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Coal ash beneficiation through critical material extraction and recovery

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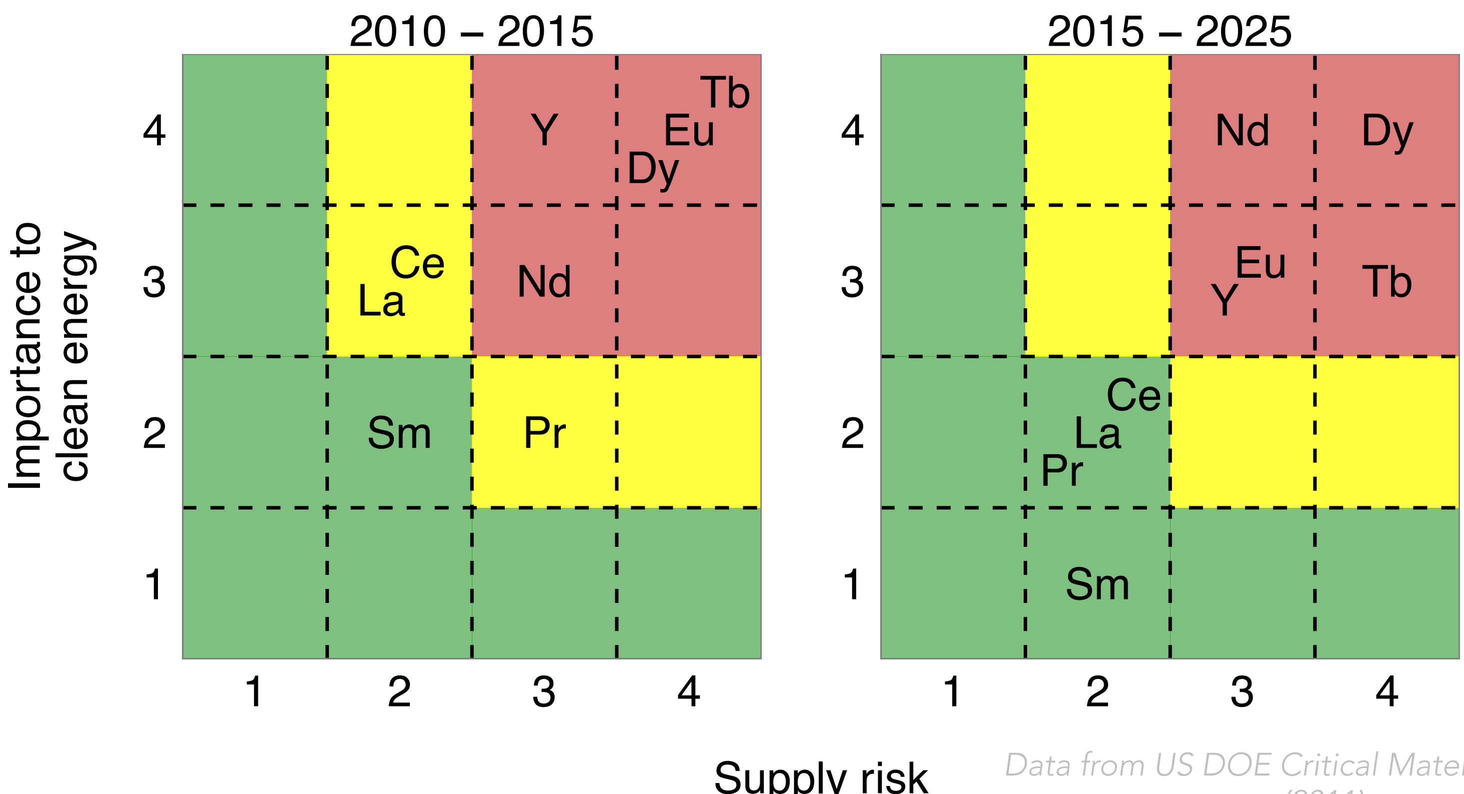
Critical materials are: "stuff you really need, but can't always get" – A. King, CMI



Data from US DOE Critical Materials Strategy (2011)

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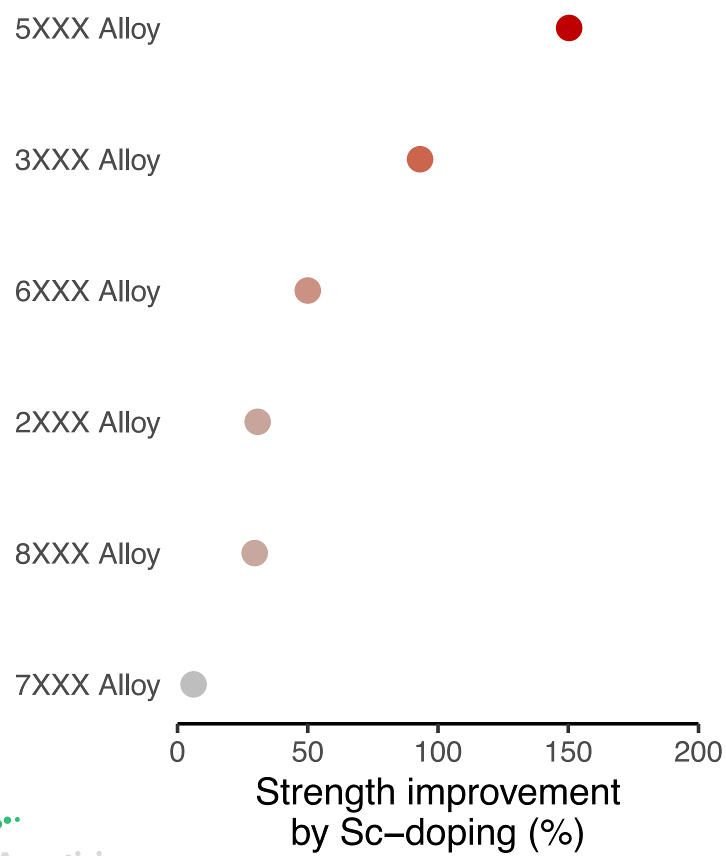
Small scandium additions transform Al-alloy properties

Stronger alloys
require less material



Source: SCALE; EU Horizon 2020

Weldable alloys increase
OEM outputs, boost profits

- 30- to 60x increase in joining rates
- 25% savings on materials
- 10% weight savings in joins
- Improved durability of high-stress areas

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Scandium supply is limiting because no high-quality ores exist and technological approaches are rudimentary

- Best rare earth ores:
  - 8-10wt% TREO
  - ≤50 ppm Sc
- Best Sc ores:
  - Ni-Co laterites ~300 ppm
  - Bauxite residue ~100 ppm
  - Ilmenite slag ~ 100 ppm
  - Fly ash ~ 50 ppm

Vast majority of technologies across comm. readiness scale still rely on staged ppt. + solvent extraction

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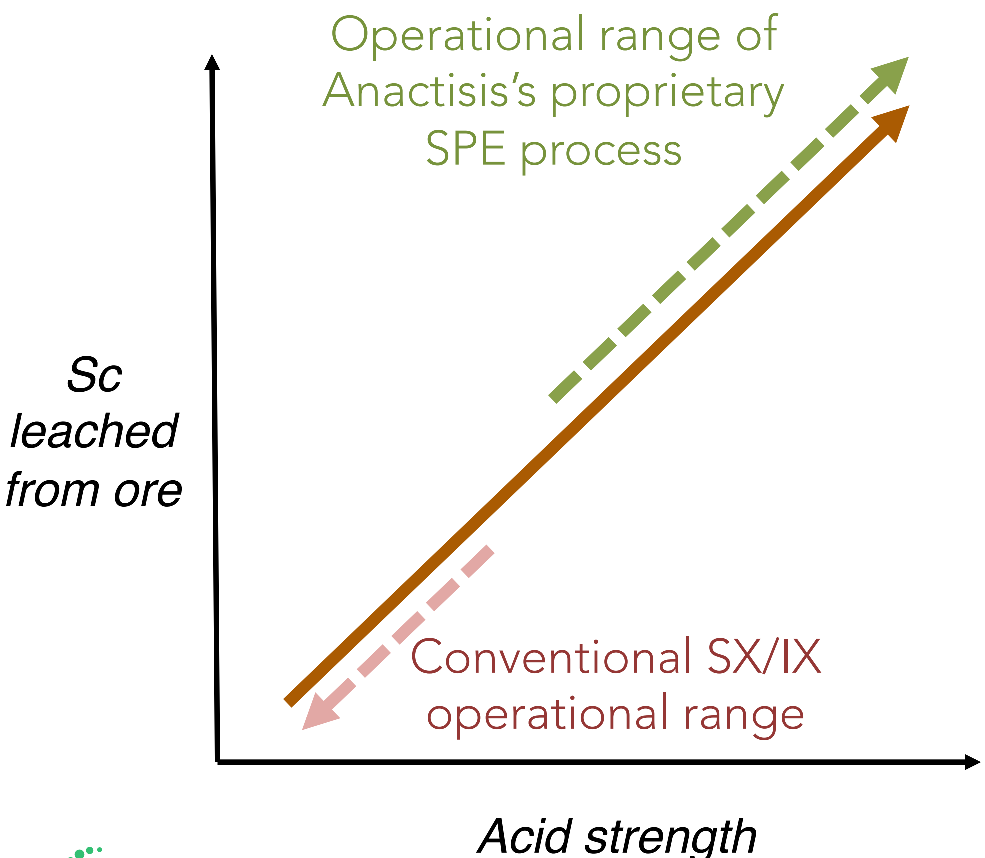
Novel adsorbent chemistries allow for maximum Sc recovery without neutralization



Conventional separations require a compromise:

(1) Sub-optimal Sc leaching (**lower revenue**); or
(2) High reagent use in acid neutralization (**higher unit costs**)

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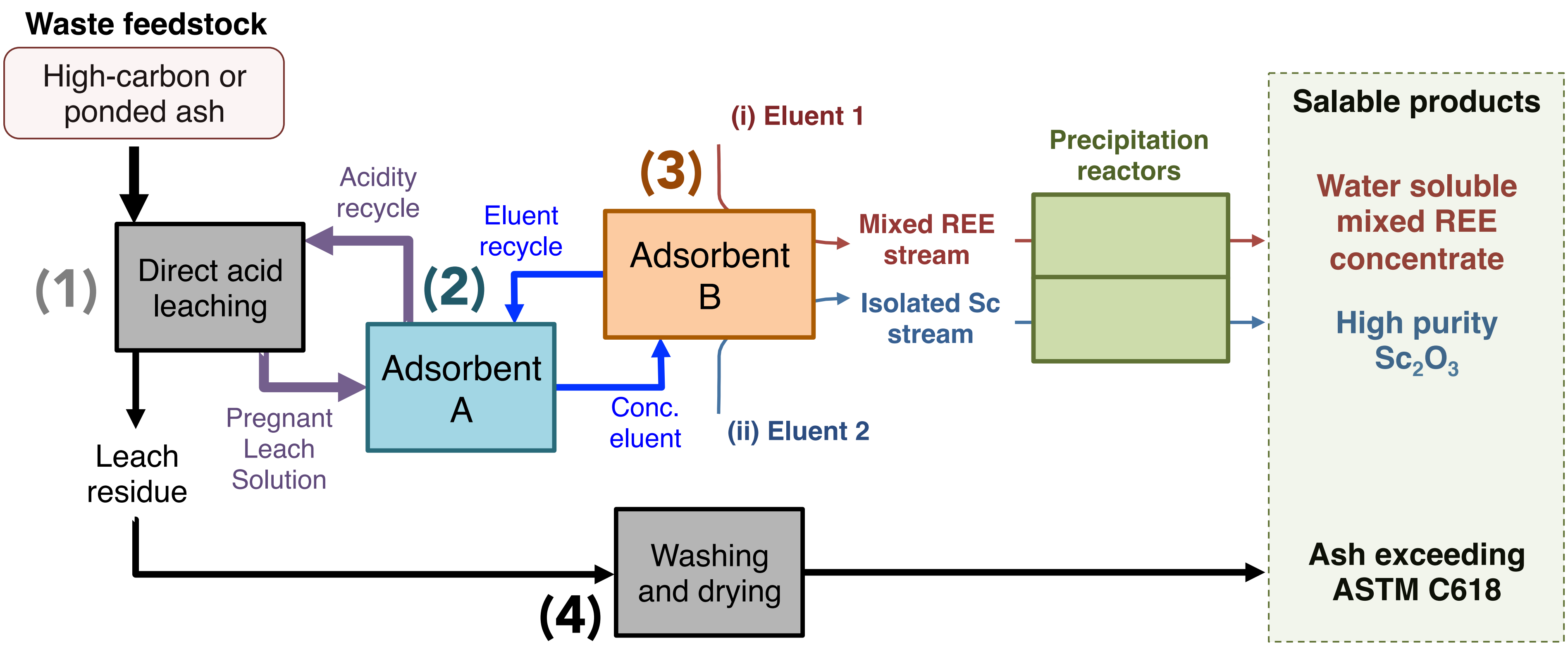
We offer a different solution: Sc recovery in the service of conventional ash beneficiation



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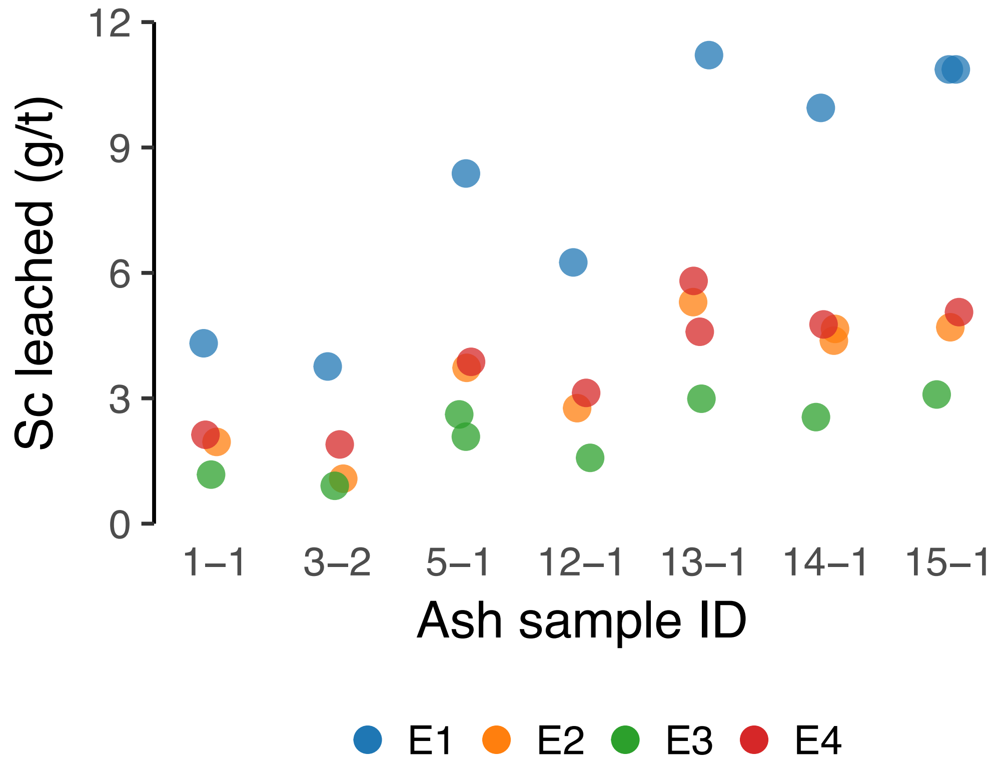
Leaching experiments to probe: process design and REE mineralogy

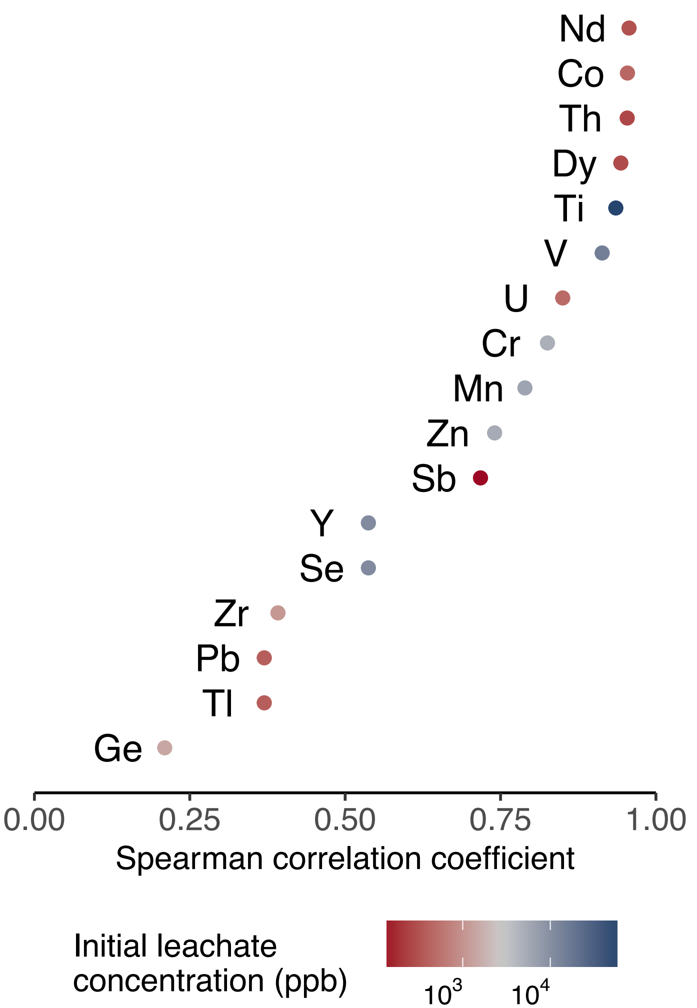
- Parametric testing to determine most important variables for scale-up
- Experimental study to enhance leachability and/or conserve acid
- Correlation analysis to determine suitable proxy metals for process control monitoring

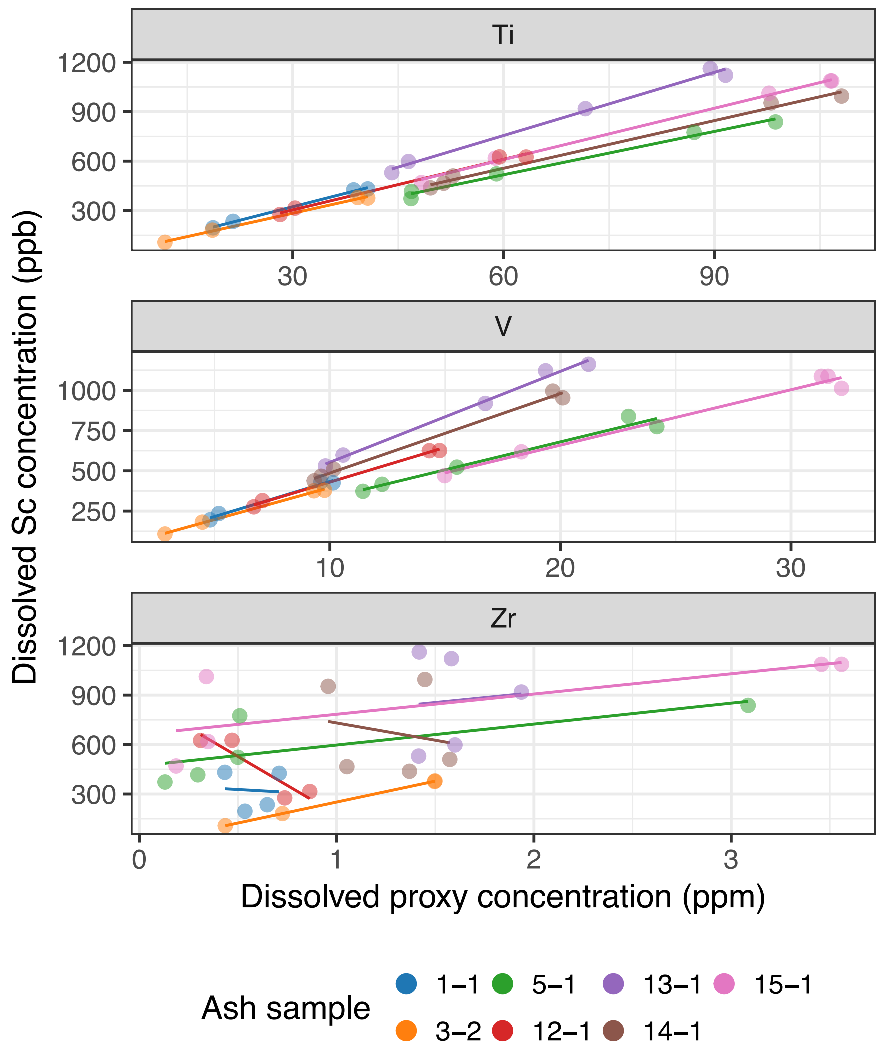
Acidity and pulp density should be prioritized over contact time

	Acidity	L/S ratio	Contact time
E1	+	+	+
E2	-	+	-
E3	-	-	+
E4	+	-	-

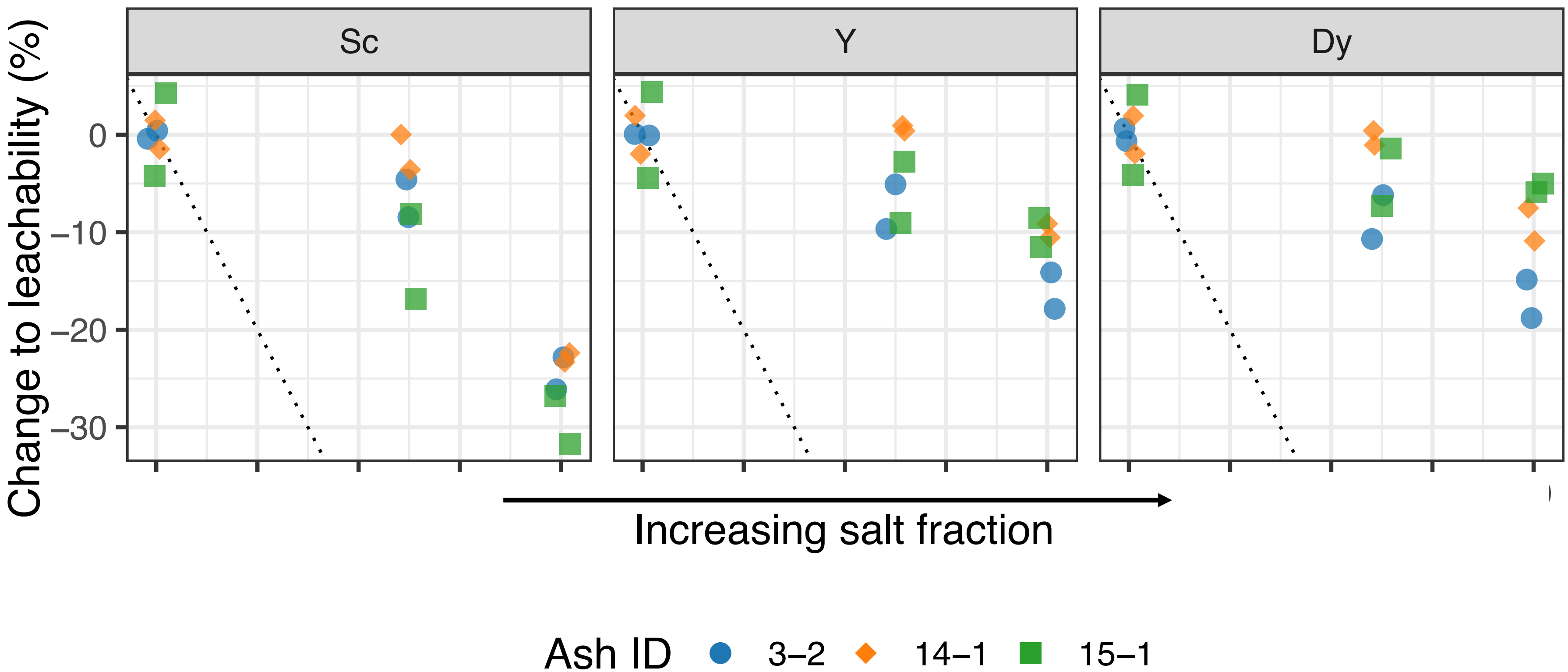


Ti may be useful Sc proxy for continuous monitoring





Constant ionic strength leaching shows promise to limit acid consumption and improve OPEX



Thermo-chemical roasts may enhance Sc+REE leachability by modifying mineralogy

- Sc+REE hypothesized to reside in: silicates, phosphates, and/or oxides
- Sodium carbonate attacks silicates
- Calcium oxide decomposes phophates
- Ammonium chloride convert oxides

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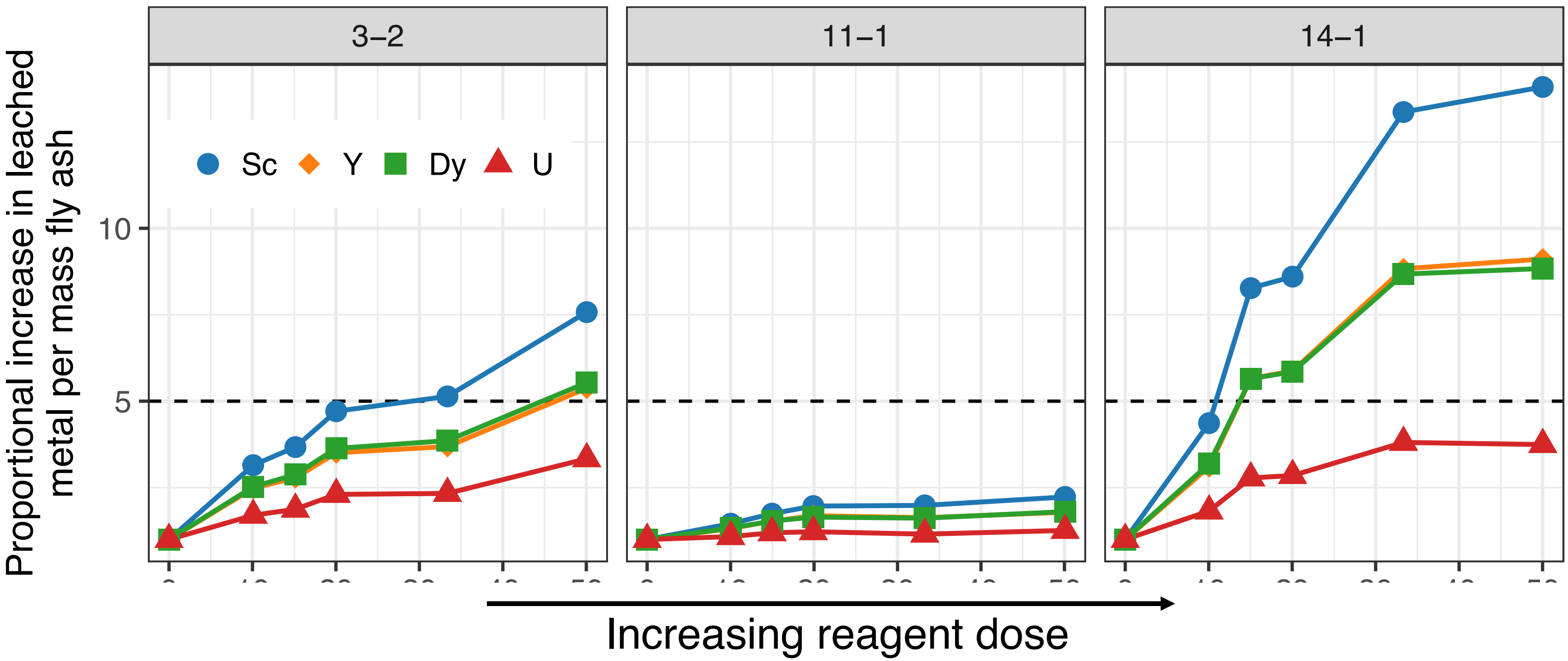
Na_2CO_3 highly effective in improving Sc+REE leachability



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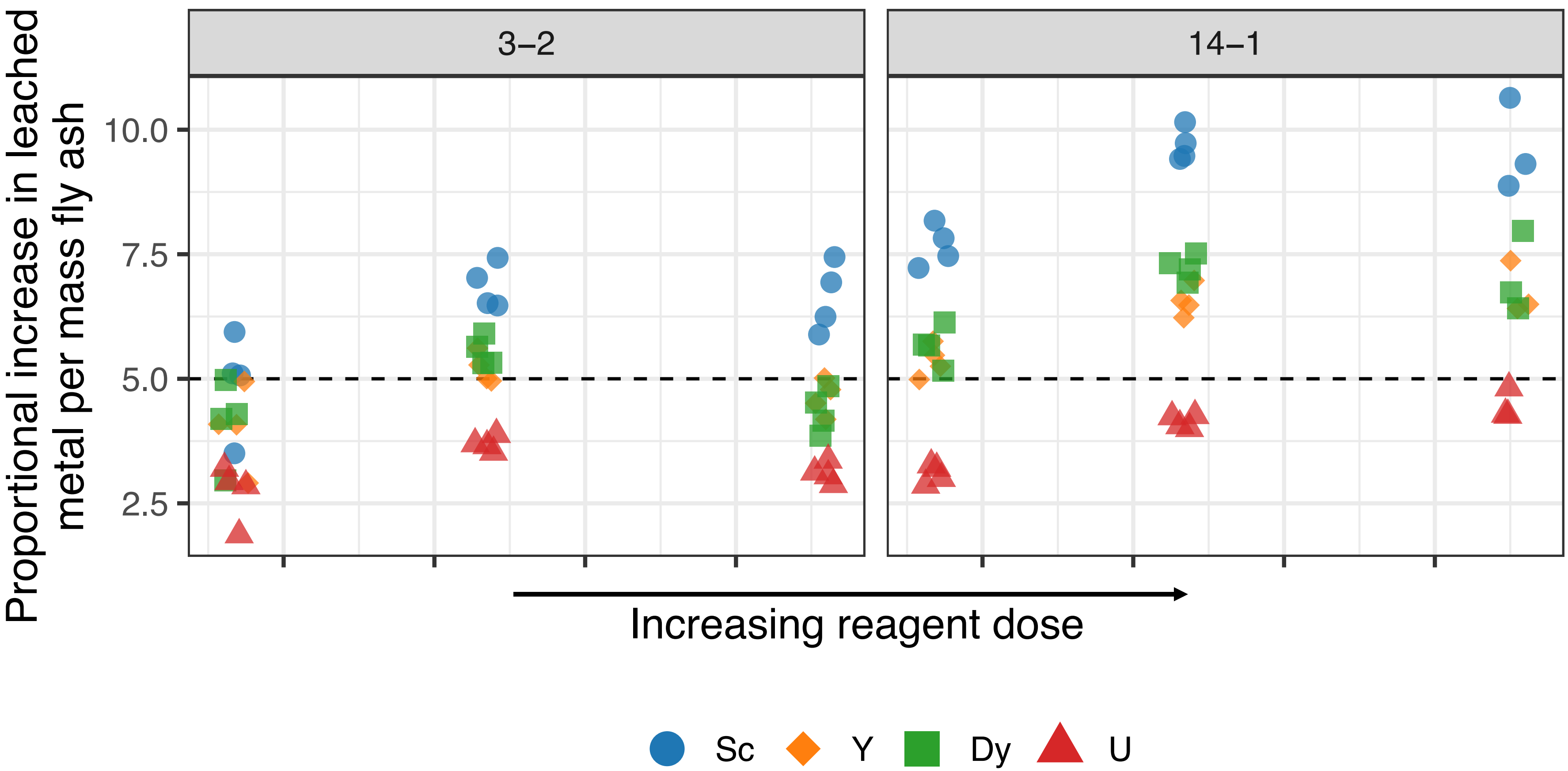
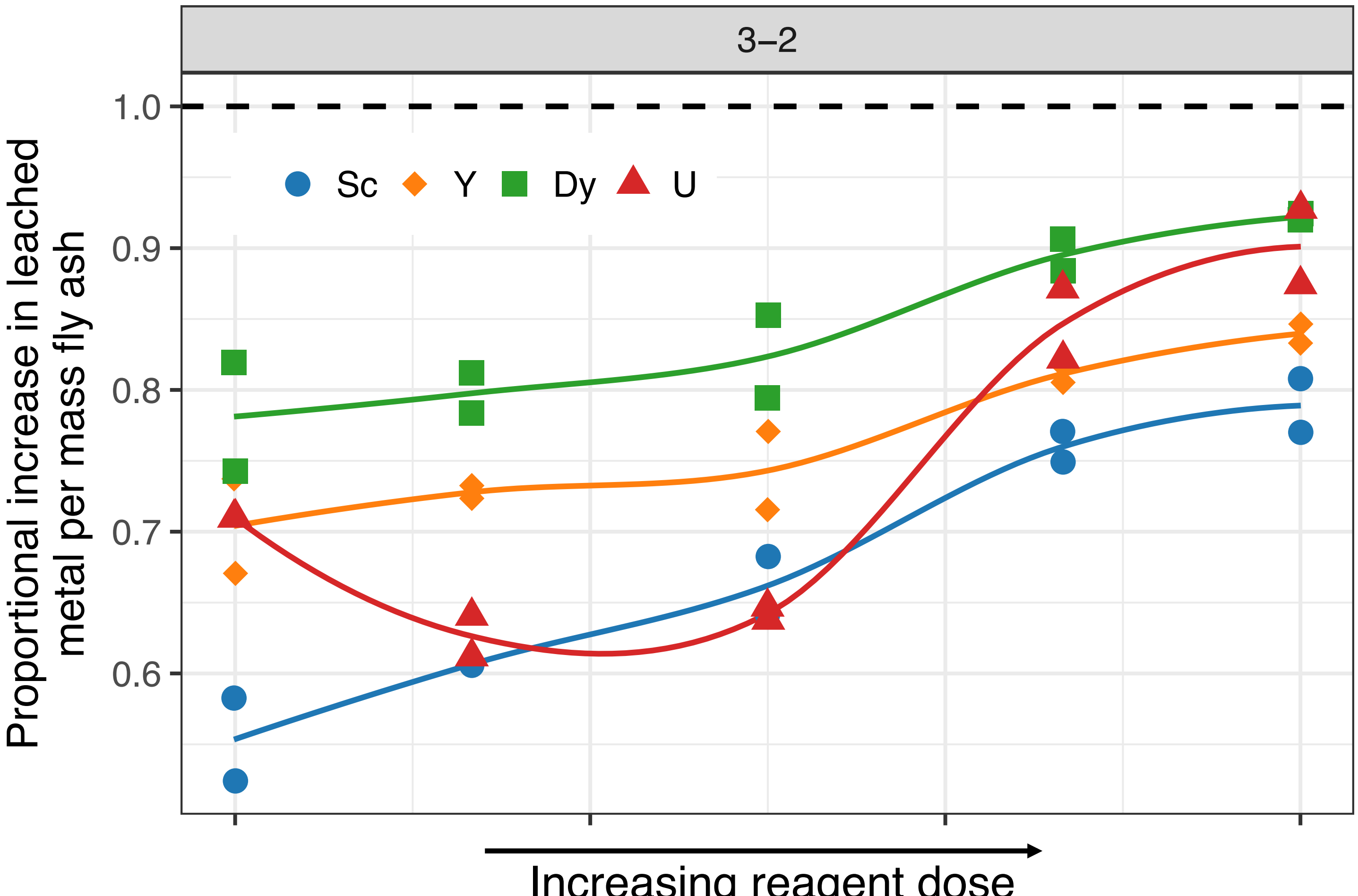
CaO similarly effective for improving Sc leaching



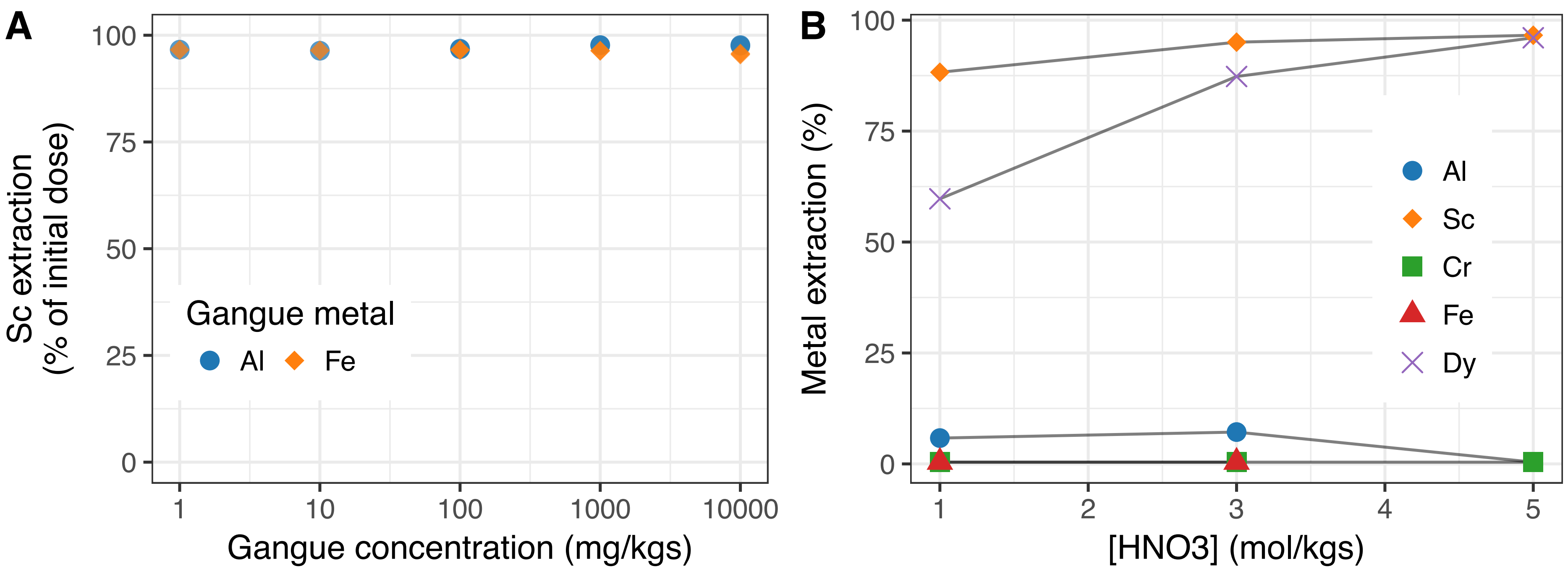
NH_4Cl shows decreased leachability for ash tested



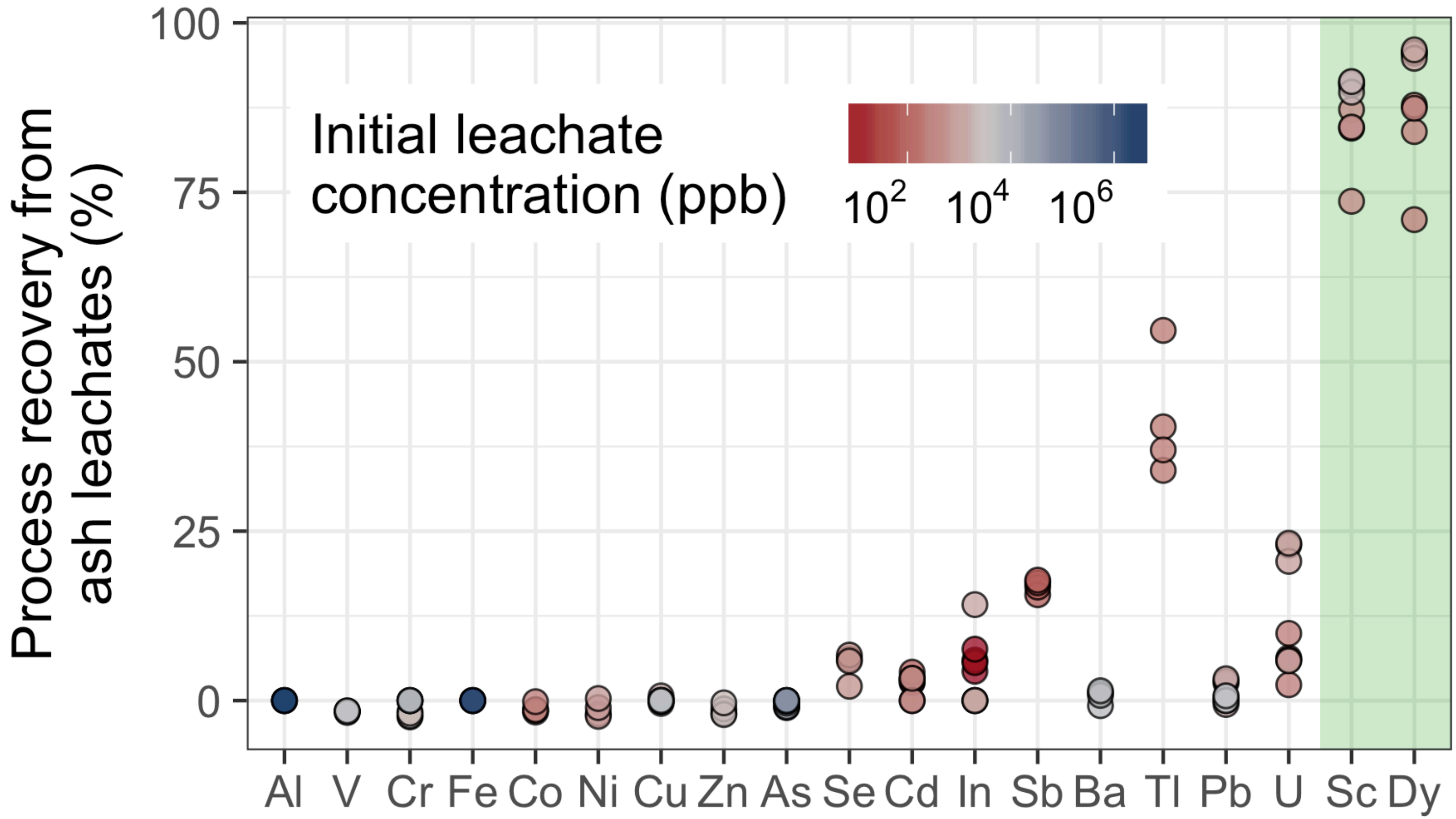
A two-stage, adsorption process is used to separate and purify Sc in leachates

- Leachates contain very high Al/Fe (1000x Sc typically)
- ≥3 mol/kgs residual acidity
- Selectivity improves downstream economics of separation

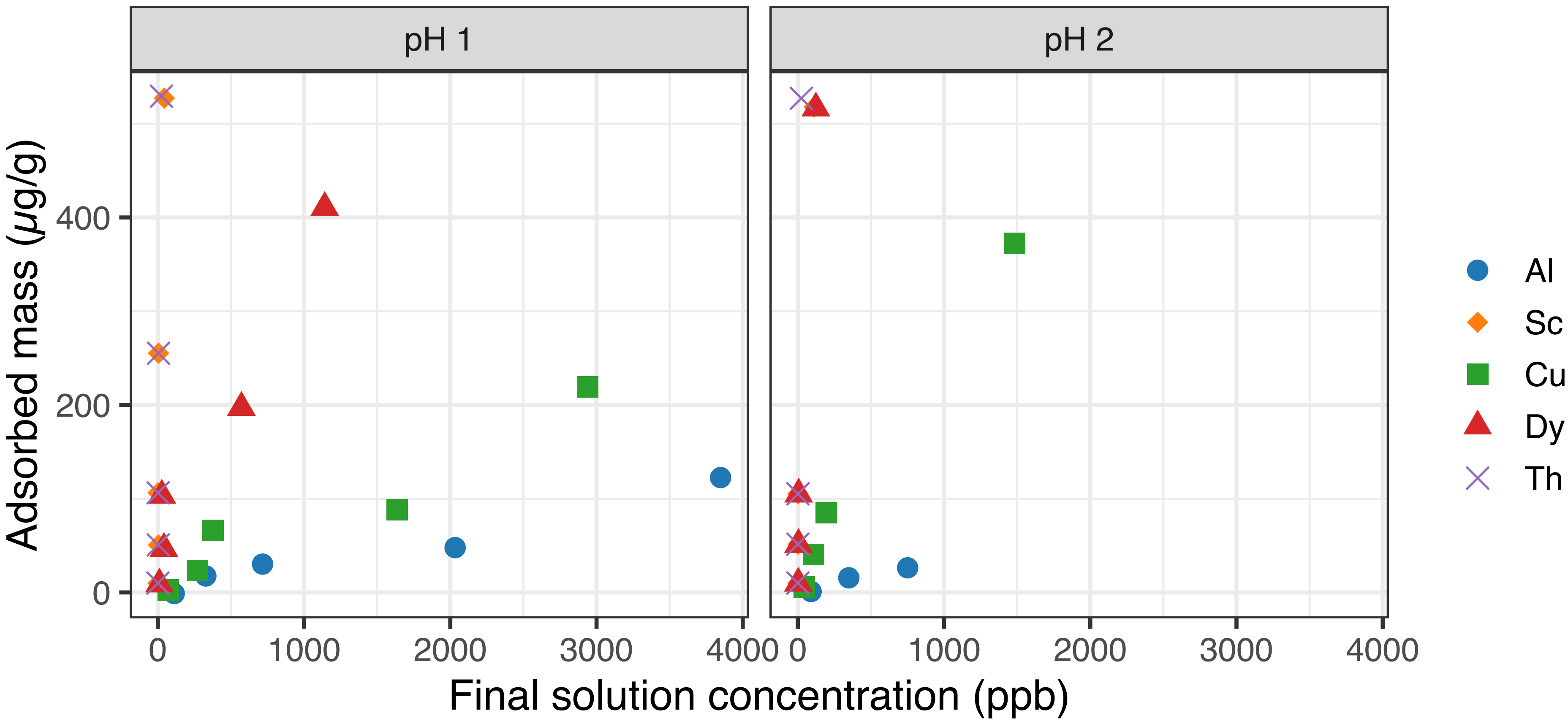
1° adsorbent demonstrates Sc+REE reactivity in strong acids and, critically, selectivity against Fe, Al



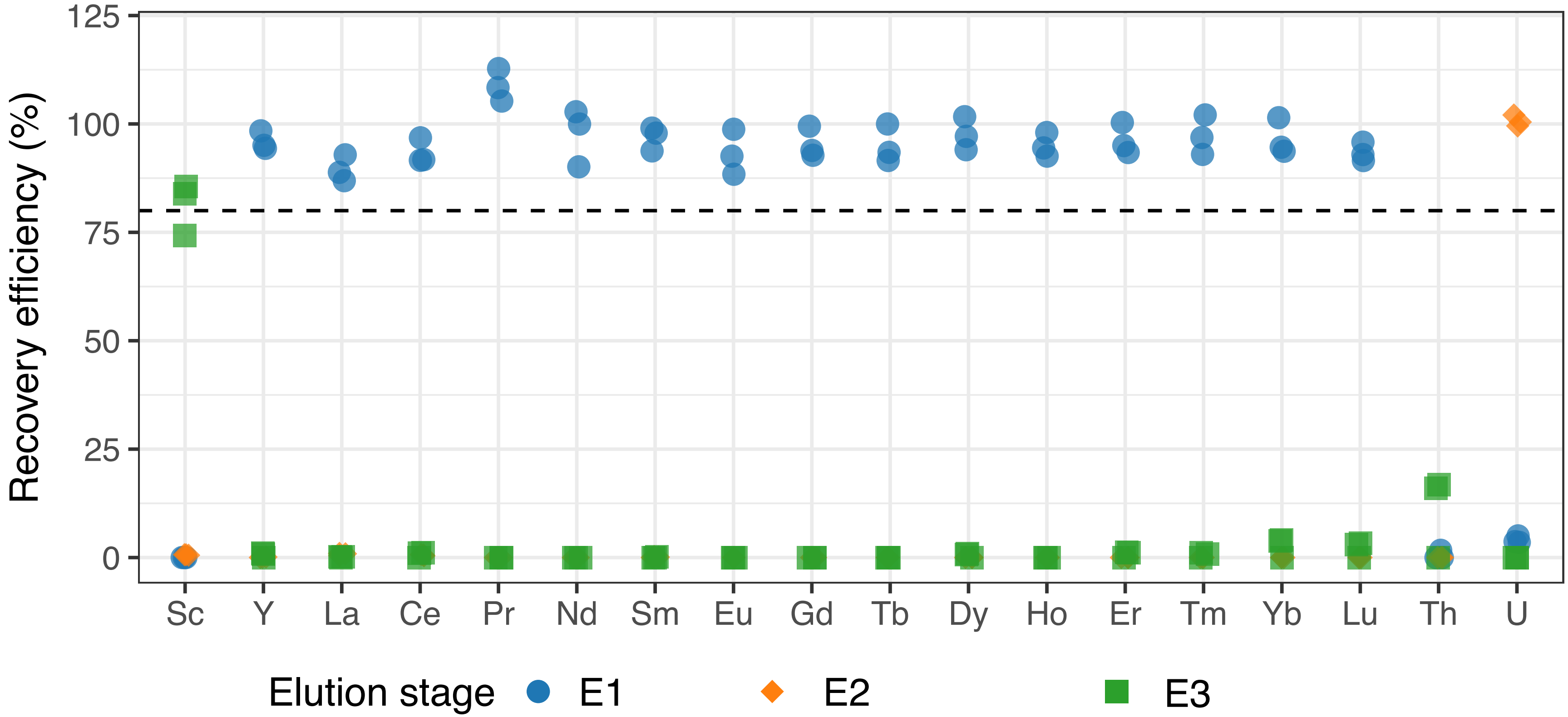
Selectivity and reactivity also demonstrated in real ash leachates



2˚ adsorbent demonstrates further selectivity and allows for facile Sc – REE separation



From 2° adsorbent, a 3-step elution and regeneration process yields separate, high purity mixed-REE and Sc phases



90x separation factor for Sc / Th+U

>300x for TREE / Th+U

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Sc recovery only truly valuable if ash remains/becomes salable

- Bare minimum requirement is to reduce TCLP-leachable metals
- For reuse, evaluate materials on two key components of ASTM C618
  - Residual carbon (loss on ignition, LOI)
  - Cementitious reactions (compressive strength)

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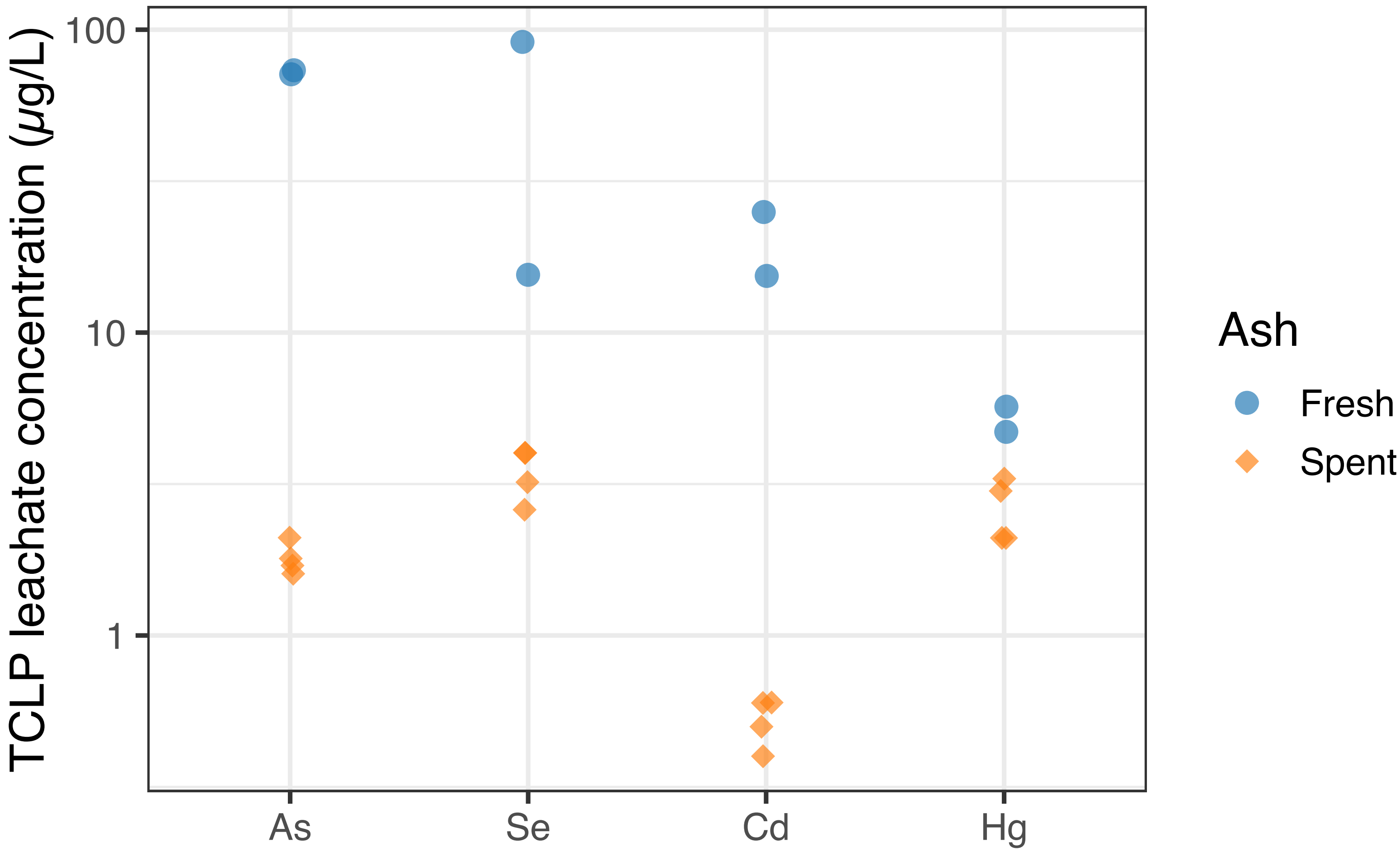
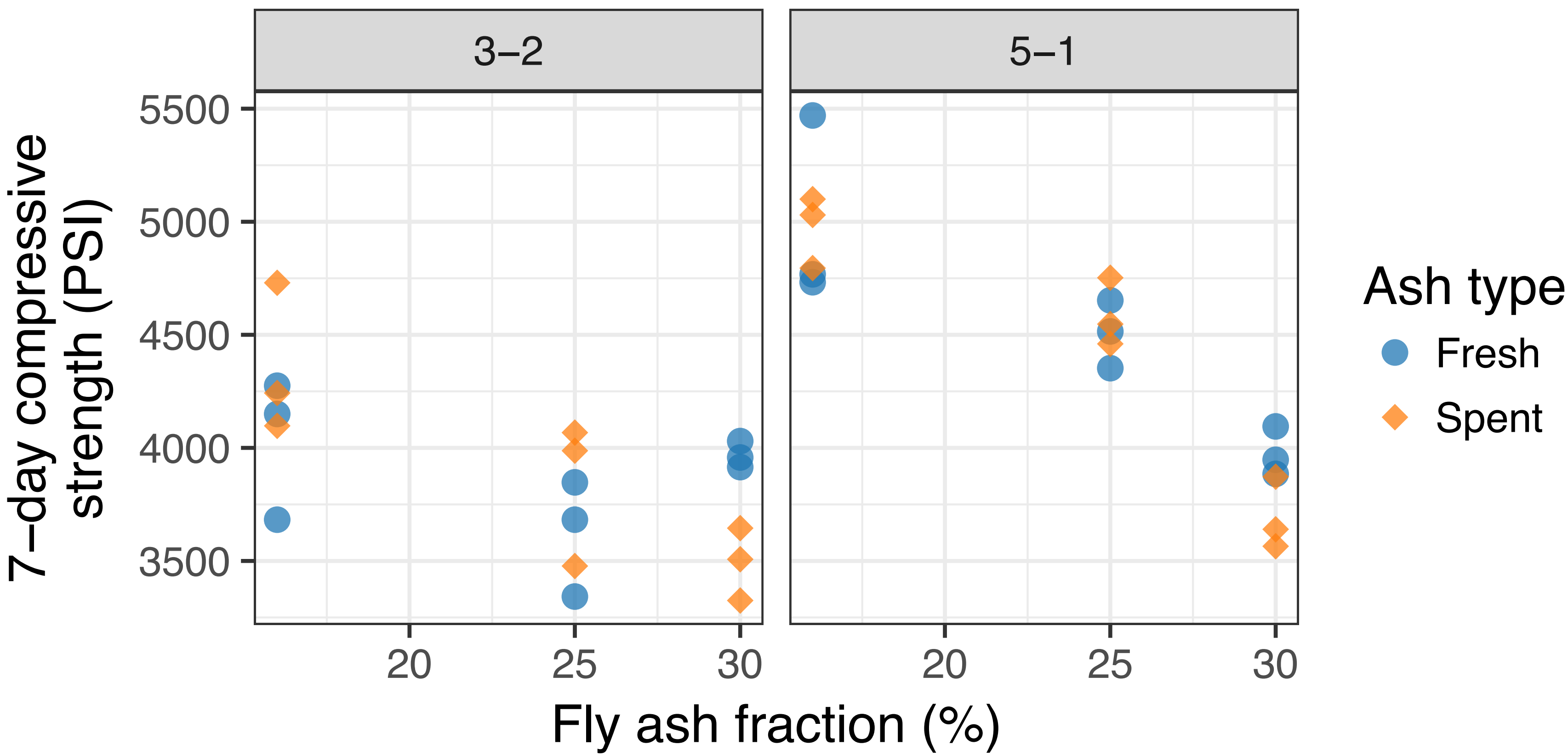
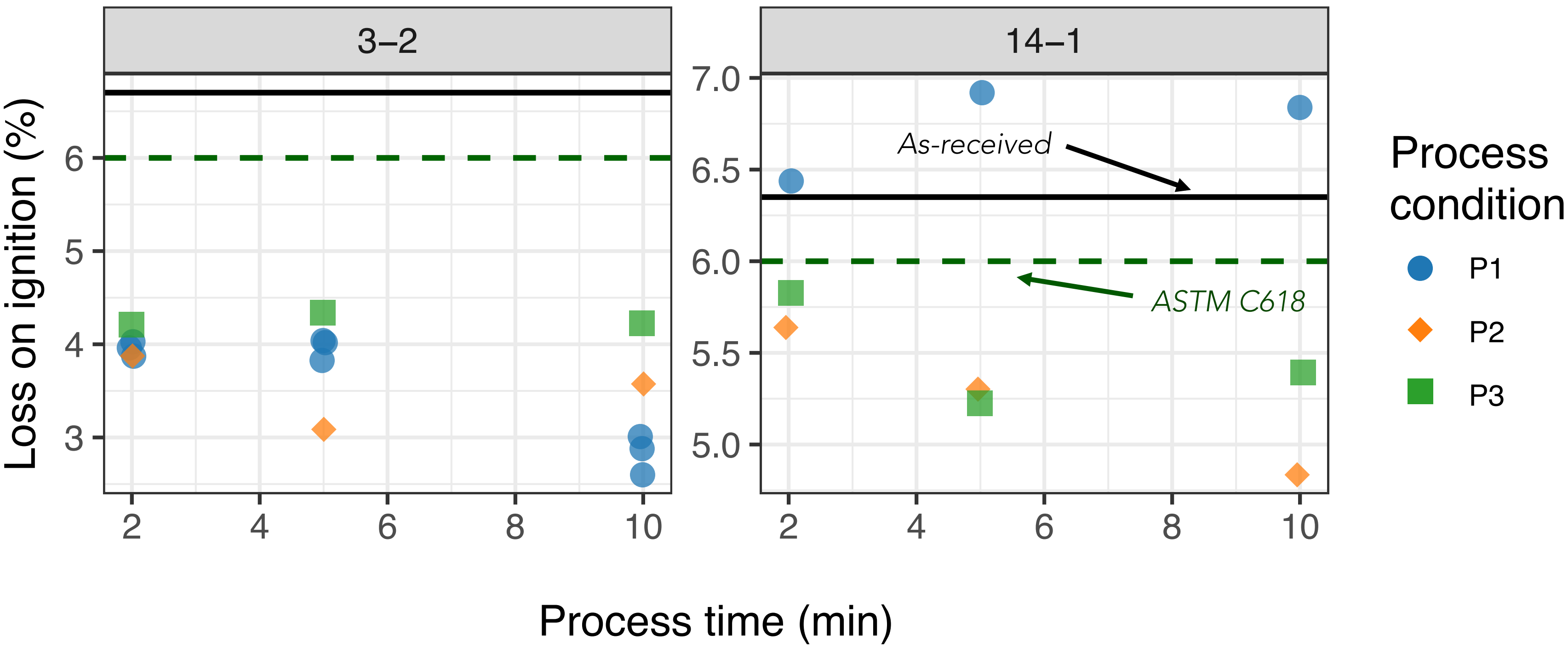
TCLP-extractable contaminants reduced 50-98% in process



Leaching process retains cementitious properties



Leaching process decreases LOI below ASTM threshold



Proof-of-concept demonstrated for waste ash to Sc + spec ash

- Novel hydrometallurgical process utilizing highly-selective adsorbents
- Further evidence of predominant silicate/ phosphate Sc+REE association
- Sc leachability and selective extraction over base/contaminant metals
- LOI reduction without loss of cementitious performance in processed ash

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Thank you!

If you would like to learn more about the commercialization of this process, contact us:

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