REE-cycling

Rare Earth Element and Critical Material Recovery from AMD

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WVWRI Seminar Series

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WVWRI

- Supported under Federal CWA
- Been serving the state of WV since 1967
- Housed at WVU in Morgantown, WV
- Focus on collaboration, economic development, education + outreach, and research to solve water quality issues
  - WVU colleges, other higher ed institutes, private consultants, industry professionals
- Oversight by the WV Advisory Academy for Water Research
  - Federal and state agencies, academia, industry

Image Source: Mel Shafer, WVWRI

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Other entities involved

- Government Agencies
  - Department of Energy (DOE)
  - Department of Defense (DOD)
  - WV Department of Environmental Protection (WVDEP)
- Academic/Research Partners
  - Virginia Tech (VT)
  - Montana Bureau of Mines and Geology (MBMG)
- Industry Partners
  - Rockwell Automation
  - Solmax Geosynthetics
  - Montana Resources

MBMG

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AMD and REE

- Acid mine drainage (AMD)
  - Pyrite oxidizes to form sulfuric acid.
  - Leached heavy metals.

- There are over 12,000 miles of streams and rivers affected by AMD in the United States.
  - 2,500 stream mi impacted by AMD in WV (WVDEP).

Image Source: Rachel Spirnak, WVWRI

AMD and REE

- 17 elements considered rare earth elements (REE).
- Currently, most of world's REE are mined in China.
- WVWRI found that REEs exist in raw coal AMD across 140 separate sites.
  - Cobalt and Nickel found to be in a 1:1 ratio with REE in AMD.

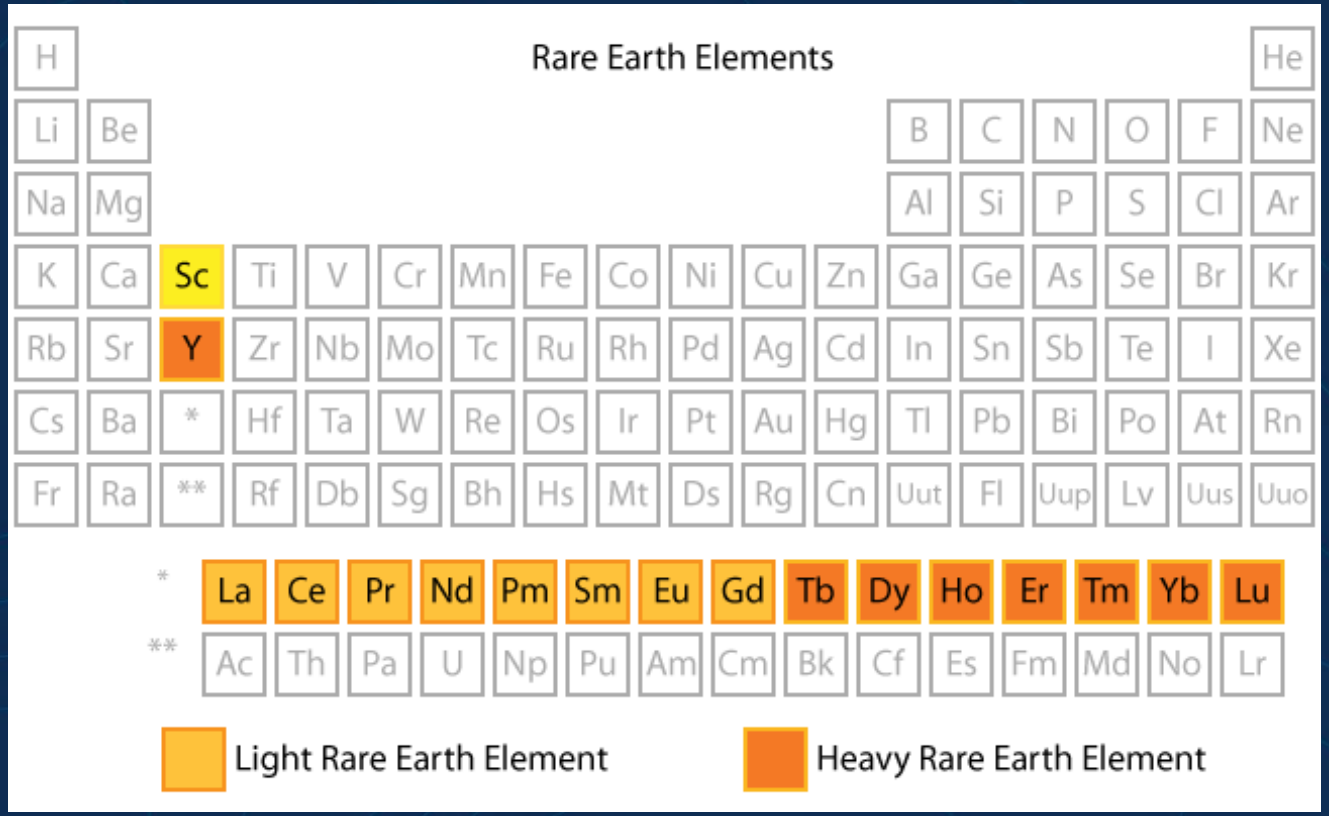

Image Source: sciencenotes.org

Timeline of WVWRI REE

2015

DOE release FOA to find REE in unconventional sources

2017

WVWRI develop two-stage AMD treatment to generate REE feedstock

2018-2020

Bench top pilot system design and testing

2020-Present

REE recovery pilot plant in Mt Storm, WV

- 500 gpm AMD treatment plant; with WVDEP

Evaluation of additional sources

Two Step AMD Treatment

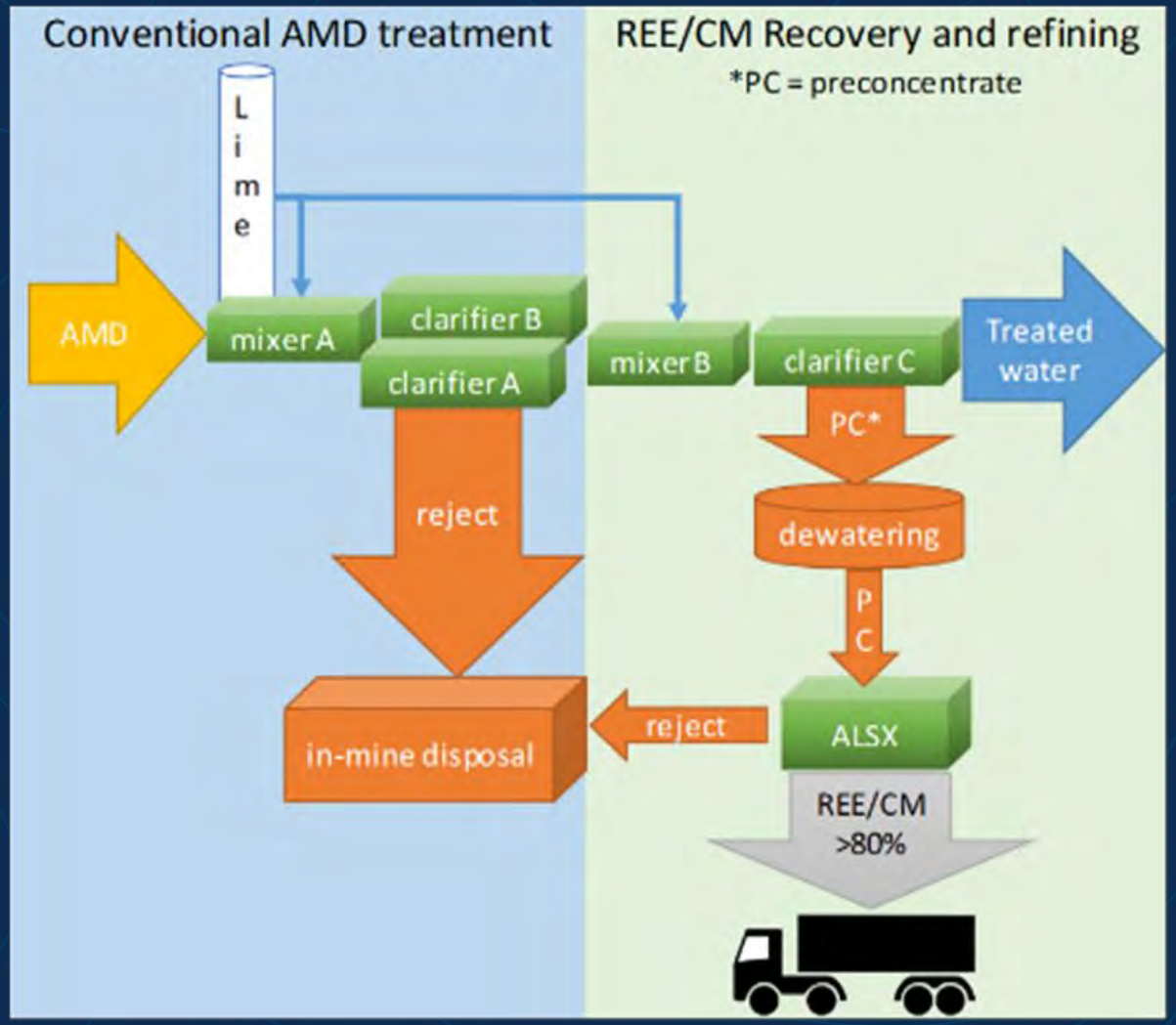

Image Source: WVWRI

- Generates half the sludge reject as convention AMD treatment
  - Other half is REE feedstock (preconcentrate) for further processing.
- The REE preconcentrate is then processed to mixed rare earth oxide prior to elemental separation.

Two Fates of HPC, Same Product

- PC can be processed as a slurry or as a solid.
  - Pump to Geotubes and passively dewatered for storage/transport.
- PC undergoes acid leaching then solvent extraction.
  - Concentrates REEs at each step.
- Solvent is then acid stripped of REEs.
- Gets purified to LREO and HREO.

Image Sources: Nate DePriest, WVWRI

MREO Production – Mt Storm, WV

- Automated system capable of being remotely monitored.
- LREO and HREO currently produced at >90% purity.
- Ability to produce 1.71 t MREO/yr with 500 gpm inflow.

Image Sources: David Hoffman, WVWRI

Current and Future State of Technology

- Final report publicly available.
- Restore AMD impacted watersheds while recovering REE/CM.
  - Utilize money generated to cover plant O+M.

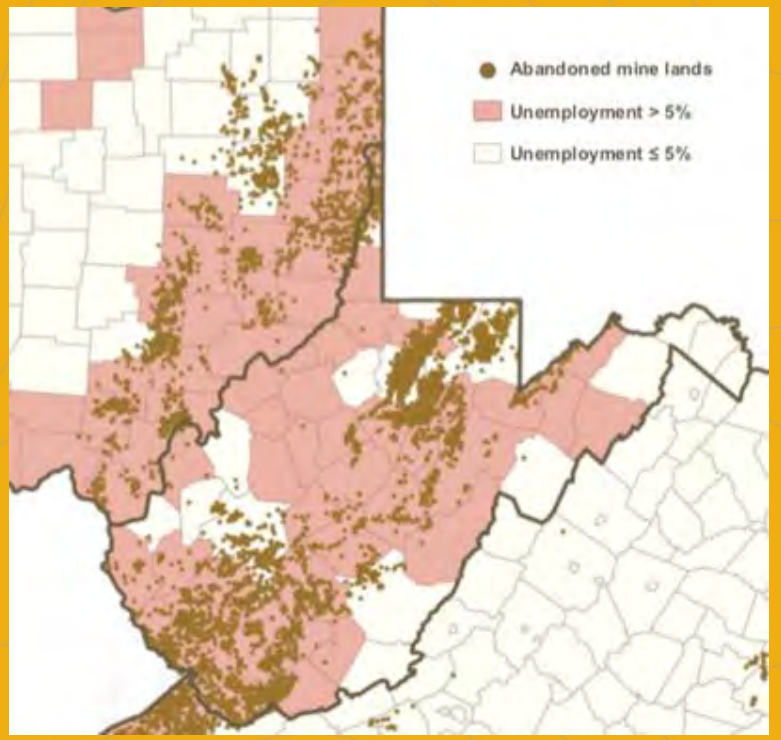

Image source: wvnews.com

WVWRI REE Program Goals

- Incentivize AMD treatment.
  - Encourage more operators and landowners to treat.
  - Restore watersheds and streams.
- Provide cost savings to reduce operation and maintenance (O&M) costs.
- Create additional jobs for economies dependent on coal.
- Develop an independent Rare Earth Supply Chain in the United States.

Image Source: Mike King, WVU

REE-covery:
Frequently Asked Questions

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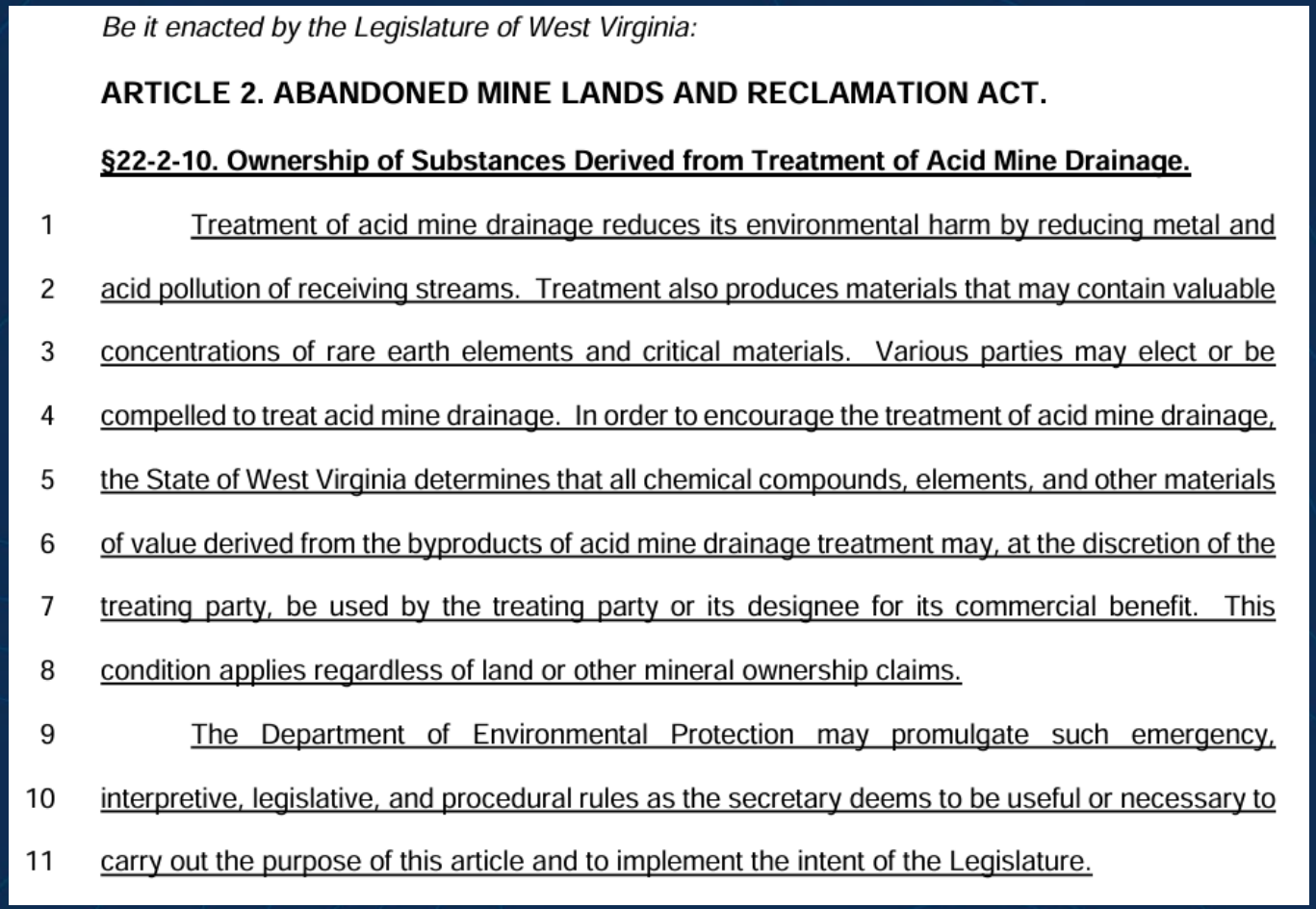
Who gets the benefit of REE recovery from AMD?

- For WV, those who treat get the AMD, get the $$$.
- WV Legislature - HB 4003
- Opportunity for other states to do the same
  - Studies indicate there would be interest for similar in other states



Be it enacted by the Legislature of West Virginia:

ARTICLE 2. ABANDONED MINE LANDS AND RECLAMATION ACT.

§22-2-10. Ownership of Substances Derived from Treatment of Acid Mine Drainage.

Treatment of acid mine drainage reduces its environmental harm by reducing metal and acid pollution of receiving streams. Treatment also produces materials that may contain valuable concentrations of rare earth elements and critical materials. Various parties may elect or be compelled to treat acid mine drainage. In order to encourage the treatment of acid mine drainage, the State of West Virginia determines that all chemical compounds, elements, and other materials of value derived from the byproducts of acid mine drainage treatment may, at the discretion of the treating party, be used by the treating party or its designee for its commercial benefit. This condition applies regardless of land or other mineral ownership claims.

The Department of Environmental Protection may promulgate such emergency, interpretive, legislative, and procedural rules as the secretary deems to be useful or necessary to carry out the purpose of this article and to implement the intent of the Legislature.

Image Source: WV Legislature

Is REE recovery environmentally beneficial?
Yes

- Goal is clean streams and rivers.
- Process is environmentally benign.
- Upstream process (pre-concentrate production) is the same as conventional AMD treatment.
- Downstream process (REE recovery from pre-concentrate) does not generate hazardous byproducts.
- Only offsite discharge is water treated to NPDES compliance.

Will REE recovery promote additional mining?

- REE is recovered from AMD during treatment.
- REE recovery offsets operation and maintenance (O&M) costs.
- Incentivizes AMD treatment at abandoned mines.
  - cost savings, restoring streams, developing supply chain.
- Main byproduct is clean water.

Image Source: Rachel Spirnak, WVWRI

What are polymers and why do you use them?

- Natural or synthetic macromolecules that increase the size of flocculated particles
- Minimize risk of contaminant solids from passing through treatment systems
- Reduce costs by separating particles from water
  - Increase rate of sludge settling, allowing more water to be treated
  - Use in AMD treatment and REE recovery process

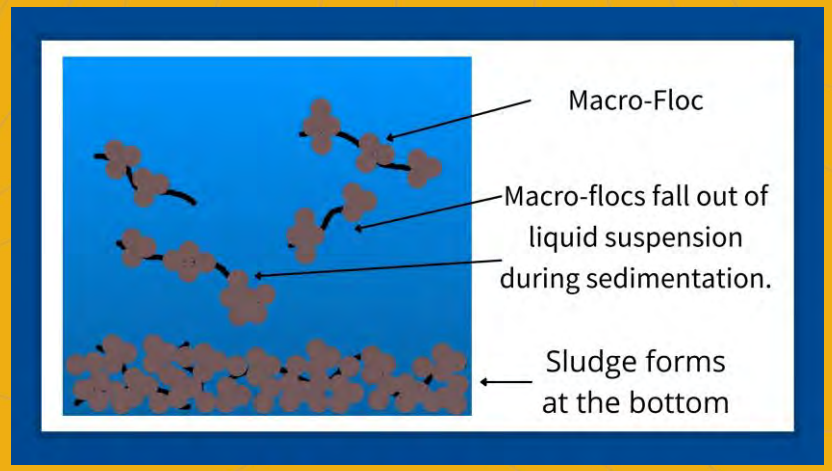


Image Source: clearwaterind.com

Looking Forward...

- Identify additional AMD sources for treatment and REE recovery.
- BIL funding for restoring AML sites.
- Watershed-scale restoration.
- REE supply chain.

Image Source: Rachel Spirnak, WVWRI

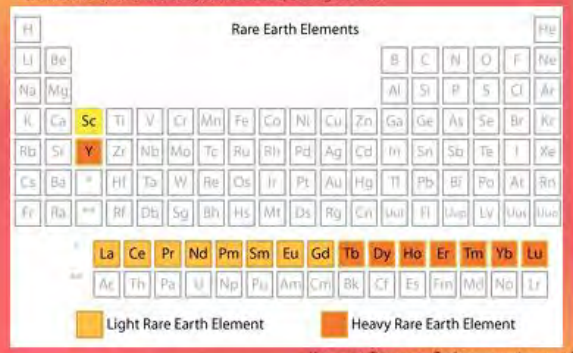
AMD-REE Fact Sheets

Acid Mine Drainage (AMD) Quick Facts

- AMD forms when pyrite rich geology is exposed to air and water. Sulfuric acid forms, and heavy metals are leached (including REEs).
- There are over 12,000 stream miles impacted by AMD in the United States.
- In WV alone, 2,500 stream miles are impacted.

Rare Earth Element (REE) Quick Facts

- 17 elements are considered REEs.
  - Includes lanthanides, scandium, and yttrium



(Image Source: Sciencenotes.org)

- REEs are used in cellphones, cars, and most of the technology today.
- Most of the world's REEs are mined in China.
  - Their practices are environmentally extractive.
  - There is no secure U.S. supply chain of REEs.
- WVWRI found that REEs exist in raw coal AMD across 140 separate site
  - Cobalt and nickel were found to be in a 1:1 ratio with REEs in AMD

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Two-Step AMD Treatment

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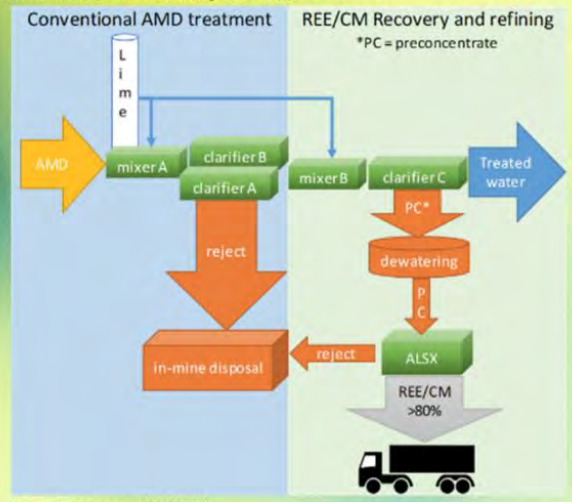
Step 1: Conventional AMD Treatment

- In this case, lime is mixed into AMD using mixer A and is used to raise the pH and extract heavy metals like aluminum and iron.
- After entering clarifier A and B, the heavy metals settle, and then stored in geo-tubes or in-mine disposal.

Step 2: HPC Generation – REE Feedstock Generation

- More lime is added to mixer B and the solution enters clarifier C, with pH rising again.
- The treated, clean water exits the system and solids precipitate out, known as rare earth element preconcentrate or PC.
- PC can be extracted as a slurry or a solid



(Image Source: WVWRI)

Step 3: Downstream Processing – REE Recovery and Refining

- HPC goes through dewatering, acid leaching, and then solvent extraction.
- The resulting solvent is acid stripped of REEs.
- REEs get purified into Light Rare Earth Oxide (LREO) and Heavy Earth Oxide (HREO)

Rare Earth Element FAQs

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WHO GETS THE BENEFIT OF RARE EARTH ELEMENT (REE) RECOVERY FROM ACID MINE DRAINAGE?

- In WV, the entity responsible for treatment of acid mine drainage (AMD) receives economic benefit.
- This was enacted in 2022 through West Virginia House Bill 4003.
- In most cases, this money covers operation and maintenance costs for treatment systems

IS REE RECOVERY ENVIRONMENTALLY BENEFICIAL?

- Yes, WVWRI's overarching goal is to clean rivers and streams, so REE processing is environmentally benign.
- Processes that occur upstream are the same as conventional AMD treatment processes.
- Downstream processes involving REE recovery, do not generate any hazardous byproducts.
- All extractants are recycled in the process.
- The only discharge from processing is effluent water which is treated to NPDES compliance.

WHAT KIND OF TESTING OR SAFETY PROCEDURES ARE IN PLACE FOR REE RECOVERY SYSTEMS?

- The system requires that only lime must be at the AMD treatment site.
- Products are monitored and tested for: gamma, beta, and alpha radiation, as well as, thorium and uranium.
- Toxic Characteristic Leaching Procedure (TCLP) Testing monitors: arsenic, barium, cadmium, chromium, lead, selenium, and silver.
  - None of these analytes have been near concentrations of concern.
- There are several parameters monitored constantly using: check valves, pH controls, conductivity controls, as well as check valves.
- If any conditions are not met, the treatment system will automatically shut down and valves automatically close to prevent accidental spills.
- Future plans for a central refinery would limit risks, since processing would not have to take place at the AMD treatment site.

WILL REE RECOVERY PROMOTE ADDITIONAL MINING?

- No, rare earth elements cannot be recovered through traditional mining practices effectively.
- Revenue generated from REE recovery does not justify additional mining.
  - REE recovery barely offsets operation and maintenance costs of AMD treatment.
    - For WVDEP sites, the money would go into their special reclamation fund
  - Only provides cost savings for reclamation.

WVWRI's goals are to incentivize AMD treatment, an independent US supply chain of REE not reliant on active mining operations, and create additional jobs in areas reliant on coal.

Polymers For Water Treatment FAQs

What are Polymers?

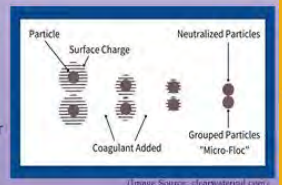
- Polymers are natural or synthetic substances composed of macromolecules which are multiples of simpler chemical units called monomers.
- Polymers help remove suspended solids and reduce sludge volumes in water treatment by increasing the size of flocculated particles, also known as flocs.
- Polymers reduce waste costs by separating particles from water and creating more concentrated mineral slurries for disposal or for processing within the WVWRI acid mine drainage treatment and rare earth element recovery process.

When are polymers used?

- The WVWRI uses polymers to expedite the rare earth element recovery process and in acid mine drainage treatment.
- Polymers are a commonly used in water treatment within applications such as sewage and acid mine drainage.
- Polymers can be used in mineral processing as a recovery reagent help reclaim valuable fine particles that would otherwise be lost.
- Polymers increase the of settling of sludge in clarifiers, this is especially important when a large amount of water needs to be processed.

How do polymers function?

- Acid mine drainage is negatively charged, while standard water treatment polymers are positively charged. This opposite charge encourages suspended metals to separate from the water.
- Polymers form long chains of metal solids which cluster together. This material is denser than the water, allowing for it to settle. This results in cleaner water and a sludge which contains the metals stuck to polymers.



(Image Source: clearwatersid.com)

What are the environmental hazards?

- The use of polymers in water treatment is not considered an environmental concern so long as proper concentrations are used.
- Natural polymers are environmentally preferred over synthetic polymers due to being more biodegradable.
- Polymers minimizes the risk of any contaminant solids passing through a treatment system to the environment. Furthermore, polymers do not alter the treated water or solids it contacts in any way that would create deleterious outcomes to the environment.

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Questions?

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