University of Nevada, Reno

TEA and LCA Considerations for Phythomining in the USA

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LCA and TEA

- **LCA** – A Life Cycle Assessment (LCA) measures the environmental impacts of a product, process or service.

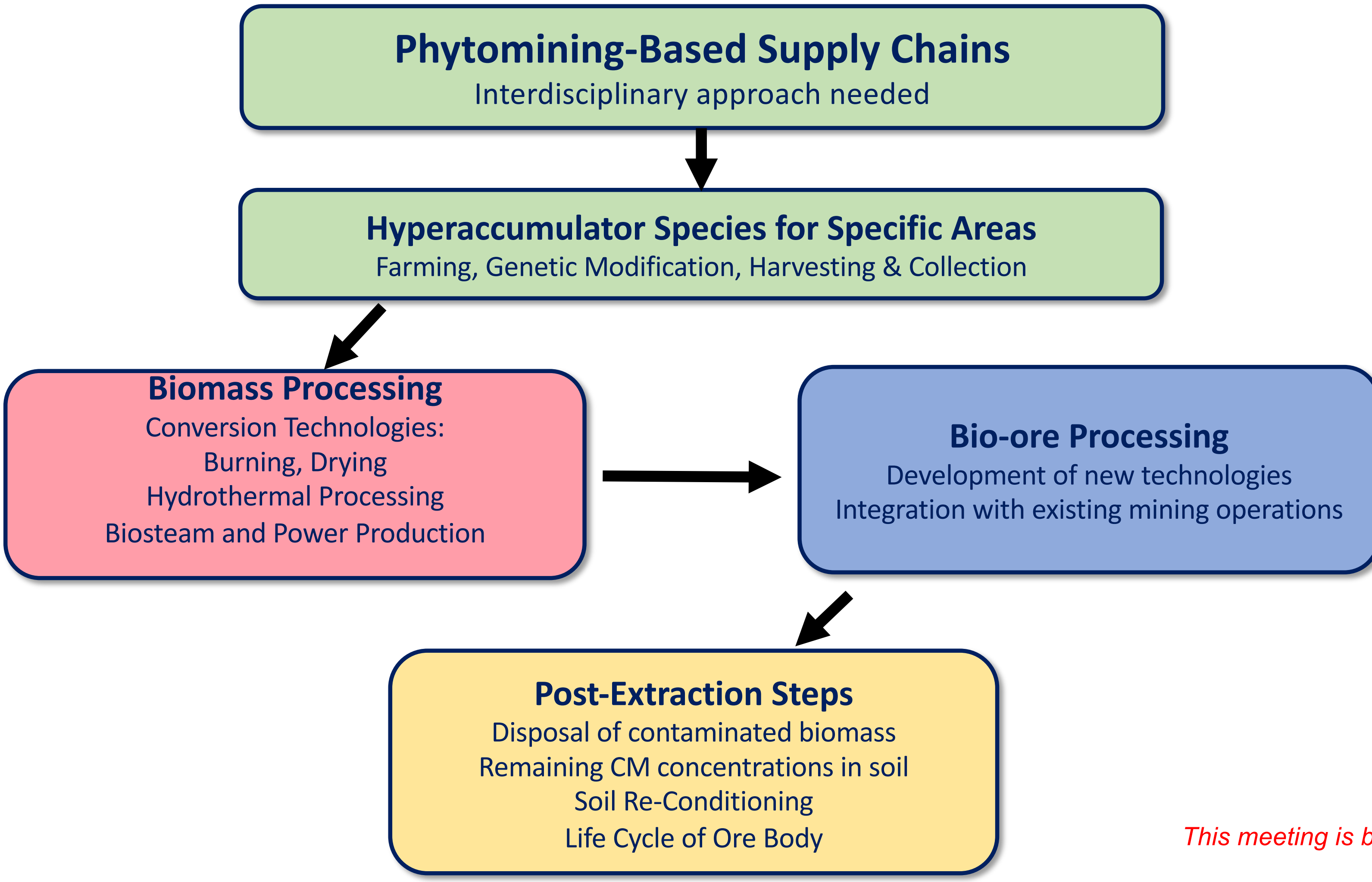
- TEA – uses process modeling and engineering design with economic evaluation:

  - Process Flow (PFD), Capital (CAPEX) and Operating Costs (OPEX), and Finance Assumptions

- TEA can be applied at any stage in the development of a project

  - The more defined the project is the more accurate the TEA can be

TEA-LCA Phytomining



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Info Needed:
Need to propose entire supply chain models & process technologies for evaluation & analysis

CM Phytomining – Five Challenges

1
Limited data on process technologies and feasibility studies

2
Little data on potential impacts including introduction of new species in ecosystems

3
Lack of skilled force in the US, lack of regulatory and permitting frameworks

4
Defining sustainable, net-circular, green and recyclable systems

5
Mapping of agriculture practices into phytomining needs: farmers vs miners

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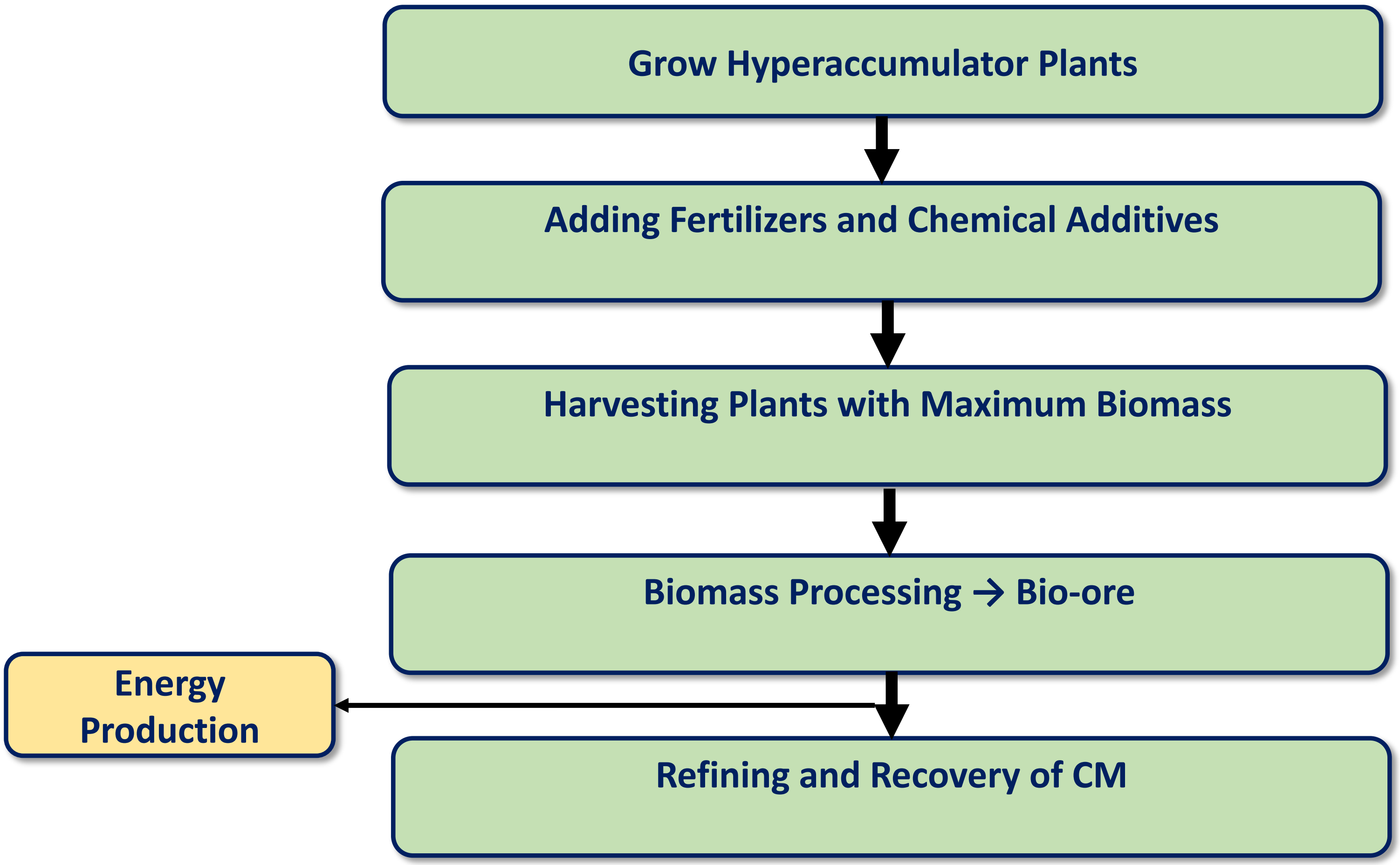
Critical Minerals from Phytomining: possible TE models

- Annual vs perennial crops (fertilization, soil exhaustion)
- Biomass processing technology strong function of type of biomass
- Development of large-scale projects on metal-rich soils vs smaller regional farming projects where biomass collected is sent to centralized facility for processing
- Need detailed **base-case** for comparison – Information available on REE (Mountain Pass)

TEA-LCA Phytomining



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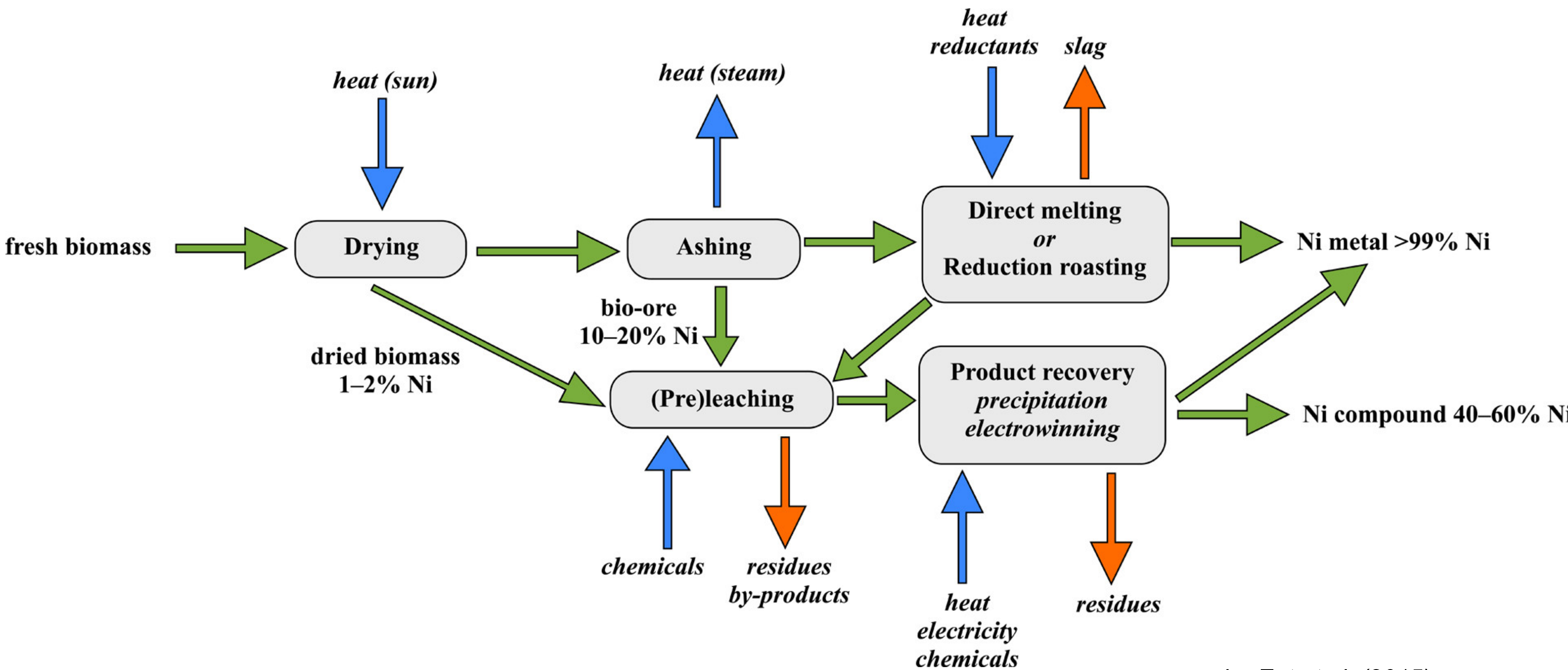
Example: Process Flow Diagram for Ni Bio-ore Processing Options



van der Ent et al. (2015)

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TEA Considerations

Minimum Costs and Information to Consider:

- Cost of phytoextraction ($)
- Total area (ha)
- Planting cost ($/ha)
- Production cost ($/ha): chemicals, fertilization, monitoring
- Production of valuable biomass (tons/ha): potential energy value and ore content
- Value of biomass ($/ton): function of number of harvests per year
- Production of bio-ore (ton/ha)
- Value of bio-ore ($/ton)
- Interest rates

Some TEA models available for Ni (Robinson et al. 2003)

Berkheya

Berkheya sp.

Scientific classification

Kingdom:	Plantae
Clade:	Tracheophytes
Clade:	Angiosperms
Clade:	Eudicots
Clade:	Asterids
Order:	Asterales
Family:	Asteraceae
Subfamily:	Vernonioideae
Tribe:	Arctotideae
Subtribe:	Gorteriinae
Genus:	***Berkheya*** Ehrh.

Berkheya coddii is a well-known hyperaccumulator. Concentration of Ni as the leaves of this species may reach 7.6% DW Ni.

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TEA Considerations for Phytomining

	Rate	Cost or value (per hectare)
Cost of producing biomass		$ 176 / ha
Cost of ashing	$ 148 / ton	$ 3258 / ha
Cost of solvent extraction	$ 732 /ton ash	$ 1611 / ha
Total cost		**$ 5044 /ha**
Total nickel extracted	220 kg/ha	
Value of nickel	$ 24 / kg	
Value of crop		$ 5280 /ha
Profit		**$ 236 /ha/harvest**

Metal recovery is via solvent extraction. All values are per harvest.

A.T. Harris et al. (2009). Inflation-adjusted to 2022.

Nickel uptake by *B. coddii* without the use of chelating agents and with no electricity generation from the harvested biomass.

TEA Considerations for Phytomining

	Rate	Cost or value (per hectare)
Cost of producing biomass		$ 176 / ha
Cost of solvent extraction	$ 732 /ton ash	$ 1611 /ha
Total cost		**$ 1787 / ha**
Value of electricity generated		$ 328 /ha
Total nickel extracted	220 kg/ha	
Value of nickel	$ 24 / kg	
Value of crop		$ 5280 /ha
Profit		**$ 3821 /ha/harvest**

Metal recovery is via solvent extraction. All values are per harvest.

A.T. Harris et al. (2009). Inflation-adjusted to 2022.

Nickel uptake by *B. coddii* without the use of chelating agents and with electricity generation from the harvested biomass.

TEA Considerations for Phytomining

	Rate	Cost or value (per hectare)
Cost of producing biomass		$ 176 / ha
Cost of solvent extraction	$ 732 /ton ash	$ 1611 /ha
Cost of thiosulphate addition	$ 0.4 /kg	$ 2776 /ha
Total cost		**$ 4563 / ha**
Value of electricity generated		$ 328 /ha
Total nickel extracted	220 kg/ha	
Value of nickel	$24 / kg	
Value of crop		$ 5280 /ha
Profit		**$ 1045 /ha/harvest**

Metal recovery is via solvent extraction. All values are per harvest.

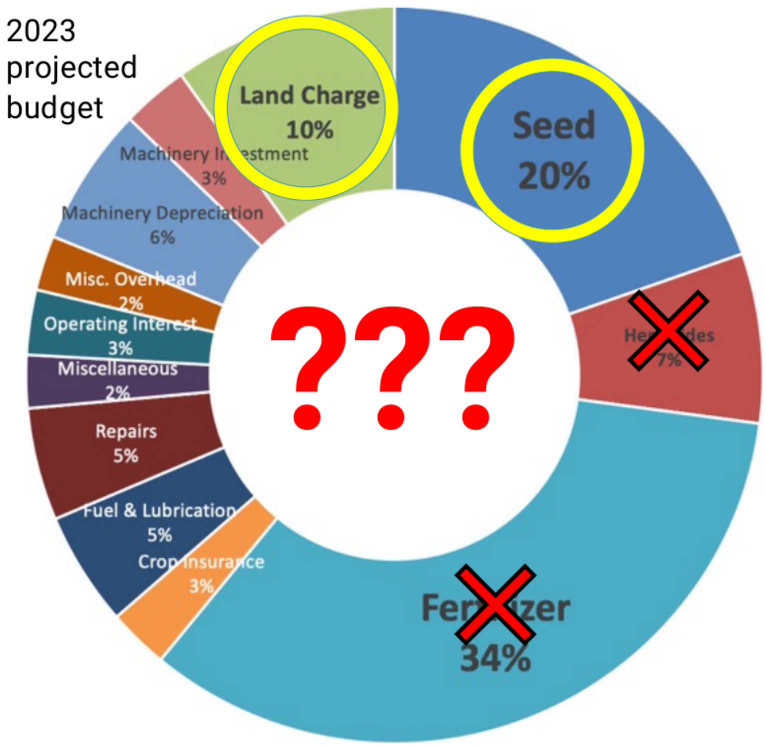
A.T. Harris et al. (2009). Inflation-adjusted to 2022.

Nickel uptake by *B. coddii* with the use of chelating agents and with electricity generation from the harvested biomass.

TEA Considerations for Phytomining

Canola Cost in NW Region of North Dakota

Provided by Phil Kim (ARPA-E)



(ha^{-1} $year^{-1}$)	Canola (intensive)
Sum of listed costs	$152.29
Total production	708.20 lb canola
Market price	$0.11/lb
Market Revenue	$184.84
Return to Labor & MGMT.	$32.56

will it translate like this???

(ha^{-1} $year^{-1}$)	Nickel bio-ore (25 wt.%)
Sum of listed costs	~$200 – $1,000 (w/ processing)
Total production	200 kg† Ni
Ni market price	$24/kg
Market Revenue (50%)	$2,400
Return to Labor & MGMT.	$1,400 - $2,200

† from field studies in Europe with natural species

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Critical Minerals from Phytomining vs Traditional Mining

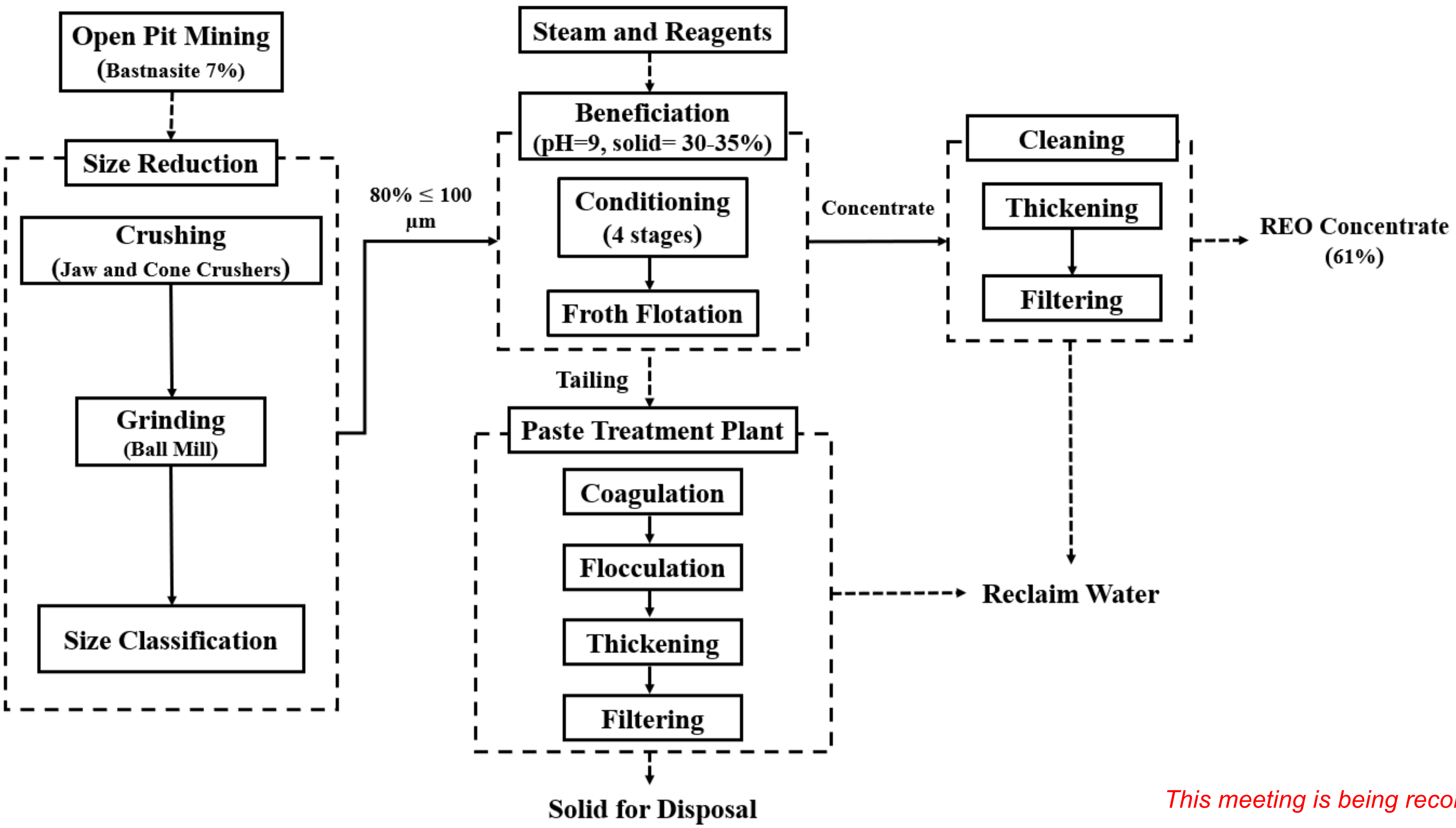
- Comparison with traditional CME methods is necessary
- Potential **base-case** for comparison – Information available on REE (Mountain Pass)

LCA-TEA Considerations, Base Case Scenario: Mountain Pass, CA

- Open pit REE mine
- 15% of world's REE
- Primarily NdPr oxide
- DoD $9.6M (2020) for
- domestic REE production
- DOE $3M (2021) for REE
- from coal by-products
- DoD $35M for domestic
- REE production (2022)
- ~$400M new earmarked
- funding to develop new
- commercial facility for
- heavy rare earth elements processing

- *Only REE mine in the US*
- 18.4 MT carbonatite ore reserves grading 7.98% REO
- cut-off at 5%, waste pile has 3.5% TREO

LCA-TEA Base Case Scenario: Mountain Pass, CA



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Closing Remarks & Directions

- **Technology**
  - Traditional REE and CME technologies will continue to improve and competing with P-CME
  - Technologies for P-CME single steps are not a barrier in general, all sectors, from agriculture to ore processing, have technologies available from various industrial sectors
  - Challenges seem to be on the systems approach, integration, regulation, and supply chains
- **TEA and LCA**
  - Information scattered for both sectors, traditional CME vs P-CME.
  - Supply chain structure for P-CME not well defined
  - LCA information increasingly more available in traditional mining sectors, not so for P-CME
  - Limited TEA studies for both approaches, almost non-existing for P-CME

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Closing Remarks & Directions: TEA and LCA

- **Moving Forward**
  - Develop detailed TEA-LCA model for a specific configurations of P-CME in the United States – regions, crops, biomass and bio-ore processing
  - Possible configurations: (a) self-contained P-CME operation (b) combined P-CME operation with traditional CME operation
  - Collect LCA inventories for agriculture steps and biomass processing in a P-CME supply chain
  - Materials handling consideration of contaminated biomass
  - P-CME will deplete CM content in soils – determine number of rotations possible and effects on P-CME process configurations
  - Many other challenges, but outside the TEA and LCA perspectives