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METALS

Bioextraction as a method for processing polymetallic nodules – an economic and environmental game changer



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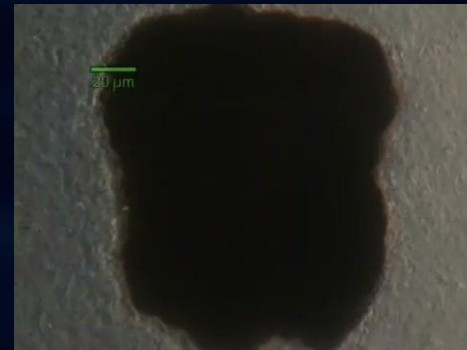
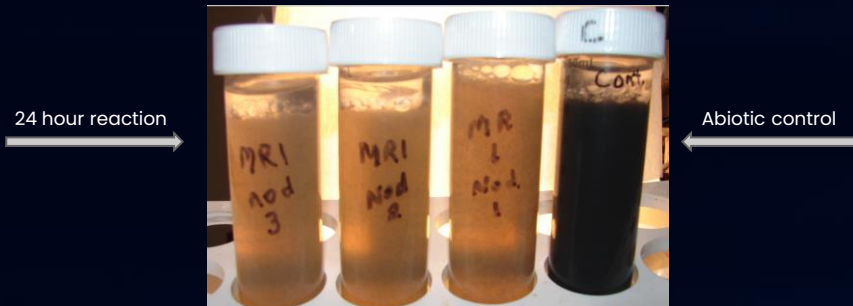
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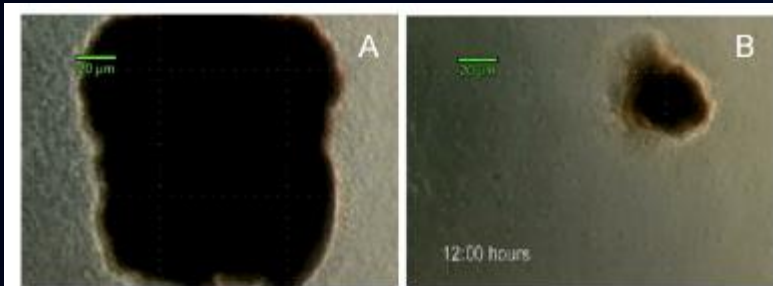
Bio-Extraction Summary

- Naturally occurring process of bacterial respiration (**not** leaching)
- Discovered by Co-Founder Prof. Ken Nealson, patent pending
- Bacterial respiration liberates metals, yielding slurry of soluble $MnCl_2$, $FeCl_2$, and chloride salts of nickel, copper and manganese
- Operating parameters - room temperature, neutral pH, fresh/saltwater
- Bacterial substrate/food source= organic carbon (e.g. food waste)
- Lab testing indicates high efficacy on polymetallic nodules (unweathered)



Bacteria

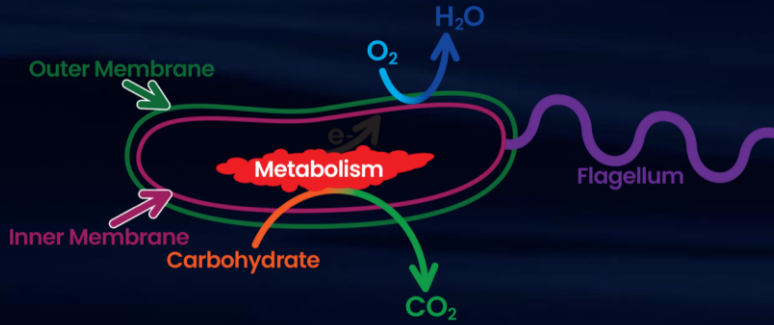
- Motile – minimal mixing required Identified strains capable of operating in low and high temperatures, salt and freshwater
- Identified strains that have a metabolic preference for iron or manganese oxides
- Adding a single organic substrate (food source), the bacteria are able to dissolve the nodules completely, yielding a solution of soluble chlorides and chloride salts (we do see a very small volume of solids left behind at present)



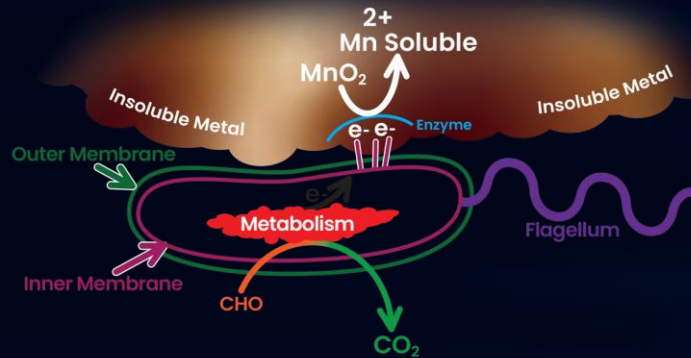
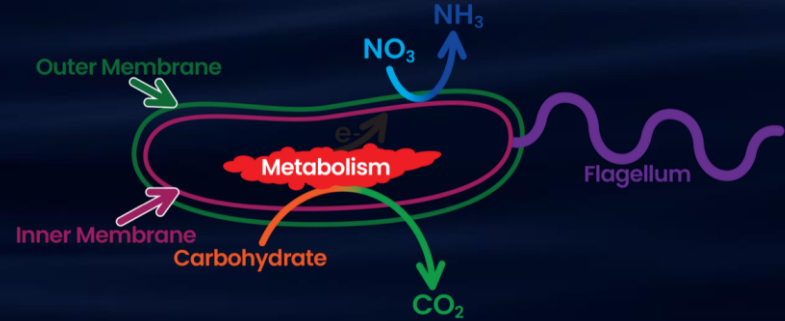
Manganese oxide reduction by *Shewanella oneidensis* MR-1. (A) Image taken at 0 hours. (B) Image taken at 12 hours.

Bacteria Respiration

Aerobic Respiration



Anaerobic Respiration

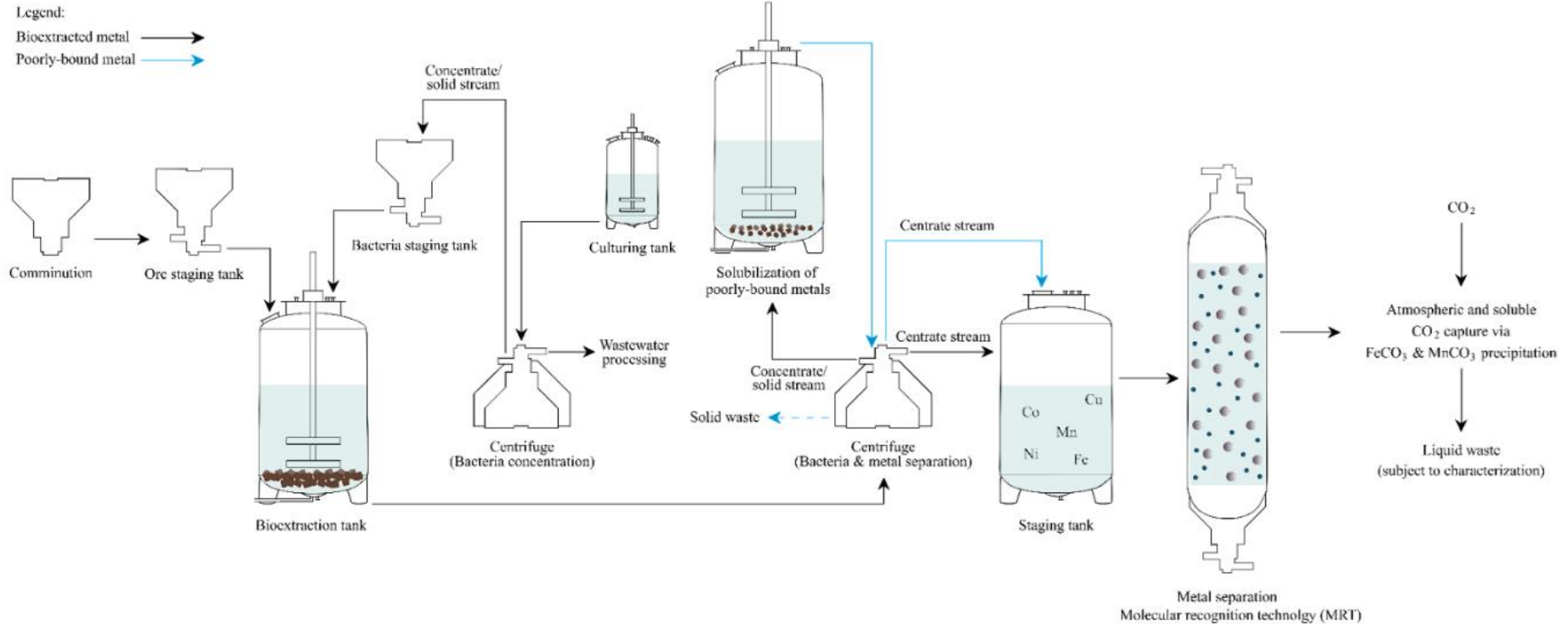


Metal Respiration

Benefits of Bio-Extraction

- No tailings
 - No use of toxic chemicals or highly concentrated acids
 - Neutral pH wastewater, suspended sediment will depend on clay content etc. – may require flocculation prior to release (low volume solid waste stream)
- Expect significantly lower CAPEX and OPEX than traditional processing
 - Higher NPV
 - Lower environmental risks and impacts
- Low energy requirements (can achieve carbon neutrality)
 - Target end users like Volkswagen (~43% of EV CO₂ burden is battery)
 - Ability to target EU Green Taxonomy funding due to low impacts – may be first mining company to achieve this

Concept Flowsheet - Bioextraction



Initial Bench-Top Findings

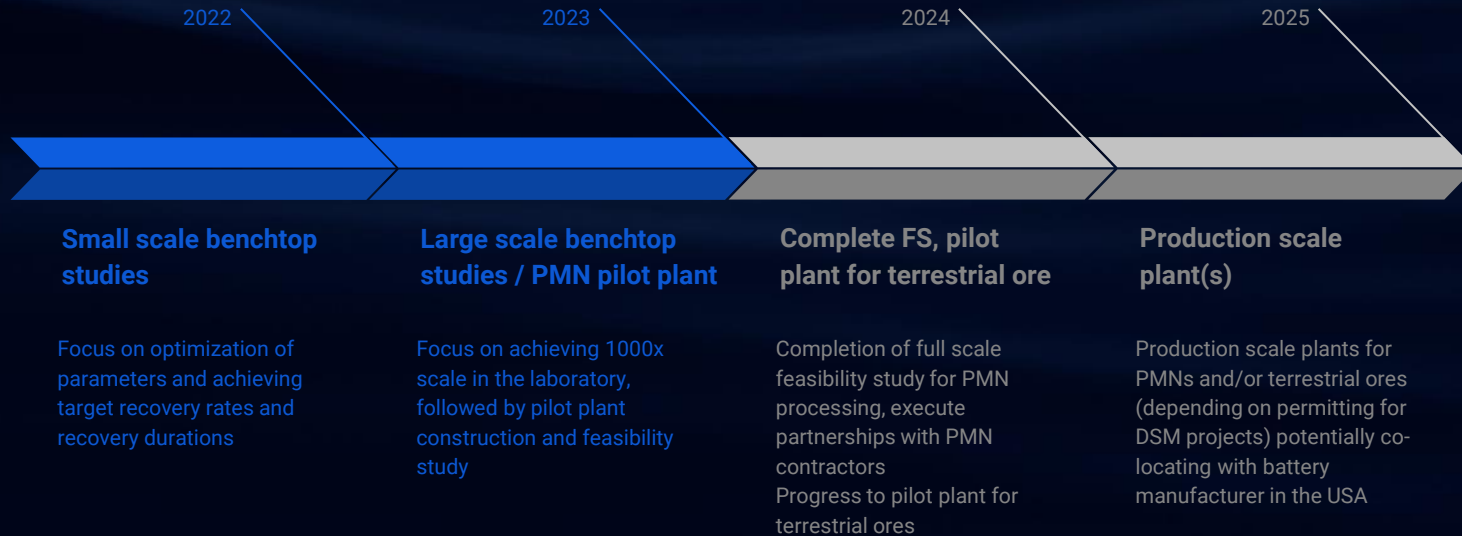
- Preliminary data on different manganese (Mn) and iron (Fe) oxides show excellent yields in short periods (multiple published studies)¹ in both fresh/sea water
- Early results show recovery approaching that of other options (e.g. Cuprion method), with concurrent solubilization of all metals.
- Findings are driving optimization on:
 - Carbon source
 - Bacterial strains
 - Combination of strains
- Adaptive evolution studies are ongoing and will take advantage of other optimization

1. e.g. <https://pubs.acs.org/doi/pdf/10.1021/es00010a012>

Concept Economic Implications

- Lower capex on processing infrastructure (no heat, no pressure, no reagents)
- ~50% energy use compared to traditional processing
- Comparable recovery rates with Cuprion method (simultaneous dissolution of multiple metals)
- No tailings – significantly reduced CAPEX and OPEX
- No terrestrial rehabilitation cost liability

Bringing Bioextraction to Market



Summary

- Significantly higher ESG performance
 - waste, energy, water, emissions, social license
- Lower CAPEX and OPEX than traditional processing
- Pathway to market ~2024 (multiple plant locations, potentially co-located with battery production)
- We are starting to work with partners, and happy to share more information under NDA

