ECOMINE: A BIOREGENERATIVE ISRU PLATFORM FOR LUNAR MINERAL EXTRACTION.

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Lunar In-situ Resource Utilization

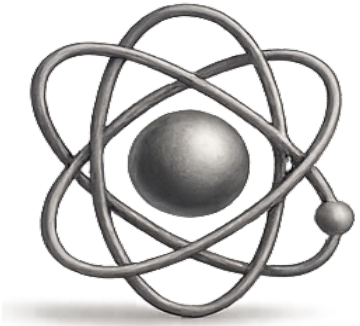
Why ISRU?

Reduce Earth Dependence

Build with Lunar Resources

Ti, Al, Fe, Si, REE

Produce fuel in Space



Provide Life Support

Metal extraction on Earth

Mining: the process of extracting valuable minerals and metals from the Earth's crust or rock (ore).

PYROMETALLURGY

- 600 - 1600 °C
- High energy
- Toxic emissions
- Mins to hours

HYDROMETALLURGY

- Ambient - 250 °C
- Chemical intensive
- Liquid toxic waste
- Hours to days

Mine waste spill at Animas River near Durango, CO

Jerry Mcbride—ZUMAPRESS.com

Require high temperatures, large quantities of chemicals, high-temperature processing infrastructure, and significant energy inputs.

Proposed methods for the Moon

MOLTEN REGOLITH ELECTROLYSIS

- 1300 - 1600 °C
- High energy
- Mins to hours

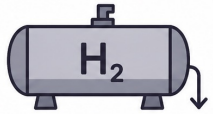
MAGMA ELECTROLYSIS

- 1300 - 1600 °C
- High energy
- Flux additives
- Mins to hours

MOLTEN SALT ELECTROLYSIS

- 850 - 950°C
- Medium energy
- Molten $CaCl_2$ bath
- Hours to days

HYDROGEN REDUCTION



- 700 - 1000 °C
- Medium energy
- Fe-rich regolith
- Hours to a day

CARBOTHERMAL REDUCTION

- 1200 - 1600°C
- High energy
- C source required
- Hours

PYROLYSIS

- 800 - 1500°C
- High energy
- Comp. & Pressure dependent
- Mins to hours

Fast kinetics ✓

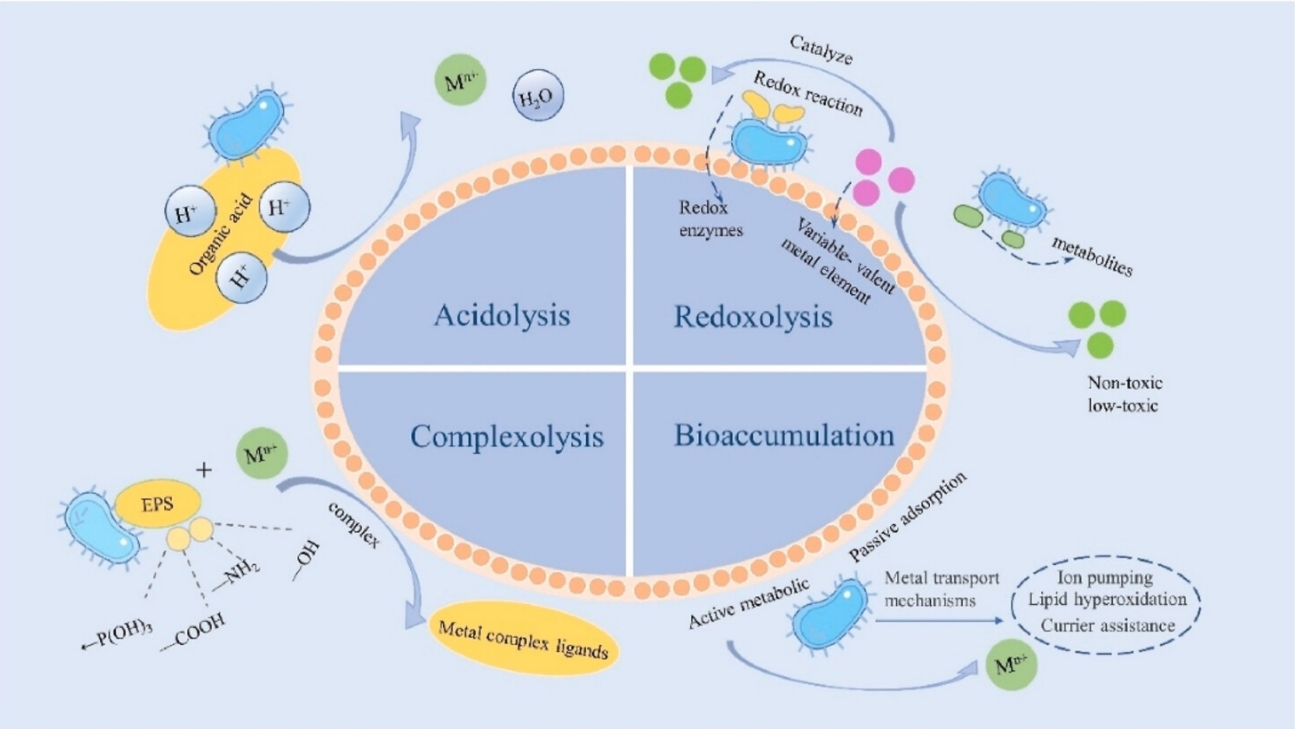
Energy-intensive
High-temp infrastructure
Complex recycling ✗

Schwandt et al., 2012; Taylor et al.,1993; Schneiderman et al., 2025; Chen et al., 2000; Guerrero-Gonzalez et al., 2026; Dottori et al., 2025; Troisiet al., 2022; Shaw et al., 2021; Senior, 1991.

Biomining

Uses microorganisms, such as bacteria or fungi, to break down minerals from ore, sediment, and even anthropogenic waste (like electronic components).

Mechanisms



Dong et al., 2023

Benefits

- Lower energy required
- No toxic chemicals
- Lower risk of pollution
- More cost effective (low grade ore)
- More efficient (low grade ore)

Disadvantages

- Slower (weeks to months)
- Maintenance & sensitivity of living organisms

Biomining on the Moon

Regolith is dominated by rock-forming oxides (SiO_2, Al_2O_3, FeO, TiO_2, MgO, and CaO), with feldspathic highland soils exhibiting Al-rich, Fe-poor compositions relative to Fe–Ti-enriched mare basalts.

Chemolithotrophs

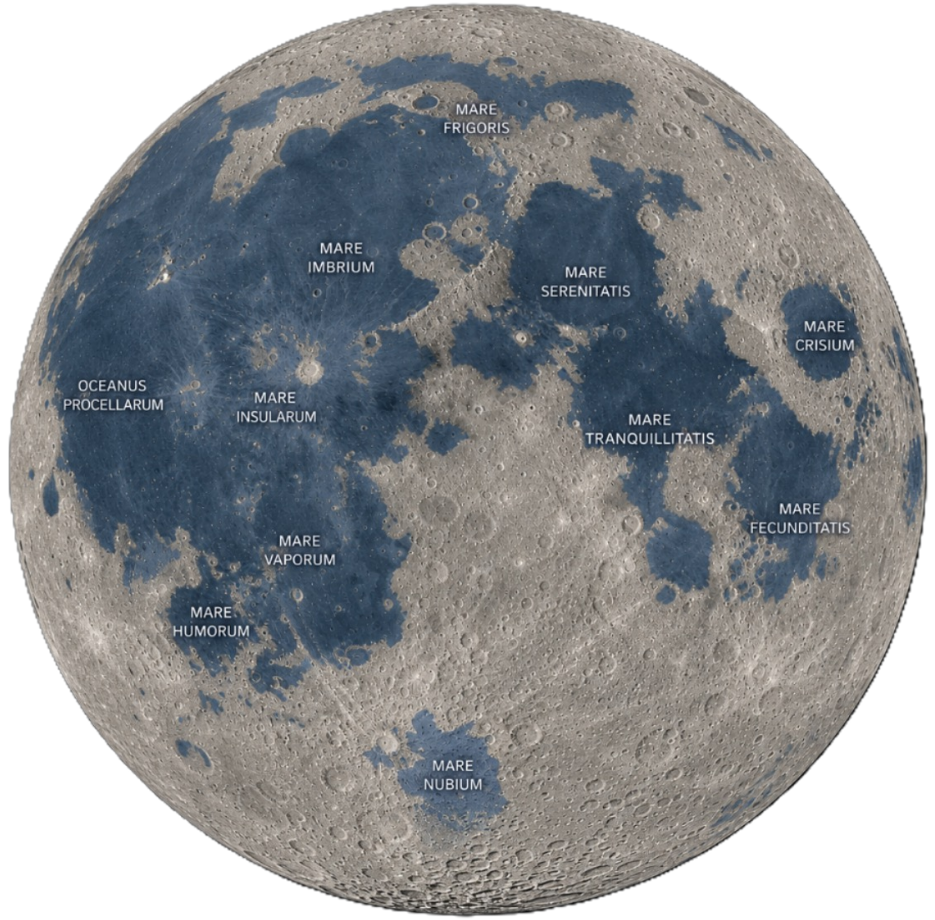
Need:
Fe^{2+} / H_2S
CO_2
O_2

Redoxolysis (Fe^{2+}/Fe^{3+}, sulfur oxidation)

Heterotrophs

Need:
Sugars
O_2

Acidolysis and Complexolysis



Mare (Basaltic plains)

Highlands (Anorthositic terrains)

Image AI generated for illustrative purposes only

Nkuna et al., 2022 & Vera et al., 2022.

EcoMine

A biomining platform that extracts minerals from lunar regolith using a closed-loop biological system that regenerates its own consumables. Designed for use on the Moon and other planetary bodies, including Earth.

Highlights

- Autonomous
- Self-powered
- Optionally mobile
- Closed-loop biomining process
- Heterotrophic, aerobic, radiation-resistant leaching organisms
- High sugar-producing photoautotrophic organisms
- Regeneration of consumables reducing structure volume and cost (H_2O, CO_2, O_2)

Credit: Neil Rowe, Elantes

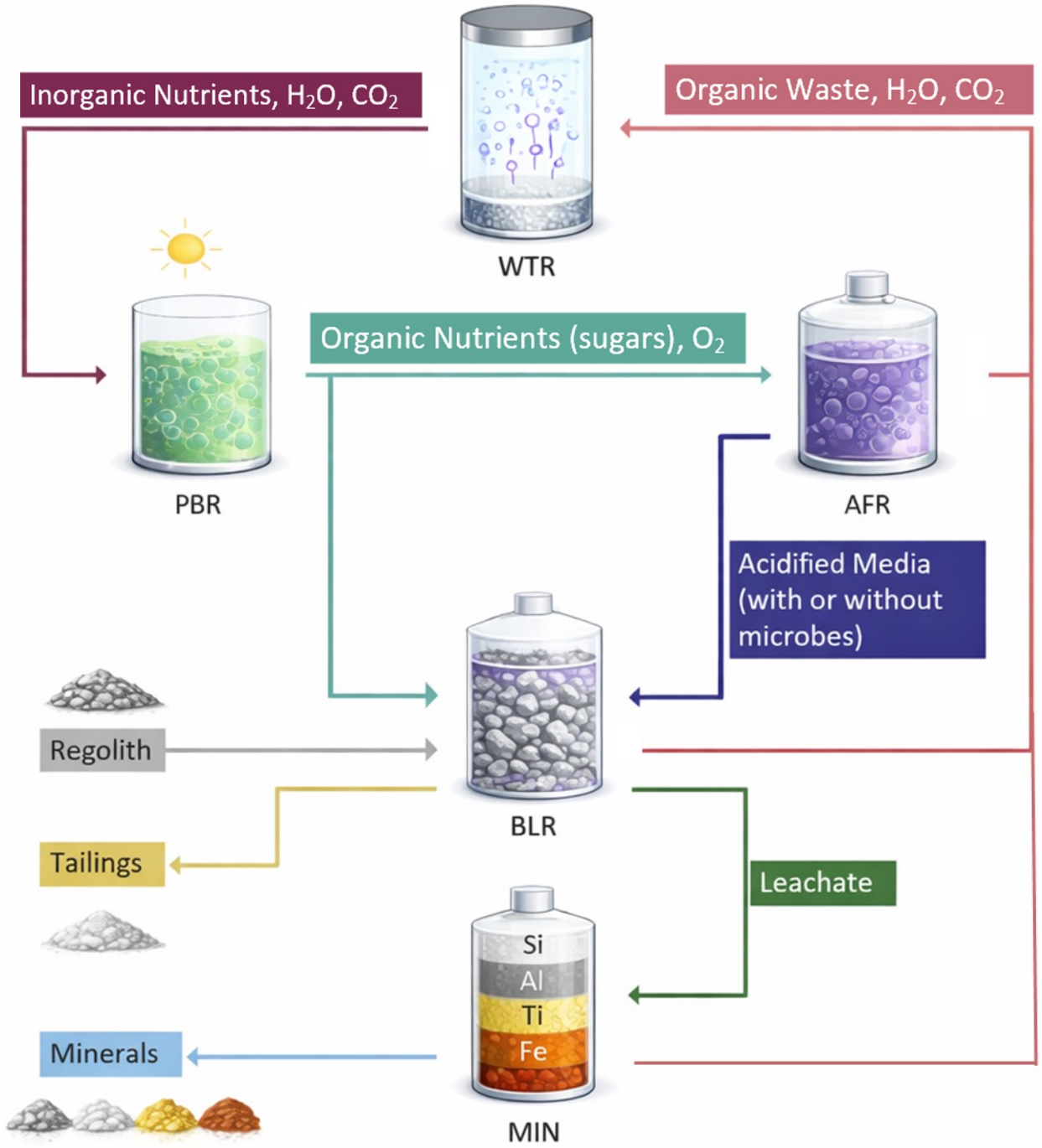
EcoMine

Bioregenerative Loop

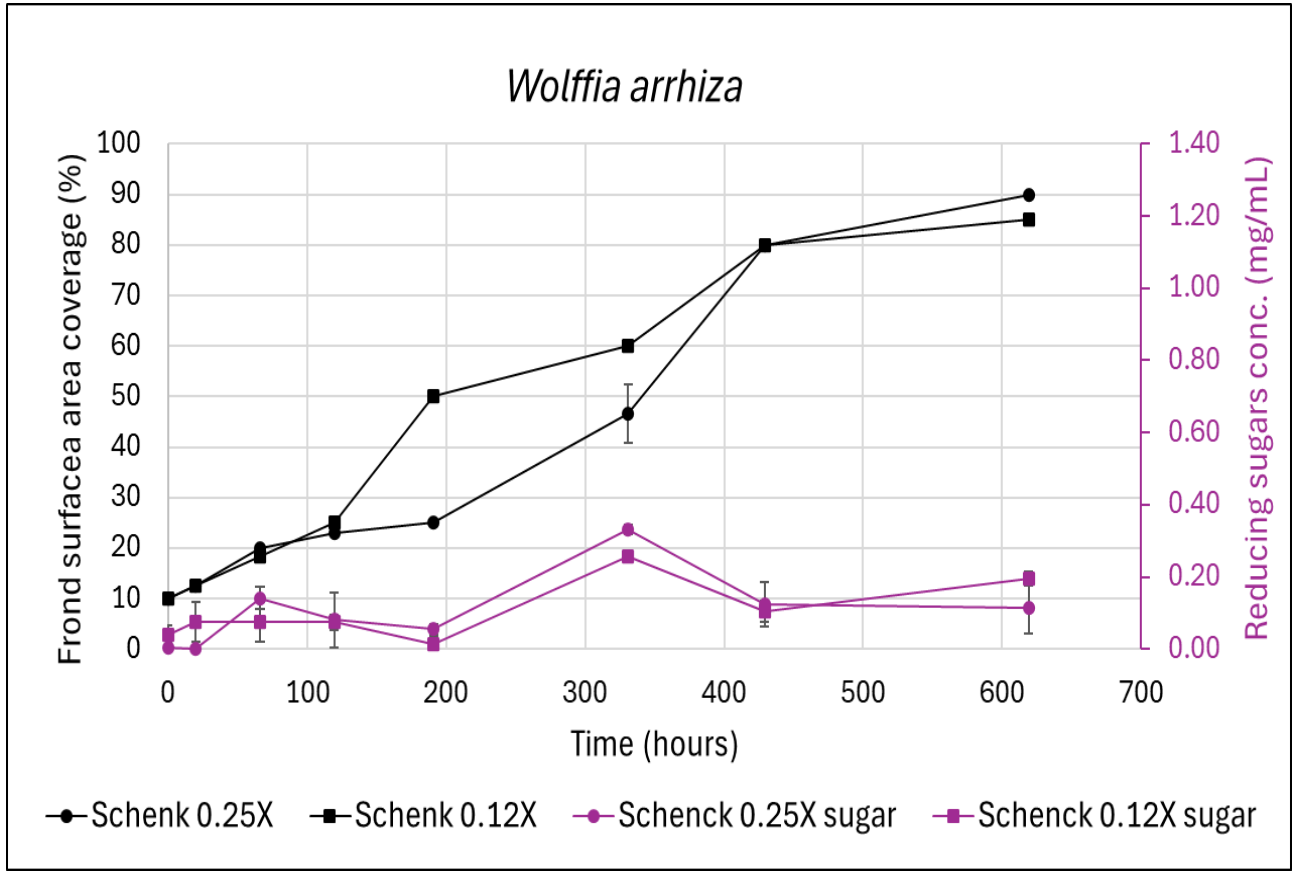
- *Photobioreactor* (PBR)
- *Aerobic Fermentation Reactor* (AFR)
- Waste Treatment Reactor (WTR)

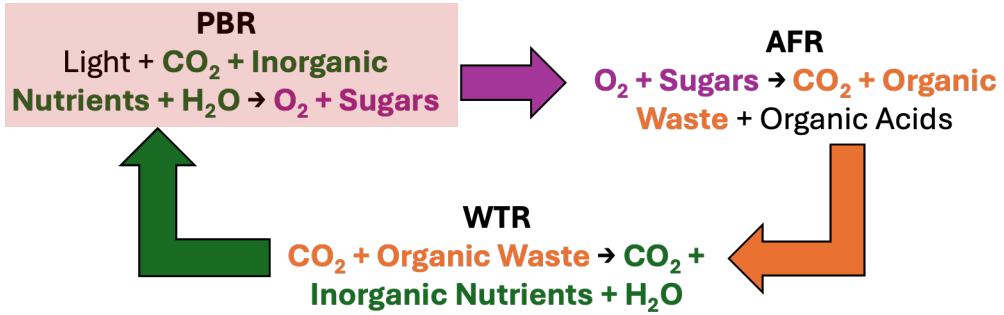
Mining

- *Bioleaching Reactor* (BLR)
- *Mineral Extraction & Recovery (MIN)*



Bioregenerative Loop



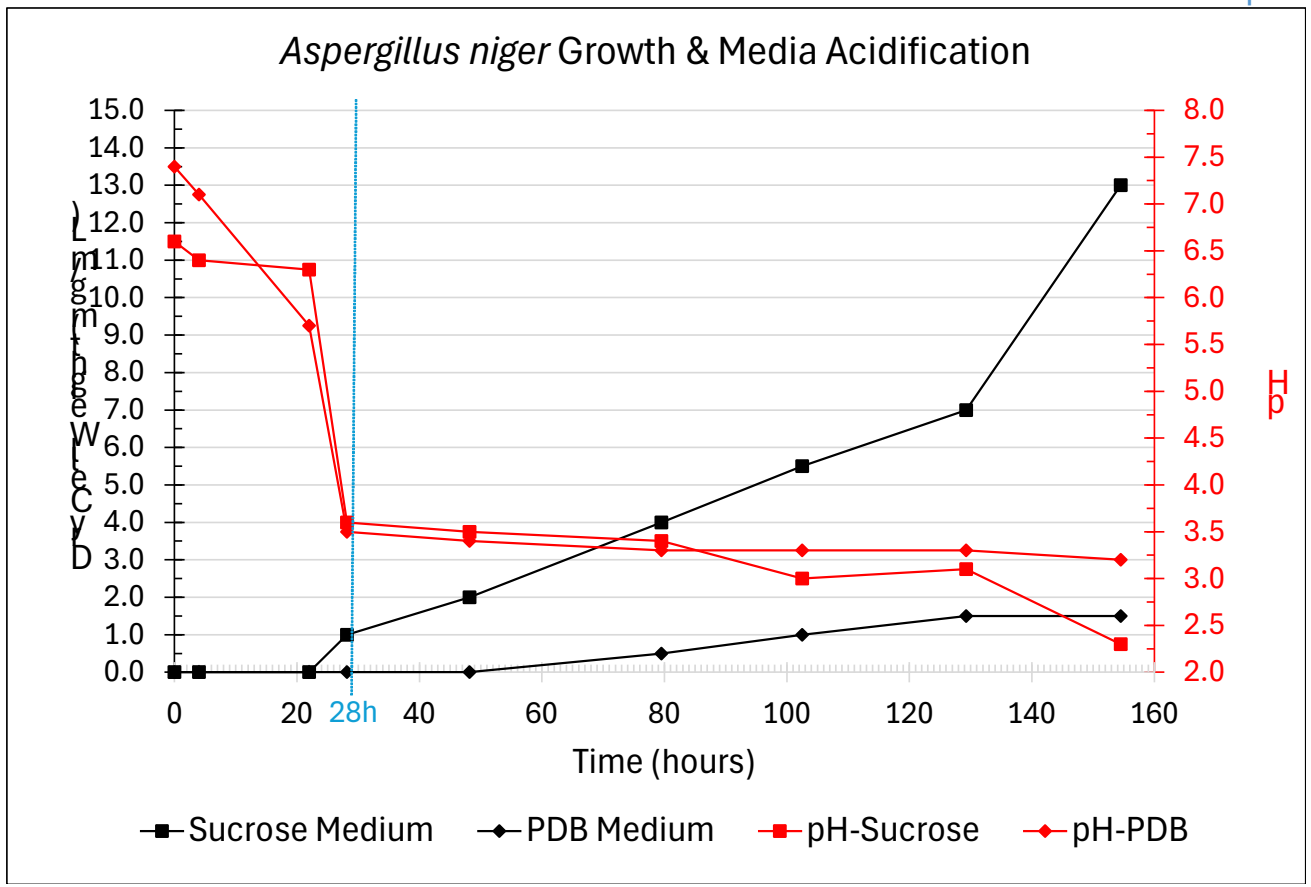


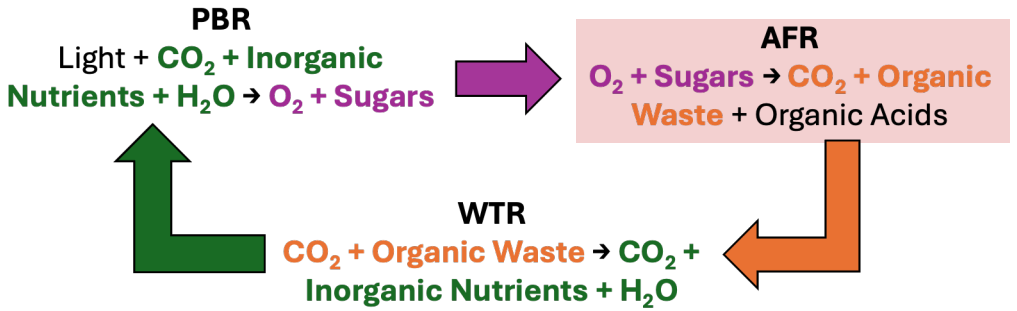
- Next: optimization of sugar production
  - ❑ CO_2 concentration
  - ❑ Media concentration
  - ❑ Light intensity
  - ❑ Photoperiod
  - ❑ Genetic Engineering

- Higher sugar concentration seems to correspond to a slower growth rate
- Diluted media does not negatively impact sugar production
- Currently low sugar production

Bioregenerative Loop

28.6±0.4°C & 110 rpm





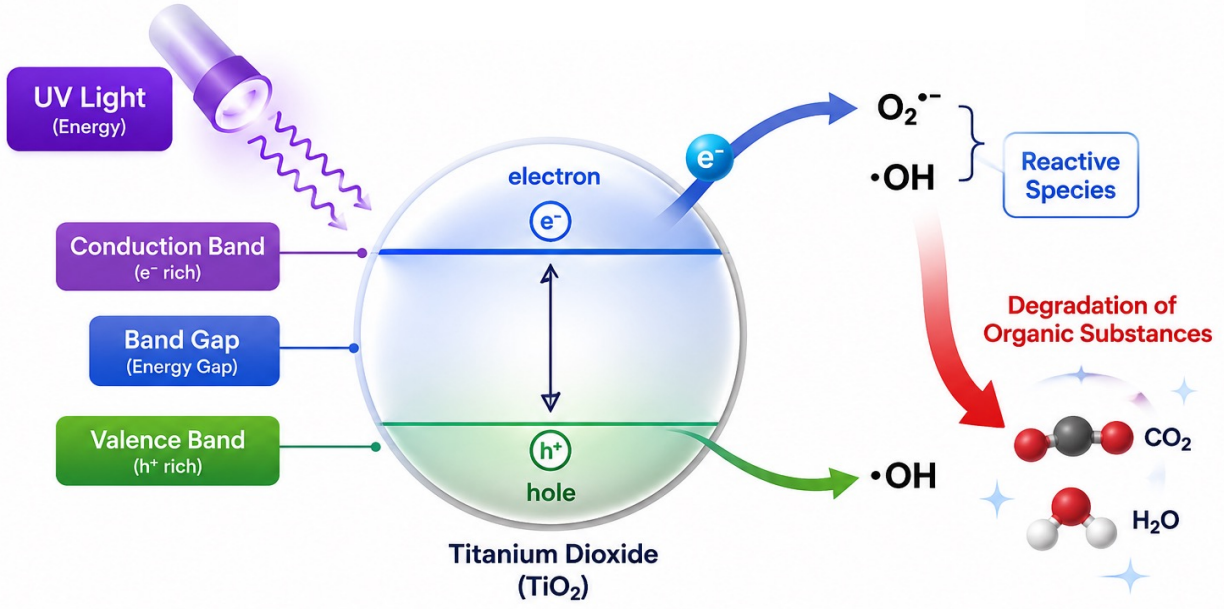
- PDB & sucrose medium were able to drop pH to similar levels
- Sucrose medium increased cell count

- Next: optimization of organic acid production
  - ❑ Media from PBR
  - ❑ Temperature
  - ❑ Scale up to Brassboard reactors

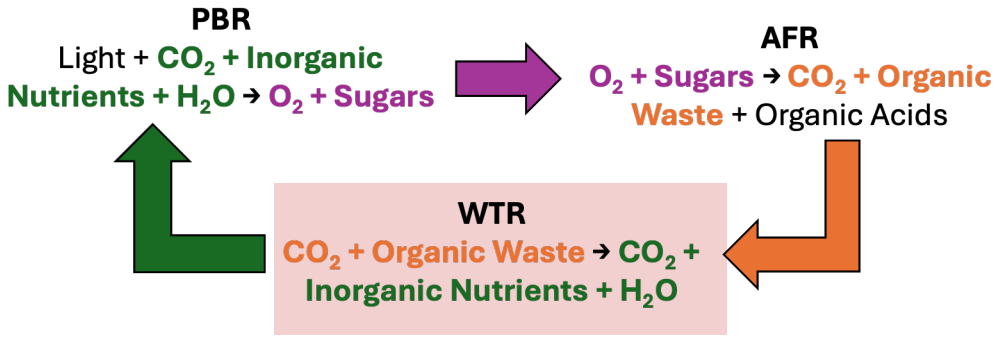
Bioregenerative Loop

TiO_2 Photocatalytic Oxidation

- TiO_2 illuminated by UV light generates ROS
- Complete mineralization of organics

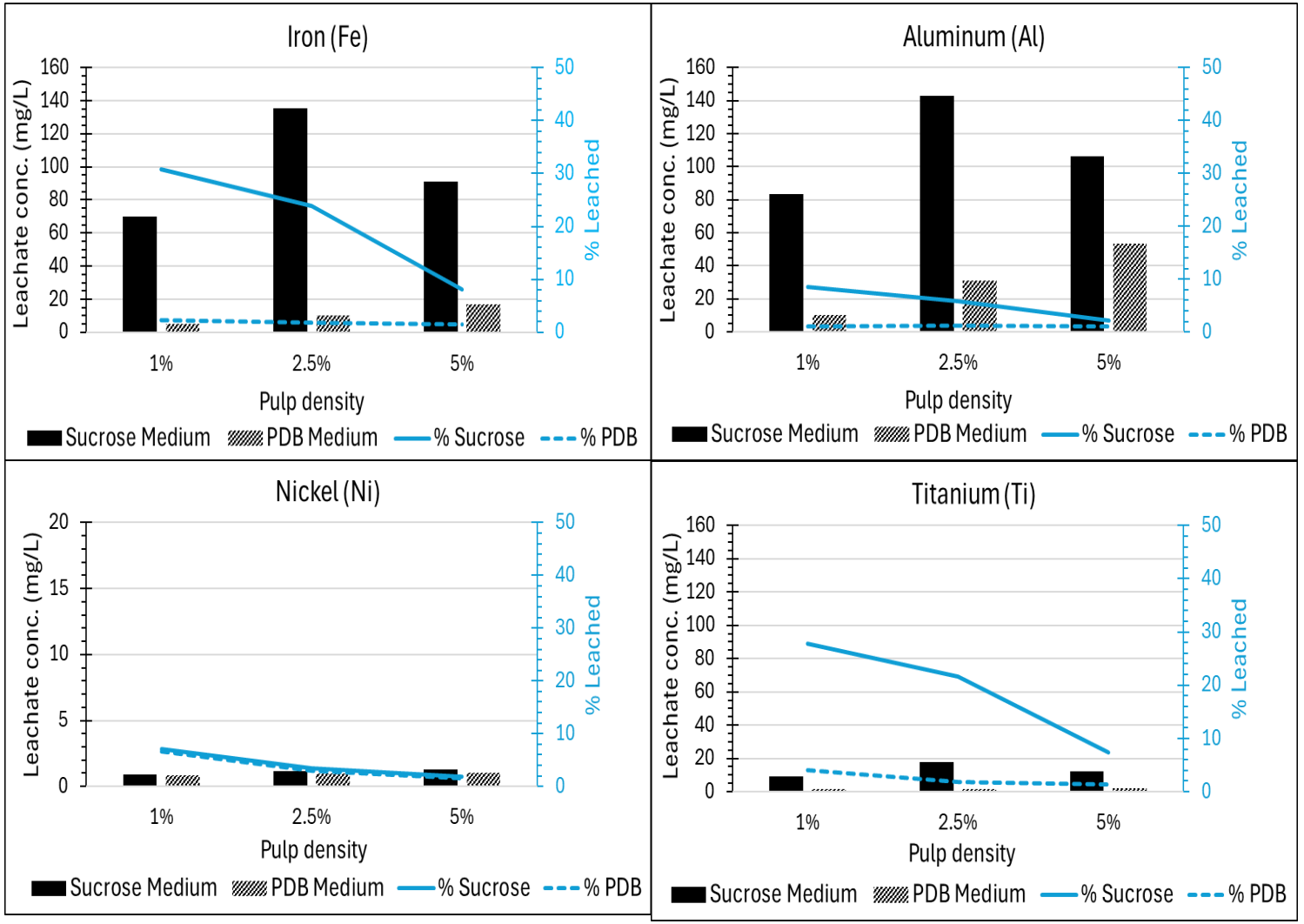


Adapted using AI from https://www.photokat.eu/en/tio2



- Regenerating:
  - ✓ Water
  - ✓ CO_2
  - ✓ Inorganic nutrients
- Next:
  - ❑ Brassboard testing

Bioleaching



- Efficiencies on sucrose medium were 1.25 to 13 times higher than on PDB (except for Ni)
- Most effective at leaching Fe>Ti>Al>Ni
- Leaching efficiency ↓ when pulp density ↑
- Next: optimization of leaching efficiencies
  - ❑ *A. niger* with optimized acid production
  - ❑ Leaching time
  - ❑ Other organisms

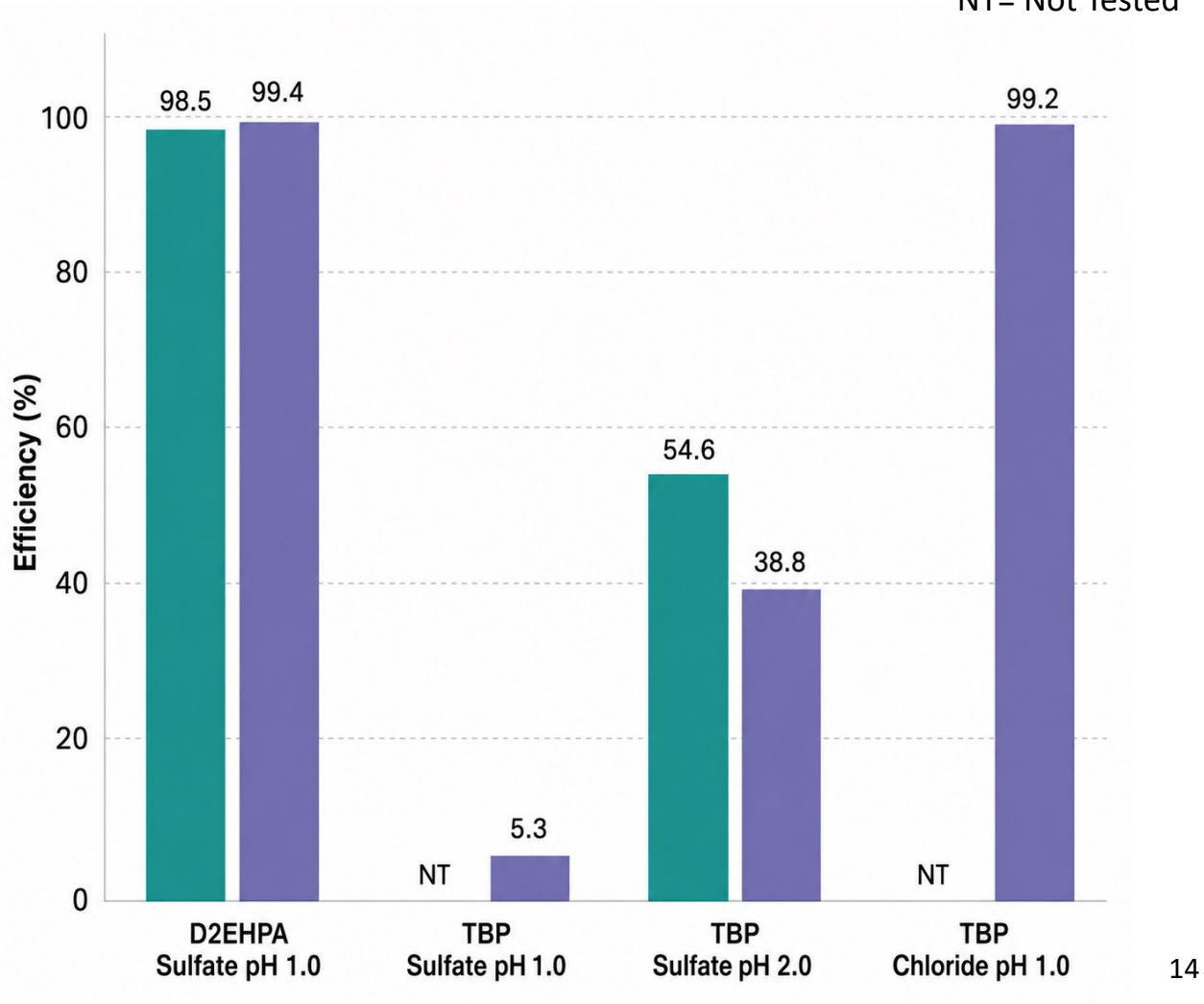
Mineral Extraction

Solvent Extraction

- ✓ High selectivity
- ✓ Moderate temperatures
- ✓ Modular process
- ✓ Scalable
- ✓ Organic phase can be regenerated by stripping

- D2EHPA achieved near-quantitative extraction from sulfate solutions.
- TBP showed low extraction in sulfate solutions but significantly improved in chloride solutions.

- Next: Extraction with bioleaching matrices
  - ❑ Citric acid
  - ❑ Gluconic acid
  - ❑ Oxalic acid



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Thank you!