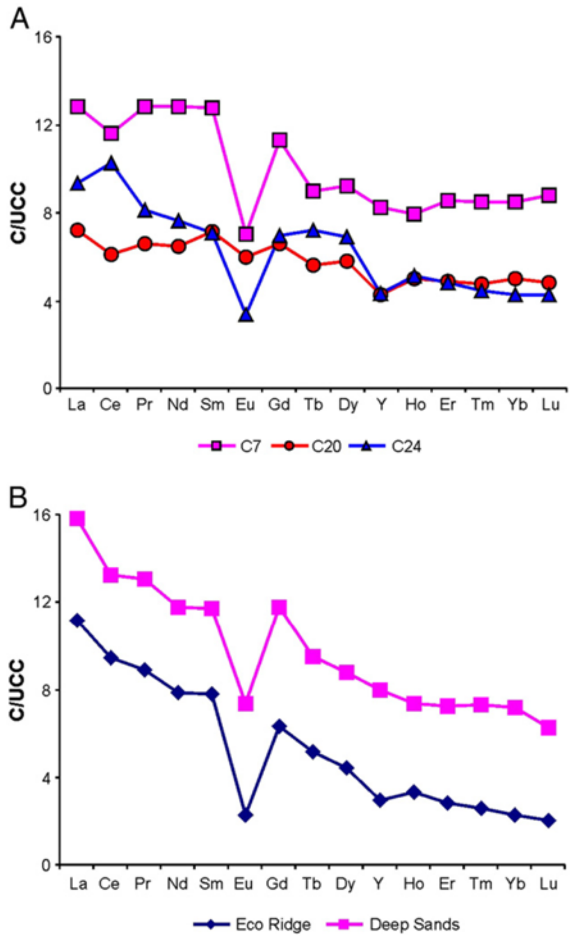


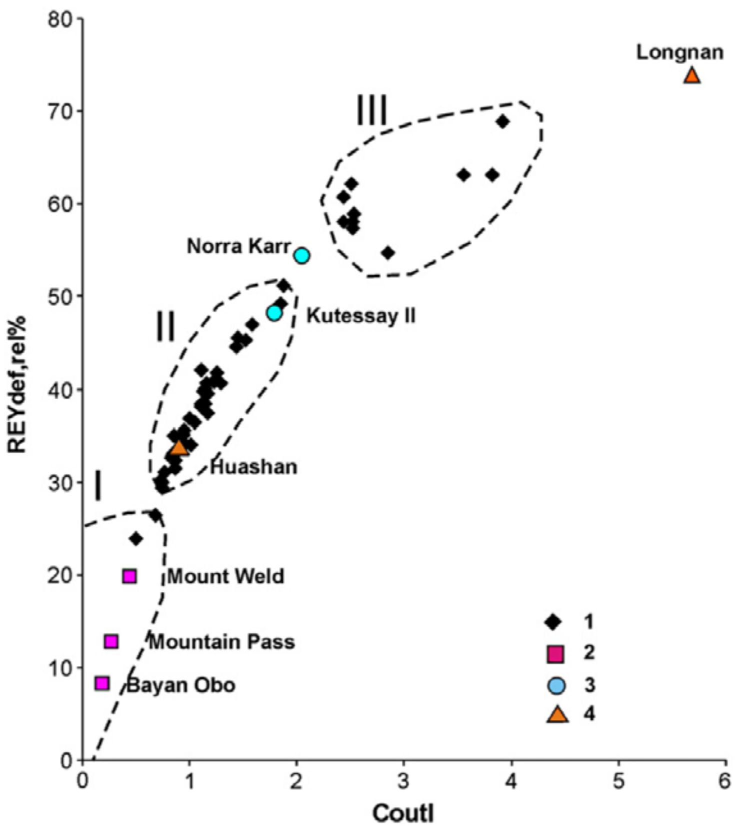
- Sample B
  - Just below Sample A



595x10 µm sample in 1 M $(NH_4)_2SO_4$
1 hr contact time

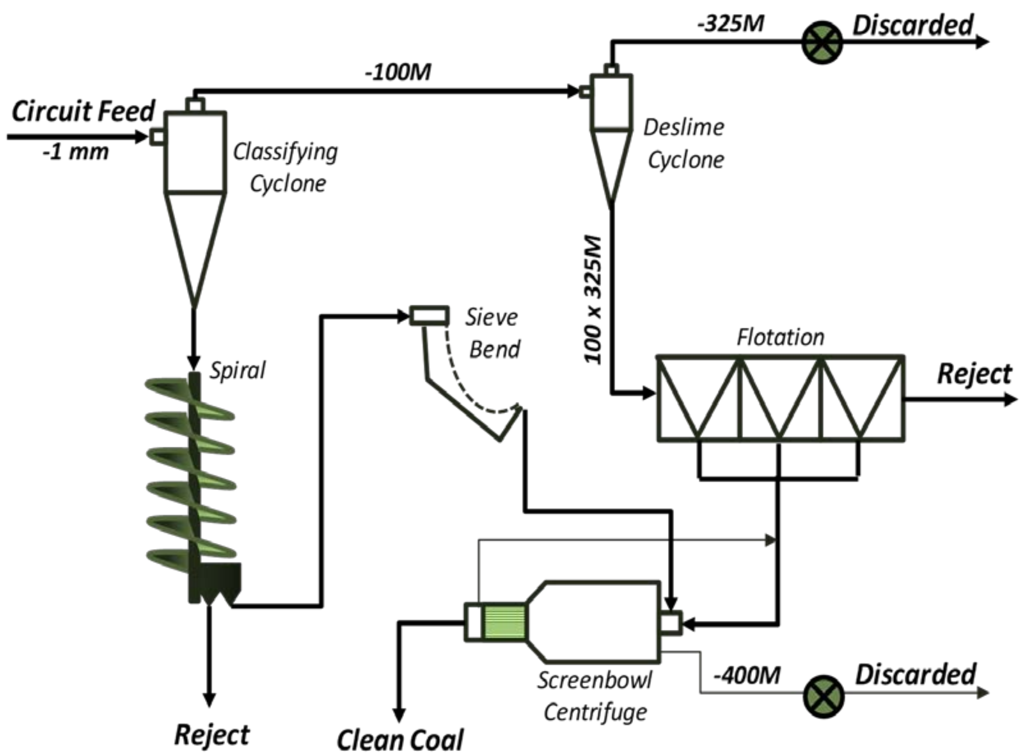
Mineral Matter in Coal:
A Rich Source of HREEs
(Serendin and Dai, 2013)





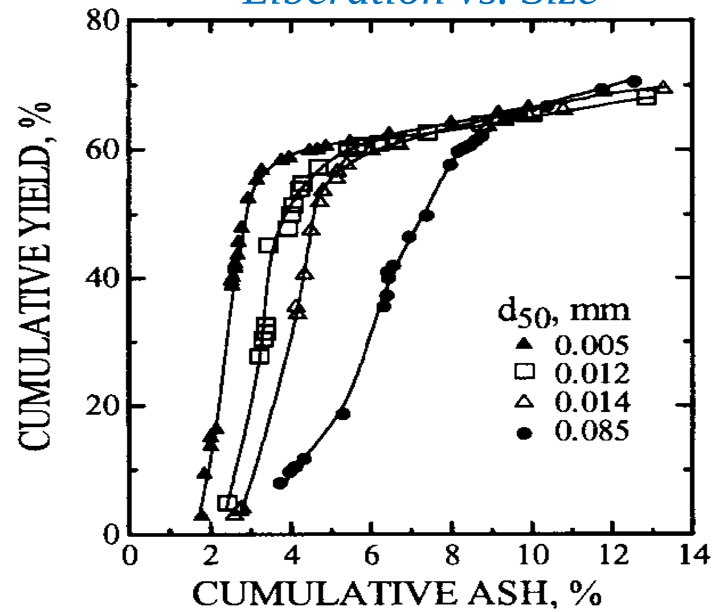
HREEs have higher adsorbabilities on clay than LHRRs.

Fine Coal Cleaning in US



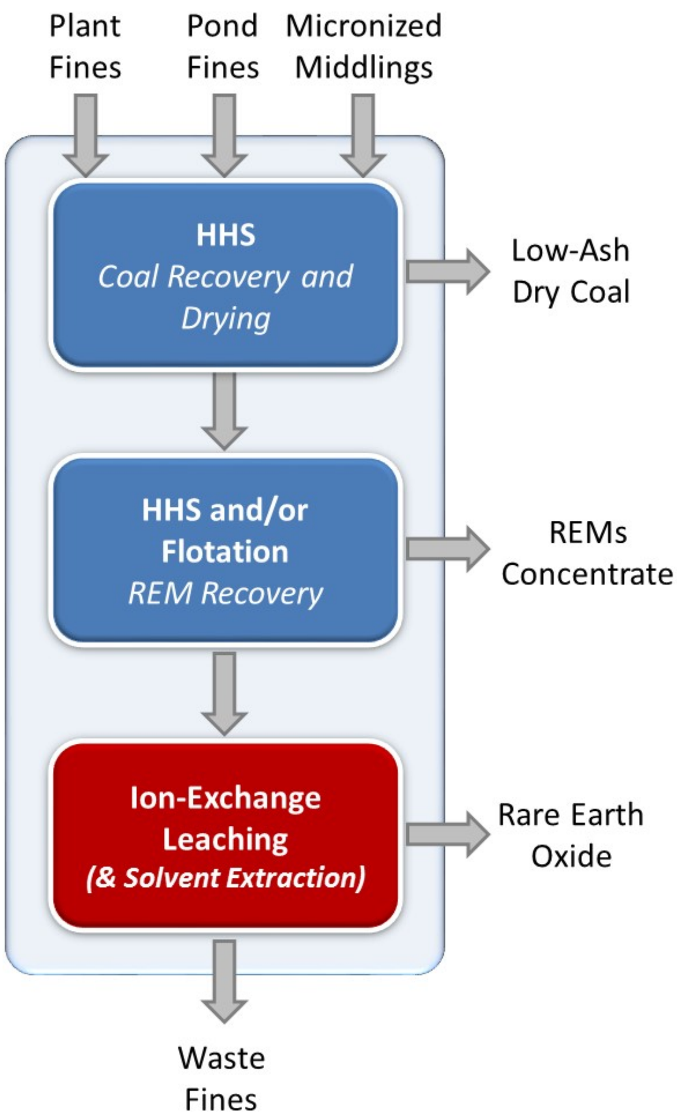
>4 billion tons in impoundments

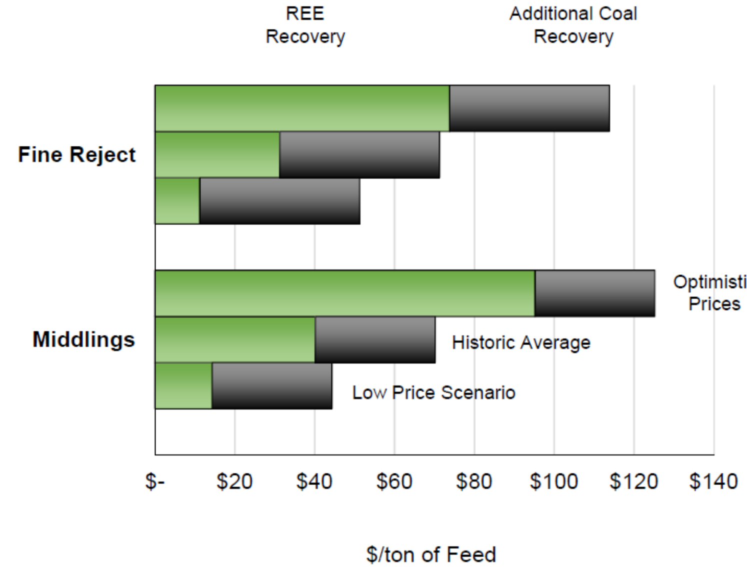
Liberation vs. Size



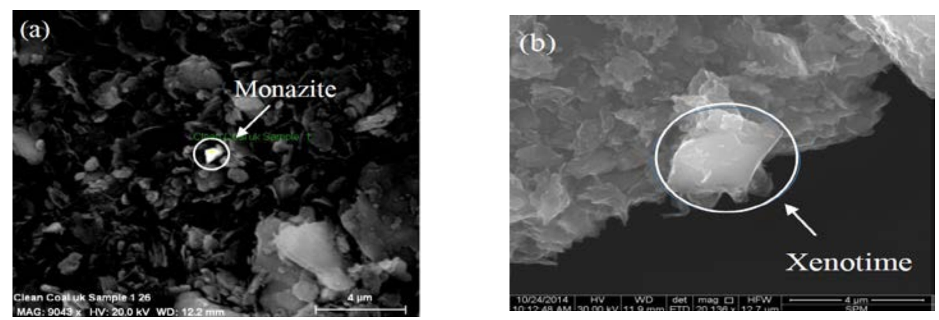
Thickener/Impoundment

Simple Approach

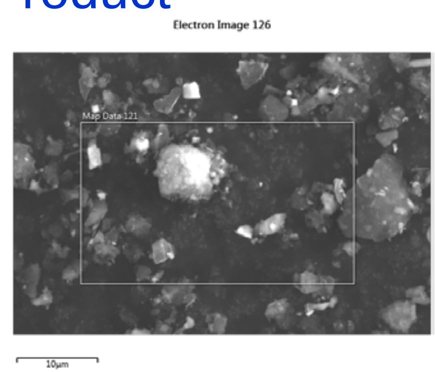




❑ Feed



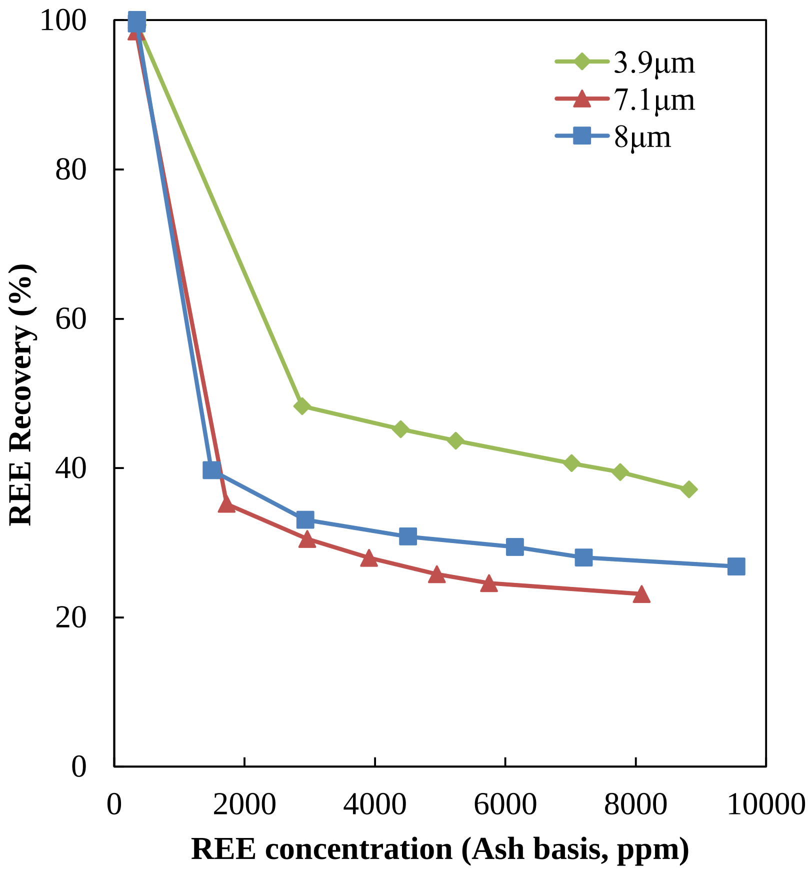
❑ Product

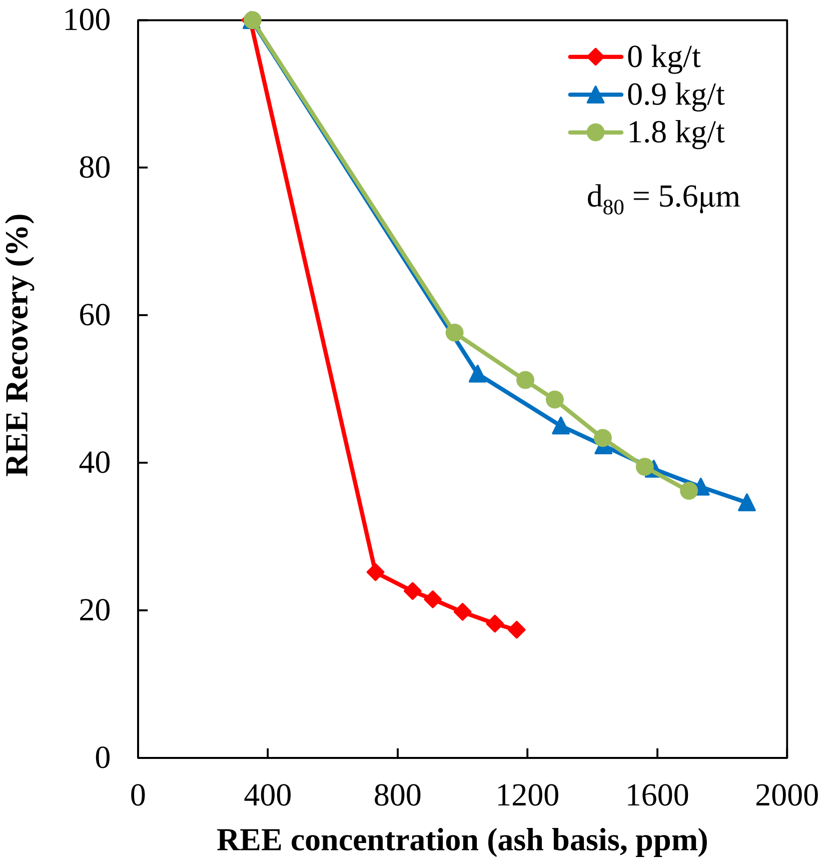


HHS Pilot Plant

No binder

Leatherwood Thickener U/F





Artificial Ores

- Chalcopyrite (d_{80} = 4 μm)

Grade (%Cu)				Cu Recovery (%)
		Concentrate		
Feed	Tailings	Two-Liquid Flotation	HHS[1]	
22.07	0.06	27.8	34.11	99.9
12.82	0.18	24.3	34.14	99.3
4.18	0.06	22.27	33.86	98.9

- Monazite (d_{80} = 3 μm)

Products	Weight	REE (%)	
	%	Grade	Recovery
Conc.	3.14	62.57	93.1
Tail	96.86	0.15	6.9
Feed*	100.00	2.11	100.0

Ion-Exchange Leaching

- Thickener U/F
  - At 50°C

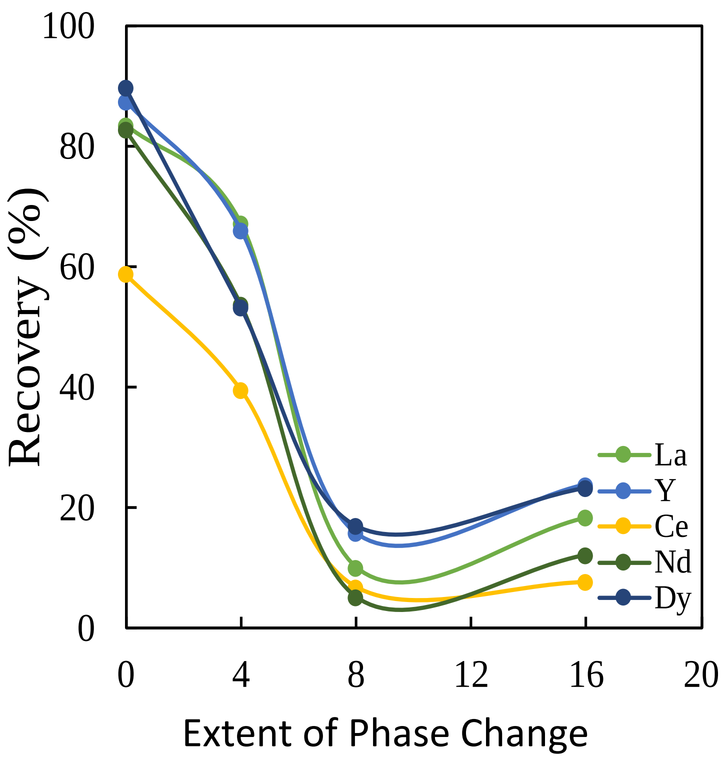
Lixiviant	Conc. (moles/l)	Feed			Solid Residue			REE Recovery (%)
		Ash (%wt)	REE (ppm)	Wt. (g)	Ash (%wt)	REE (ppm)	Wt. (g)	
$(NH_4)_2SO_4$	0.5	92.03	234.58	30.0	90.85	232.05	29.2	3.7
A	0.5	92.03	234.58	30.0	90.01	198.79	28.1	20.6
B	0.5	92.03	234.58	30.0	89.51	227.96	29.2	5.4

- Artificial Ion-Exchange Clay at 25°C

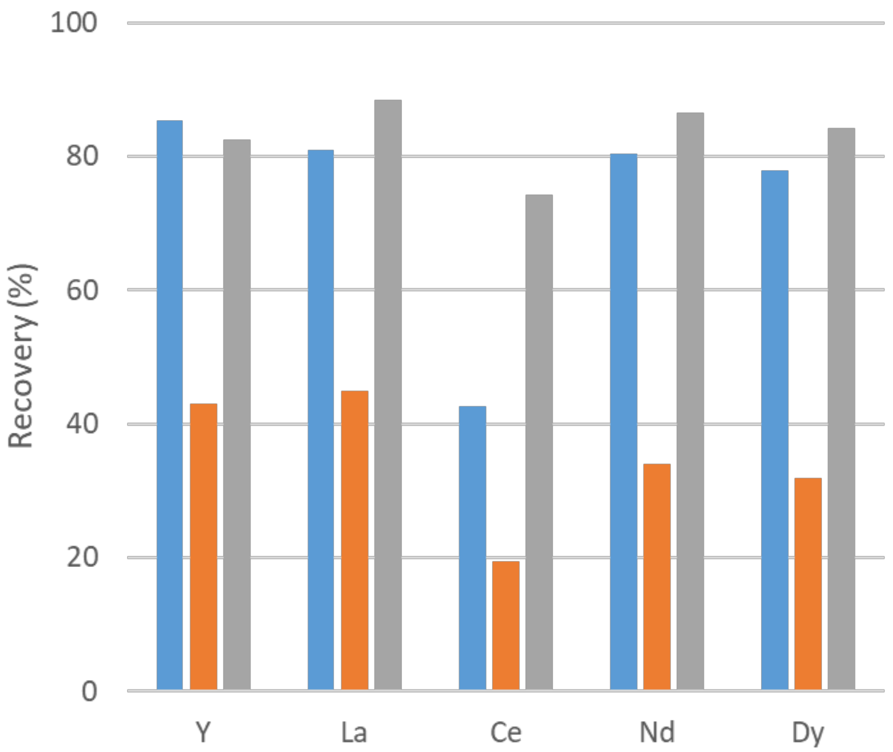
Lixiviant	Conc. (moles/l)	Feed		Solid Residue		REE Recovery (%)
		REE (ppm)	Wt. (g)	REE (ppm)	Wt. (g)	
$(NH_4)_2SO_4$	0.5	1812.5	15.0	726.8	14.9	60.1
A	0.5	1812.5	15.0	932.9	14.9	48.7
B	0.5	1812.5	15.0	1235.9	14.8	32.9
C	0.05	1812.5	15.0	643.3	14.4	65.9

Problem & Solution

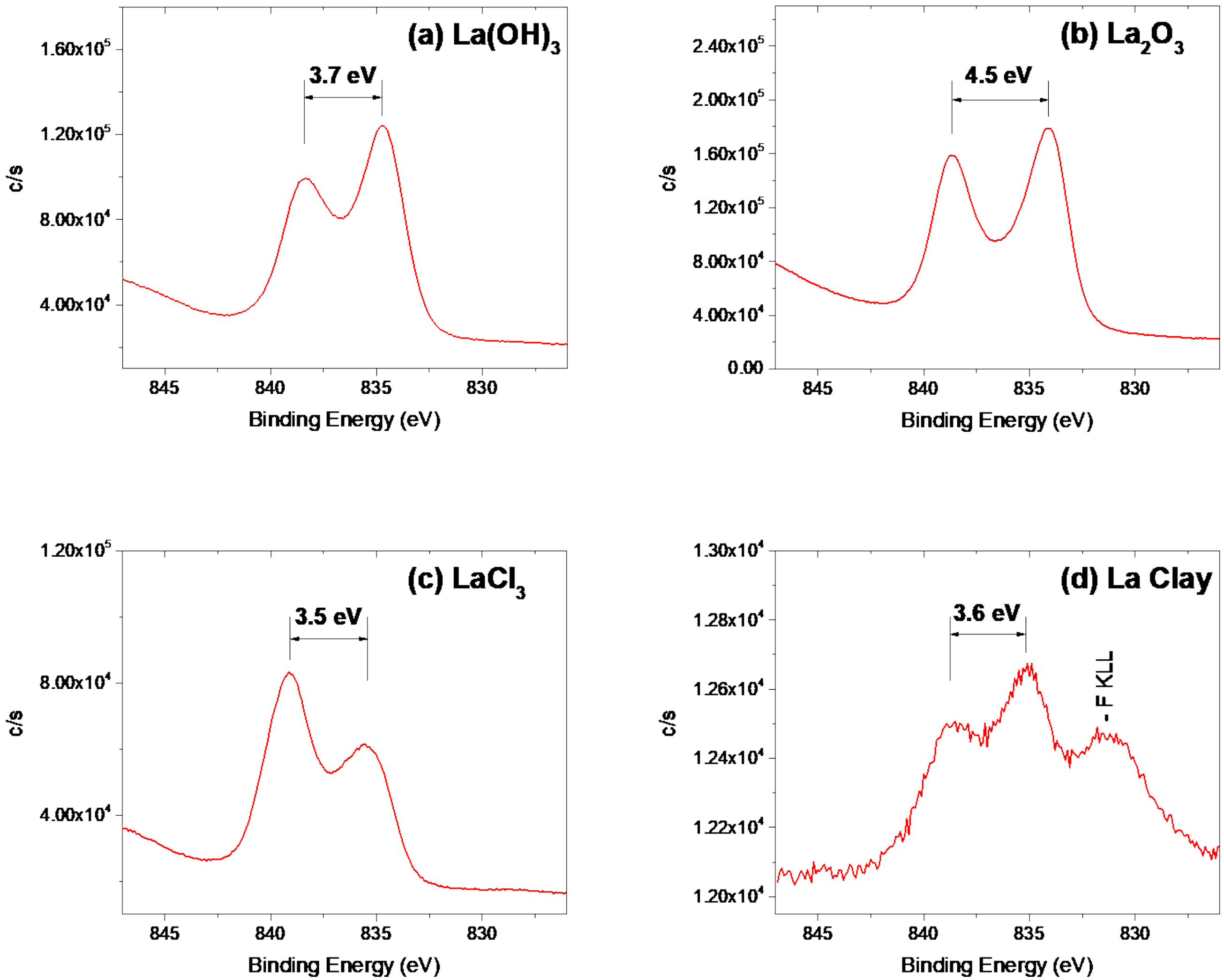
❑ Colloidal phase



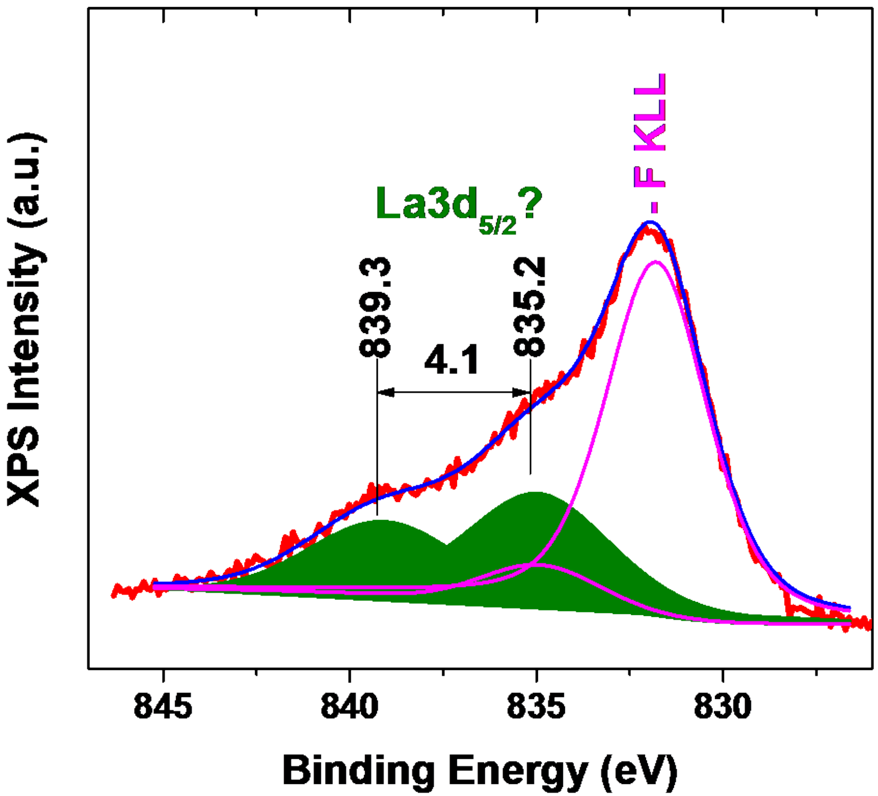
❑ Solution



XPS Spectra of La on Artificial IAC



XPS Spectra of a Mineral Matter of a Middling Sample



Implication

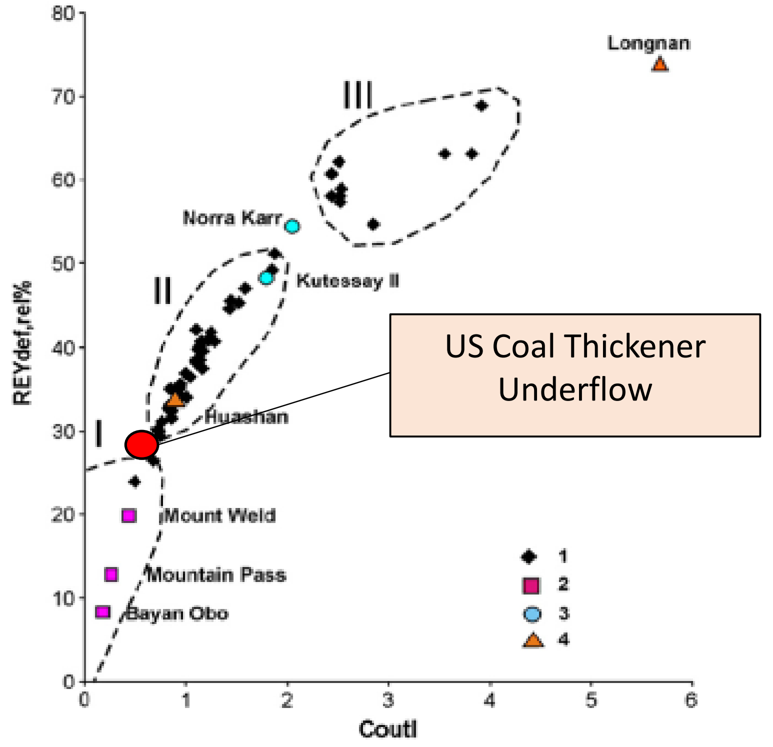
- LTI Project (2014)
  - Audited 15 coal beneficiation plants in Central Appalachia
  - Fine coal refuse produced 1,313 TPY REE.

Table 3. Production of mass, ash and REEs for 15 coal processing facilities.

Stream	Mass TPY	Ash TPY	REE TPY	REE/Whole	REE/Ash
Plant Feed	78,567,376	36,986,176	9,899	126	268
Clean Coal	36,697,676	3,435,608	1,620	44	472
Coarse Refuse	33,279,712	28,160,683	6,285	189	223
Fine Refuse	8,589,993	5,227,936	1,313	153	251

  - Thus, each of the 15 plants produced 87 TPY REE.
  - Multiplying this number with 248, the number of operating plants, gives 21,700 TPY
  - *Assuming 50% recovery*, US beneficiation plants can produce 10,850 TPY REE.
  - In 2018, US consumed 9,500 tons.

Comparison with Other REE Sources



HHS Mobile Pilot-Plant

Summary

- Clay minerals in coal are rich sources of heavy REEs.
- Clay minerals congregate to thickener underflows.
- Heavy and critical REEs can be readily recovered at low cost and with minimal disruption.
  - produce salable coal from waste streams
  - ~4 billion tons of pond fines can be an additional source
- XPS studies showed evidence for ion-adsorption clays in US coal byproducts
  - most likely in colloidal phase
  - makes IX leaching difficult
  - characterization and extraction studies ongoing