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Unlocking the Hidden Value of Coal Waste: Critical Minerals Recovery and Extraction

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Rare Earth Associations & Process Requirements

- Mineral association (≅ 160 mineral associations)
  - monazite $(Ce,La,Pr,Nd,Th,Y)PO_4$
  - crandallite $(CaAl_3(PO4)_2(OH)_5•(H_2O))$
  - xenotime (YPO_4)
  - bastnaesite $(Ce, La)CO_3F$
  - zircon $ZrSiO_4$, $(Zr_{1-y}, REE_y)(SiO4)_{1-x}(OH)_{4x-y}$
  - apatite $Ca_{10}(PO_4)_6(OH,F,Cl)_2$

Requires Pretreatment: Roasting, Acid Baking, Alkaline Cracking

- Ion substitution in clay

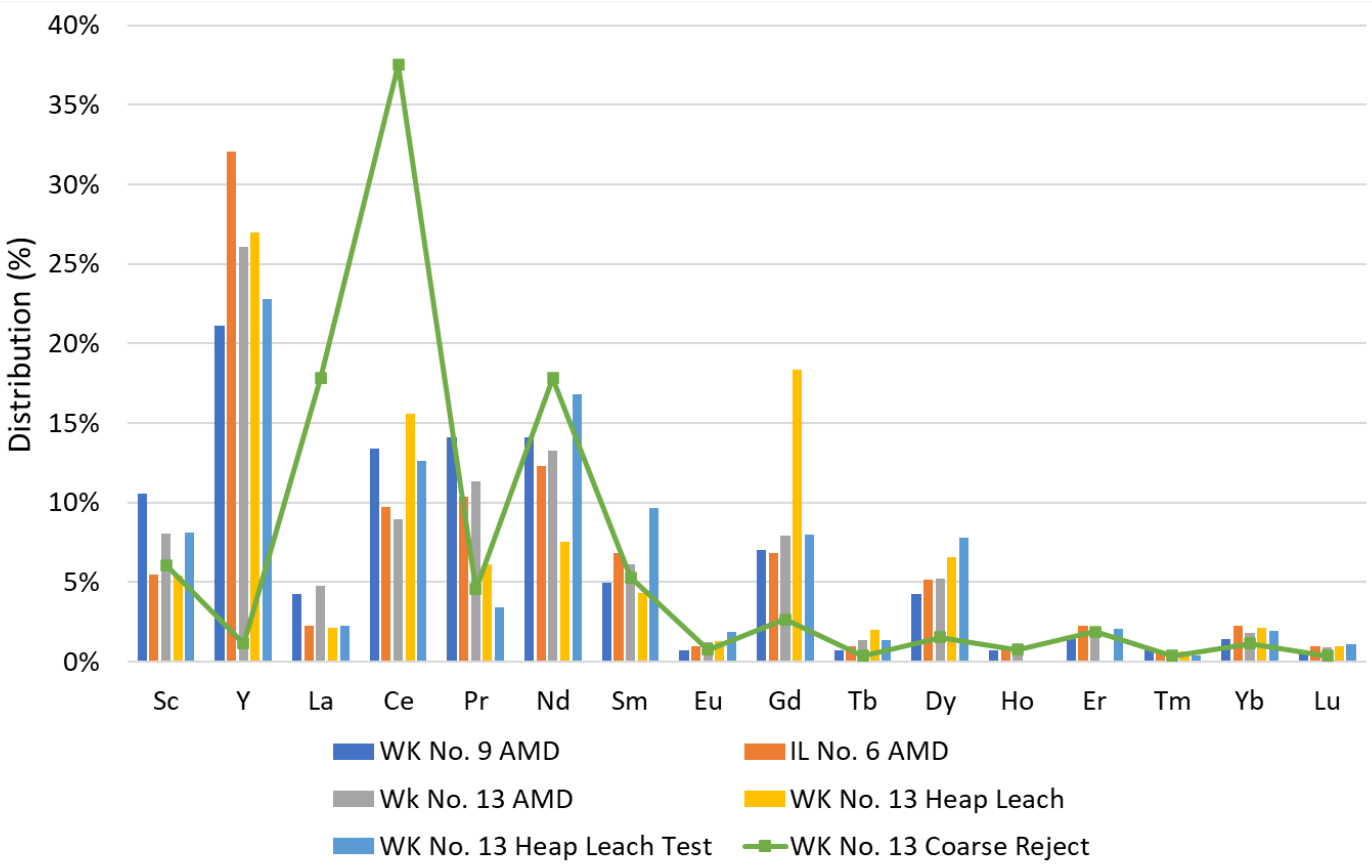
Ammonium Sulfate

- Organic association

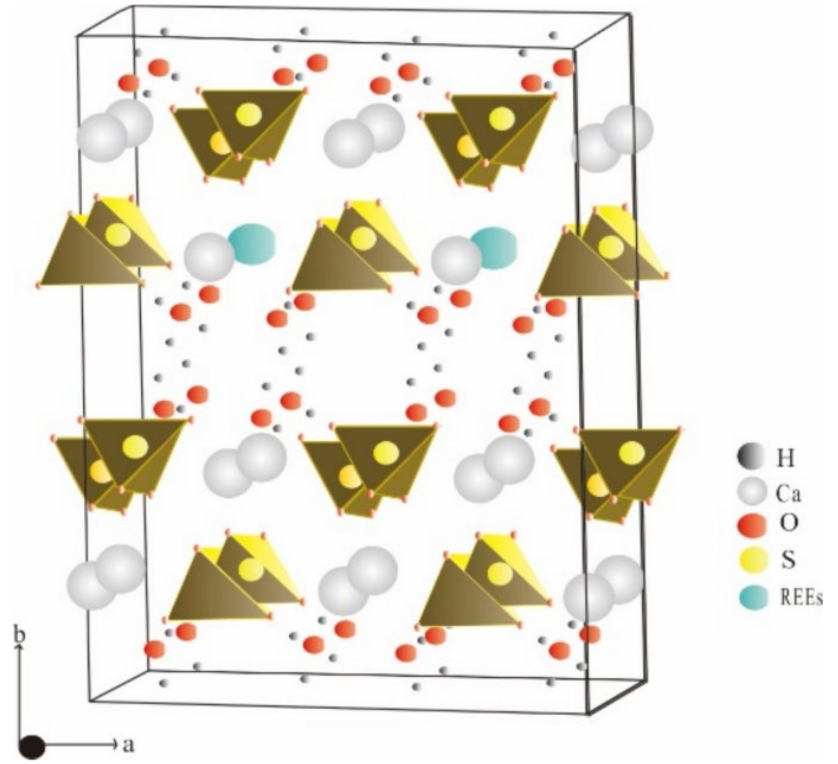
Mild Acid

Rare Earth Distributions in Coal Sources

REE Distributions



Gypsum Crystal Structure



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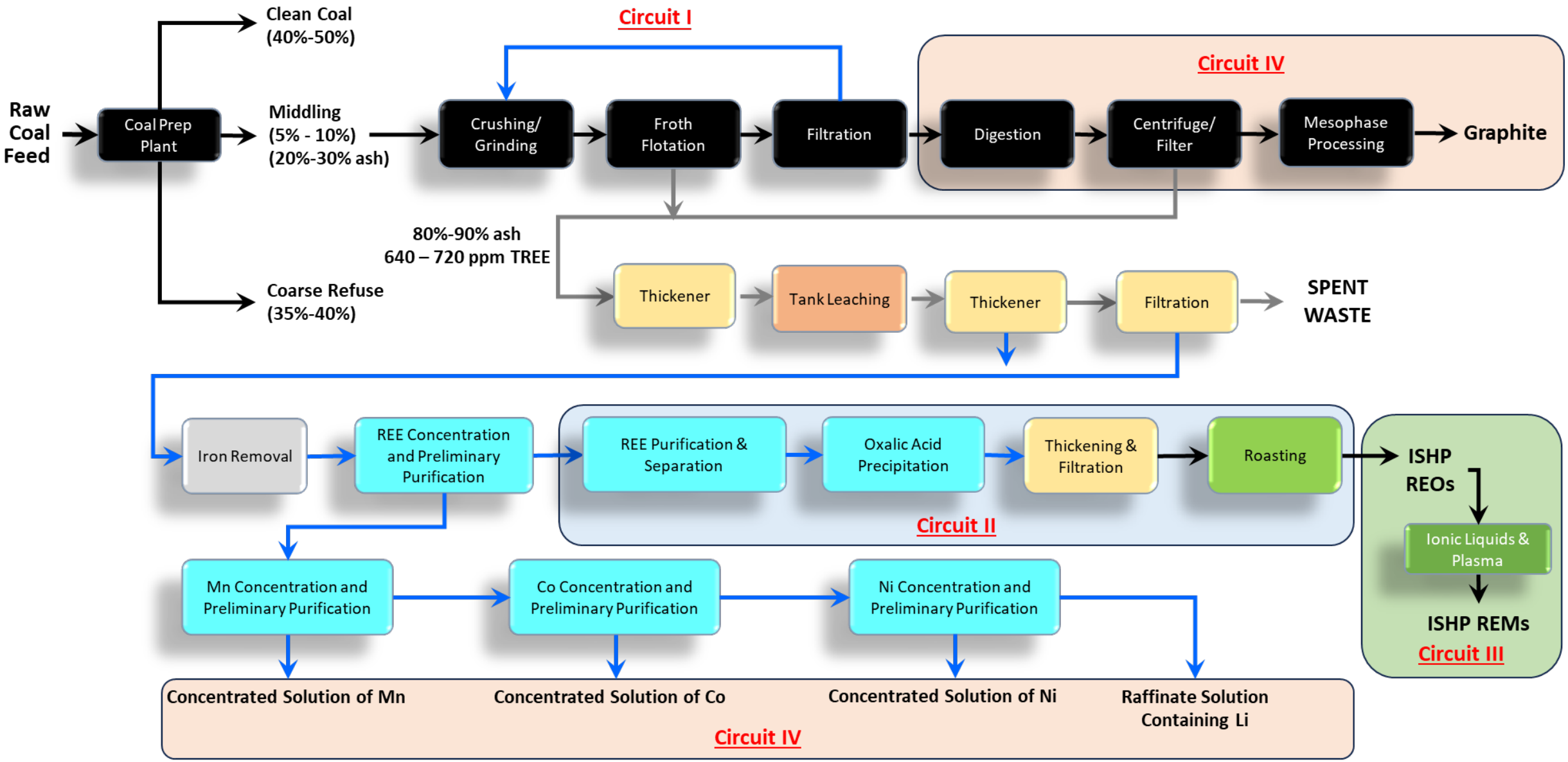
Coal-to-High Purity Critical Metal Production



Critical Materials Pilot Plant

Heap Leach Test Pad

- 2000 tons coarse coal refuse; material had been compacted in-place and through more than 10 years of weathering.
- 65 x 65 square feet heap leach area with a 15-ft vertical lift
- Underlined with a clay liner and a HDPE 60 mil liner
- Surrounding berm constructed based on a 100-yr rain event
- Sump to collect 3000 gallons of the pregnant leach solution (PLS)
- A 5000 gallon PLS storage tank and four 5000 gallon tanks for rain event water storage

Coal-Based Rare Earth Oxide Products

Rare earth oxides concentrations generated through testing of various feedstocks under different circuit arrangements.

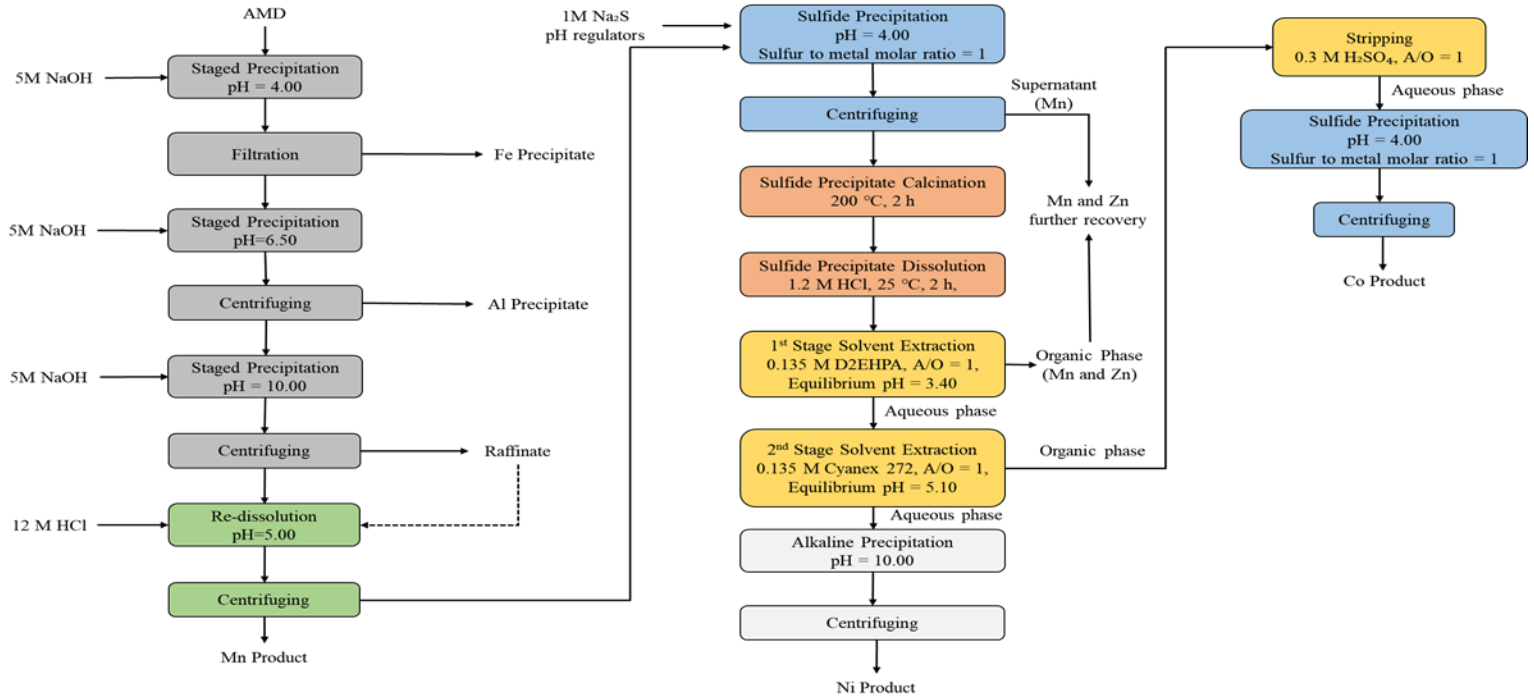
Test Type-Number	% REO	%Heavy REO
Heap Leach PLS / Acid Mine Drainage		
PLS-1	60.81	36.61
PLS-2	61.16	37.81
PLS-3	87.02	53.57
PLS-4	82.31	38.58
Coal Refuse-Western Kentucky No.13		
WK-1	95.45	11.52
WK-2	88.19	5.37
WK-3	40.90	3.27
WK-4	49.82	3.46
Secondary Source- Lignite		
SHXP-1	65.39	7.02
SHXP-2	36.19	9.60
SHXP-3	97.10	31.82
SHXP-4	80.52	23.11
SHXP-5	77.71	20.01

Heap Leach PLS from WK #13 coarse refuse

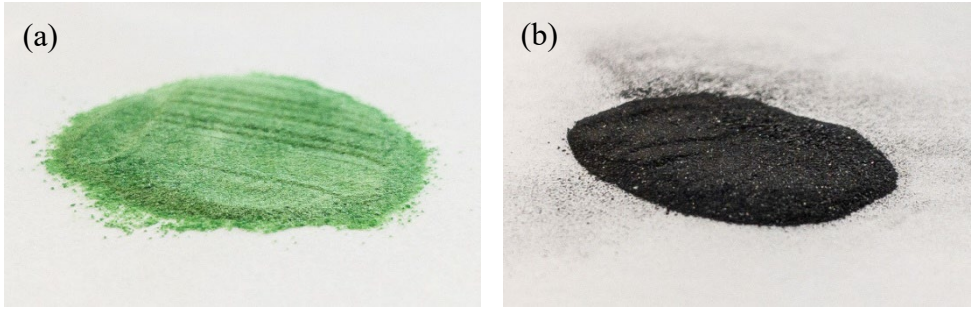
Direct Tank Leach of WK #13 coarse refuse

Lignite coal from a waste product of construction sand production

High Purity Co/Ni/Mn Production



NiO = 96.2%



CoS = 98.0%