Plasma Arc Based Rare Earth Element Recovery from Coal Fly Ash

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Project Goals and Objectives (Phase 1)

- Overall Objective – pilot-scale thermal process to concentrate REEs from coal fly ash
- DOE Key Goal – final product(s) with mixed total REE 2 wt%
- Task 1 – Project Management Planning
- Task 2 – Sampling and Characterization of Proposed Feedstocks
- Task 3 – Feasibility Study
  – 3.1 Bench-scale Experimentation
  – 3.2 Computational Modeling
- Go/No-Go Decision Point
- Task 4 – Design Package for Phase 2 Pilot-Scale Unit
- Task 5 – Phase 1 Summary Report and Phase 2 Renewal Application

Presentation Outline

- Plasma-arc based recovery process technology
- Coal ash feedstock characteristics
- Bench-scale experiments
- Computational modeling study
- Simple Economic Analysis
- Preliminary Phase 2 pilot-scale design features
- Summary and conclusions

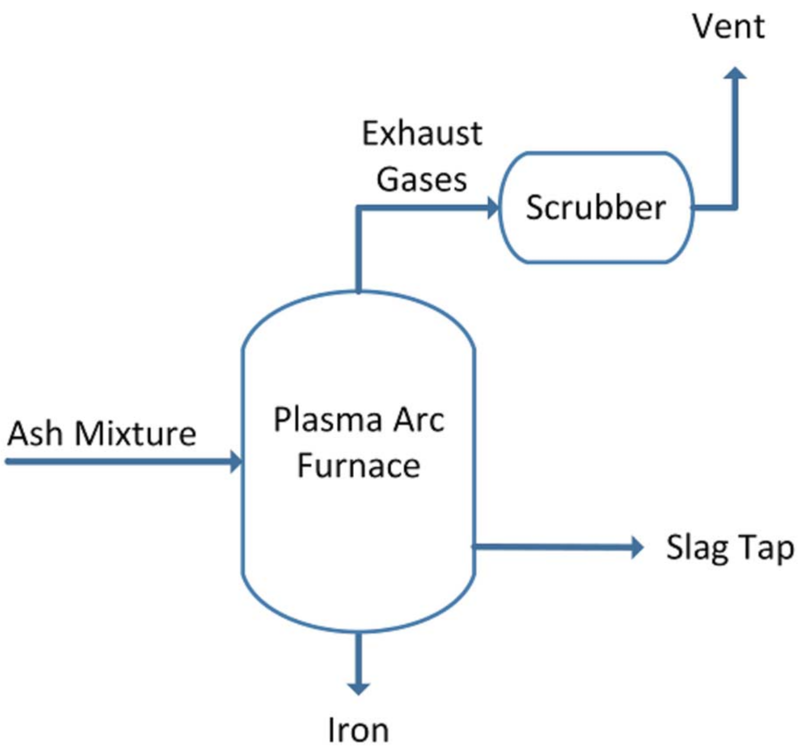
Proposed REE Recovery Technology

- Thermal process using plasma arc technology
- Two process options:

1 – Smelting ash into slag and metal fractions, REEs collect in metal.

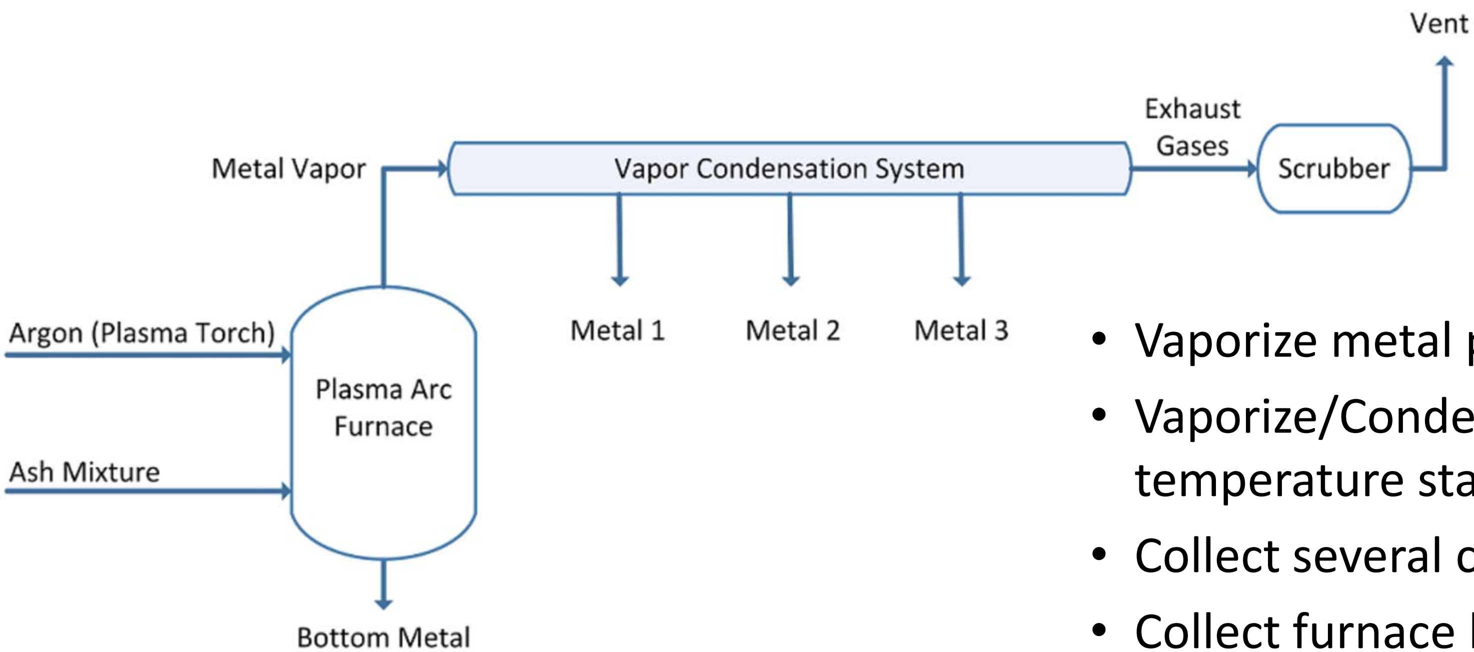
2 – Smelting + Vaporization/condensation of metal fraction to produce further REE enrichments.

Ash Smelting Process



- Heat ash mixture under reducing conditions to 1500 – 1900 C
- Reducing conditions
  - Addition of carbon reductant
  - Conducted in absence of air(O_2)
- Reduce Fe_2O_3 to iron metal
- Separate ash into slag and metal
- Reduce REOs, collect REEs in iron
- Goal: iron product with ~2 wt% REEs
- Bench-scale experiments for proof-of-concept

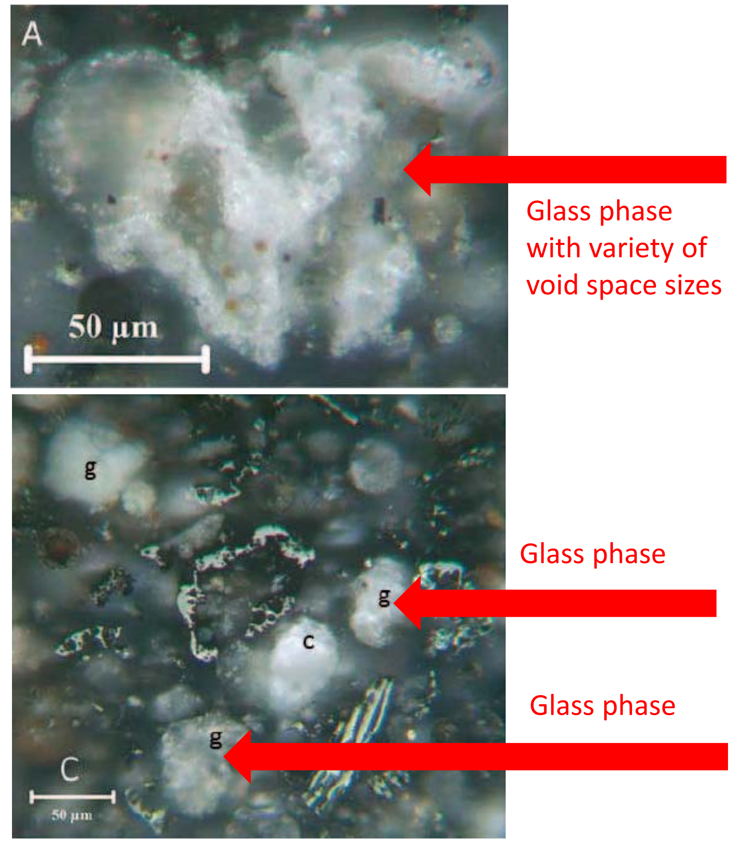
Smelting + Vaporization/Condensation



- Vaporize metal produced during smelting
- Vaporize/Condense at discrete temperature stages (2000 – 3000 C)
- Collect several condensed metal fractions
- Collect furnace bottom fraction
- Equilibrium and CFD modeling for Proof-of-concept

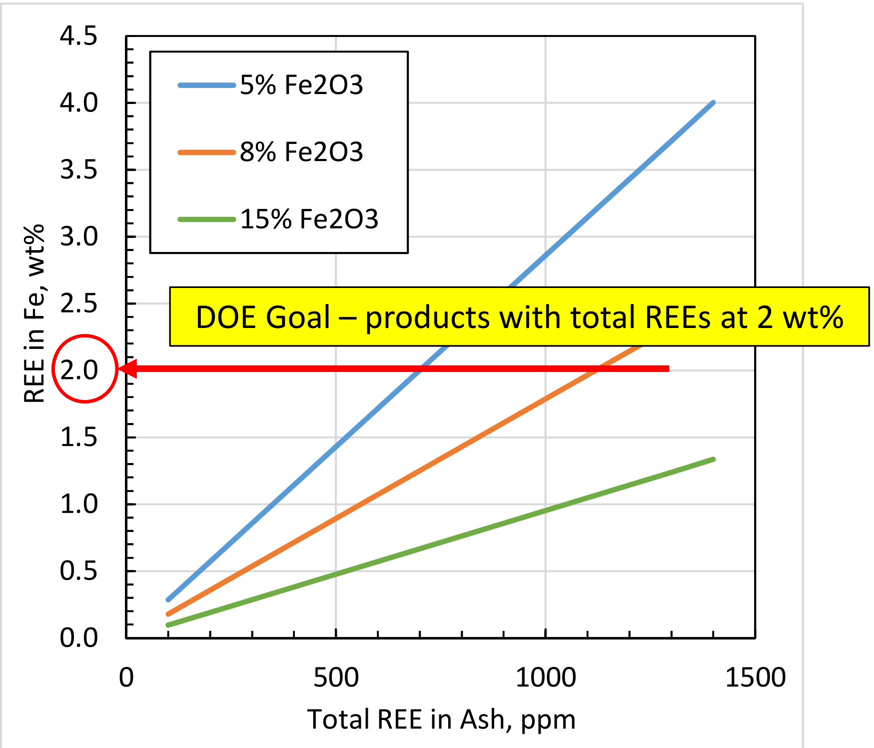
REE Occurrence in Coal Ash

- REEs are expected to behave similarly in combustion process.
- REEs are non-volatile and not found enriched on ash particle surface (Hower et al., 2013).
- REEs have been found evenly distributed in the amorphous glassy alumina-silicate phase of ash (Hower et al., 2013).
- Challenge - entire glassy phase would have to be leached to recover 100% REEs from CFA (Hower et al., 2013).



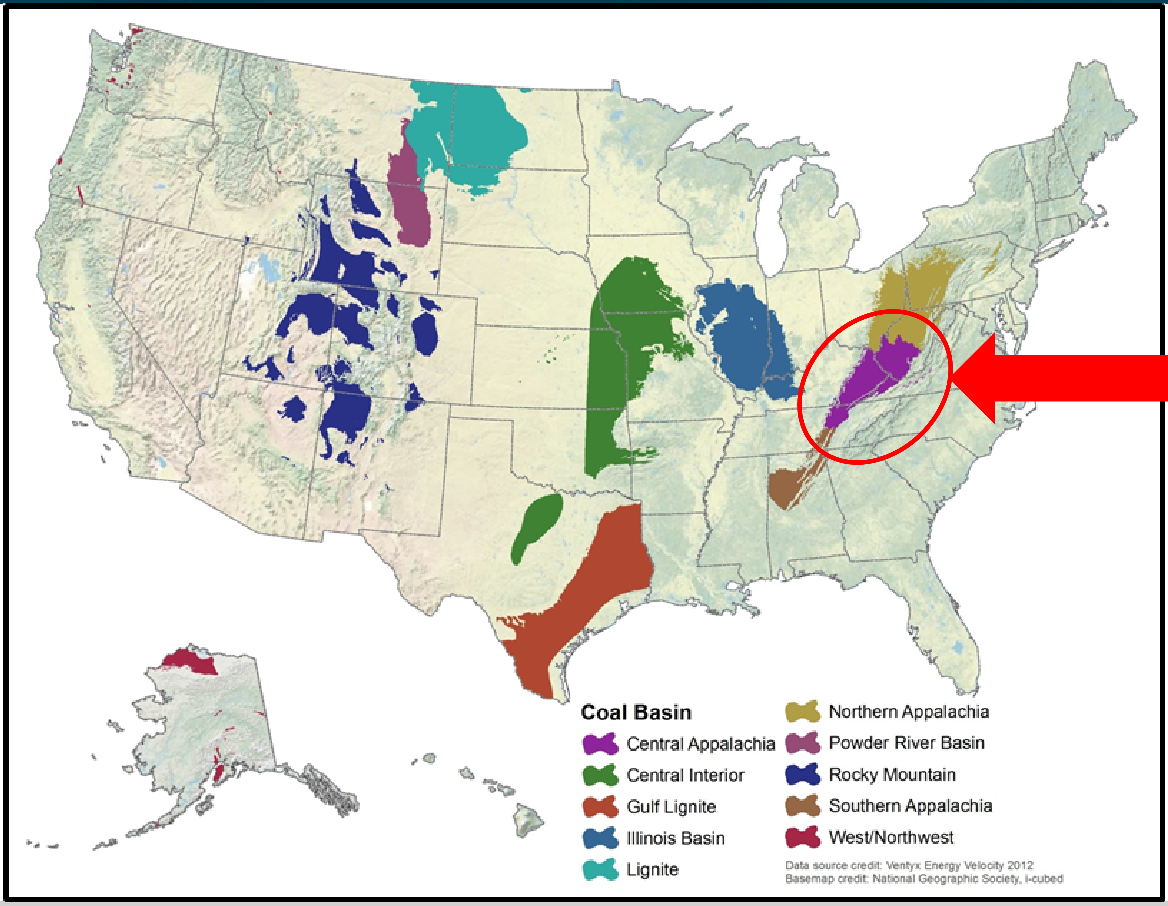
CFA SEM Graphic Source - Hower et al., 2013 Study

Coal Ash Feedstock Selection



- REE content in metal product depends on ash composition
- Total REE Content > 700 ppm (average ~500 ppm)
- Iron oxide content 5 – 8% (range is 4 – 25%)
- Best opportunity: ash from Central Appalachian coals

Coal Seams In United States



Central Appalachia Coal – total REE + Y concentrations as high as 1,668 ppm in coal fly ash from plants using this coal (Hower et al)

Graphic Source - ("Rare Earth Elements from Coal and Coal By-Products," 2016)

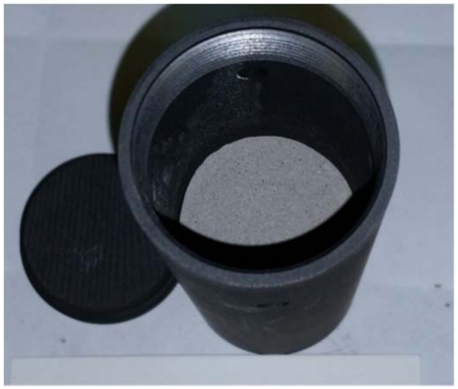
Smelting Experiments

Sample Mixtures

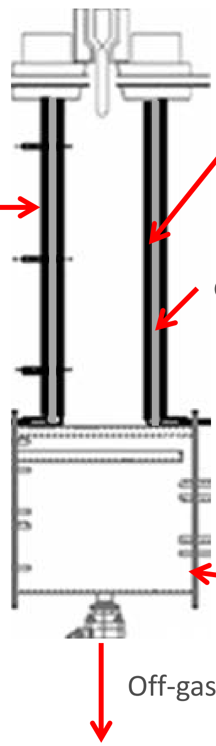
- Raw ash:
  - 400 – 1200 ppm Total REE
  - ~5% Fe_2O_3
- Fluxing agent (CaO/Lime)
- Reductant (activated charcoal)
- Supplemental metal

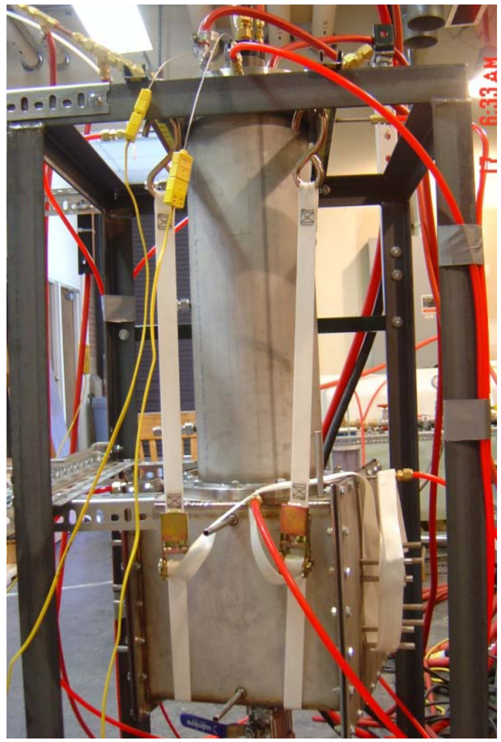
Key Processing Variables

- Smelting temperature
- Smelting time



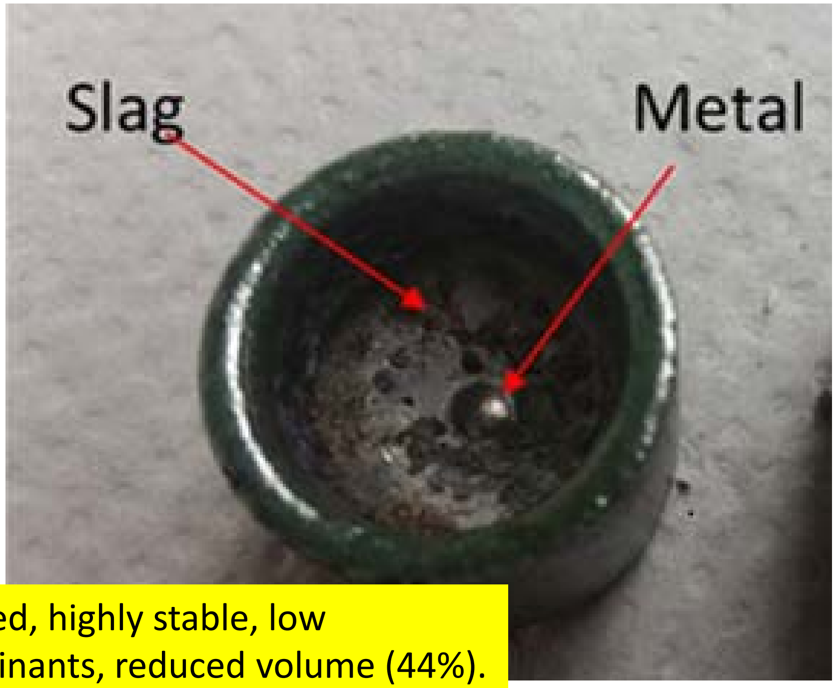
Bench-scale Plasma Reactor – U of UT





Water cooled reactor vessel

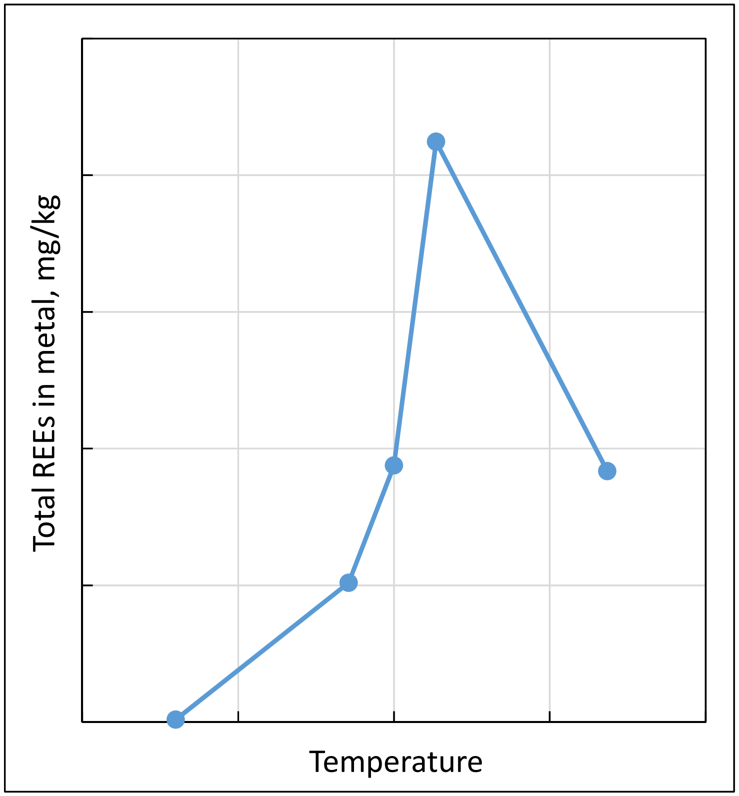
Slag-Metal Separation

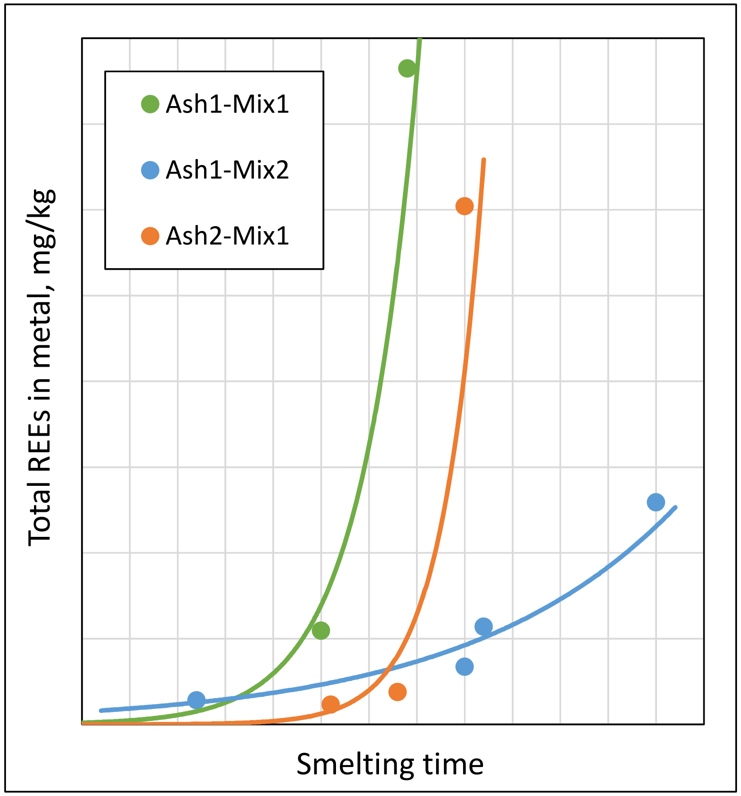


Slag compared to raw ash: vitrified, highly stable, low susceptibility to leaching contaminants, reduced volume (44%).

Metal and Slag portions analyzed for REE content using ICP-MS

Smelting Results





Vaporization/Condensation Modeling

Equilibrium Calculations

- Predict species in gas phase
- Determine potential separation of individual REE species

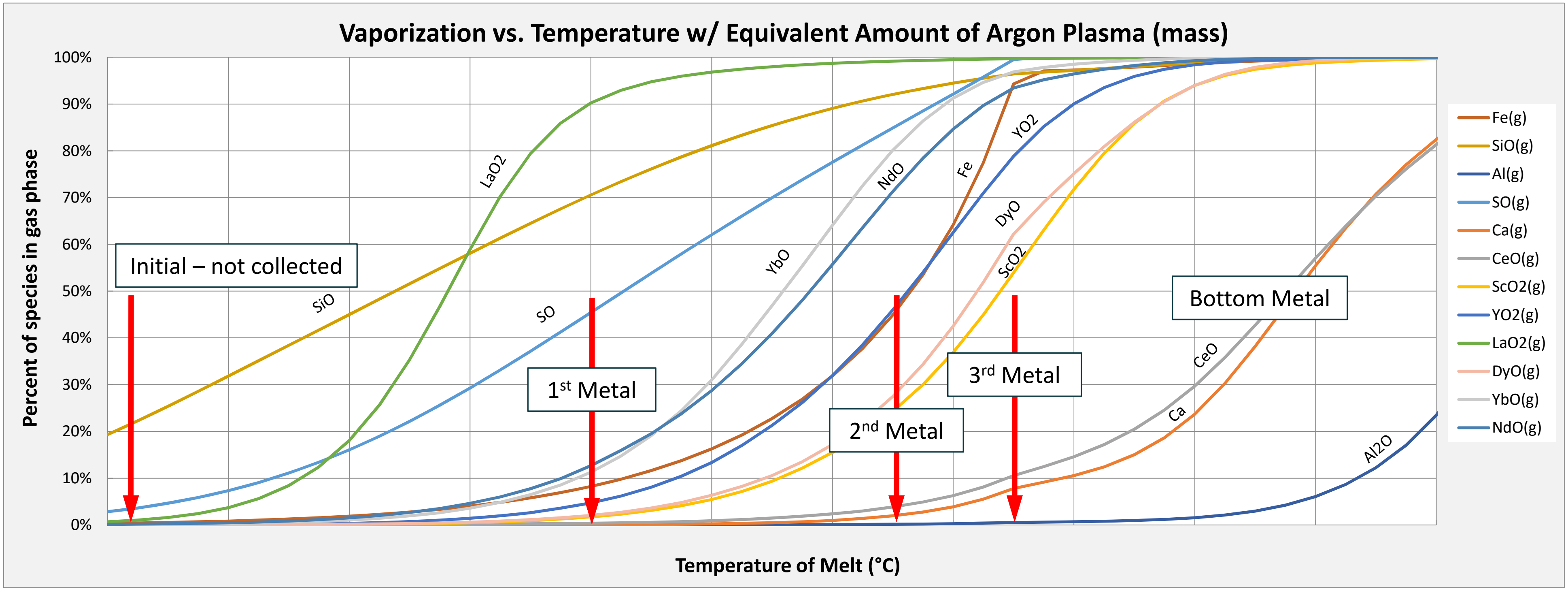
CFD Modeling

- Nucleation of metal fume particles
- Particle growth by coagulation
- Deposition on condenser surfaces

Output/Results

- Equilibrium gas phase composition vs temperature
- Select condensation temperature stages
- Composition of new condensed metal fractions
- Flow profile through the condensation/collection system

Equilibrium Calculations



Produced using Outotec HSC Chemistry 9.0

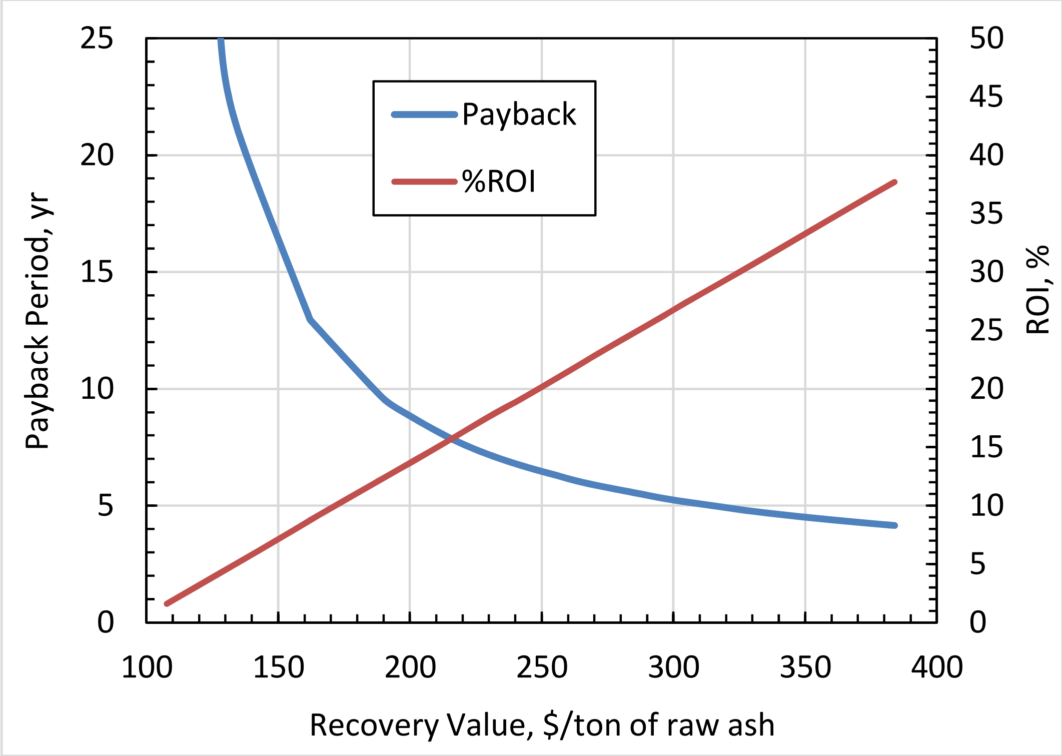
Modeling Case Study

Element	Enrichment: Concentration in metal product/concentration in raw ash			
	1st Metal	2nd Metal	3rd Metal	Bottom
Ce	0.5	1.4	2.1	95.1
Sc	2.4	9.2	9.3	48.9
Y	6.6	16.9	10.3	22.5
La	124.4	3.7	0.2	0.3
Nd	17.4	24.0	7.0	7.0
Dy	2.8	10.4	10.9	40.2
Yb	15.6	28.2	5.3	3.3
Total REEs, wt%	2.8	1.0	0.5	4.7

Base assumptions – starting ash with 1200 ppm total REEs, 50% REE recovery during smelting.

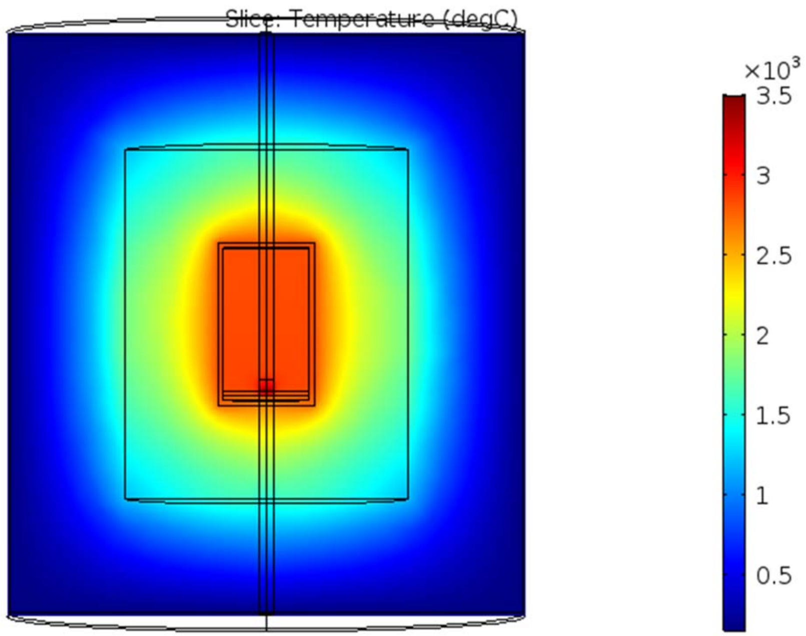
Simple Economic Analysis

- Full-scale unit
  - 350 tpd raw ash
  - Co-located at ~1000 MW power plant
- Value Streams
  - REEs
  - Metal (iron)
  - Slag for construction materials



Preliminary Phase 2 Pilot-Scale Design

- DC plasma arc furnace, graphite electrodes
- Thermal profile modeling – conduction and radiation
  - Insulation/refractory requirements
  - Overall furnace dimensions/weight
- Core crucible sizing
  - Feed/processing rates
  - Power requirements



Summary and Conclusions

- Smelting process is effective to separate ash into slag and metal
- Observed positive correlations between REE recovery and smelting time/temperature
- Vitrified slag environmentally benign compared to raw ash
- Vaporization/Condensation process modeling demonstrated
  - Individual REE separations achievable
  - Metal fractions with higher REE enrichments produced
- Economic potential
- Iterative process for pilot-scale plasma furnace design

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Thanks for Listening! Questions?

SOUTHERN RESEARCH

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