

Recovery of Rare Earth Elements from Acid Mine Drainage Feedstocks

Presented By:

David Hoffman
Critical Materials Program
Manager



Major Contributors and Partners

- **West Virginia University**
 - Dr. Paul Ziemkiewicz- WVVRI Director
 - David Hoffman- Critical Materials Program Director
 - Dr. John Quaranta- Geosynthetic Capture
 - Dr. Nathan DePriest- Geosynthetic Capture/Engineering Manager
- **Virginia Tech**
 - Dr. Aaron Noble- Department Head of Mining and Minerals Engineering
- **L3 Engineering**
 - Dr. Tommee Larochelle- Process Development Engineer
- **WVDEP**
- **Rockwell Automation**
- **Solmax**

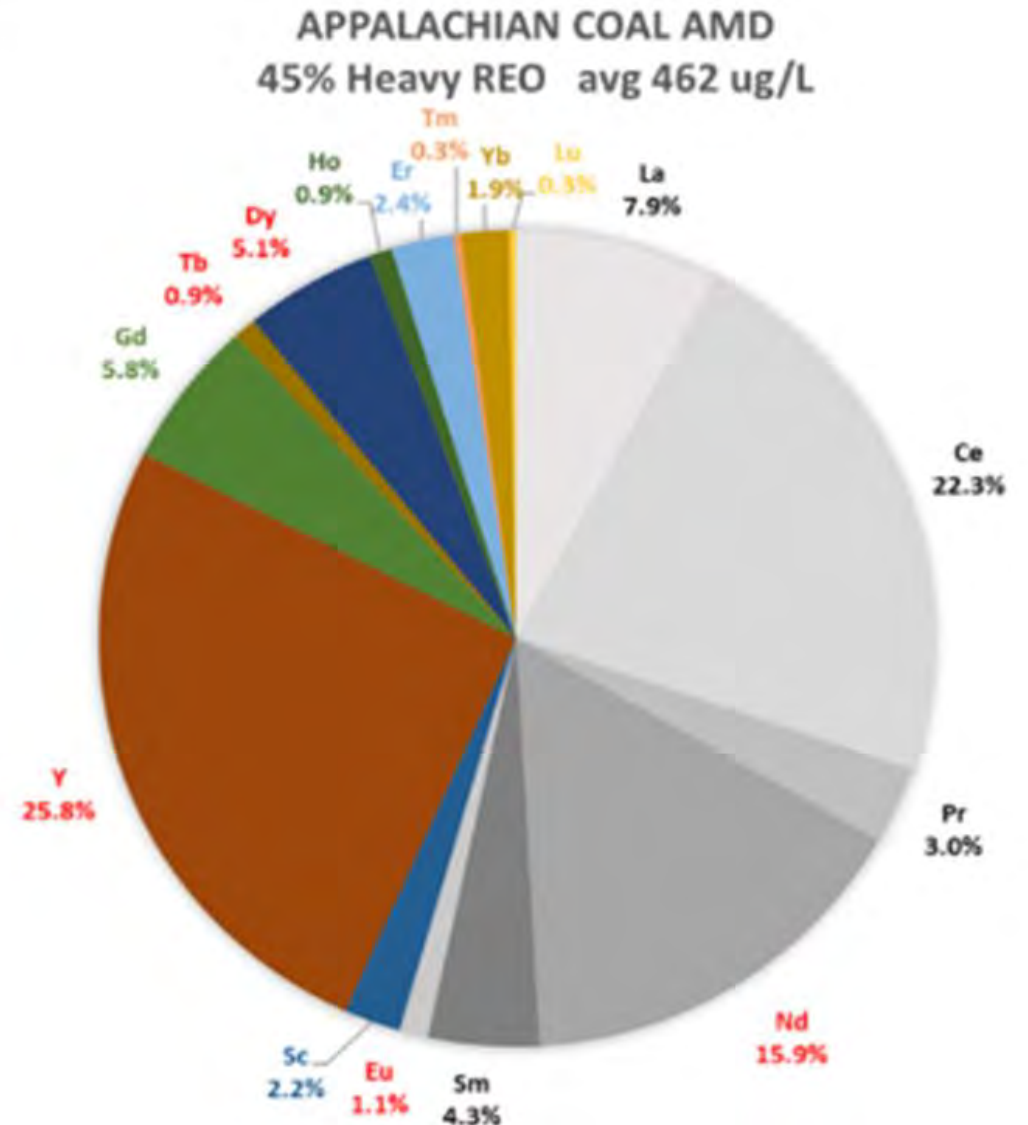
The United States rush for domestic REE

- **United States relies on several Rare Earth Elements and Critical Minerals for use in manufacturing national defense related items**
- **China has banned sale of Gallium, Germanium, and Antimony to United States as of December 2024**
 - Effects not yet known but a previous restriction caused an 63% price increase for Germanium, 34% price increase for Gallium
- **Department of Defense Federal Acquisition Regulations (DFAR) require some CM's and REE's be obtained through "covered" countries by December 2026.**
 - Will require sources are obtained outside of China

The Significance of REE in AMD

- **45% distribution of critically needed Heavy Rare Earth Elements**
 - Mountain Pass REE mine has primary distribution of Light Rare Earth Elements
- **Consistent distribution of heavy rare earth elements in both Appalachian and Hard Rock mine drainage**
- ***1 t/day REE separation facility using AMD feedstocks could generate 7-8% of worlds Tb/Dy supply**
 - ***Projections indicate by 2030 only 50% of Tb/Dy demand will be met with current suppliers**

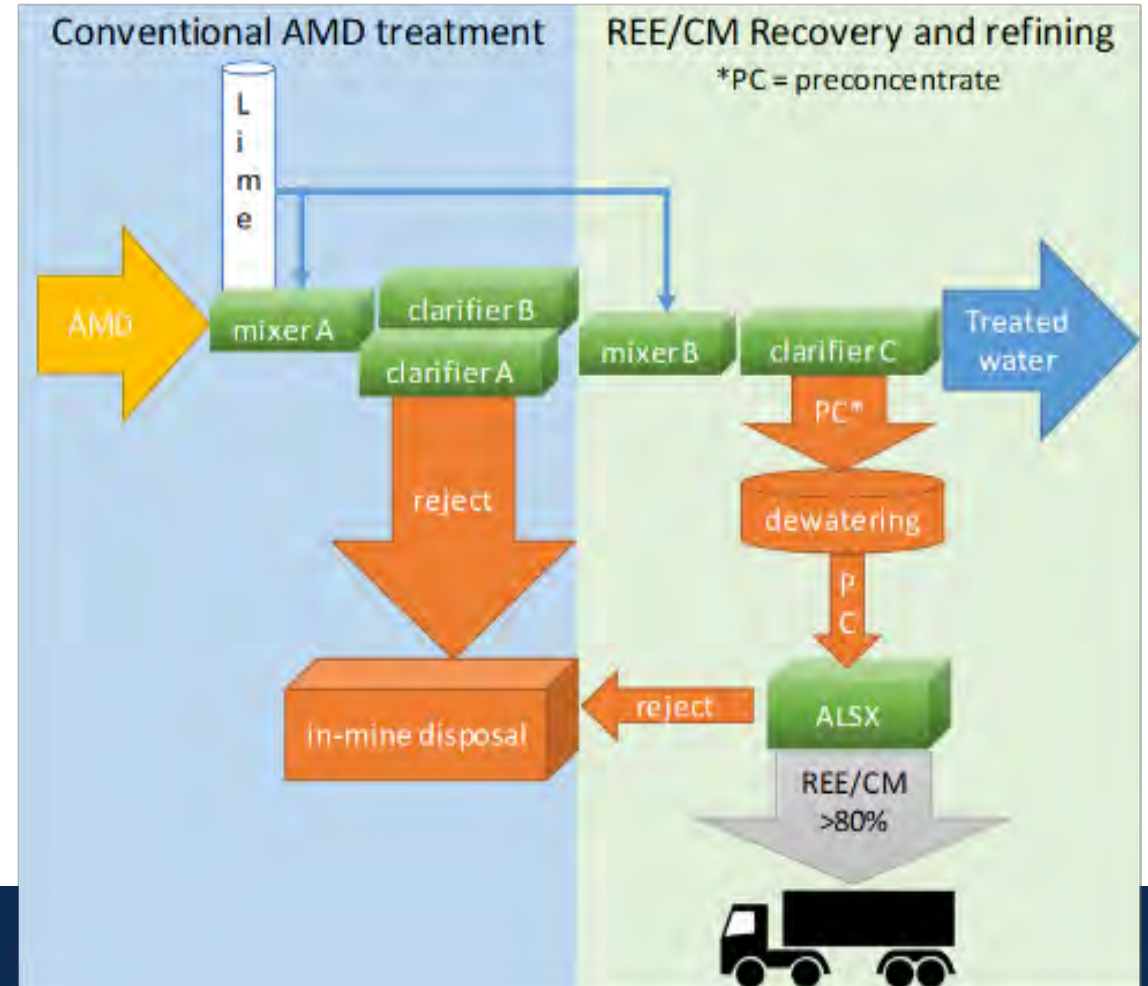
*Source: Adamas Intelligence



WVWRI's REE extraction from AMD development story

An Environmentally Benign and Cost-Effective Solution

- In 2017 WVWRI developed a two-stage treatment to generate a REE feed stock
 - Many AMD treatment facilities can be easily converted to REE/CM recovery
 - Need 2 clarifiers with independent pH controls
 - WVWRI method meets water compliance criteria
 - Capture of HPC decreases sludge disposal cost



Proof of Concept 2016-2017

- **Evaluated whether REE and CM exist in economic quantities in AMD and its treatment concentrates**
 - **Furthermore, characterize AMD Pre-Concentrate**
- **Acid Leaching of Pre-Concentrate was explored for REE recovery**
- **Solvent Extraction was explored for selective extraction of REE**

Small-Scale Field Demo 2017-2019

- **Develop elemental separation via pH precipitation specific to AMD**
 - **Determined that two step pH adjustment of AMD removed Fe, Al, Si prior to REE precipitation**
- **WVWRI designed and deployed a mobile unit capable of generating REE enriched PC**



Bench Top Pilot System 2018-2019

- **Project developed Acid Leaching Solvent Extraction circuit (ALSX)**
 - **Circuit leaches REE from PC generating Pregnant Liquor Solution (PLS)**
 - **REE are selectively extracted from PLS into organic extractant**
- **In partnership with Rockwell Automation, an automated SX system was installed**
- **Successfully generated 90% Pure Mixed Rare Earth Oxide (MREO) using ALSX circuit**



Development Stage (2020 to 2022)

- **WVWRI uses COVID slow downs to scale up research operations prior to plant construction**



REE Recovery Pilot Plant 2020-Present

- DOE awards WVWRI funding to install the first of its kind REE recovery plant from AMD
- WVWRI partners with WVDEP to build a 500 GPM AMD treatment plant
 - Partners with Rockwell Automation for automation and controls
 - Partners with Solmax (formerly Tencate) for geosynthetic filtration



Project Timeline

- **WVWRI Begins Engineering and Design: March 2020**
- **WVDEP Groundbreaking: November 2020**
- **WVWRI Mobilization of REE Plant construction: June 2022**
- **WVDEP Plant Start Up: September 2022**
- **WVWRI Start of Partial Operation: October 2022**
- **WVWRI final plant commissioning: March 2023**
- **Official End to original project December 2023**



Project goals:

- **Separation of Gangue Metals from Feedstock**
- **Capture and dewatering of Pre-Concentrate**
- **Creating High Purity Mixed Rare Earth Oxides suitable for elemental separation**
- **Demonstration of an economically feasible process**

REE Recovery Pilot Plant Components

Dewater_Leach_precipitate

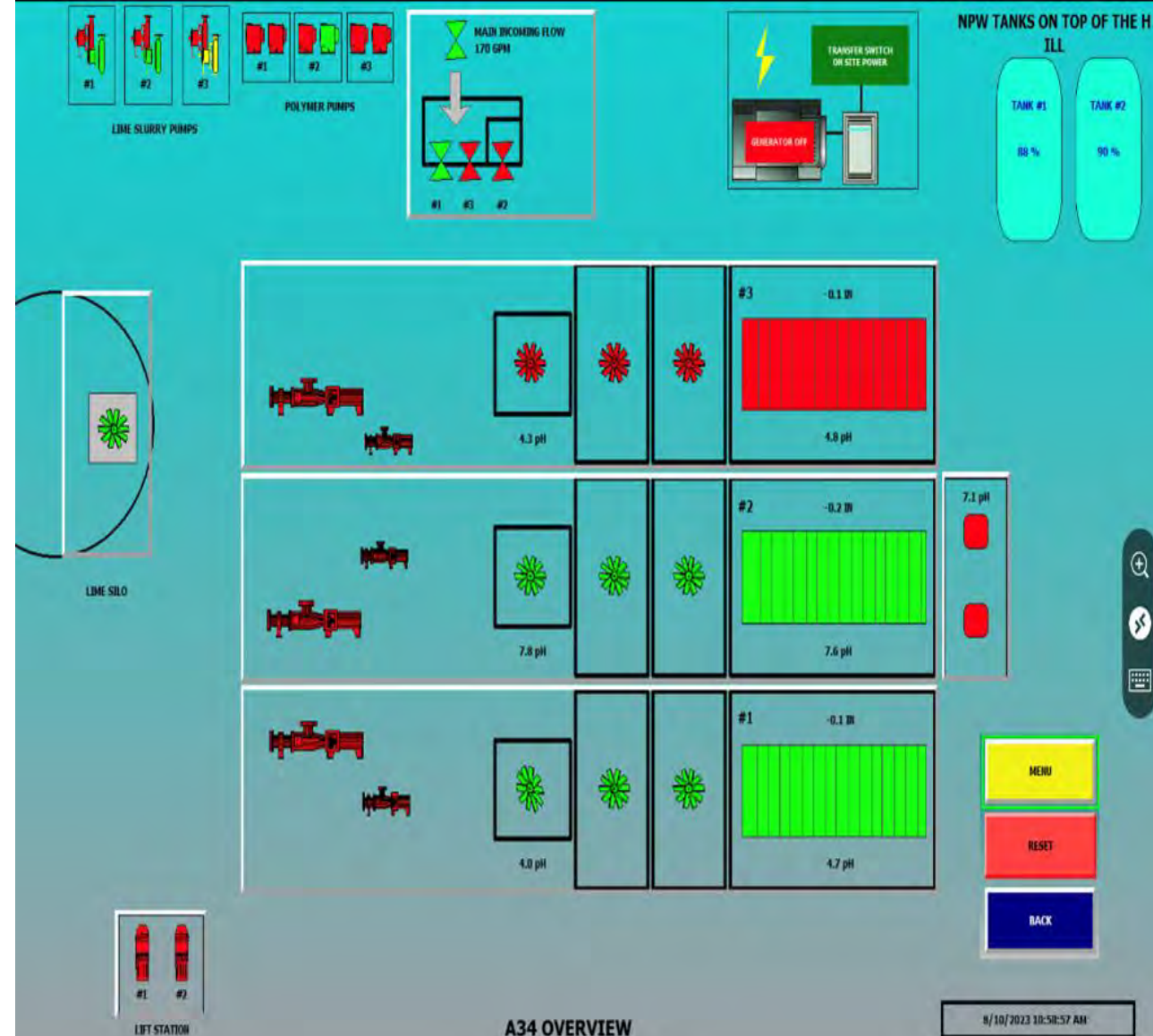


Dewatered Preconcentrate



Plant Operations

- Fully Automated System capable of being remotely monitored
- 500 GPM Average AMD inflow
- 2 stage treatment for REE enriched PC fully utilized
 - Works for flows up to 1000 gpm
- First pH split rejects ~80% of Iron
- Second pH split generates ~0.22g/L HPC
- Average TREE grade of ~0.6%
- Average TREE recovery to HPC is 92%



Optimal REE Plant Operation

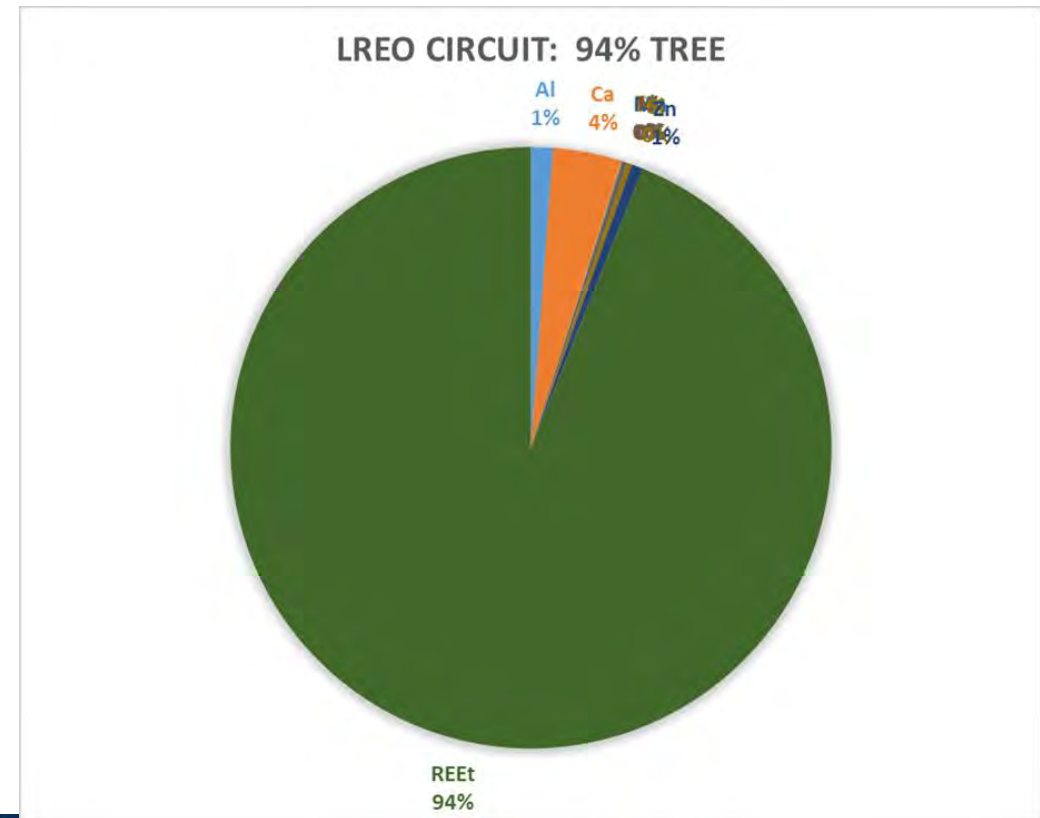
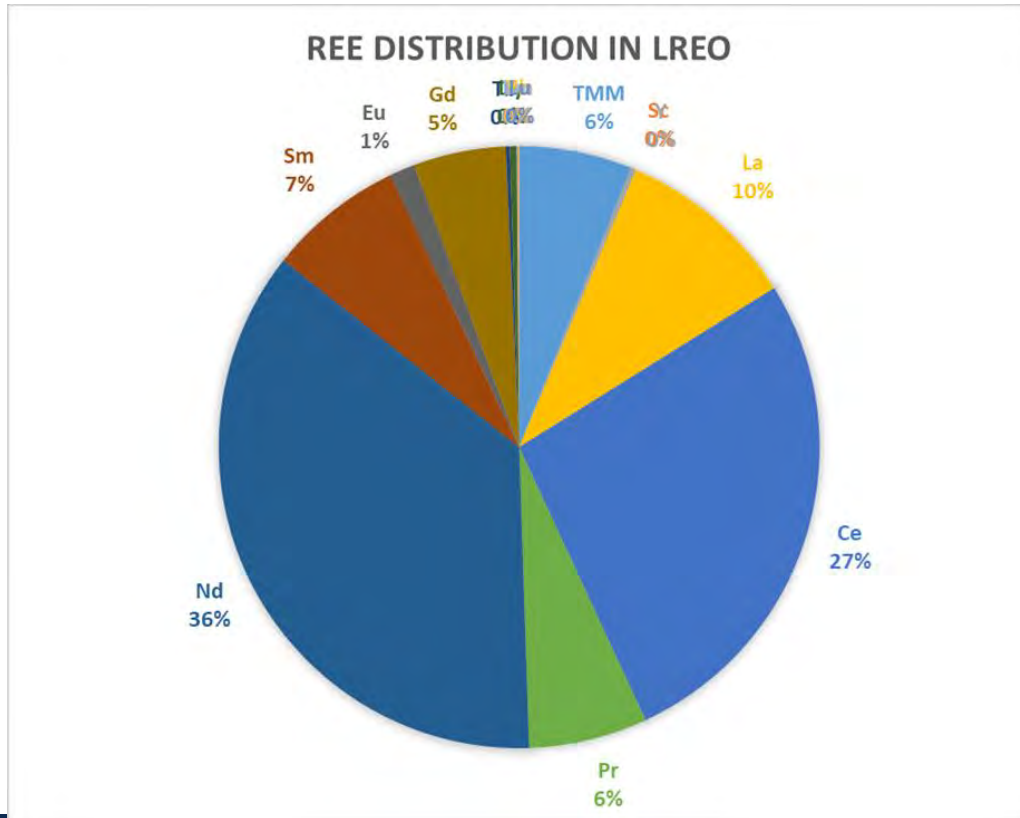
Assumes 4 day/ 20 hours per day operation

- Also assumes the following
 - Plant is fully automated
 - Plant is running at designed efficiency
 - No downtime
 - Two PLS trains
 - Does not account for LREO and HREO separation
 - 90% Purity
- 4.68 kg MREO/day
- 1.71 t MREO/yr



Recent Results at REE Pilot Plant

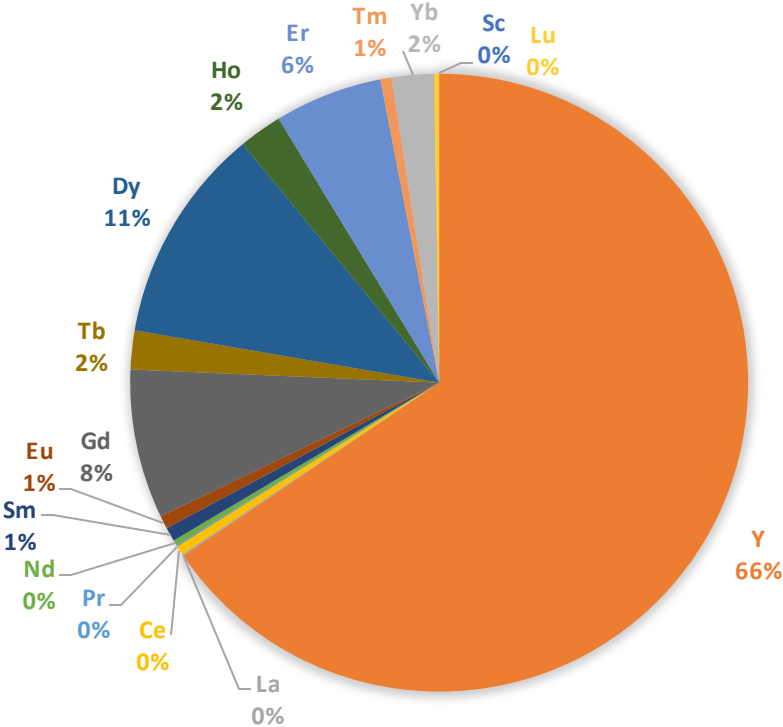
Light REO



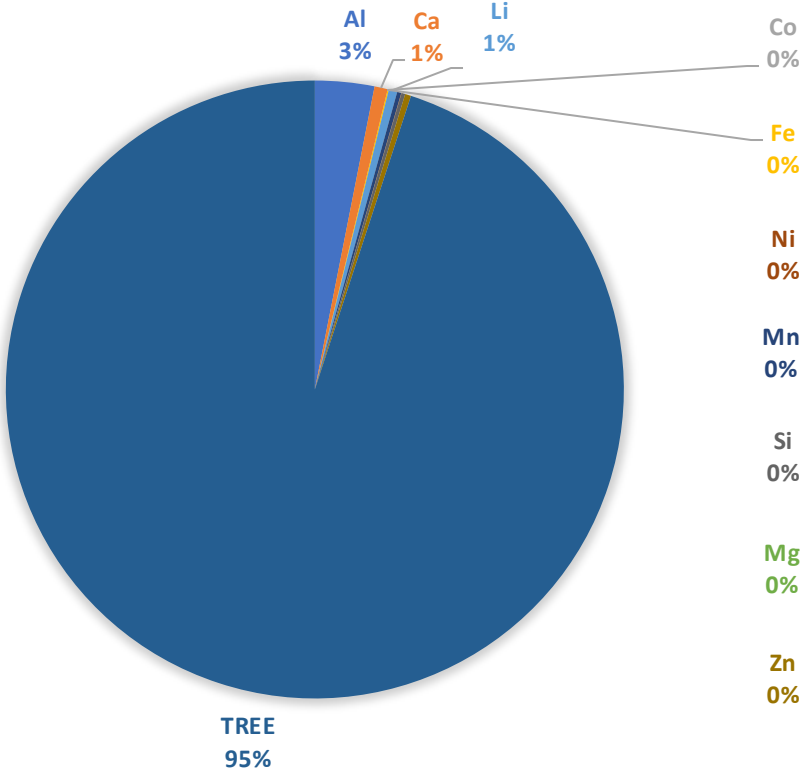
Recent Results at REE Pilot Plant

Heavy REO

HREO REE DISTRIBUTION



ELEMENTAL DISTRIBUTION OF HREO



Passive Dewatering

Production Rates

- **HPC Volume**
 - **System now capable of running HPC 24/7 to bags due to installation of automated controls**
 - **Feed varies by seasonal changes**
 - **Average feed is 0.7 dry t/day at 24/7 operation**
 - **Received as 1% average solids content slurry at geotubes**
- **Dewatering**
 - **Rate: 0.1-0.2% per day**
 - **Time to 40% solids: 6-12 months**



Optimal HPC Capture

Assumes 24/7/365 Operation

Estimated yields at 600 gpm:

- 729 dry kg/day of HPC
- 266 dry t/yr of HPC
- 9.7 kg MREO/day at 90% purity assuming 80% recovery of TREE
- **3.6 t MREO/yr**
- Plus roughly:
 - 7.2 t (Ni+Co)/yr in equal proportions
 - 36.0 t Mn/yr
 - 17.0 t Zn/yr
 - **63.8 t/yr REE/CM oxide basis**



REE Recovery Pilot Plant 2024 upgrades

- Design and Implementation of Automation cabinet to fully automate HPC transfer and dewatering
- Implementation of new SNF polymer unit to enhance dewatering
- Design and Implementation of high solids leach circuit and rotary drum filter



Top: High Solids Leach Circuit,
Bot: Automation Cabinet

Expansion to Hard Rock AMD 2023-Present

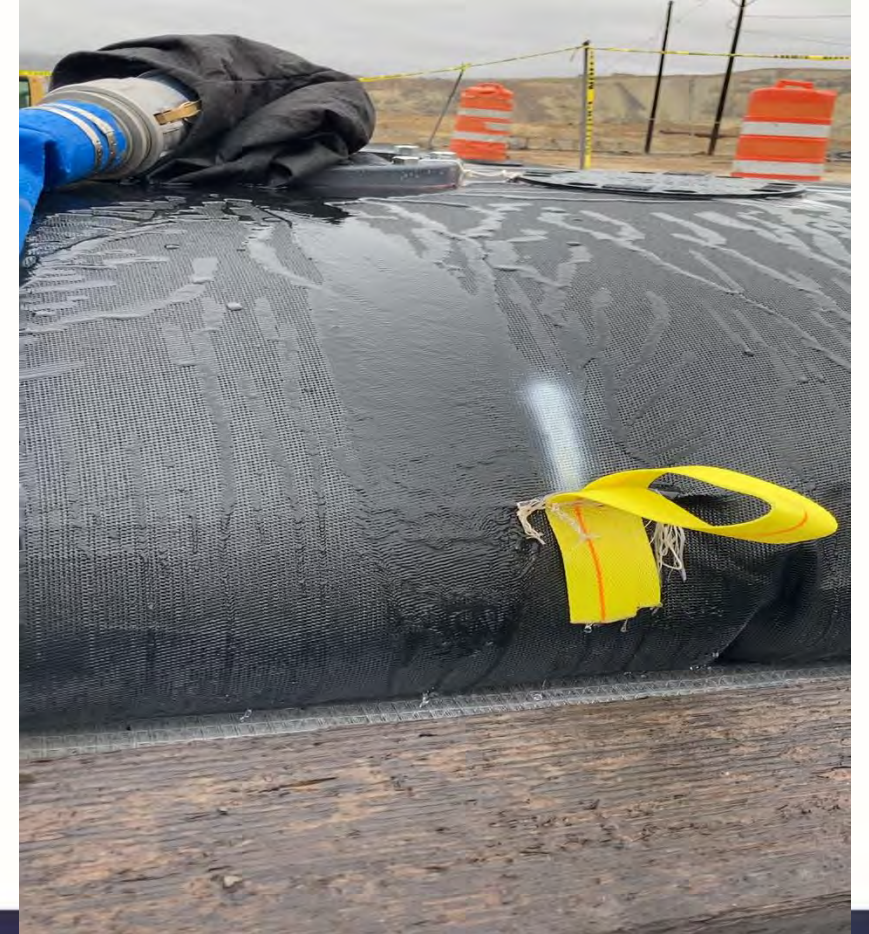
- **WVWRI awarded first Department of Defense Contract to investigate recovery of REE and CM from Hard Rock AMD feedstocks**
- **Horseshoe Bend Water Treatment Plant chosen as initial test site**
 - **Treats AMD from the Berkley Pit**
 - **Montana Resources and Montana Bureau of Mines and Geology partner with WVWRI and VT on project**
- **Uses WRI developed technologies to generate and capture HPC as well as generate LREO and HREO products**

Project ETD99 USDOD IBAS-Montana Resources

Copper Mine:

We Converted a conventional AMD plant to HPC production in a **month!**

Horseshoe Bend WTP



Project Results

- **Established Production Rates from Berkley Pit AMD**
 - 30 t/yr of TREE
 - 7,500 t/yr of CM
 - CM include Co, Ni, Mn, Zn
- **Successful generation of REE enriched HPC (0.2% REE grade, 50% CM grade)**
- **Successful capture of HPC with conventional Geotubes**
 - Dewatering of material to 40% solids in just over 40 days
- **Successful use of WRI process to generate LREO and HREO**
- **In final stages of development to capture Zinc from REE recovery process**



Central Refinery Development Project 2023-Present

- **WVWRI, VT, and L3 Engineering Partner to develop engineering design package for first of its kind US-based rare earth elemental separation facility using AMD sources**
- **Utilizes concept of regional mid-stream HPC to MREO processors and one single down stream elemental separation facility**
- **Currently in process of validating design parameters at A34 plant and developing a business case as required by DOE.**

Conceptual supply chain: Concentrates move to central processing facilities

D. Iron Mt. CA



E. Butte MT

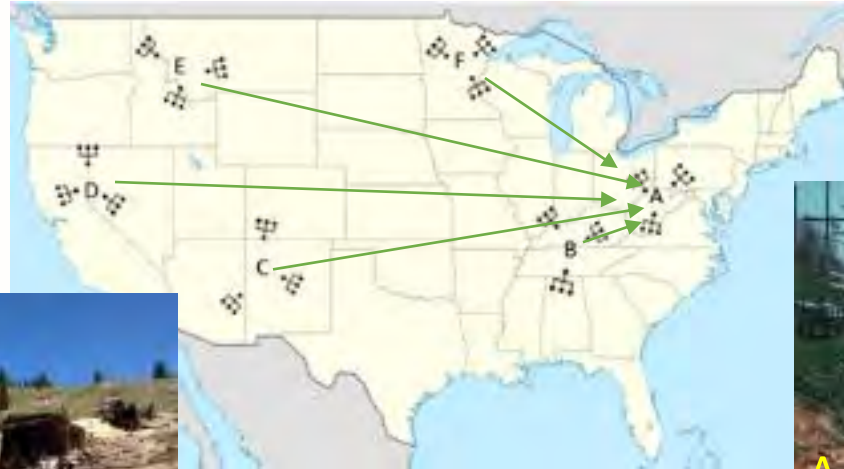


F. Iron Range MN



Potential source districts

- A: Northern/Central APP
- B: Southern APP/Illinois basin
- C: Southern Rockies metal belt
- D: Sierra metal belt
- E: Northern Rockies metal belt
- F: Minnesota iron range



C. Four Corners



B. Southern App Coal



A. Northern App Coal



Elemental Separation and alternative feed stock recovery project- upcoming

- **WVWRI awarded 3-year project in spring of 2024 to evaluate elemental separation techniques and processing of additional waste feedstocks**
- **Began October 1st 2024**
- **Funds operation of REE pilot plant with operators through 2026**
- **Funds expanded use of NRCCE High Bay Research Laboratory on WVU Evansdale campus**
- **Currently in process of switching to new Canadian sourced extractant at A34 pilot facility prior to beginning major testing and development**

WVWRI's Future REE Development

- **Continued partnerships with government agencies to find sources of REE and CMs in other waste feeds**
- **Continue to build partnerships with industry partners to find both sources of REE and CM's, and find environmentally benign solutions to treating waste streams**
- **Scale up AMD treatment to restore watersheds while recovering REE/CM**
- **Develop further separation technologies for critical minerals and REE elemental separation**
- **Encourage and support government policy for treatment operator REE ownership in U.S. and for protection of REE pricing in U.S. to prevent Chinese price crashing**

Questions

David Hoffman
Critical Materials Program Director
Water Research Institute
West Virginia University

David.hoffman@mail.wvu.edu

304-293-6894

