Earth Engineering Center
CITY COLLEGE of NEW YORK

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Transforming **Waste-to-Energy Ashes** into a Cementitious Material through **Chlorellestadite** Formation

Vikram Kumar, Aniruddha Baral, Mohamed Abdelrahman, Jeffery R. Roesler, & Nishant Garg

PhD Student

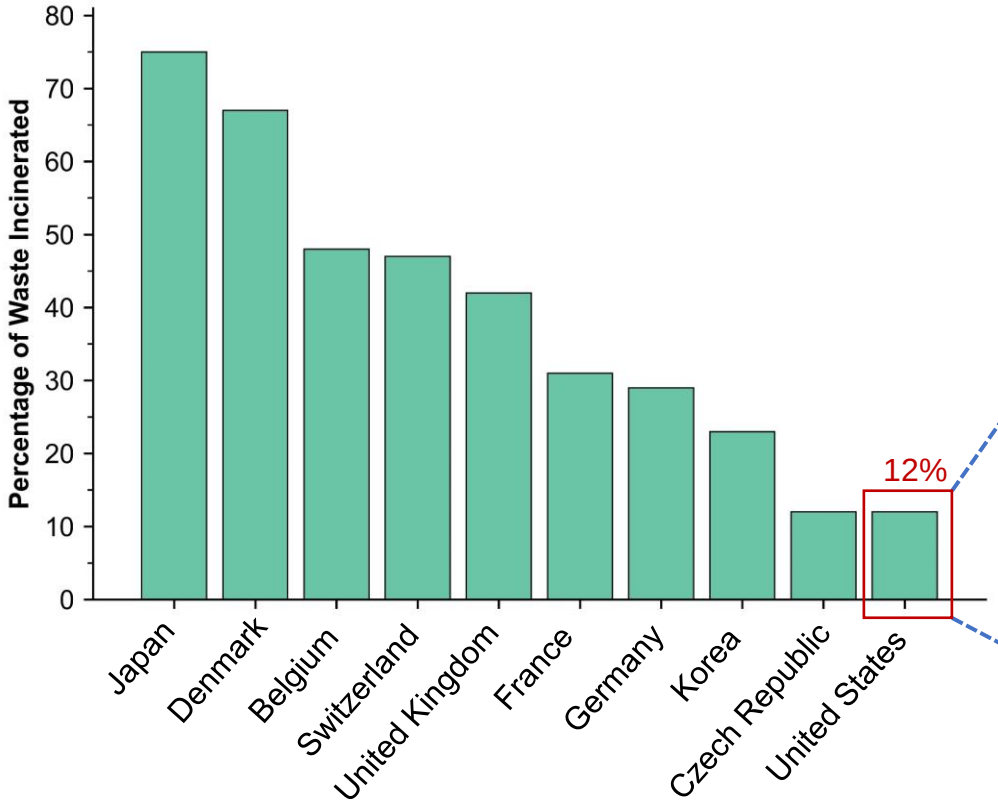
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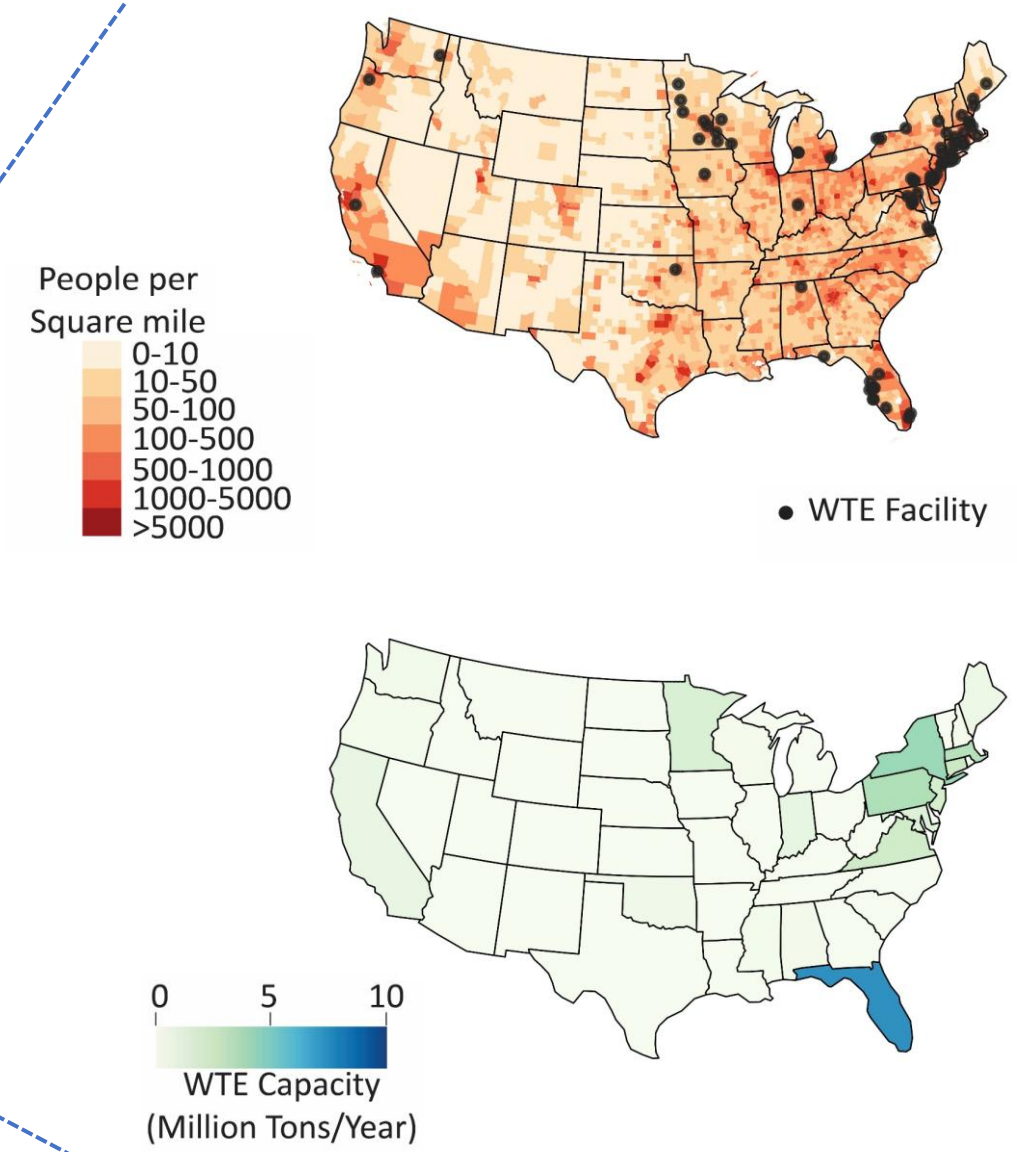
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Waste Incineration

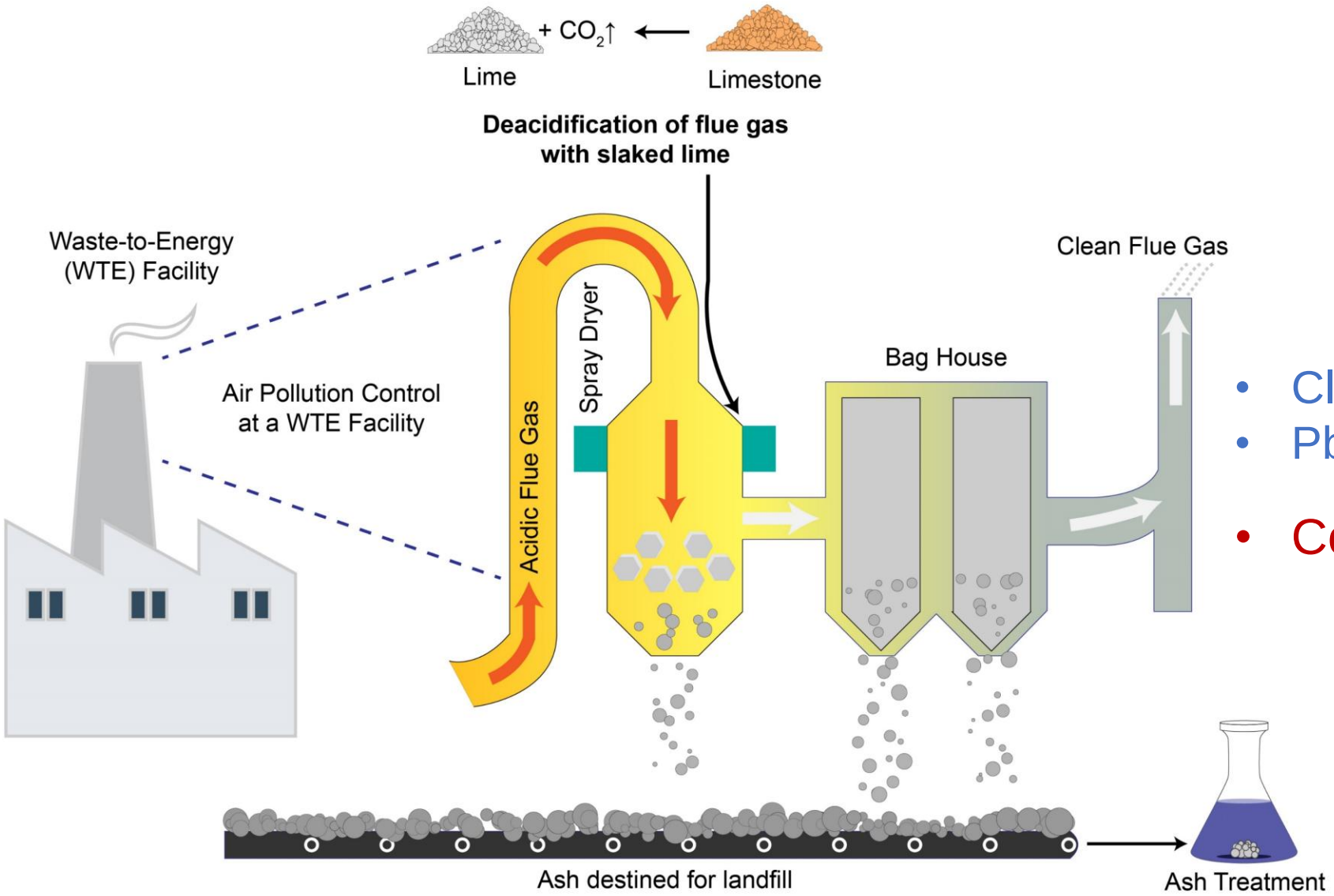




U.S. Energy Information Administration

Kumar and Garg, *Environmental Research Infrastructure and Sustainability*, 2021

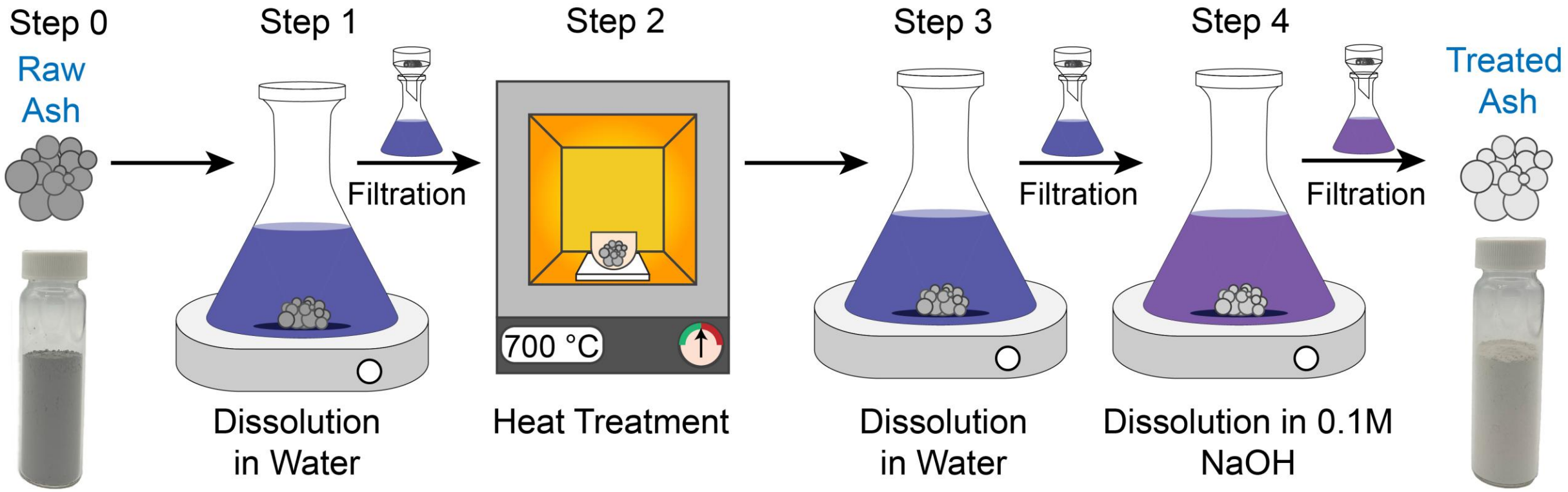
Waste-to-Energy Fly Ashes



- Cl in ash 0.8 – 21 %
- Pb in ash 0.24 – 0.89 %
- Corrosion and Leaching Risks

Initially, we did not like chlorides!

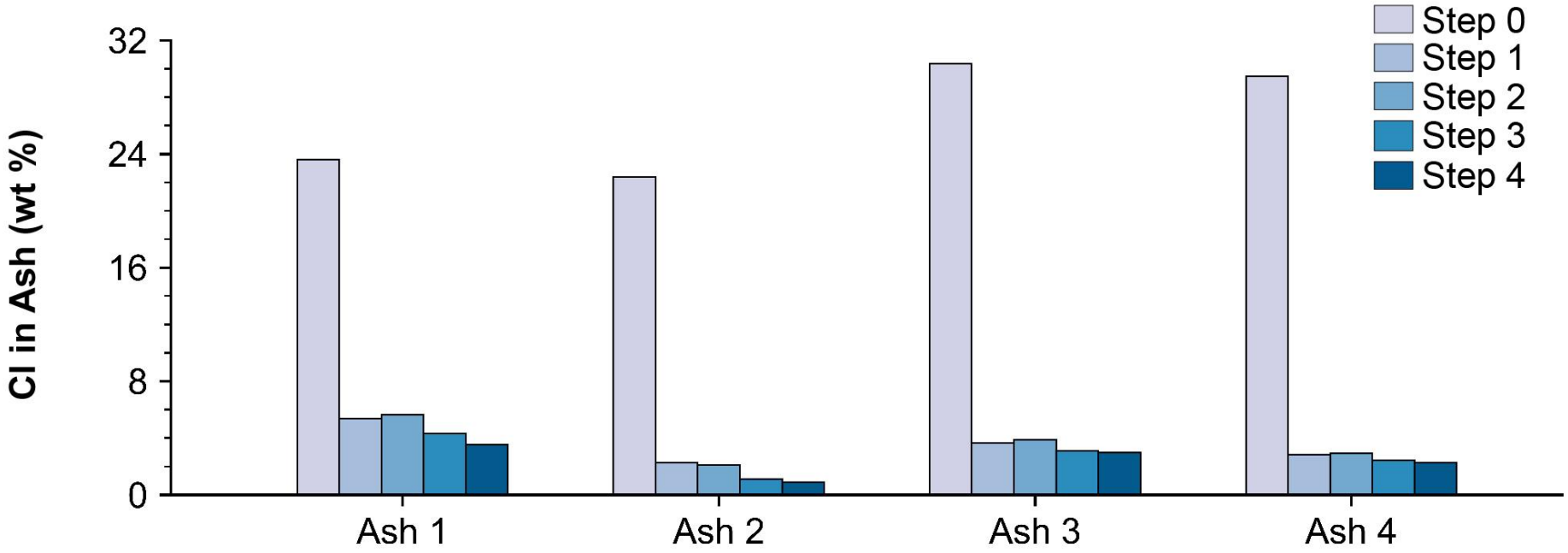
Ash Treatment



Kumar et al., *ACS ES&T Engineering*, 2024

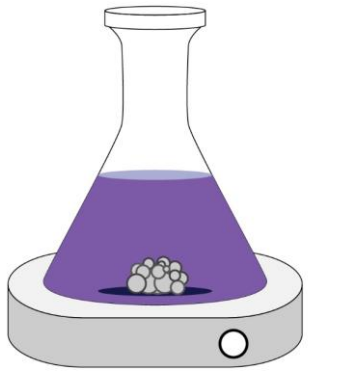
Chloride Concentration in Ash



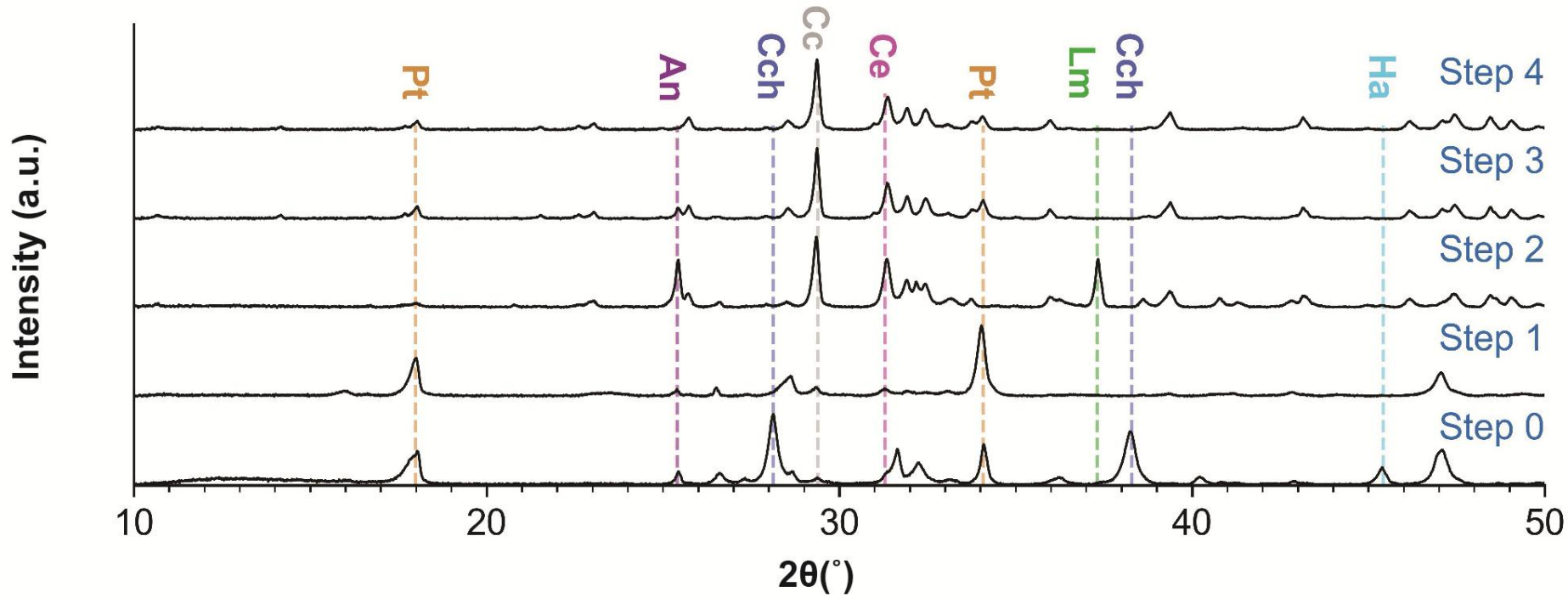


Mineralogical Transformations





Pt – $Ca(OH)_2$ Cch – CaClOH Ce – $Ca_5(SiO_4)_{1.5}(SO_4)_{1.5}Cl$ Ha – NaCl
An – $CaSO_4$ Cc – $CaCO_3$ Lm – CaO



$$CaClOH\,(s) + H_2O \rightarrow Ca(OH)_2(s) + HCl\,(aq)$$

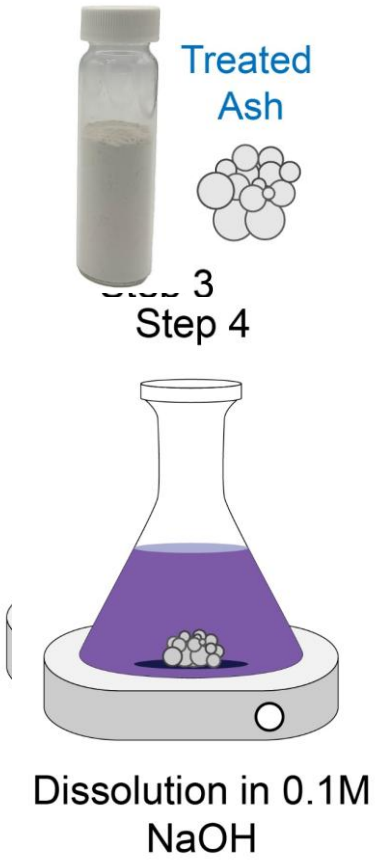
$$3CaO\,(s) + 0.5CaCl_2\,(s) + 1.5CaSO_4\,(s) + 1.5SiO_2\,(s) \xrightarrow{\Delta} Ca_5(SiO_4)_{1.5}(SO_4)_{1.5}Cl(s)$$

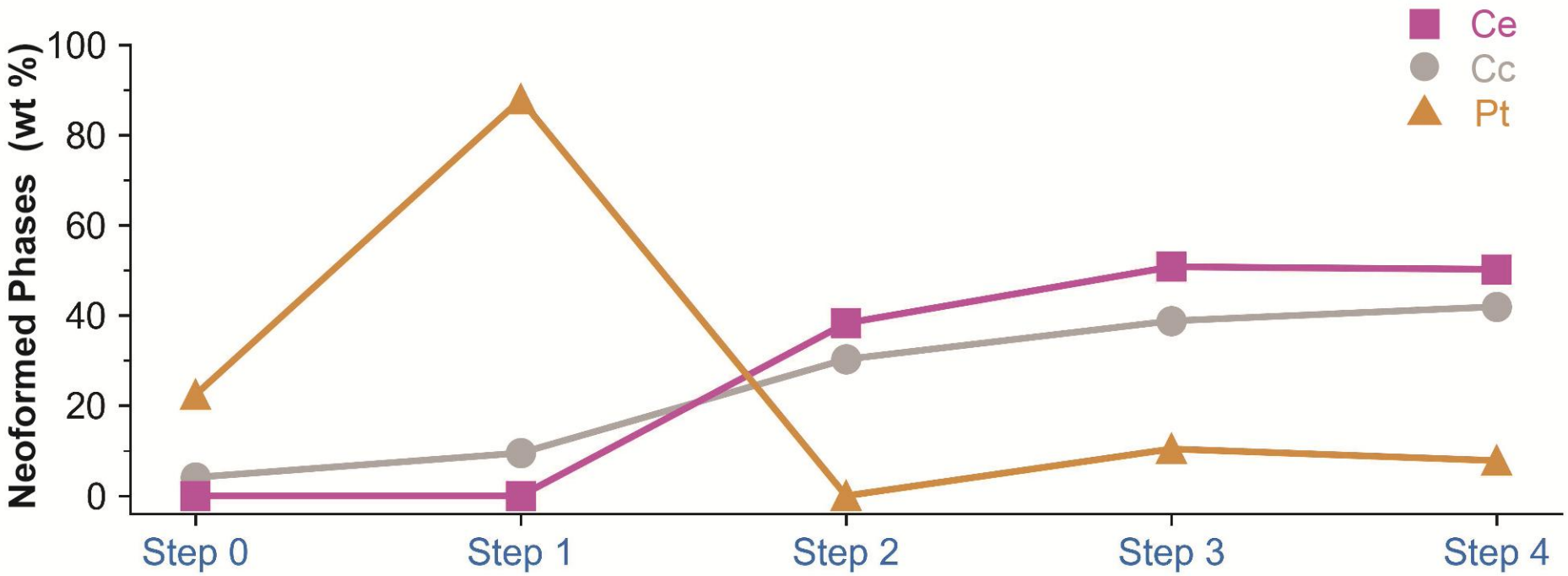
Mineralogical Transformations

Ce – $Ca_5(SiO_4)_{1.5}(SO_4)_{1.5}Cl$

Cc – $CaCO_3$

Pt – $Ca(OH)_2$

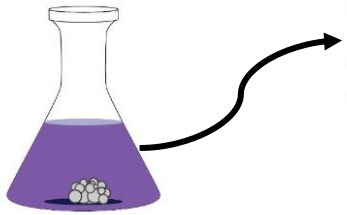


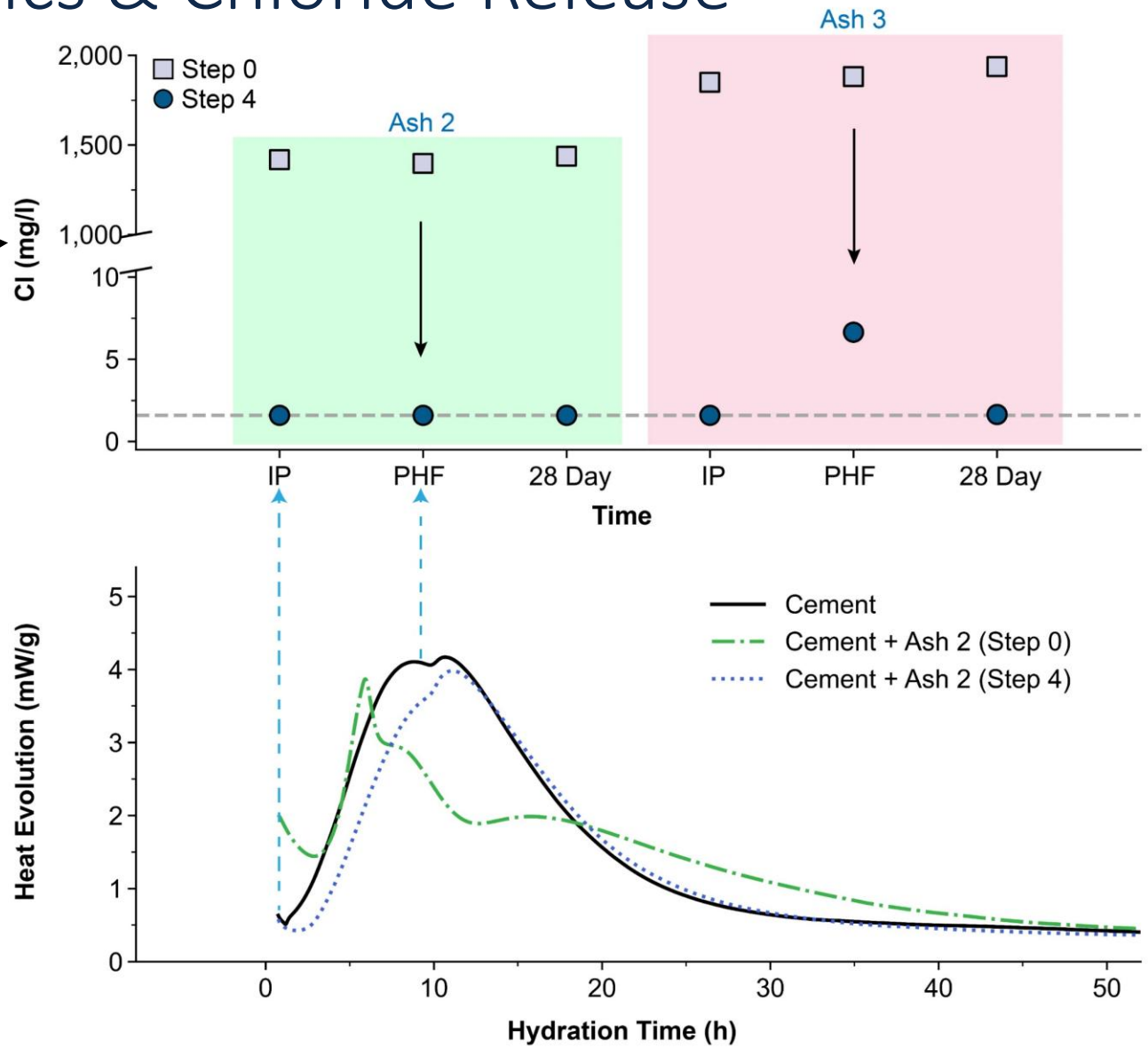


$$3CaO\,(s) + 0.5CaCl_2\,(s) + 1.5CaSO_4\,(s) + 1.5SiO_2\,(s) \xrightarrow{\Delta} Ca_5(SiO_4)_{1.5}(SO_4)_{1.5}Cl(s)$$

Hydration Kinetics & Chloride Release

Dissolution in an Alkaline Pore Solution

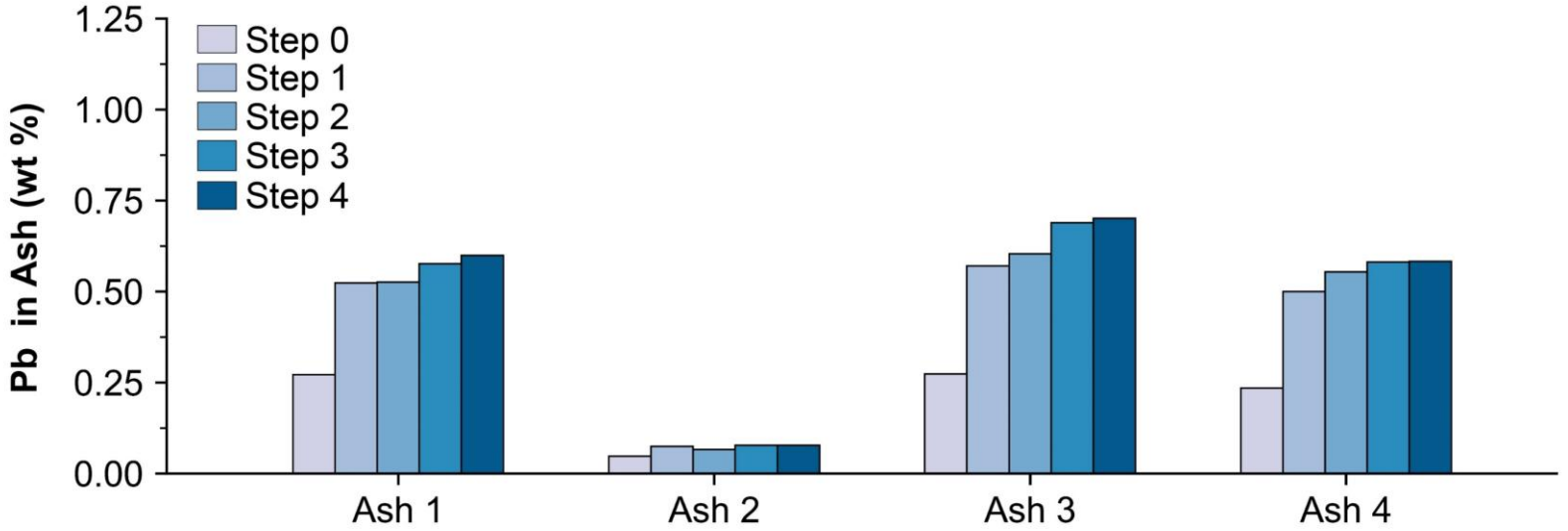


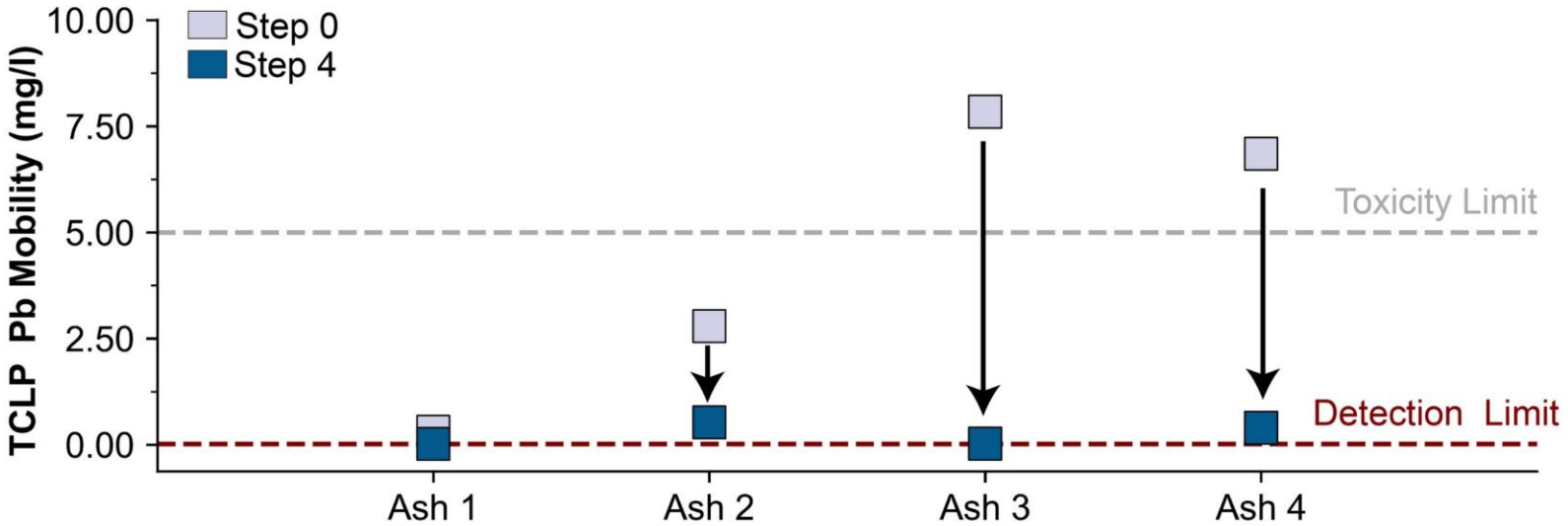


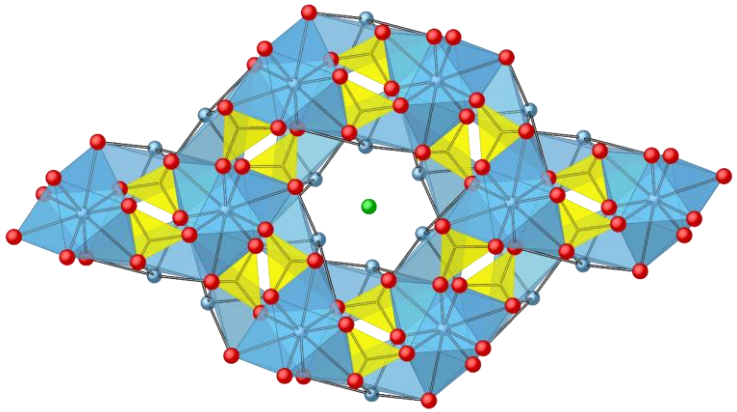
Reduction in chloride release by over two orders of magnitude

This observation suggests that chlorellestadite is stable in an alkaline pore solution

Pb in Ash & TCLP Pb Mobility







$[A(1)]_4[A(2)]_6(BO_4)_6X_2$

A = Ca
B = Si/S
X = Cl

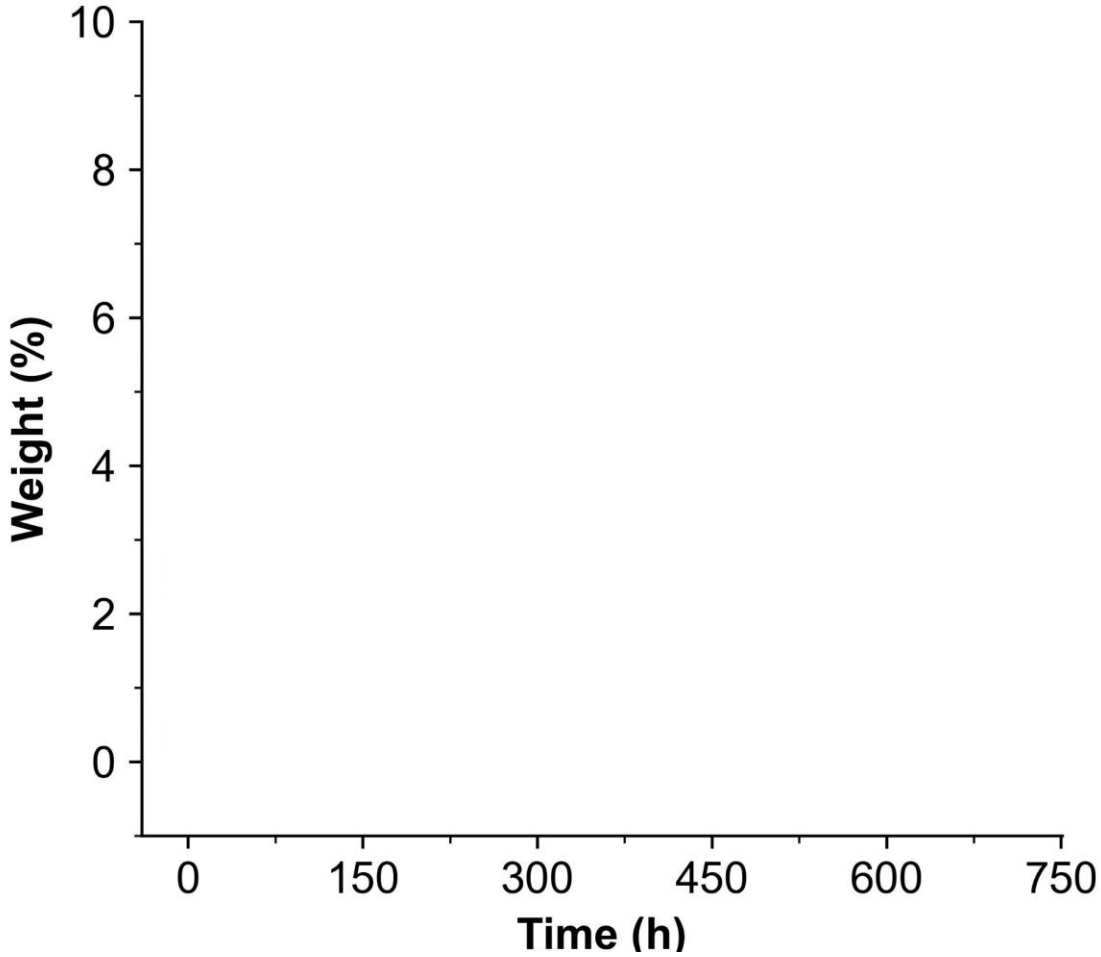
Position A can be partially occupied by Pb, resulting in reduced Pb mobility.

Kumar et al., *ACS ES&T Engineering*, 2024

This is where we start to like chlorides!

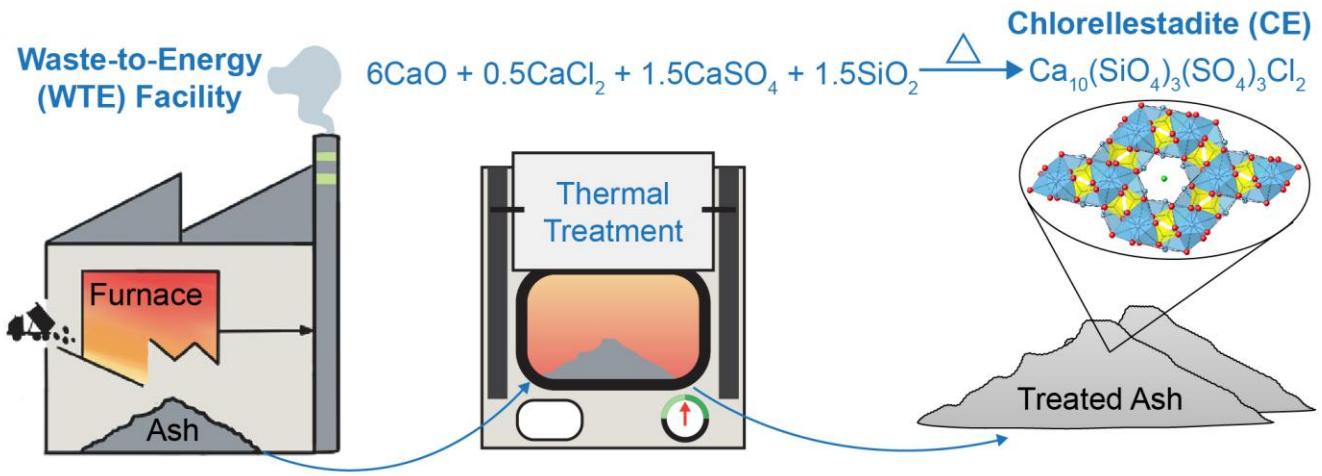
Beyond Inert Fillers: Chlorellestadite Activation with CO_2

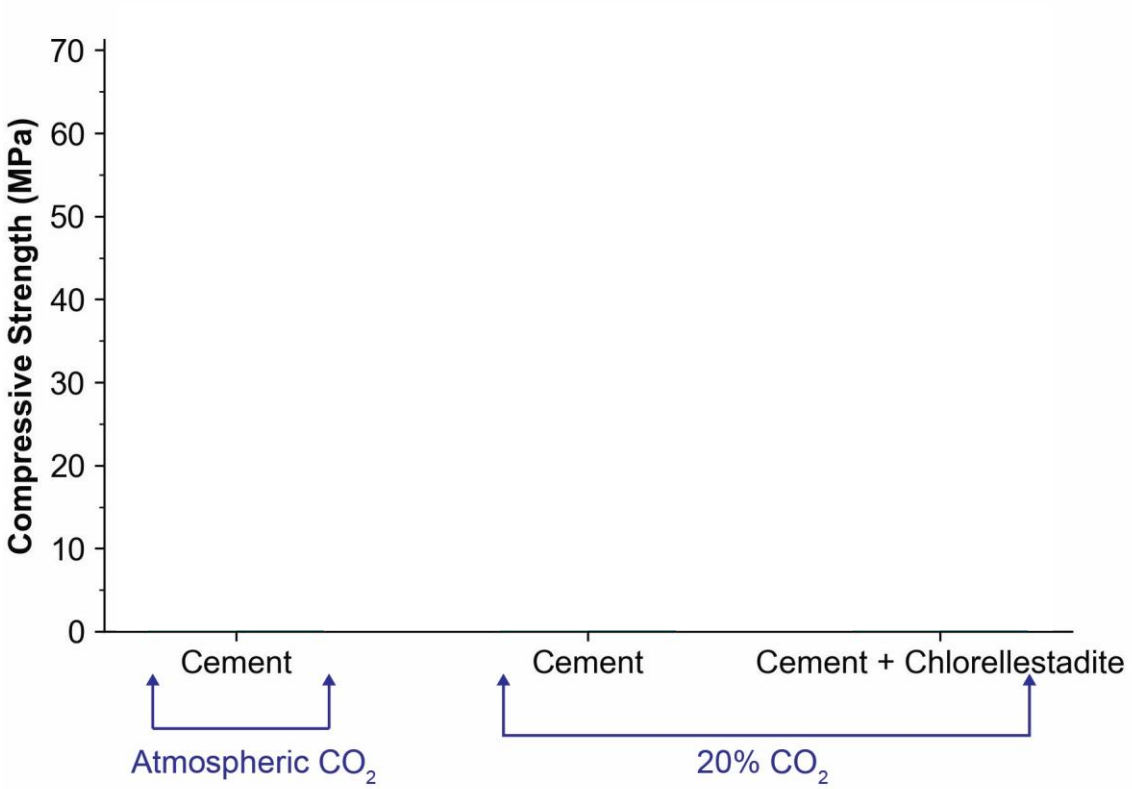
$$Ca_{10}(SiO_4)_3(SO_4)_3Cl_2\ (s) + 6CO_2\ (g) + 6H_2O \rightarrow 6CaCO_3\ (s) + 3CaSO_4.2H_2O\ (s) + CaCl_2\ (s) + 3SiO_2\ (s)$$



Minerals formed upon chlorellestadite carbonation – polymorphs of $CaCO_3$, gypsum, and amorphous SiO_2

Beyond Inert Fillers: Chlorellestadite Activation with CO_2





Abdelrahman et al., *In Review,* 2024

Outlook

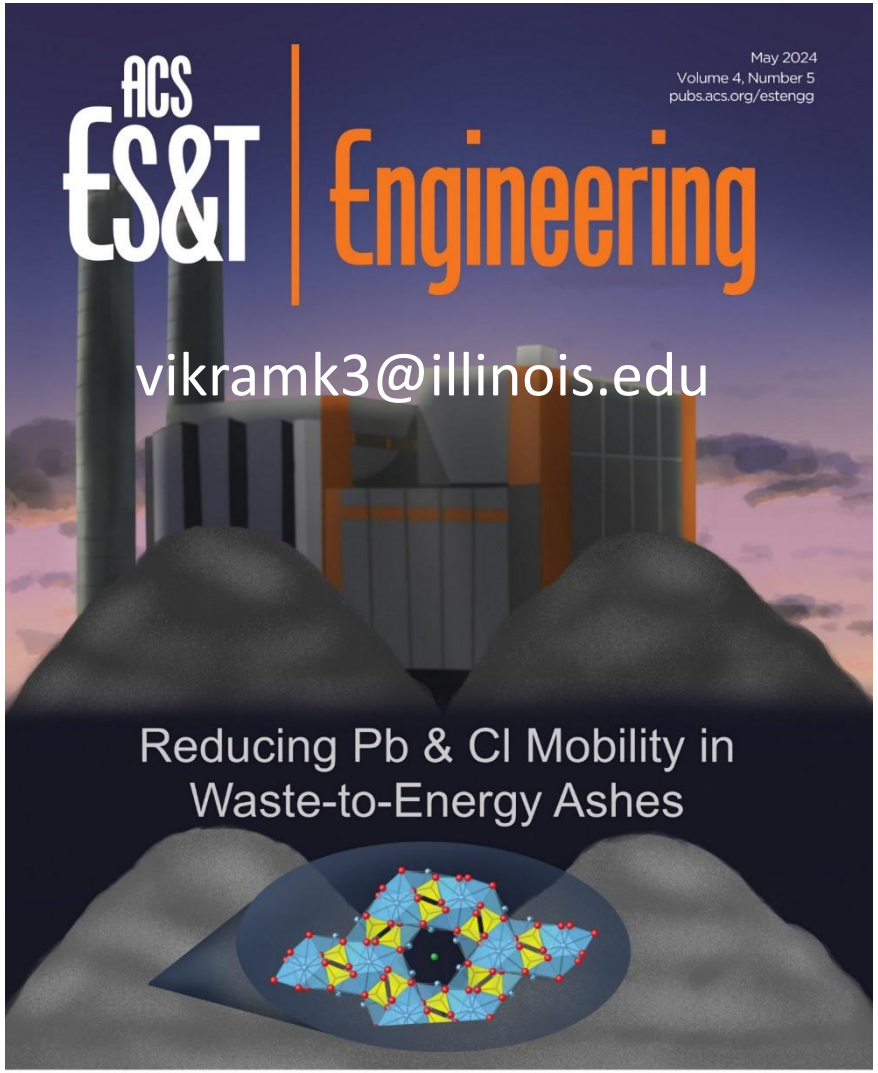
- Transformation of non-readily removable chlorides to chlorellestadite reduces chloride release in an alkaline pore solution to negligible levels (from 1500 mg/l to less than 10 mg/l).
- Ca in chlorellestadite can be replaced by Pb, explaining the observed reduction in Pb mobility in the TCLP test (from >5 mg/l to <0.5 mg/l).
- Chlorellestadite reacts with CO_2 to form polymorphs of $CaCO_3$, amorphous SiO_2, and gypsum. This reactivity with CO_2 can be leveraged to enhance the microstructural properties of cementitious systems containing chlorellestadite.

Kumar and Garg, *Environmental Research: Infra & Sus.*, 2021
Kumar and Garg, *Resour Conserv & Recycling*, 2022
Samouh et al., *J Hazard Mater*, 2023

Kumar et al., *ACS ES&T Engineering*, 2024
Baral et al., *Chemical Engineering Journal*, 2024
Abdelrahman et al., *In Review*, 2024

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