Mine Tailings: Crisis, Response and Opportunities

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Outline

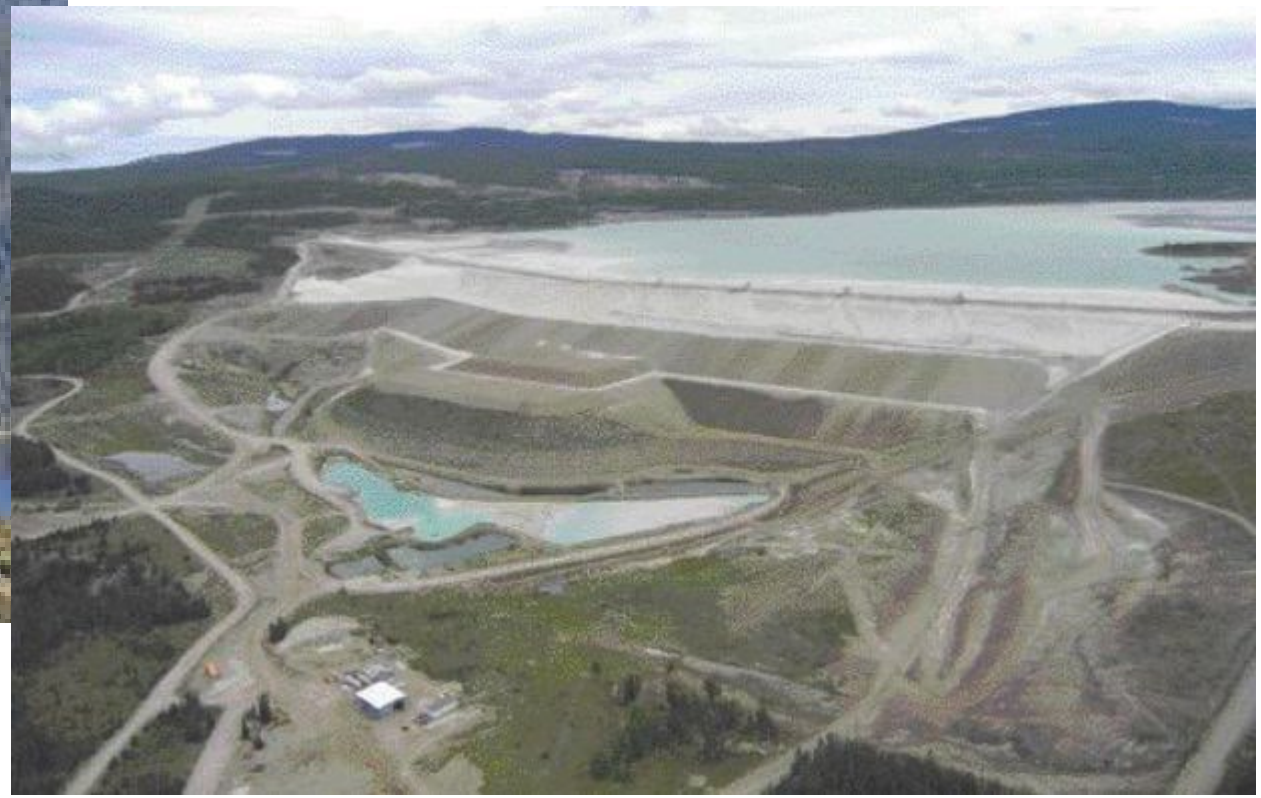
1. The Problem
2. Tailings – the Blood of Mining
3. Circular Economy
4. Minimize Volume
5. Change the Flotation
6. Co-Production and Remining
7. New Materials from Tailings
8. Environmental Management

Part 1: The problem

The problem is VOLUME

- The worldwide generation of wastes from metals mining is > 100 billion tonnes each year.
- Volumes will increase in the future due to lower-grade ores and rising demand.
- The world has ~30,000 existing active, inactive and legacy Tailings Storage Facilities (TSFs).
- Biggest contributors: copper and gold.

The problem is TSF SIZE



Tailings Dams are among the largest manmade structures on Earth!

https://graphics.reuters.com/MINING-TAILINGS1/0100B4S72K1/index.html

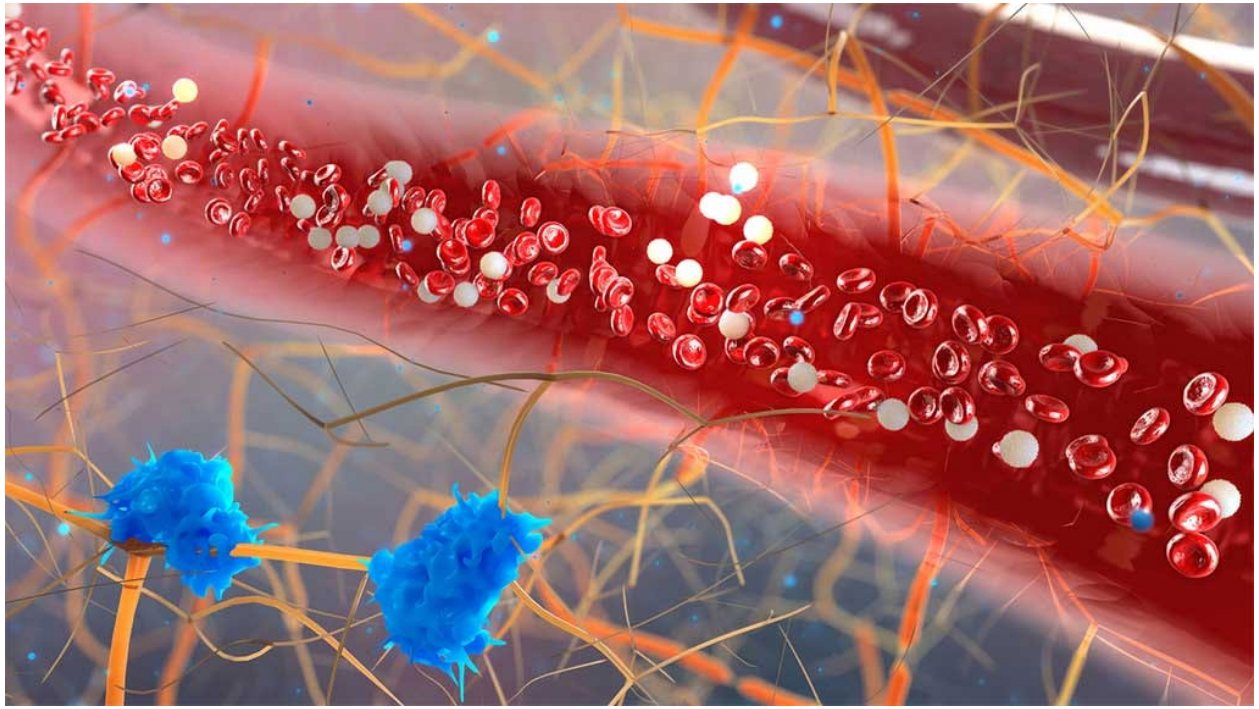
The problem is TSF Failures

Despite improvements in safe design for TSFs, major failures continue annually due to physical and chemical instabilities.

Canada

Brazil

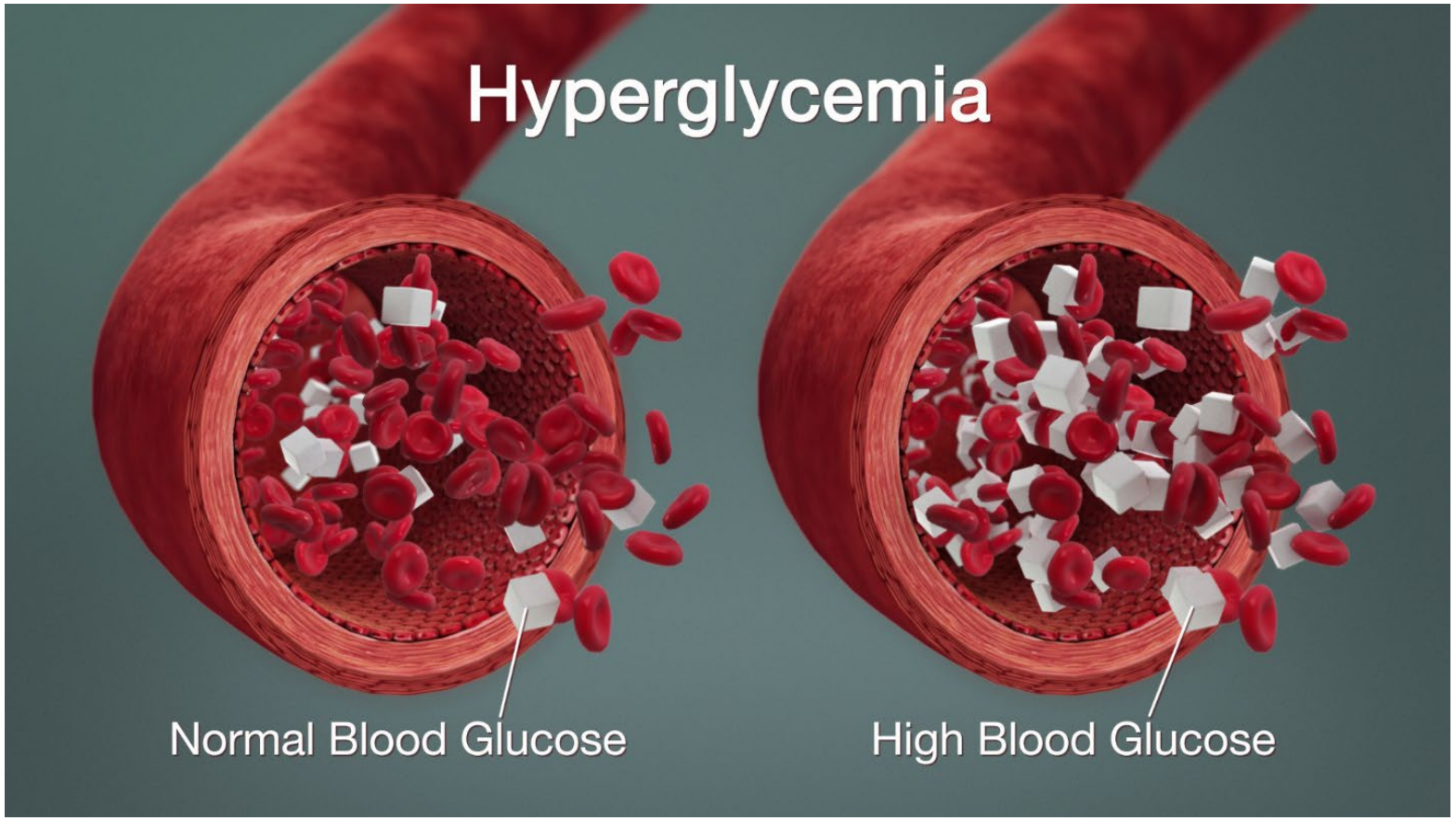
Part 2: Tailings are the Blood of Mining (my hypothesis)



Blood is basic - the first thing a Doctor does when you visit is often to order blood tests.

Tailings are the Blood of the Mining Industry

If we study our tailings, we will find many things we did not know about our mining and extractive processes.



https://spirit-pharmacy.co.uk/blood-glucose-your-questions-answered/

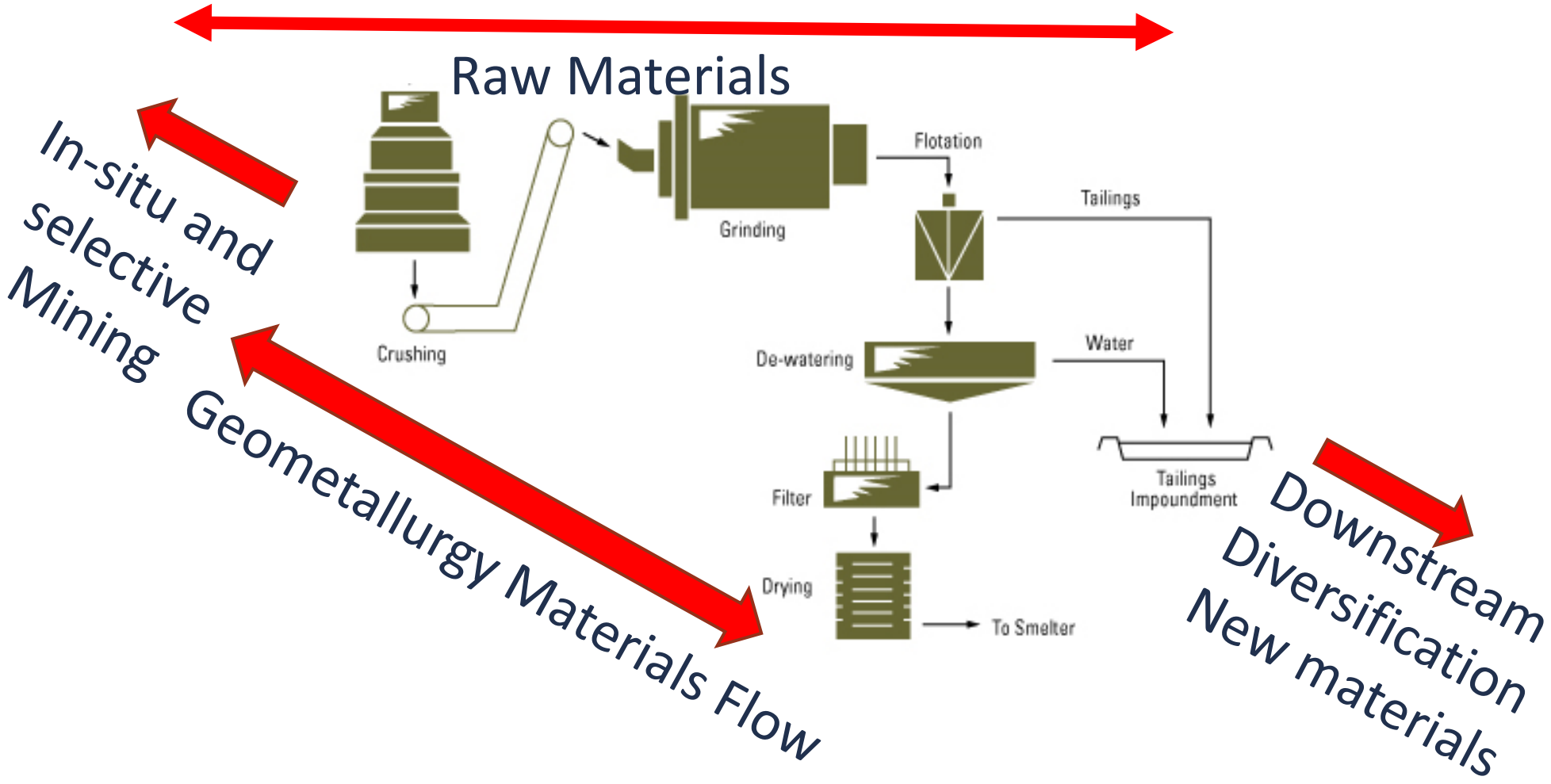
Characterizing our Tailings Blood is Mandatory for Zero Waste

We need real-time characterization of tailings to understand:

- Effectiveness of new methods of comminution and extraction.
- Rheology of slurries for tailings transport, thickening and filtration.
- Opportunities for real-time waste stream segregation or partitioning.
- Occurrence, distribution, and sequestration of (critical) minerals/elements.

Part 3: The Circular Economy

The industry focus cannot be just the mill – but from mine to tailings – upstream and downstream



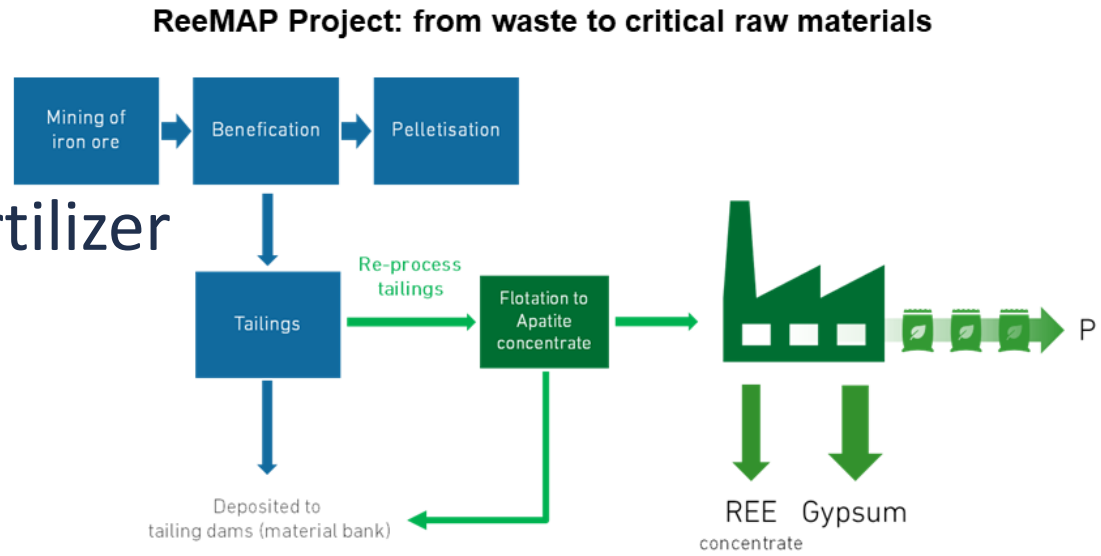
A new paradigm for the Mining industry

Extractive-waste problem

Resource-recovery opportunity

LKAB (Sweden) and Zero Waste Mining - ReeMAP

- The ores that LKAB mines to produce iron concentrates also contain phosphorus and rare earth elements
- LKAB can extract phosphate minerals from what is currently mining waste
- The phosphate concentrate (apatite) will be processed using pyrite from Boliden's operations to produce:
  - 5 times Sweden's need for mineral fertilizer
  - 30% of Europe's need for REEs
  - Sweden's entire need for gypsum

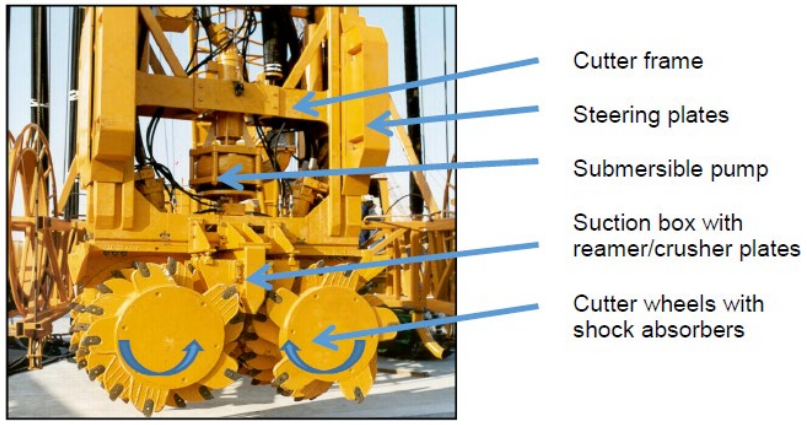


https://www.greencarcongress.com/2023/01/20230117-lkab.html
https://lkab.com/en/news/mine-waste-will-now-be-utilised/
https://lkab.com/en/press/lkab-and-boliden-collaborate-to-recycle-mining-waste-and-create-circular-products/

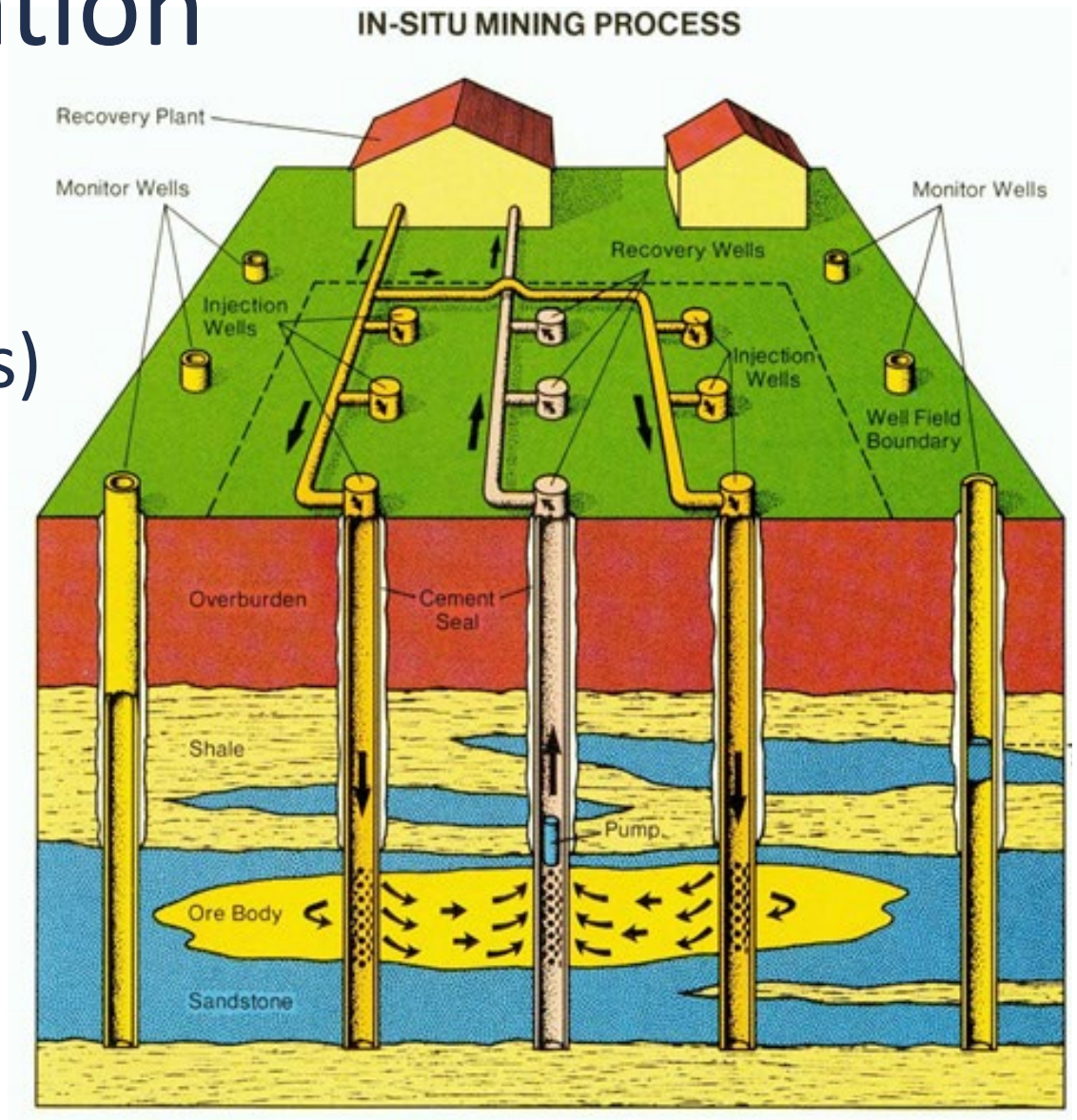
Part 4: Volume Minimization

Opportunities

- In situ and selective mining
- In situ leaching (+ electrokinetics)
- Biomining
- Classifying and sortation

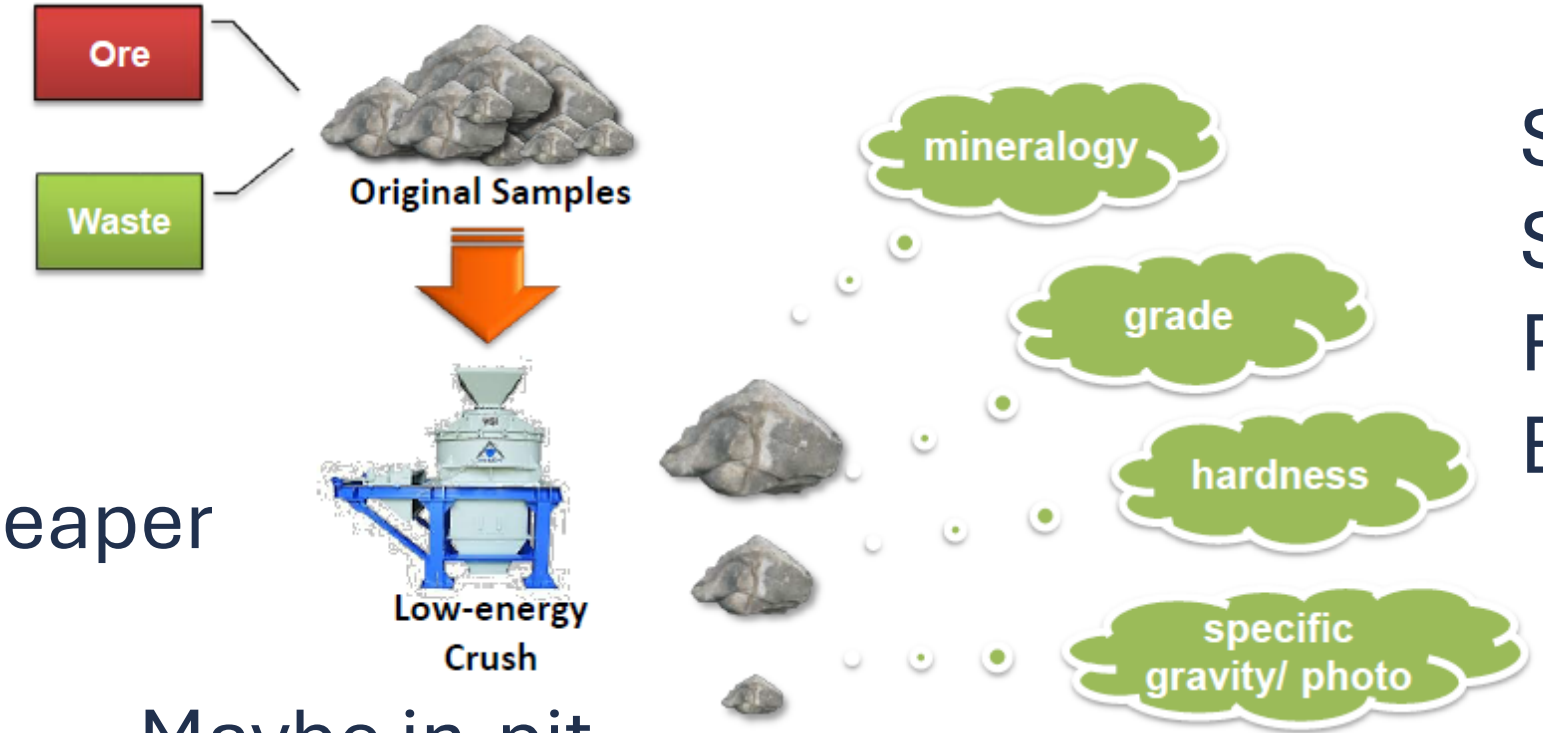


https://www.bauer.de/bma/Produkte/Weitere-Produkte/mining-solutions/



Before the Mill – Dry Sorting

Identify distinct metallurgical domains and use metal deportment vs. particle size to separate valuable (ore) from impurities (gangue) at the mine site (pit or underground)



Cheaper

Maybe in-pit

Smart Separations – Resource Efficiency

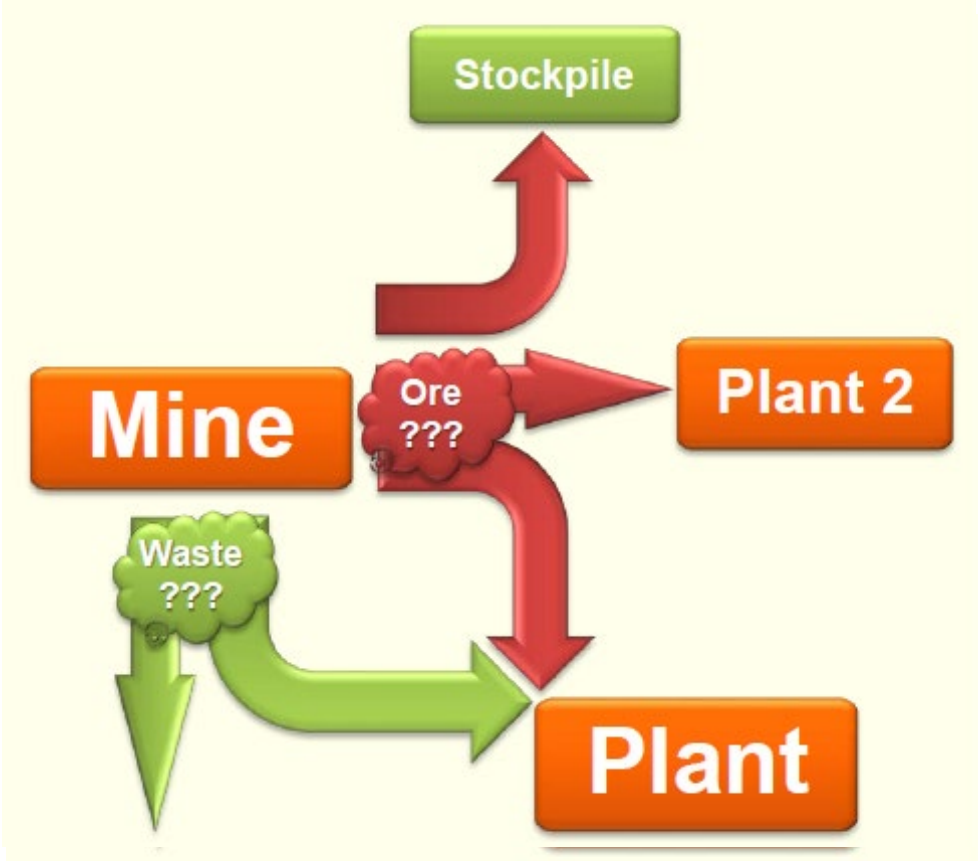
Revisit the Mine-Mill Interface

Typical – 100% of the feed goes to the plant. All is operated on with the same:

- Power intensity
- Water intensity
- Tailings storage method

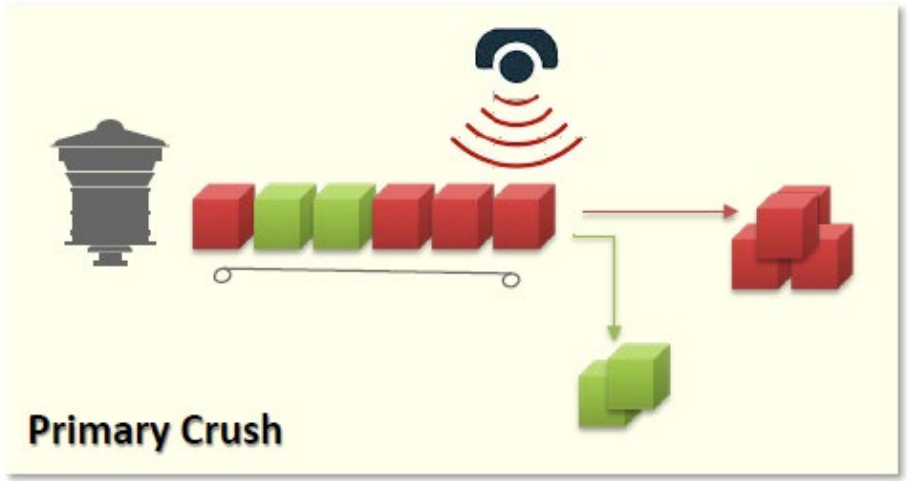
This is a waste of power, water and storage.

The Future: Sorting, Classification and Dynamic Ore Scheduling (which changes the tailings as well)



Dance 2022

Revisit the Mine-Mill Interface: Sorting and Pre-concentration



Sensor Technologies

- Radiometric
- X-ray transmission (XRT)
- X-ray fluorescence (XRF)
- X-ray luminescence (XRL)
- Visual spectrometry (VIS)
- CCD color camera
- Photometric
- Near-IR spectrometry
- Infrared camera
- Thermal IR
- Laser triangulation
- Gamma neutron activation
- Laser techniques (e.g., LIBS, LIF)
- Electrical conductivity

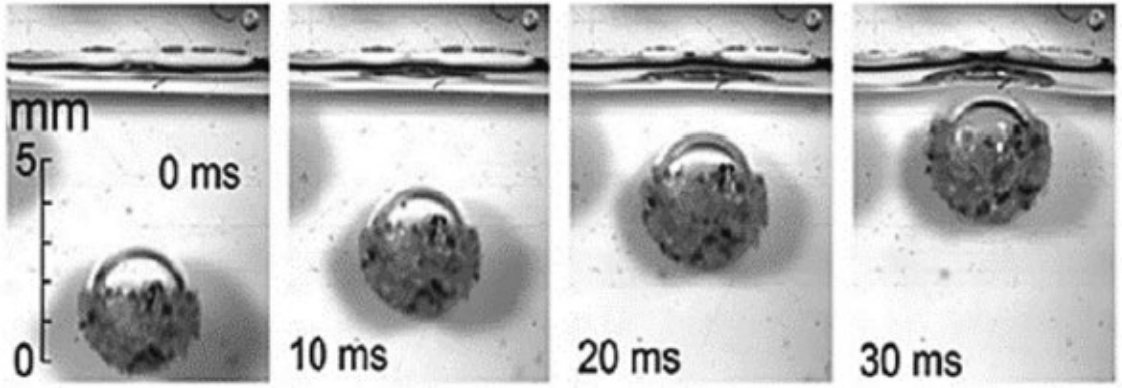
Part 5: Change the Flotation

Online sampling and analysis may permit effective and selective flotation automation.

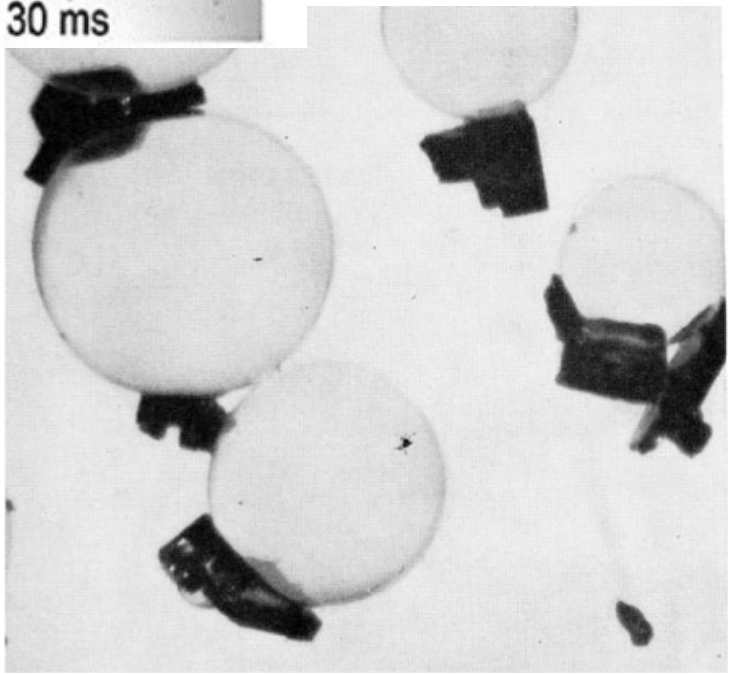
Note: Modified mining and milling processes will change the character the tailings.

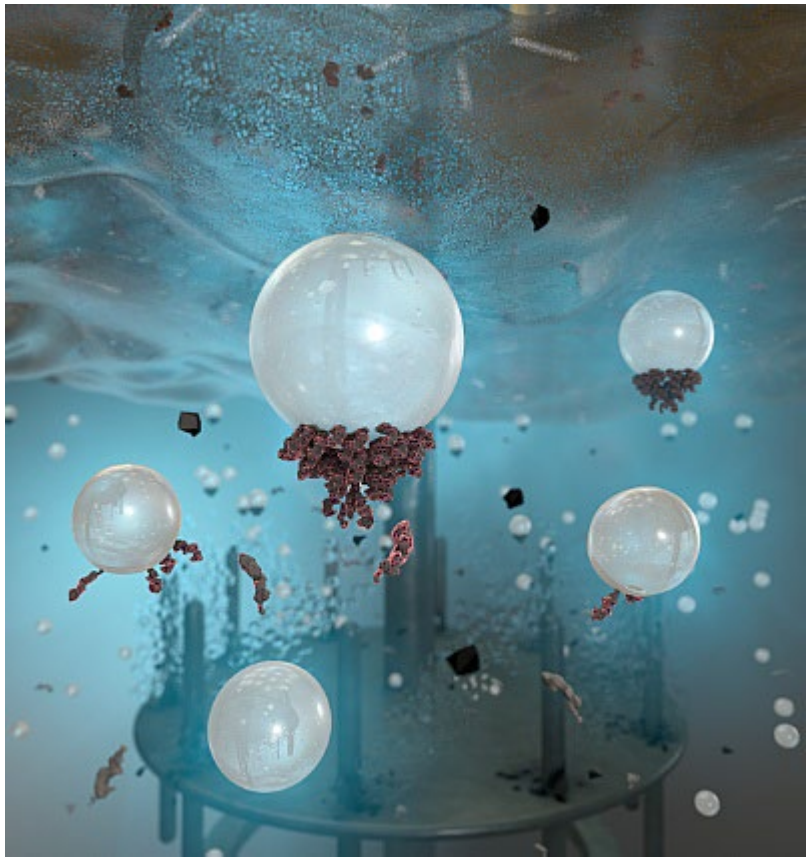
Coarser tailings are easier to manage, but – there's an effect of particle size on flotation recovery for sulfide minerals.

Flotation recovery depends on bubble size and particle size (nanobubbles)



S. Janishar Anzoom et al. 2024



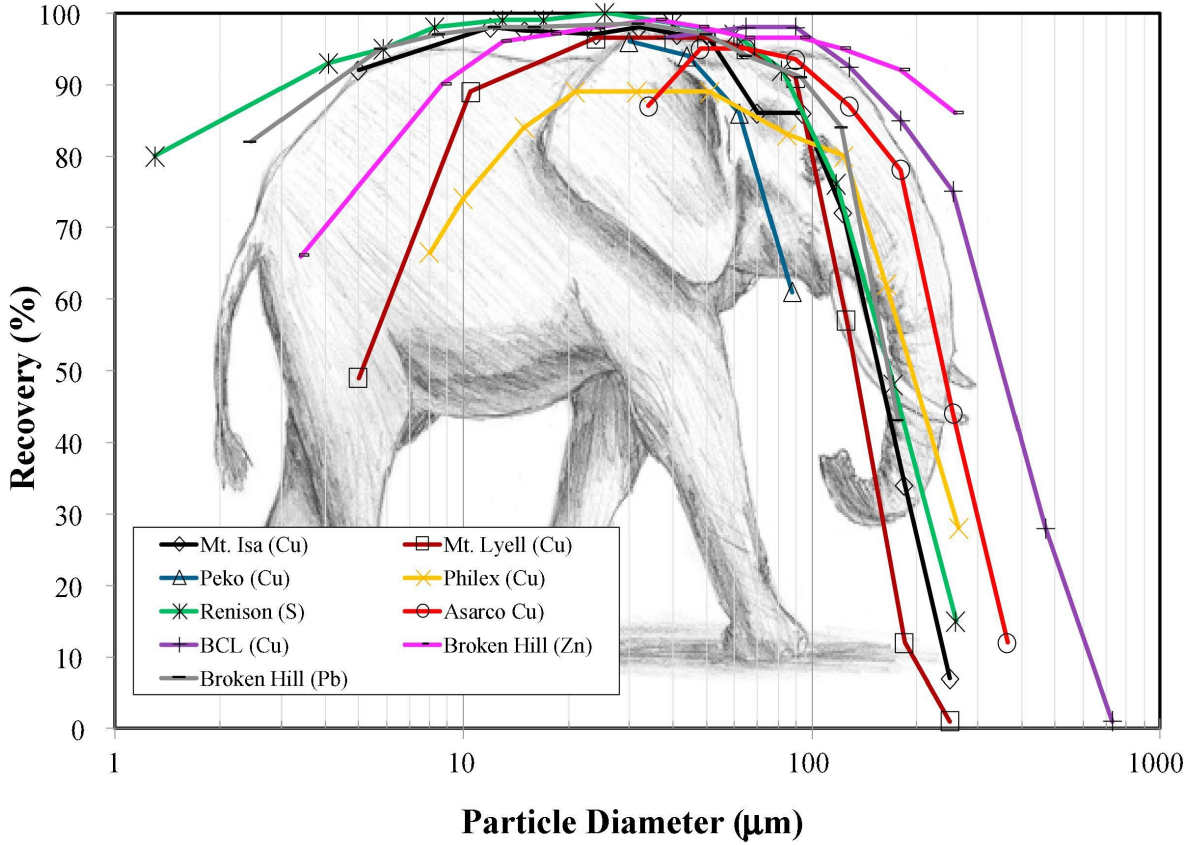


Flotation recovery also depends on the water quality (ions present) and temperature

K.C. Corin et al. 2024

The “Elephant Diagram”

Small particles – poor bubble collision



Kohmuench et al., 2018

Coarse particles - turbulence

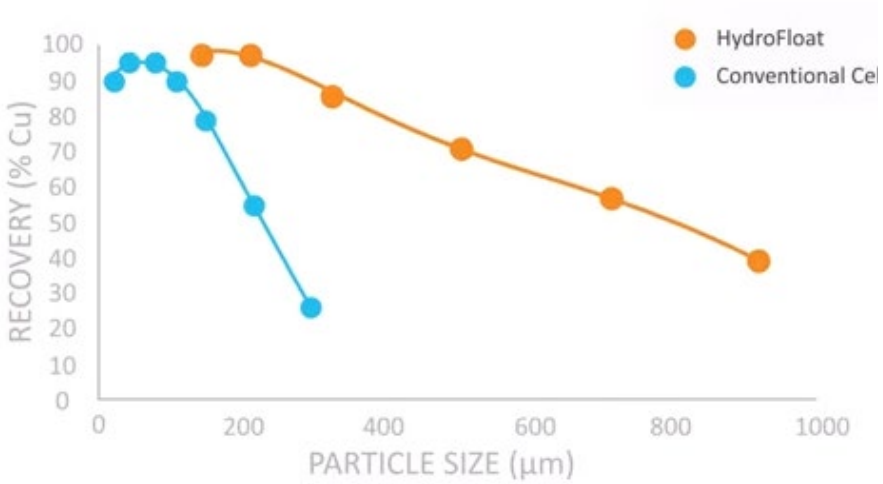
Example: 50 % of the copper lost in tailings occurs at particle size < 20 µm, while around 30 –40 % is lost in tailings at particle size > 150 µm

Hassanzadeh et al., 2022

Coarse Flotation

Eriez HydroFloat

Recovers particles more than 2 times coarser than conventional flotation cells



85% increase in water recovery

10% to 20% decrease in energy consumption

Facilitates dewatering and disposal of dry tailings

10% to 35% increase in processing capacity

2% to 6% increase in global recovery

https://www.eriez.com/NA/EN/Flotation/HydroFloat-Flotation.htm

Part 6: Co-production and Remining (recover metals from tailings and impacted water)

- Recovery from secondary circuits in current operations
- Remining and recovery from company-owned mine waste and tailings
- Remining and recovery from legacy or abandoned mine waste and tailings
- Recovery from entrained and seepage water

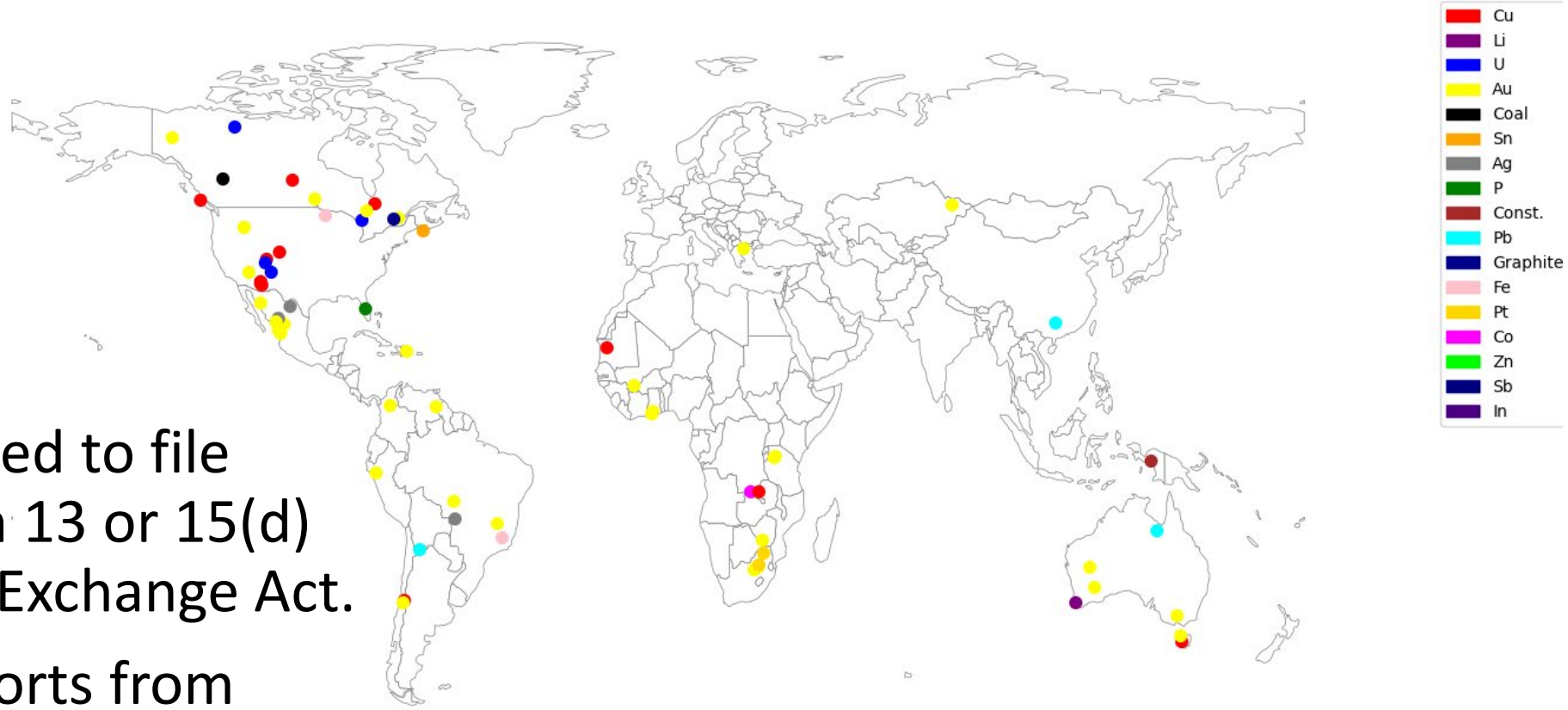
Remining

Generally, won’t result in a significant reduction of tailings volumes, but can generate reputational, social license and environmental and permitting benefits.

However, most legacy tailings facilities lack proper characterization, which increases safety risks, particularly related to instability and liquefaction.

Without sufficient data, companies face difficulties in safely and economically re-mining these deposits. Environmental risks and the responsibility to manage leftover tailings further complicate permitting and reprocessing efforts.

Status of Remining



Companies are required to file reports under Section 13 or 15(d) of the U.S. Securities Exchange Act.

A search of these reports from 2002-2023 identified only 21 sites that had actually reprocessed, and most were processed by the operator.

Locations and commodity type for sites where tailings reprocessing has been conducted or considered based on SEC filings

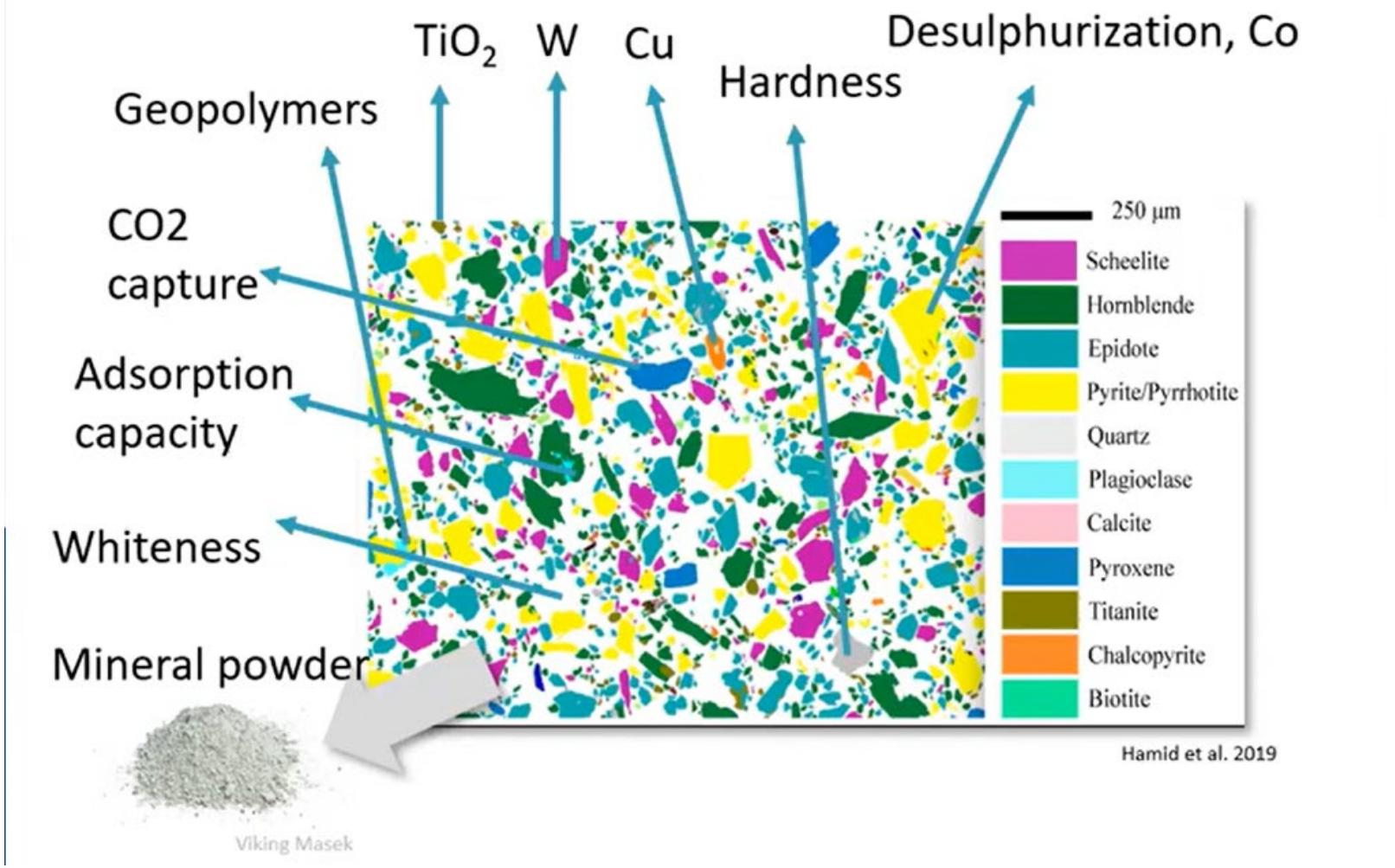
Is the US ready for Remining?

Tailings reprocessing projects need to win the confidence of communities, investors, regulators, and qualified persons responsible for resource reporting.

- 300 MMSA QPs were surveyed and only 2 had ever signed off on a report dealing with metals production from tailings.
- Few of the world's largest mining companies have evaluated the reprocessing potential of their tailings.
- Our data indicate that the mining sector does not have near-term capacity for broad implementation of tailings reprocessing.
- Few potential remining sites have adequate depositional records. Even if a sufficient sampling and analytical program were conducted, there is no established protocol for geostatistical evaluation of tailings as a resource.

Part 7: New Materials from Tailings

Zero waste – find uses for all minerals/grains in the waste



Modify tailings to be utilized in high-value products, e.g.,:

- Sand (fine aggregates)
- Cementitious materials to replace cement
- Geopolymers
- Ceramics and foam products
- Glass and fibers
- Nanoparticles

The world is running out of sand!

Vale

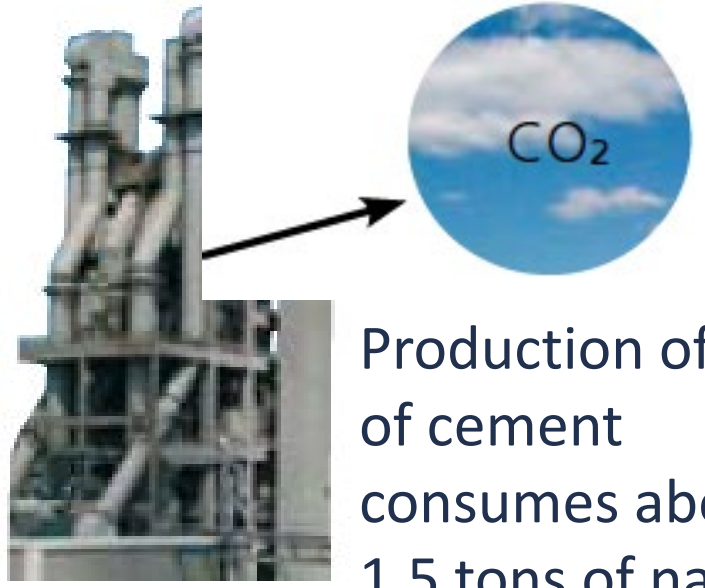
4/12/22 • Innovation

Sand produced by Vale is a solution to sand sustainability and mine tailings reduction, according to universities

A report by the University of Queensland and the University of Geneva also indicates that sand from iron ore production can reduce carbon emissions

Tailings as Substitutes for Cement in Concrete

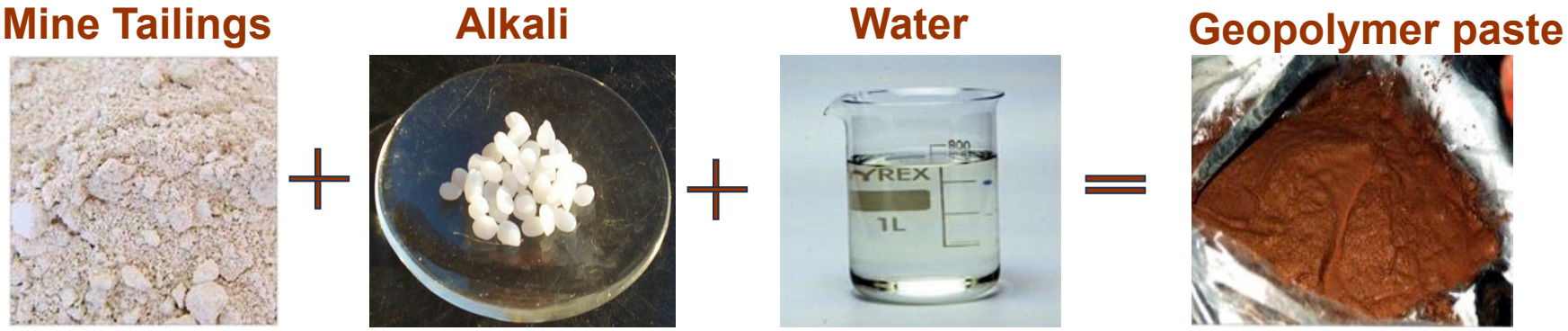
- Concrete is the 2nd-most consumed substance on Earth (after water). The annual use rate of concrete is expected to rise to >15 tonnes/person/year by 2050 (little recycling).
- Many tailings types may be substituted for cement, reducing global emissions of CO_2.



Production of 1 ton of cement consumes about 1.5 tons of natural materials and releases 1 ton of CO_2 to the atmosphere

“Geopolymers“

Alkali activation transforms aluminosilicate materials



Make construction materials (transport costs may limit market)

Geofoam

Insulation

- Low thermal conductivity
- Low Density (0.32 g/cm^3 vs 2.4 for concrete)
- Molded/Sprayed/3D printed
- Immobilization of heavy metals (maybe)

Ceramics and Glass - If you can melt sand for fiberglass, you can melt rock (and tailings)!

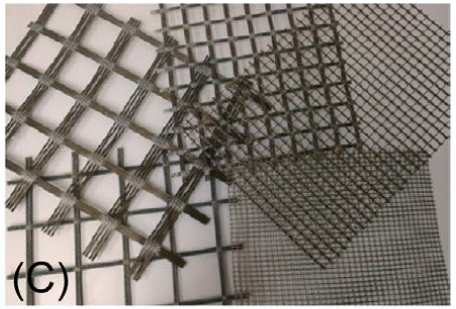
Explosive Eruption of Mafic lava (Basalt) on Kilauea in Hawaii

Basalt-based fiber products (buy on eBay)

NO CORROSION

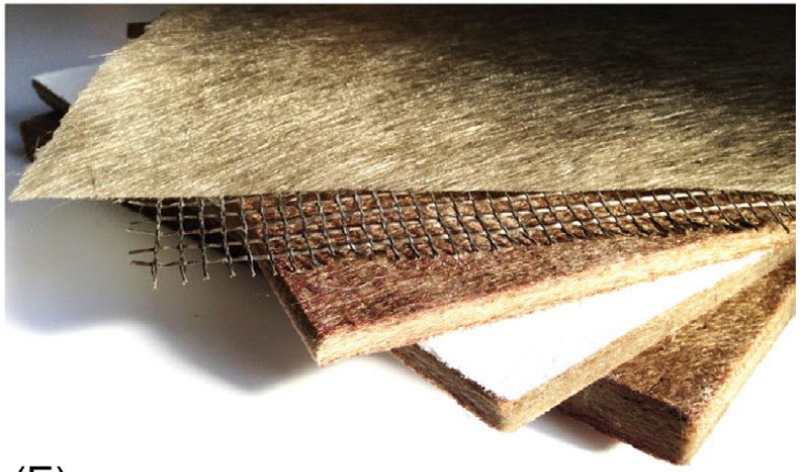
(A) Chopped fibers

(B) Continuous Fiber (Roving)



(D) Grids

(D) Rebars


(E)

(E) insulating panels and netting

Let’s melt tailings! – maybe concentrated solar at the mine site

Nanoparticles (NPs) from Tailings

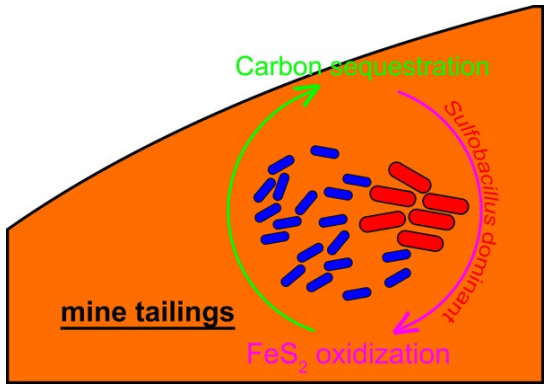
"Nanomining" and "Bionanomining" techniques have been used to produce copper or other metal nanoparticles from mine waste.

BUT - the components of tailings are complex, and the mineral characteristics of tailings vary greatly for different geologies, ores and processing.

We need to establish a tailings resource database with comprehensive data for different tailings. This means sharing data. If we do this, we can identify optimal schemes to produce industry-useful nanoparticles from different tailings resources.

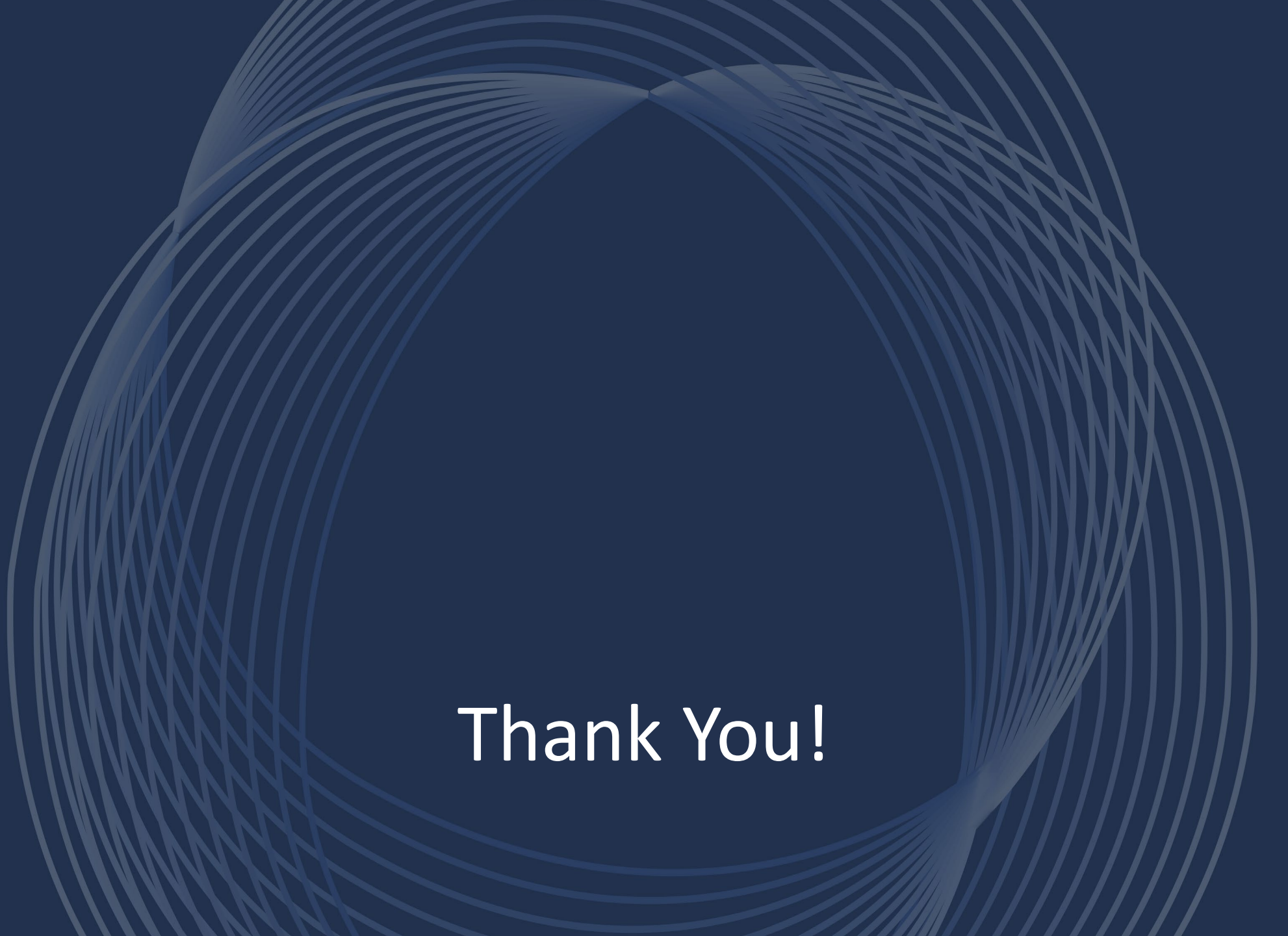
Part 8: Environmental Management

- Nanoparticles (NPs) in Acid Mine Drainage (AMD) treatment
- Tailings and Carbon Sequestration: The process of capture and long-term storage of atmospheric carbon dioxide by mineral carbonation.



Summary – Zero Waste and Zero Harm

- We cannot just consider tailings as waste – they must be considered as a resource.
- New mine operations will not be permitted without including explicit and equitable incorporation of ESG and SDG benefits, and the goals of ZERO WASTE and ZERO HARM will increasingly be expected for any successful mining proposal.


Thank You!