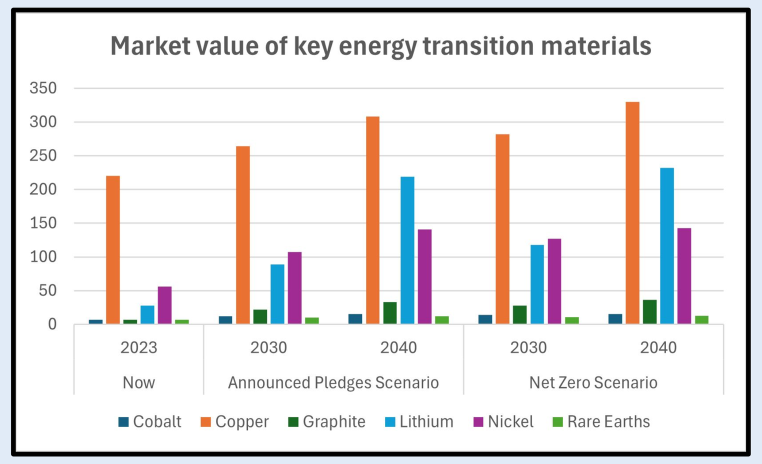
Sourcing critical elements from mine tailings: analyzing the impact of magnetic separation on critical element extraction

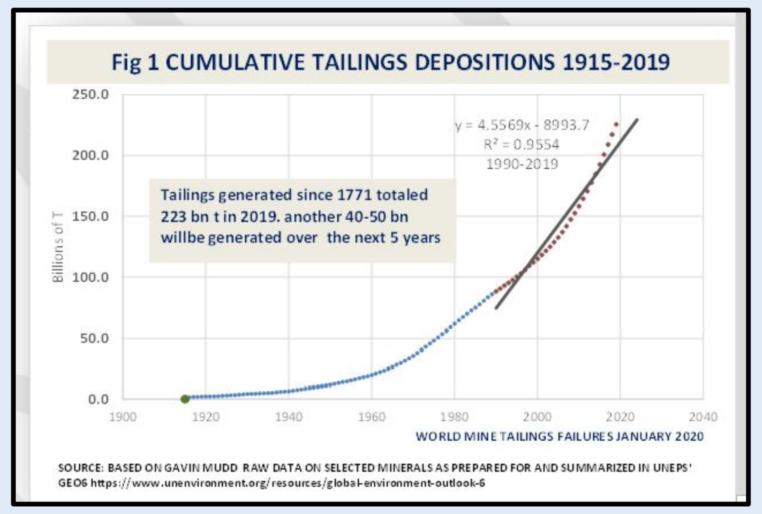
Rithika Ramkumar, Shelvey Swett, Katherine Vaz Gomes, Jennifer Wilcox

Introduction

To reach climate goals, new sources of critical minerals need to be found due to their importance in green energy technologies. **Critical mineral extraction** aims to solve this problem by separating elements of interest from natural feedstocks and industrial waste products. Furthermore, the process can be paired with carbon mineralization, a method to store carbon dioxide. Carbon mineralization reacts carbon dioxide gas with magnesium and calcium to make magnesium and calcium carbonates.



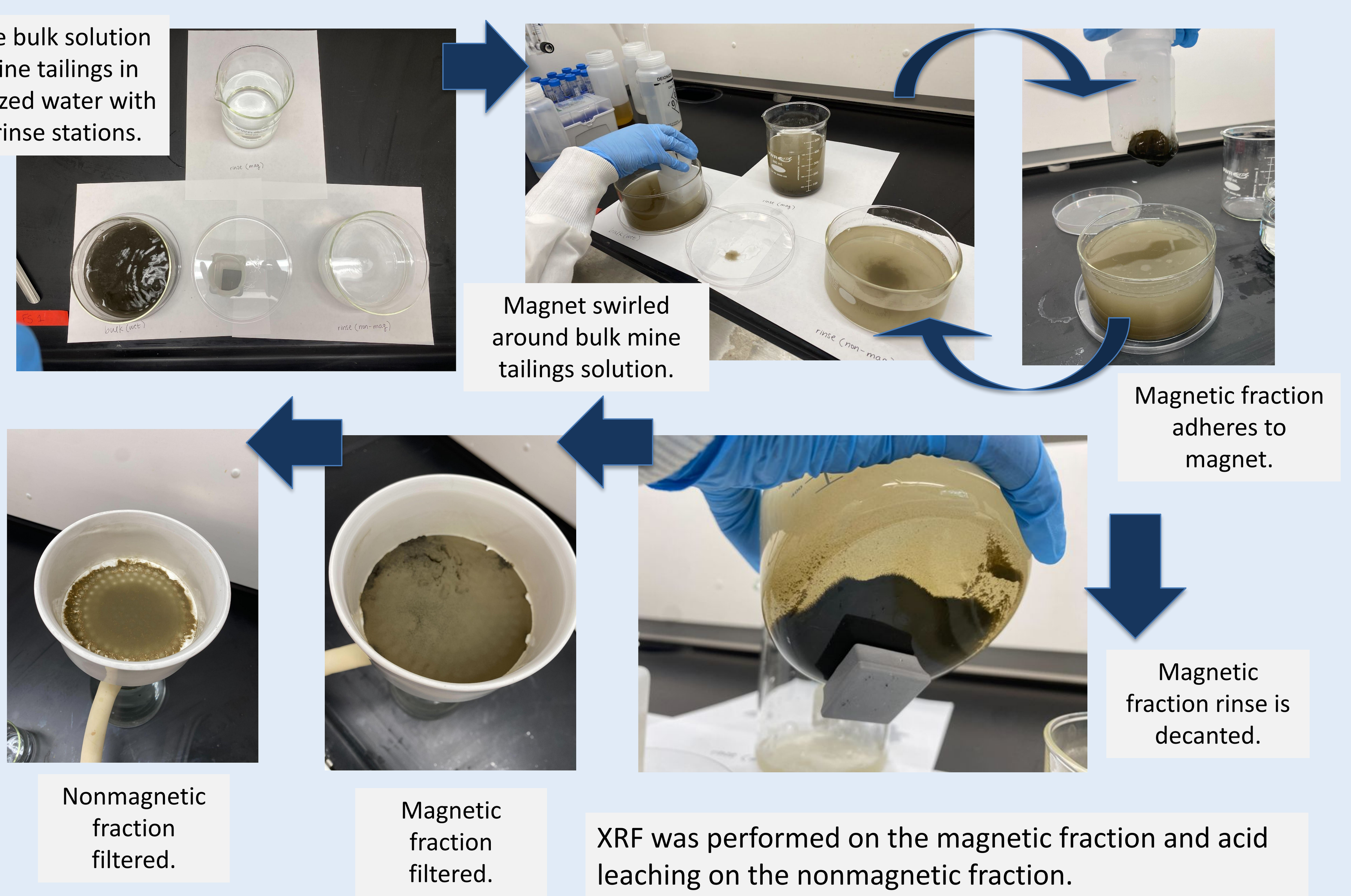
A possible source for both carbon mineralization and critical element extraction is mine tailings because certain tailings contain magnesium, calcium, and other valuable elements, such as rare earth elements (REEs). The increasing costs of key energy transition materials that can be extracted can make the mineralization process more cost-effective by producing valuable products. Additionally, mining contributes to 4-7% of global emissions worldwide; using mine tailings as feedstock of critical elements could help make the industry significantly more sustainable.



In our experiments, we used Stillwater mine tailings from the Stillwater mine in Montana. The typical critical element extraction process consists of two steps: acid leaching and precipitation. These steps require much acid and base, contributing to the overall emissions and cost of the process. This study proposed to add a pre-processing step of magnetic separation to remove iron. This course should reduce the amount of acid and base needed and improve extraction efficiencies for the elements of interest.

Our Question: Does including a magnetic separation step in critical element extraction from mining and industrial wastes improve extraction efficiency?

Magnetic Separation Method



Magnetic Separation Results

Magnetic Separation Yield

	Mass (g)	
	≤125 μm	≤63 μm
Mine tailings	32.00	18.51
Magnetic fraction	30.33	17.72
Nonmagnetic fraction	1.46	0.79

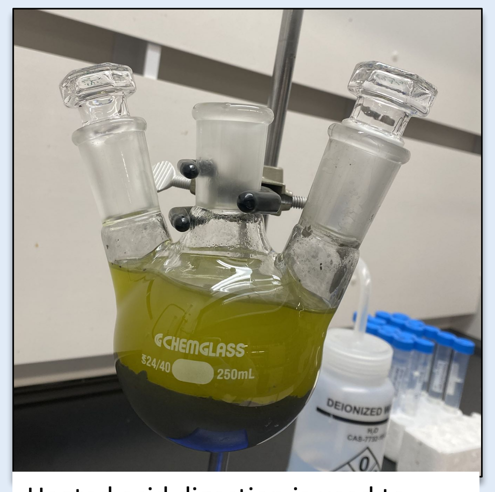
- Initial data suggested that Stillwater mine tailings were about 5% iron oxide
- However, 94% of the less than 125 μm tailings and 95.7% of the less than 63 μm tailings separated out as magnetic
- Hypothesized that iron was closely bound with other elements, so iron was not completely separated out of mine tailings

Magnetic Fraction Analysis

Initial x-ray fluorescence results suggest that the magnetic separation increases certain element concentration in the magnetic fraction, such as titanium, terbium, and more. Furthermore, rare earth elements such as terbium and holmium were found in unexpectedly large concentrations in the magnetic fraction. However, certain elements such as barium, lanthanum, and more experienced the opposite effect, so this method only concentrated certain elements.

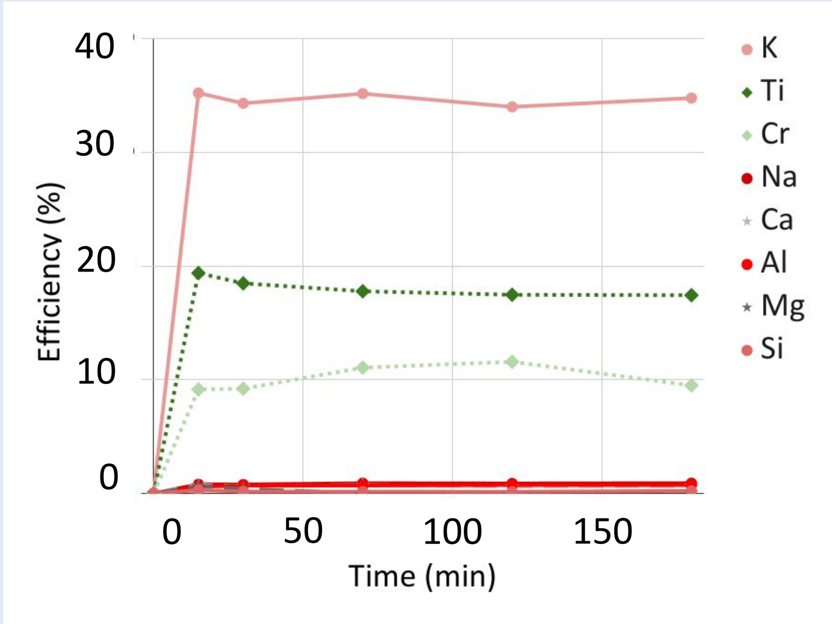
The present x-ray fluorescence data are inconsistent with previously acquired data. Additional data analysis is needed to understand the source of this discrepancy.

Acid Leaching



Heated acid digestion is used to extract elements into a leachate solution. ≤125 um tailings were placed in 6 M HCl at 90 C, with samples being taken at 15, 30, 60, 120, and 180 minutes

Extraction Efficiency, Standard



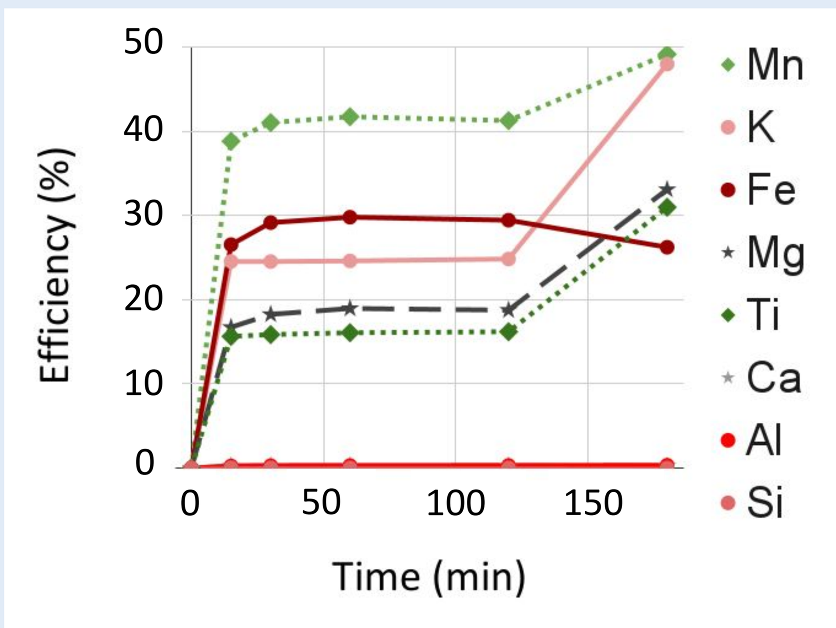
Key:

Gray, star, dashed line: Alkaline elements

Green, dotted line, diamond: Critical elements

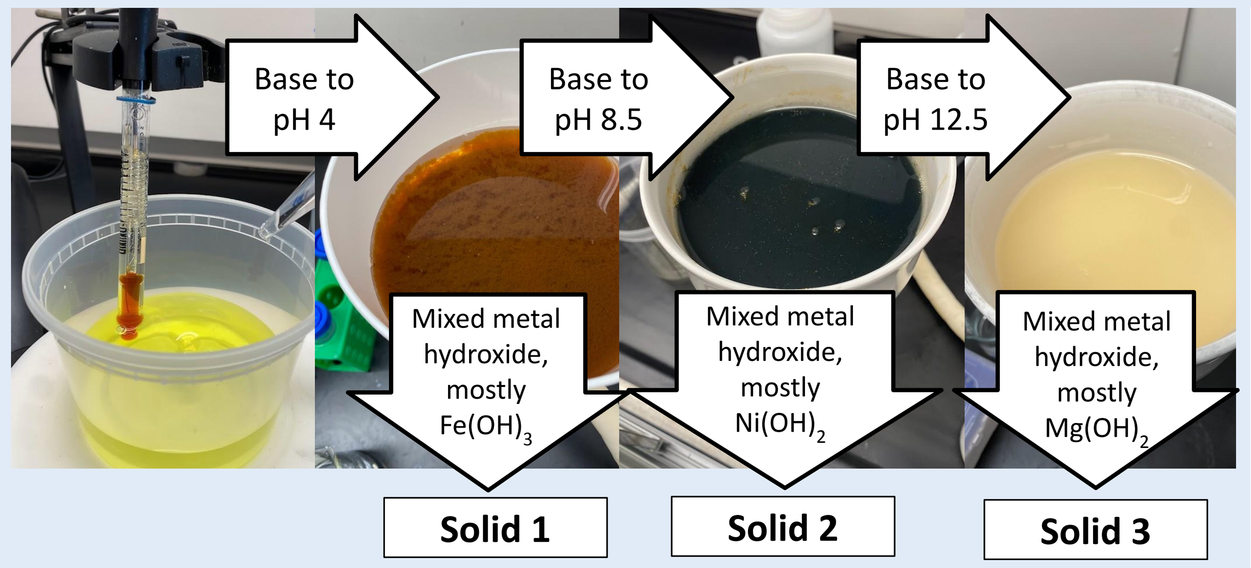
Red, circle: Other

Extraction Efficiency, Nonmagnetic Fraction



- Extraction of critical elements was improved in the leaching process after the magnetic separation.
- Elements of interest, such as manganese, titanium, and magnesium displayed higher extraction efficiencies after the magnetic separation step was incorporated.
- However, it is possible that this was caused by a change in the solid:liquid ratio.
- Due to the small yield of nonmagnetic material, the same solid:liquid ratio could not be done with the nonmagnetic fraction as done with the standard leaching method.

Precipitation



Stepwise addition of base swings the pH up to selectively precipitate out hydroxides. Precipitation was done in 3 stages: at pH 3-4, iron precipitates, at pH 8-9 nickel precipitates, and at pH 12.3-13, magnesium and calcium precipitate

- Solid 1, predominantly $Fe(OH)_3$, did not form for the post-magnetically separated precipitation procedure. This indicates magnetic separation was likely successful at removing iron.
- Due to ICP readings maxing out, separation efficiencies of each hydroxide (iron, nickel, and magnesium/calcium) were not calculated. However, since solid 1 did not form post-magnetic separation, it can be assumed most of the iron was separated via magnet.

Discussion

Preliminary Results

- The magnetic separations method of swirling a magnet in solution rather than running a bulk mine tailings solution down a bed of magnets was effective at removing magnetic particles and has shown promising for separating critical elements from Stillwater mine tailings
- More of the Stillwater mine tailings were magnetic than nonmagnetic; more than just iron is separated with a magnet. The magnetic fraction contains critical elements of interest for the energy transition.

Future Research

- Why most of the mine tailings were magnetic should be the subject of future studies. Due to the discrepancies between the XRF results and previous characterization data, more data points should be collected with XRF and XRD to accurately measure the chemical composition of the magnetic and non-magnetic fractions, and understand better the magnetic separations process.
- Proper comparison of the standard critical mineral extraction procedure and the extraction procedure with magnetic separation cannot be done with the current data
  - In future studies, the standard critical mineral extraction procedure should be redone with the same solid:liquid ratio for the standard extraction process and the process with magnetic separation
  - Furthermore, the current ICP data for the standard critical mineral extraction process did not have readings for iron or magnesium. For instance, 1000x dilute samples should be prepared to avoid maxing out readings
- Technoeconomic analysis should be done to see if the magnetic separation process reduces the cost of critical element extraction by reducing the amount of acid and base needed

References

Thank you to the Clean Energy Conversions Lab, The Nature Conservancy Nevada, and Climateworks for funding this study. I would like to thank all the members of the lab, especially Katherine Vaz Gomes, for their invaluable mentorship and guidance.

1. *Carbon Mineralization with North American PGM Mine Tailings—Characterization and Reactivity Analysis*. (n.d.). Retrieved August 8, 2024, from https://www.researchgate.net/publication/353724439_Carbon_Mineralization_with_North_American_PGM_Mine_Tailings-Characterization_and_Reactivity_Analysis
2. *Climate risk and decarbonization: What every mining CEO needs to know | McKinsey*. (n.d.). Retrieved August 1, 2024, from https://www.mckinsey.com/capabilities/sustainability/our-insights/climate-risk-and-decarbonization-what-every-mining-ceo-needs-to-know
3. *Global Critical Minerals Outlook 2024 – Analysis*. (n.d.). IEA. Retrieved July 18, 2024, from https://www.iea.org/reports/global-critical-minerals-outlook-2024
4. *World Mine Tailings Failures—From 1915 – supporting global research in tailings failure root cause, loss prevention and trend analysis*. (n.d.). Retrieved August 6, 2024, from https://worldminetailingsfailures.org/