Economic Extraction, Recovery, and Upgrading of Rare Earth Elements From Coal-Based Resources

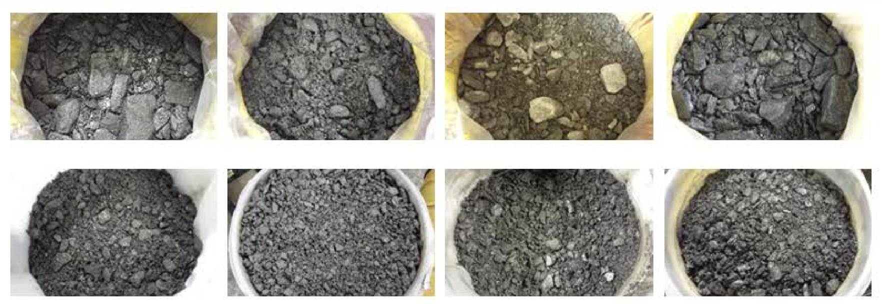
THE UNIVERSITY OF UTAH

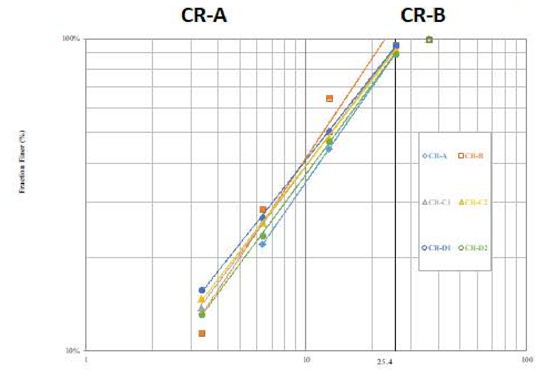
Michael Free, Prashant Sarswat, Gerald Luttrell, Aaron Noble, Xianwei Hu, Landon Allen, Marina McNeill, Dae Jin Kim, and Isaias Arce

VIRGINIA TECH

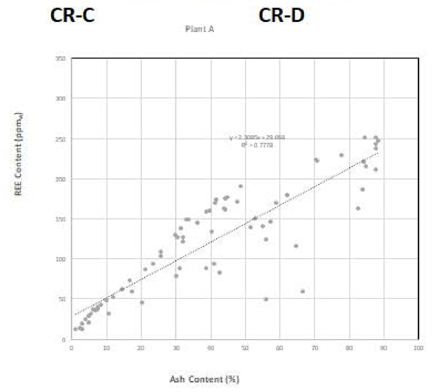
Sample Acquisition and Analysis

- Course refuse samples from four coal plants in WV, PA, and VA.
- All crushed to -1 inch; REE content varies from 250 to 300 PPM





Gaudin-Schumann Plot for Coarse Refuse Sample



REE Content of Various Preparation Plant Products

Integration with Coal Processing

Some coal seams tend to be elevated in pyrite, which can oxidize to produce sulfuric acid.

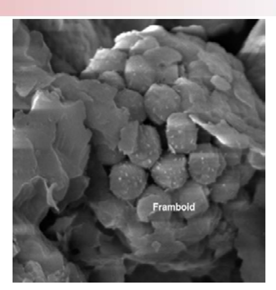
To counteract downstream environmental issues, some modern coal preparation facilities employ a "desulfurization circuit" to isolate pyrite from the clean coal product.

Three cases for further investigation:

A) High Sulfur Coal With Desulfurization

B) High Sulfur Coal Without Desulfurization

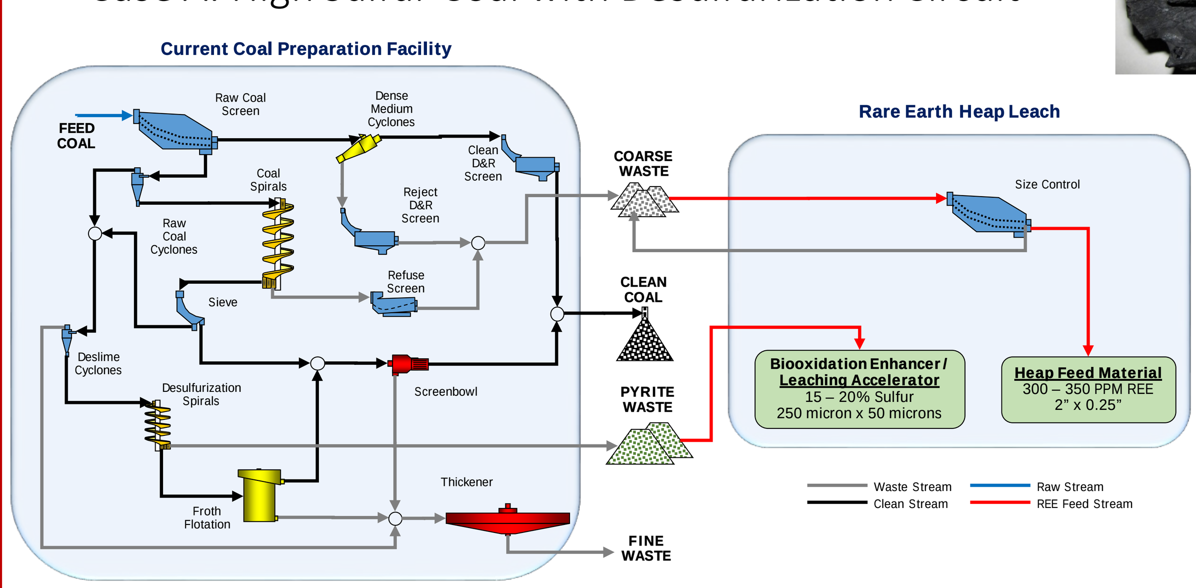
C) Low Sulfur Coal



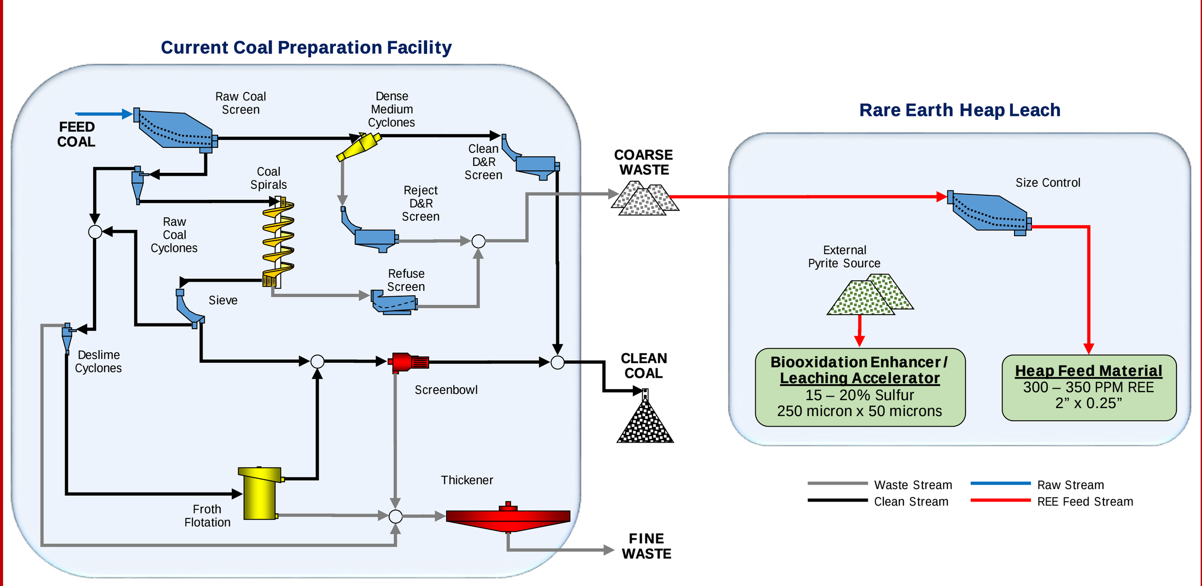
Framboidal Pyrite = Highly Reactive

Pyrite vein in coal sample.

Case A: High Sulfur Coal with Desulfurization Circuit



CASE C: Low Sulfur Coal



Project Overview

- Utilize low-cost technologies to enable larger resource utilization
- Utilize selective separation technologies to upgrade REE concentration in feedstock.
- Utilize heap leaching technology for large-scale, low cost extraction
- Utilize biooxidation and pyrite to provide low cost reagents and rapid leaching
- Utilize solvent extraction and precipitation to concentrate and recover product
- Perform a technoeconomic analysis to provide investment and commercialization guidance

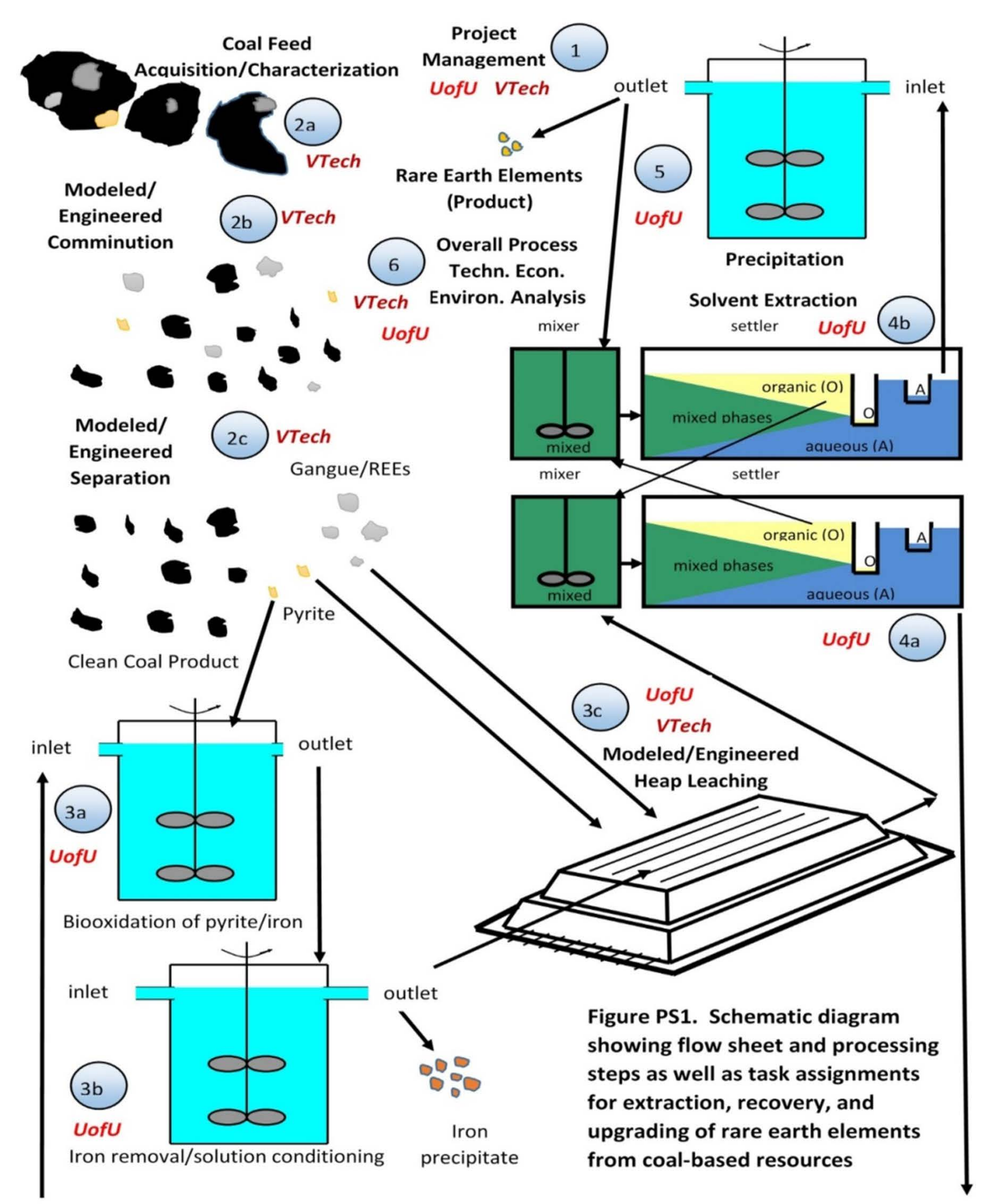
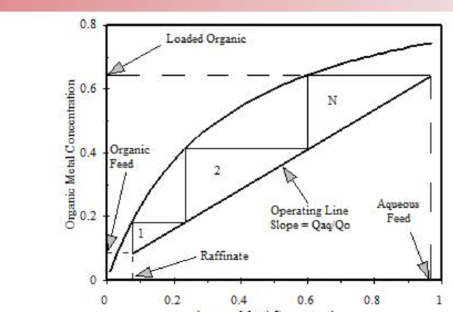


Figure PS1. Schematic diagram showing flow sheet and processing steps as well as task assignments for extraction, recovery, and upgrading of rare earth elements from coal-based resources

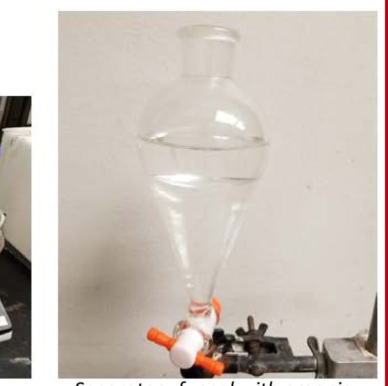
Solvent extraction

- To test solvent extraction a solution of 50 ppm Dy, Nd, Pr, and Sm with 1000 ppm Fe was made to simulate leaching product.
- 10mL 10% D2EHPA in kerosene was used to load 30mL of solution.
- It was observed from the loading of organic that it is possible to load 100% of the rare earths by a pH of 1.9.
- Stripping was done using 30mL Nitric Acid with 10 mL loaded organic.
- Stripping results gave fairly good recovery by pH 0.2, though stripping at even lower values should yield higher recovery.



McCabe-Thiele diagram showing the relationship between the metal content in the organic and aqueous phases

Loading of organic with REEs

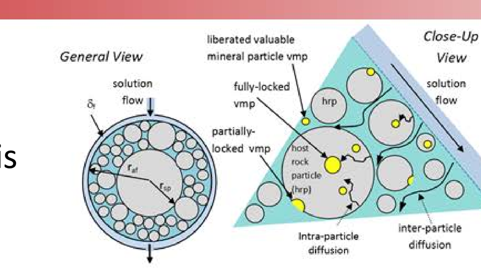


Separatory funnel with organic and aqueous phases

Coal Waste Leaching

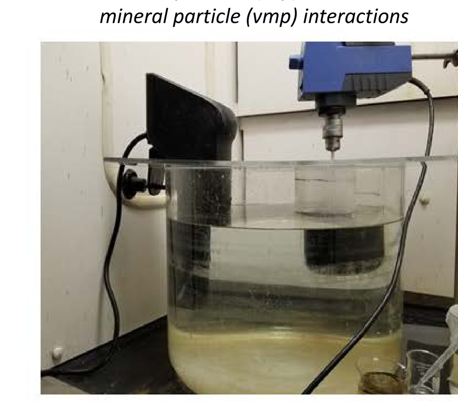
Coal Comparisons

- Each of the coal samples is being leached using:
- 30 wt% Coal waste
- 10 g/L Ferric Sulfate in DI Water
- 150 mL Ferric Sulfate solution
- pH 1.5
- pH adjusted hourly for the first 8 hours, then again at 25 hours for acid consumption.
- 96 hours



Schematic diagram showing flows and host rock particles (hrp) and valuable mineral particle (vmp) interactions

Comparison leaching tests

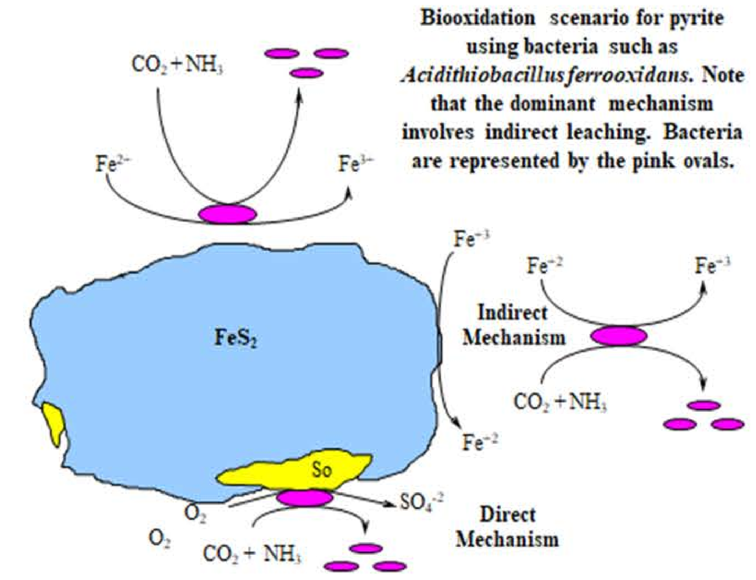


Bath and mixer for use in 500mL leach tests

Biooxidation

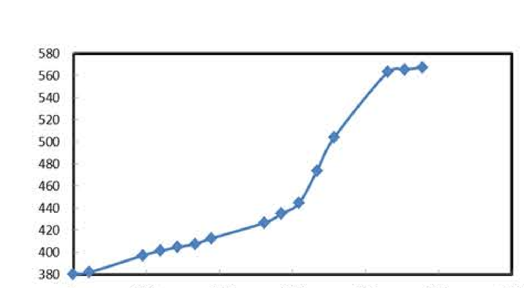
- Acquisition of active bacteria cultures (acidithiobacillus ferrooxidans) to facilitate biooxidation. Growth of bacteria in 9K base medium (using essential salts with potassium, nitrogen, magnesium, phosphorus, and additional ferrous sulfate) along with air-sparging for numerous leaching tests.
- Monitoring of redox potential to check the bioactivity of the bacteria cultures.
- Periodic ferrous oxidation testing to quantify the bacterial population using predetermined quantity of ferrous ion addition.

Biooxidation scenario for pyrite using bacteria such as *Acidithiobacillus ferrooxidans*. Note that the dominant mechanism involves indirect leaching. Bacteria are represented by the pink ovals.



Bacterial growth vessels

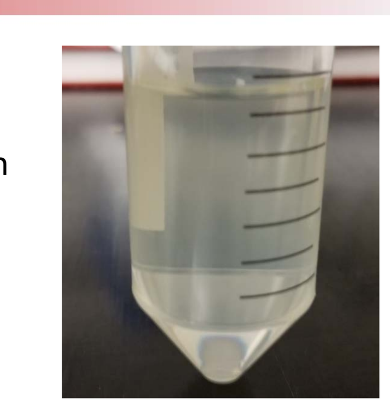
Iron precipitate



Eh vs time (indicative of bacterial activity)

Rare Earth Element Recovery

- The rare earth elements will be recovered by precipitation from the solvent extraction stripping solution.



Stripping solution from solvent extraction

- **Acknowledgement:**
- Funding provided by the Department of Energy: Grant # DE-FE0031526

NATIONAL ENERGY TECHNOLOGY LABORATORY