Recovering Critical Minerals from AMD: Estimated costs and revenue return

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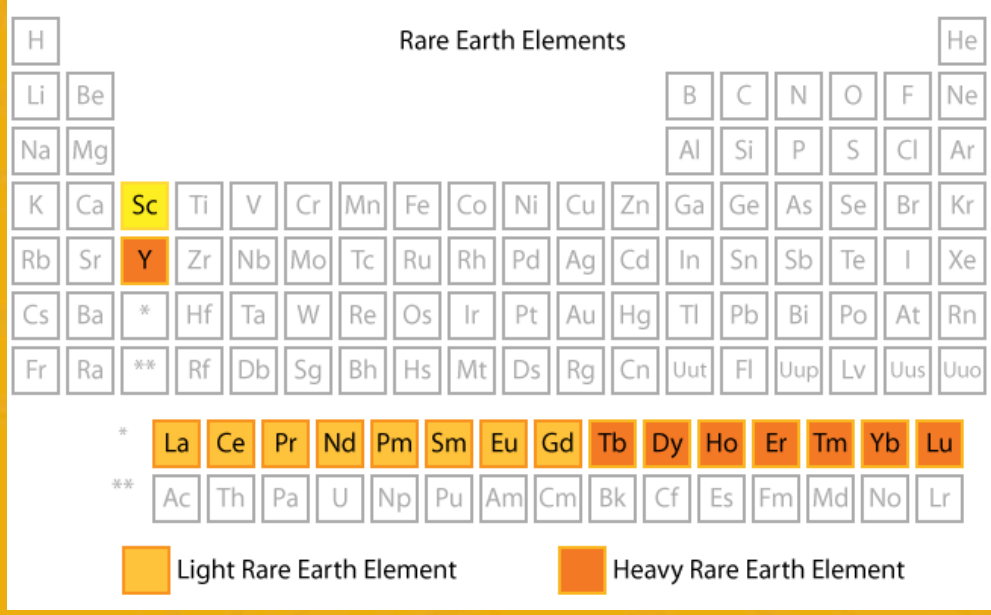
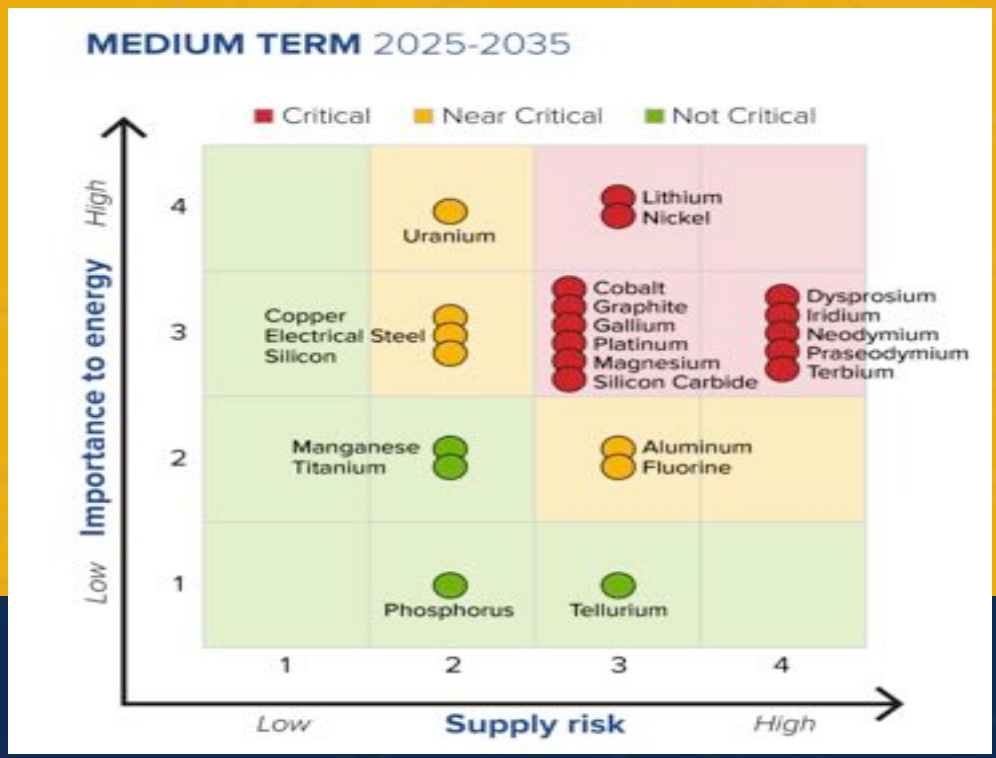
What are Critical Minerals

- The Secretary of the Interior defined a list of 50 critical minerals through the USGS in 2022
- Of these critical minerals 17 are considered rare earth elements
  - Can be split into heavy and light rare earth elements
- Final list published by Secretary of Energy in 2023 defining critical and near critical elements in the short term and medium term.



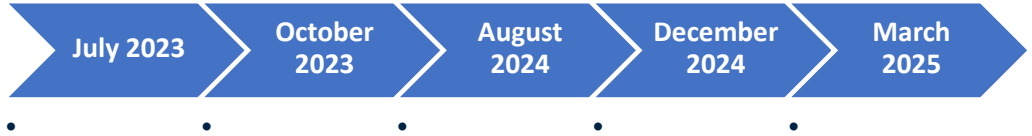


Source: US Department of Energy

Why are Critical Minerals so important to the United States?

- United States relies on several rare earth elements and critical Minerals for use in manufacturing national defense related items
- Realized fears of China cutting supply to the United States
- 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
- Several other US based manufactures of automobiles, medical devices, magnets, etc. rely upon China's critical minerals to manufacture parts and stay in business.

A timeline of the US struggle for Critical Materials with China



Source: TDi-Sustainability.com

Element	Price January 1st 2023 ($/kg)	Price April 14th 2025 ($/kg)	% Increase
Gallium	$640.80	$959.00	49.7%
Germanium	$2344.00	$4176.30	78.2%

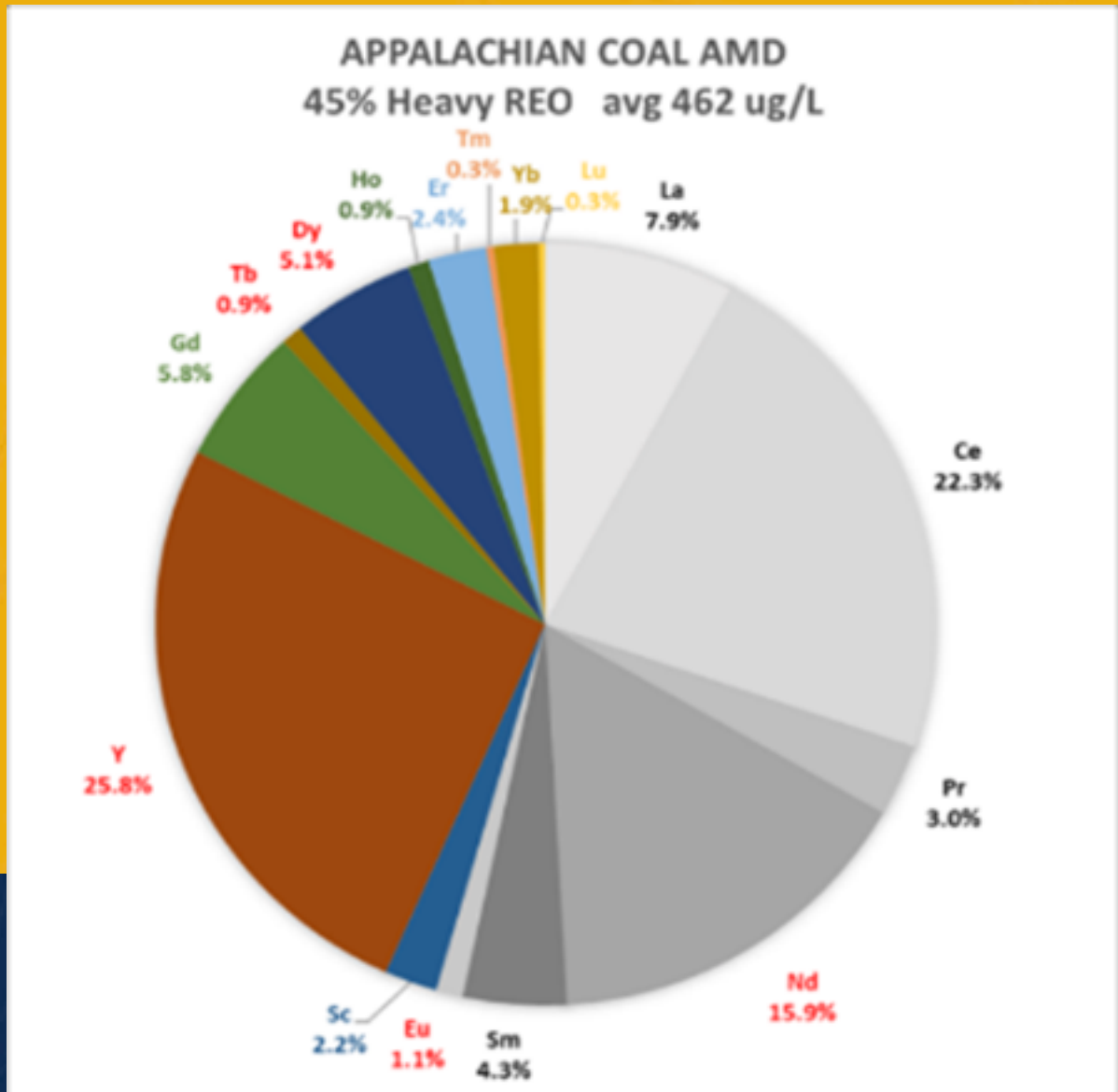
Element	Price January 1st 2025 ($/kg)	Price April 14th 2025 ($/kg)	% Increase
Dysprosium	$349.58	$453.90	28.6%
Terbium	$1382.59	$1983.40	42.0%

Source: strategicmetalsinvest.com

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 acid mine drainage across the United States.
- *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



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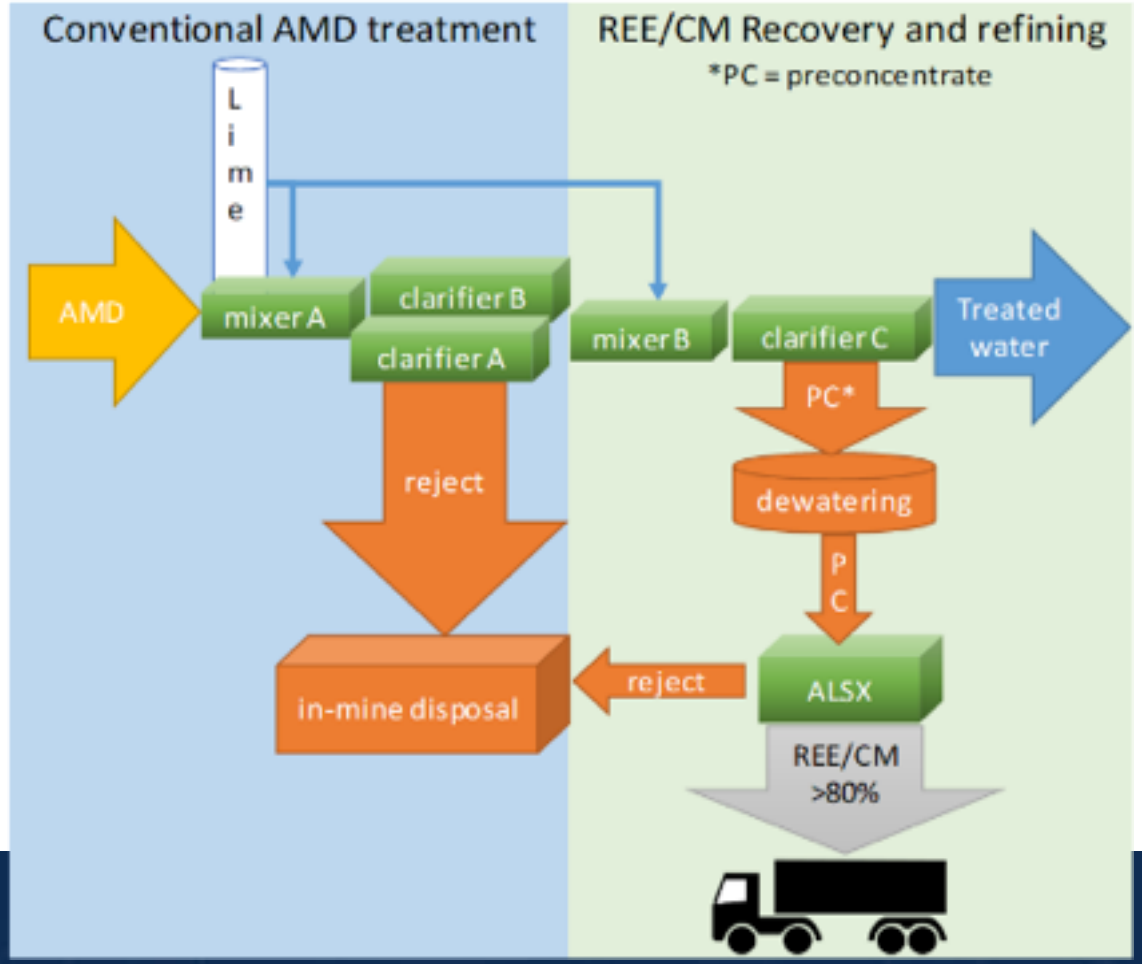
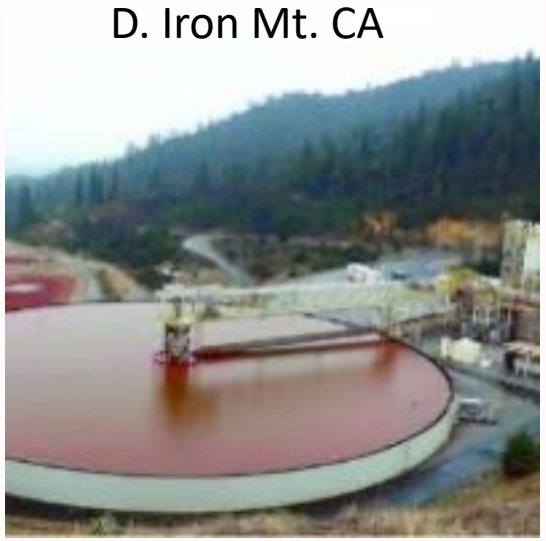
An Environmentally Benign and Cost-Effective Solution

- In 2017 WVVWRI 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



Conceptual supply chain:
HPC Concentrates move to central processing facilities to produce mixed MREO products



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

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Capital Costs of two recently designed treatment facilities

Richard AMDREE Treatment Plant

Richard Treatment Facility		
Designed Treatment Capacity per Clarifier	500	GPM
Clarifiers Installed	3	
Stream Miles Recovered	5	mi
Capital cost standard treatment system	$ 5,179,687	
Additional Capital Cost REE Capture System	$ 2,395,000	
Yearly Estimated Operational Cost	$ 400,000	

Credit: Chris Schulz, West Virginia Public Broadcasting

T&T Retrofit CAPx for REE capture add on

T&T Treatment Facility	
Average Flow (GPM)	1433
Existing Clarifiers*	2
Proposed new clarifiers	2
Stream miles restored	3.4
Capital Cost	$ 6,401,334
Opx (new clarifiers only)	$ 100,061.00

*Note: Not Independently controlled

Revenue Background

- **Contained Value (CV) is the market price on an oxide basis of elements of value in feedstocks**
- **Note: REE Prices in 2022 are extremely depressed**
- **Revenue is calculated as 20% of the CV**
  - **Accounts for costs of midstream and down-stream refining of pre-concentrates to generate CM and REE products**
- **Revenue does not account for costs incurred by the treatment operator to build or operate a facility**

Products	Unit Price $/kg
Yttrium Oxide	$ 6.26
Nd(Pr)2 Oxide (Neodymium, Praseodymium)	$ 55.65
SEG Oxide (Samarium, Europium, Gadolinium)	$ 28.60
Terbium Oxide	$ 883.67
Dysprosium Metal	$ 337.64
Cobolt Sulfate	$ 4.15
Manganese Oxide	$ 1.77
Nickel Sulfate	$ 4.56
Zinc Oxide	$ 2.85
Lanthanum Oxide	$ 0.78
Cerium Oxide	$ 1.11
Holmium Oxide	$ 72.11
Erbium Oxide	$ 44.20
Thulium Oxide	$ -
Ytterbium Oxide	$ 13.26
Lutetium Oxide	$ 752.90
Scandium Oxide	$ 649.30
Lithium Oxide	$ 13.00
Germanium metal	$ 4,000.00
Gallium Metal	$ 931.00

Note: Rare Earth Oxides are 2022 Unit Prices

Contained Value and Revenue for current and potential REE capture facilities

Site	A34 (Buffalo Coal Permit)	Richard Mine	T&T (Muddy Creek)
State	WV	WV	WV
Average Flow (GPM)	500.0	424.0	1433
REE (t/yr)	1.4	0.3	0.6
Cobalt (t/yr)	1.4	0.4	0.5
Maganese (t/yr)	43.3	2.9	7.9
Nickel (t/yr)	1.4	0.4	0.9
Lithium (t/yr)	0.0	0.8	0.6
Zinc (t/yr)	3.1	0.9	2.7
Contained Value	$ 267,100.42	$ 99,959.54	$ 158,718.66
Revenue	$ 53,420.08	$ 19,991.91	$ 31,743.73

Note: Ga, Ge, and other critical minerals not included in revenue calculations due to inability to get accurate analytical data

A34 Buffalo Coal Permit Case Study

A34 Background

- 500 gpm active AMD treatment plant located near Mt.Storm WV
- On the former Buffalo coal permit
- WVDEP required to meet NPDES discharge permit
- Formerly a passive lime dose and settling pond treatment site
- Active treatment required to meet discharge permit regardless of REE plant
- WVDEP and WVWRI partnered in 2020 to build AMDREE capture facility

Site A34 Conventional treatment vs AMDREE costs

- Chemical cost remain unchanged due to similar discharge pH requirements
- Under optimal scenario only 2 clarifiers are installed to eliminate large amount of additional CAPx
- Revenue is based upon 2022 pricing
- Ga and Ge is not included in revenue but is found in MREO products.
  - Could add a minimum of $6,000 in revenue annually

	Conventional Plant	AMDREE	Opimal AMDREE costs
Average Flow (GPM)	500	500	500
Clarifiers	2	3	2
Designed Capacity (GPM)	1000	1500	1000
Capital Cost	$ 6,577,145	$9,192,885	$ 6,577,145
Geotube laydown area	$ -	$ 30,000	$ 30,000
Operational Cost	$ 258,036	$ 223,036	$ 223,036
Geotube annaul cost	$ -	$ 12,000	$ 12,000
Sludge Disposal Savings	$ -	$ 35,000	$ 35,000
REE Revenue	$ -	$ 53,420	$ 53,420
Total Capital Cost	$ 6,577,145	$9,222,885	$ 6,607,145
Total Annual Operational Cost	$ 258,036	$ 181,616	$ 181,616
Capital Cost % increase	-	40.2%	0.5%
Operational Cost % decrease	-	30%	30%

CAPx considerations and lessons learned

- Only two independently pH-controlled clarifiers are needed
  - WVDEP currently designs all facilities with at least two clarifiers
  - REE capture can be shut down for high flow seasons that only occur a few weeks per year
- CAPx at A34 is increased due to pour in place vs oversized clarifiers
  - Richard costs were decreased due pre-cast construction and shortened clarifier length
- CAPx at Richard increased due to designing REE plant after groundbreaking of conventional facility

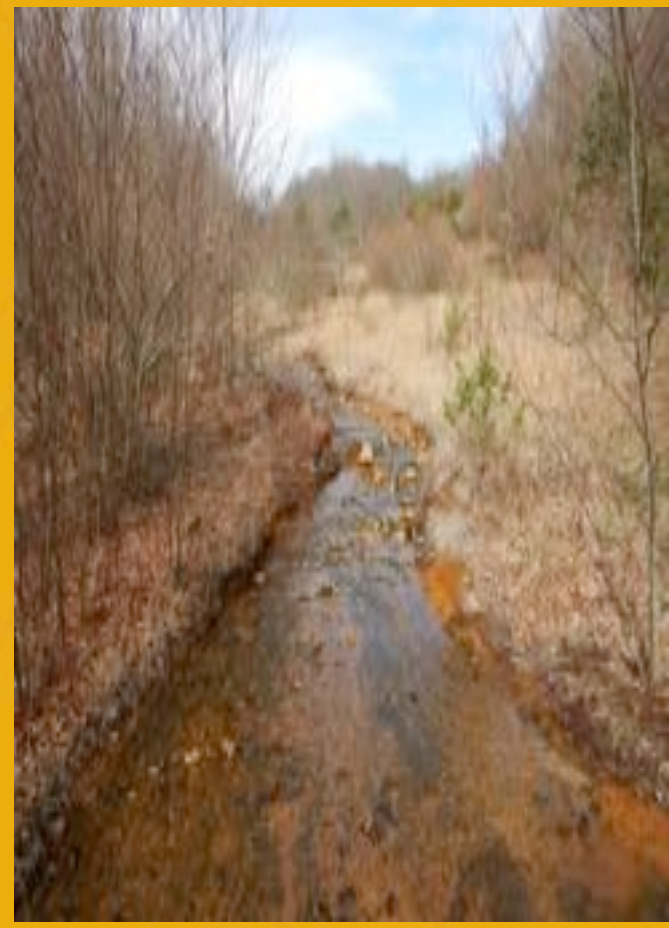
OPx lessons learned

- By recovering REE enriched pre-concentrates, sludge disposal costs can decrease by 50%
  - Varies by site due to type of disposal
- Rare Earth price variability can greatly impact revenue
  - I.E. Terbium and Dysprosium prices have doubled since January 1st 2025 but can also rapidly decline in price due to Chinese market manipulation
- Flow and critical mineral water concentration also greatly affects Opx and Revenue
  - I.E. Richard has similar flow to A34 but produces 1/3 the products due to geological location of facility

Theoretical Optimal AMDREE treatment vs conventional treatment on Greens Run Watershed

- **CAPx increase due to both land acquisition and additional pipeline installation for watershed scale treatment**
- **REE/CM watershed has decreased concentration in water leading to less revenue**
- **CAPx increase for REE vs conventional facility minimal**

Greens Run Water Shed Treatmetn Plant (preliminary)		
	Conventional	Optimal AMDREE
Average Flow (GPM)	1032	1032
Clarifiers	2	2
Stream Miles recovered	5	5
Capital Cost	$ 9,391,478	$ 9,491,478
Geotube laydown area cost	$ -	$ 100,000
Operational Cost	$ 203,650	$ 168,650
Geotube annaul cost	$ -	$ 32,000
Sludge Disposal Savings	$ -	$ 35,000
REE Revenue	$ -	$ 29,284
Total operational cost	$ 203,650	$ 171,366
Capital Cost % Increase		1%
Operational Cost %		



Roadblocks to REE recovery from AMD

- Unstable critical mineral market inhibits United States investment in separation technologies
  - China has ability to crash market at any time
- Lack of individuals educated in critical mineral recovery in United States
  - No official university programs in United States
  - China has ~40 university programs for critical mineral and rare earth element recovery
- Lack of policy regarding mineral ownership from waste feedstocks in United States
- Lack of existing REE enriched feedstock to encourage construction of mid-stream separation facility

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/CM ownership in U.S. and for protection of REE/CM pricing in U.S. to prevent Chinese price crashing

Conclusions

- AMDREE recovery has minimal CAPx cost increases if additional clarifiers are not added to the treatment system
- Operational cost savings from 16 to 30+% can be obtained through REE revenue and decreased sludge disposal costs
  - Future cost savings could improve based upon REE market
- Ideally existing systems with independent pH controls would be modified to capture REE and CM products without high capital investment.
- Constructing a new conventional treatment system does not provide justifiable cost savings over AMDREE treatment

Questions

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