Mitigation of Aerosol Impacts on Ash Deposition and Emissions from Coal Combustion

FE00031756 2021 Project Review Meeting

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Project team and contributors

Project team

- Barr Engineering Co. (Barr)
- University of North Dakota (UND)
- Envergex LLC
- Microbeam Technologies Inc. (MTI)
- Milton R. Young Station (MRY)
- MLJ Consulting, LLC

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- National Energy Technology Laboratory - U.S. DOE
- Minnkota Power Cooperative
- North American Coal
- Coyote Station
- Lignite Research Program - North Dakota Industrial Commission

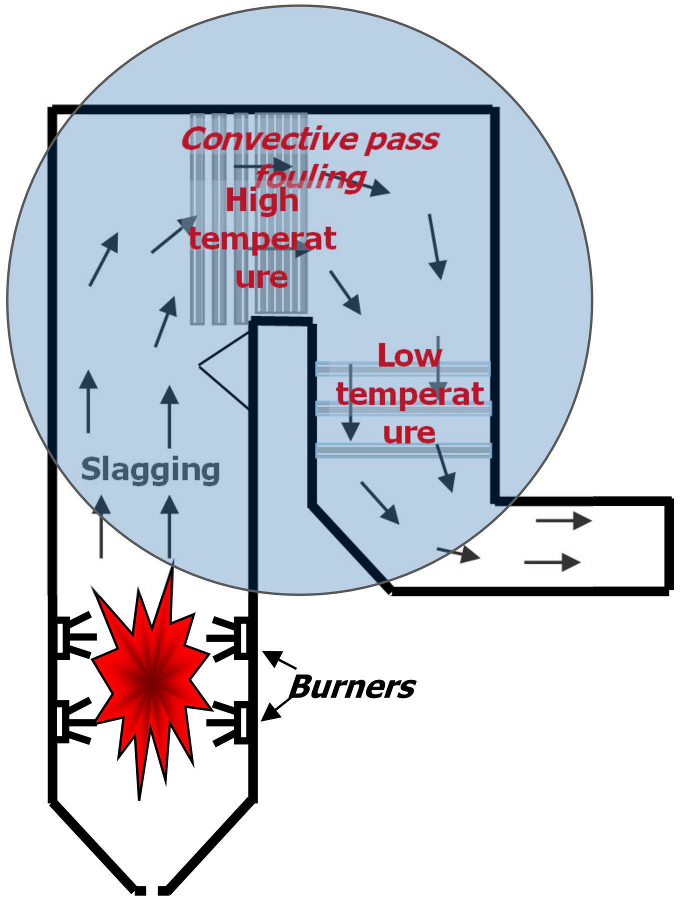
MLJ Consulting

Agenda

- Background
- Budget Period 1 Objectives / Milestone Schedule
- Results Task 2: Lab Test Overview / Conclusion
- Results Task 3: Modeling Overview / Conclusion
- Results Task 4: Demonstration Overview / Conclusion
- Budget Period 1 Success Criteria and Results
- Budget Period 2 Objectives / Milestone Schedule
- Budget Period 2 Success Criteria
- Questions

Background

- DE-FOA-0001989 “IMPROVING EFFICIENCY, RELIABILITY, AND FLEXIBILITY OF EXISTING COAL-BASED POWER PLANTS” -Area of Interest 2 Subtopic 2A: High-Fidelity Field Testing of Technologies
- Problem: Coals containing high alkali are known to form low-melting point-ash particles that lead to higher ash-deposition rates, and fine particulate emissions which results in reduced boiler efficiency and capacity and increased O&M time and cost.
  - Current technologies such as targeted in-furnace injection (TIFI) or thermal shock by load cycling are either too costly or less effective for high-sodium lignite.
  - Other technologies show promise for alkali capture like Koalin injection, but high delivered cost, including cost of transportation, is a factor.



From Microbeam Technologies Inc.

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Background

- Goal: Field test and advance a technology to mitigate ash fouling and aerosol emissions with sorbent injection in coal-fired utilities with high-alkali fuel resulting in reduction of plant O&M cost and increase of fuel usage flexibility.
- Approach: Bench, CFD Modeling, Preliminary Design, Parametric and Extended Field Testing at Minnkota 250 MW Site, Cost Review, and Final Reporting
- Budget – $4,996,410 Total Cost
- Budget Period 1 (BP1); Lab Testing and Modeling
  - October 2019 – March 2021 (approx. 30% budget)
  - Go / No Go before progressing to next budget period
- Budget Period 2 (BP2); Field Demonstration
  - April 2021 – September 2022 (approx. 70% Budget)
  - Go / No Go before progressing to extended field testing

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Significant Findings after Budget Period 1

- Sorbents are effective in capturing and inerting alkali compounds on bench-scale combustor
  - Optimal sorbent recommended for further evaluation on demonstration site
- Boiler CFD modeling indicates methodologies for sorbent injection with adequate dispersion
- Commercial equipment is available to process sorbents to suitable size and inject in optimal location
- Recommend to move forward with field demonstration

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Background: Plant Challenges

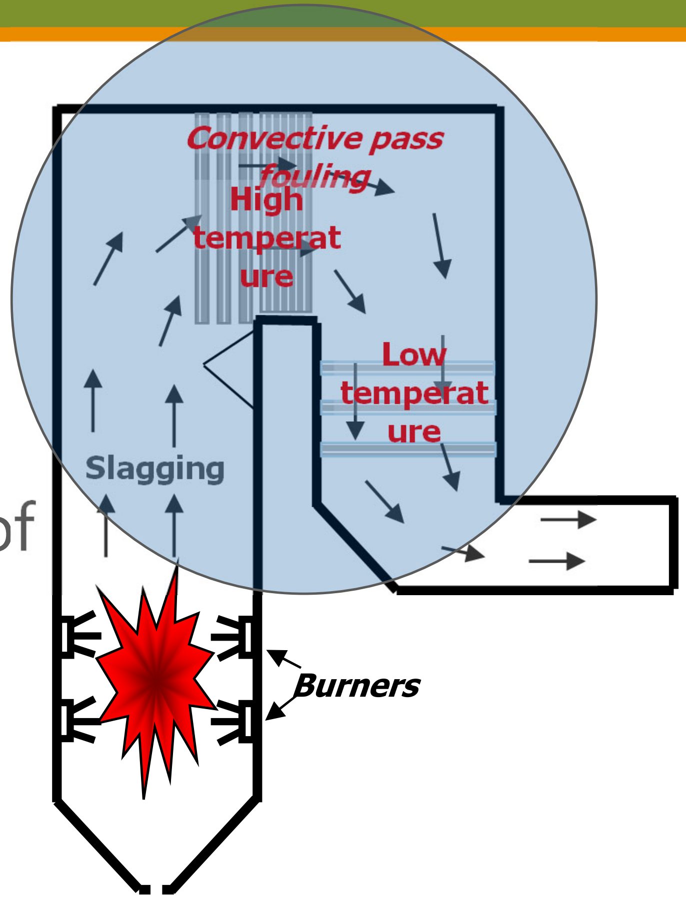
In cyclone boilers, up to 70% of the ash is trapped as a molten slag (less for lignite), and >30% is transported as entrained fly ash into the main boiler section (more for lignite).

1. *High temperature fouling*. Occurs with inertial and turbulent transport deposition of alkali silicates in regions of the boiler with temperatures of 1600 – 2400°F.

2. *Low temperature fouling*. Occurs with heterogeneous condensation as alkali sulfates in the convective section of the boiler 1000 – 1700°F.

3. *Fine particulate emission*. The sub-micron alkali aerosols are captured with only a moderate efficiency (~90%) by electrostatic precipitators (ESP). For particles from .6 to 1 micron, it is significantly less.

– EPRI: Annual economic impact of fouling and other ash behavior to the US coal-fired power industry = $1.2 billion (EPRI, 2007)



From Microbeam Technologies Inc.

Background: Past Issues Ash Formation

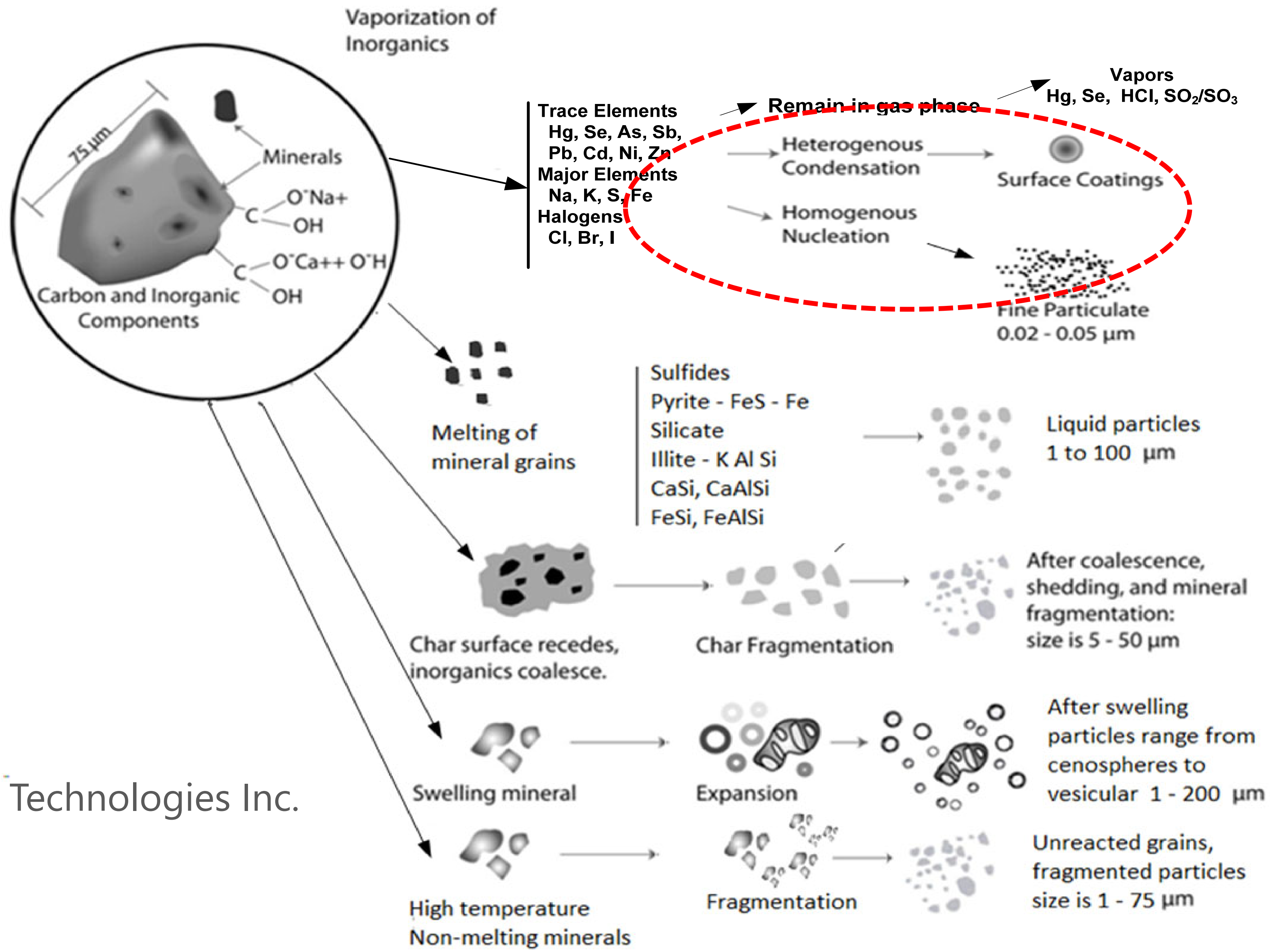


Image from Microbeam Technologies Inc.

Background: Partitioning of Na, SO_3 (MTI & UND Study)

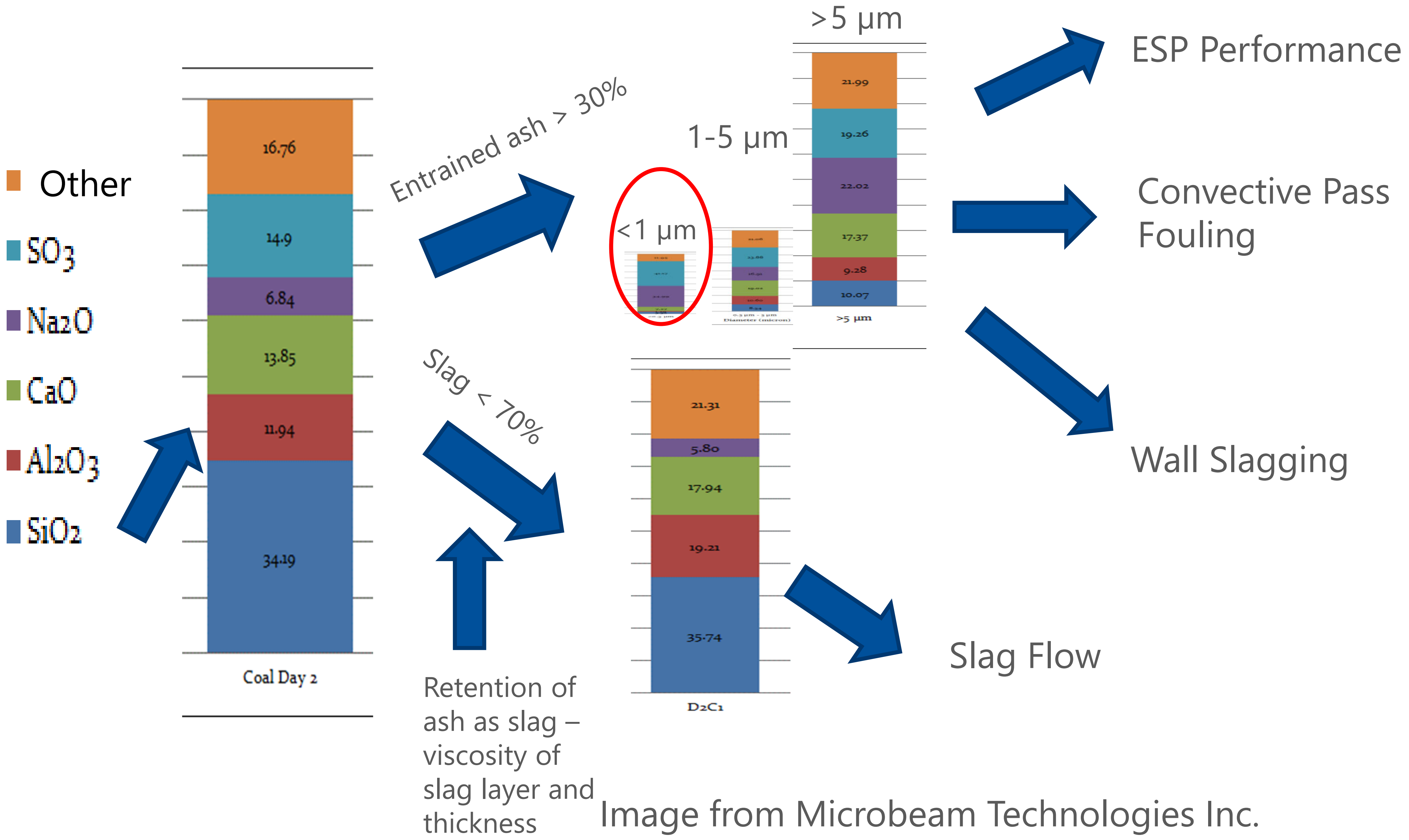


Image from Microbeam Technologies Inc.

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Objectives – Budget Period 1

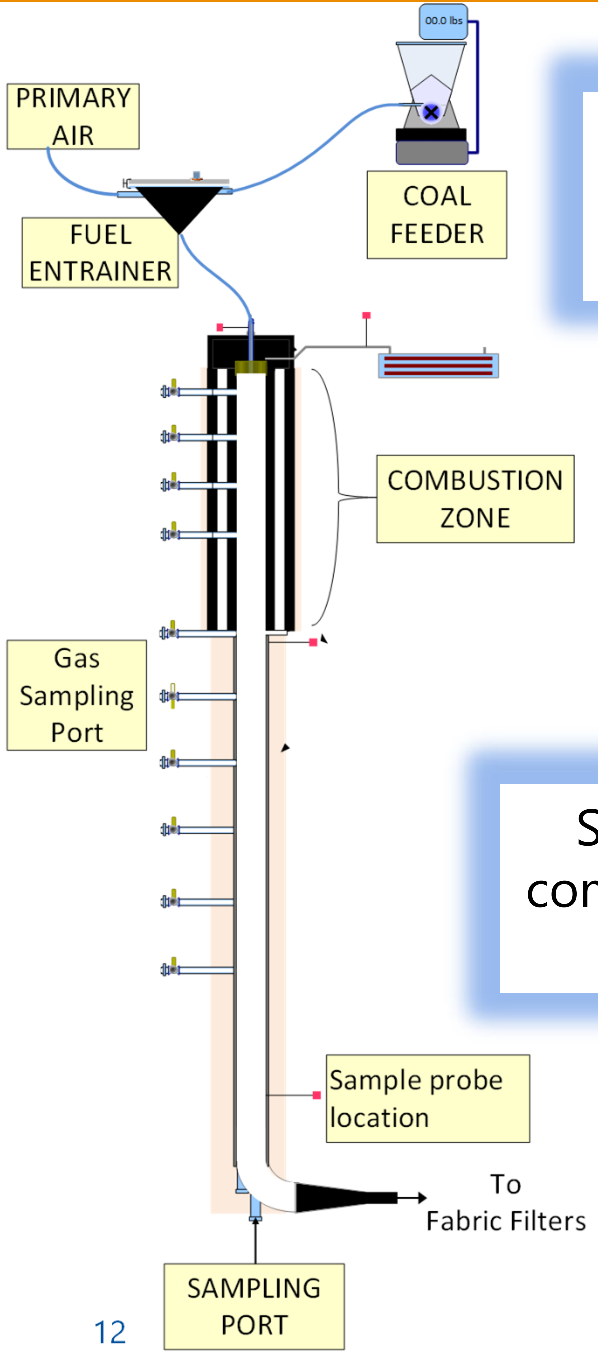
Budget Period 1 (October 2019 – March 2021)

- Task 2 – Lab Testing
  - Gather and Characterize Feedstock (Various Sorbents, Lignite Coal)
  - Equipment Setup at UND
  - Testing / Data Reduction
- Task 3 – Modeling / Mesh Structure
- Task 4 – Demonstration Equipment Preliminary Design and Procurement
- Accomplish Success Criteria to Continue to Budget Period 2 (December – March 2021)

Task 2: UND Lab-Scale Testing

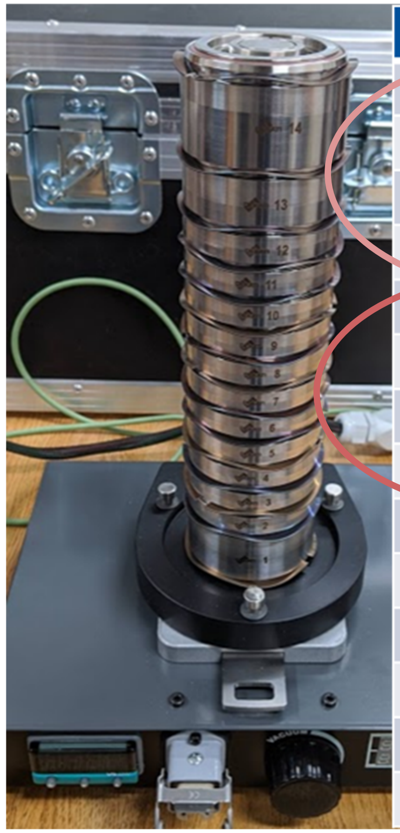
Lab Testing (Task 2) – Objective: Show Na Capture Bench-Scale

Combust coal blended with sorbents



UND Combustor

Sample combustion ash

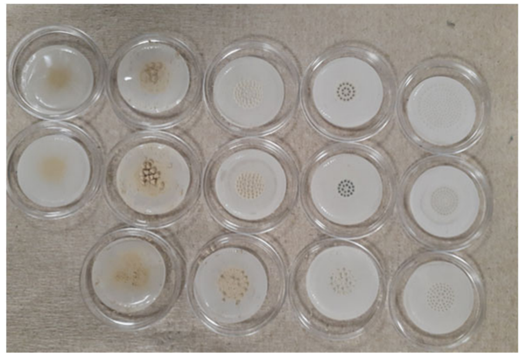


Stage	D50% (µm)
1	0.015
2	0.031
3	0.054
4	0.095
5	0.16
6	0.26
7	0.38
8	0.61
9	0.96
10	1.6
11	2.5
12	3.7
13	5.4
14	9.96

Sorbent segregate sodium from fine size bins to larger particle bins

Dekati® Low Pressure Impactor

Ash collected on filters



Filters digested and analyzed by ICP-OES

Agilent 5110 ICP-OES

Lab Testing (Task 2) – Gather/Characterization: Coal

- Two coals obtained – from two mines
- Confirmed coal samples obtained optimal for testing based on proximate/ultimate/ash composition, mineral analysis – CCSEM, organically associated elements – chemical fractionation
- Pulverized and stored coal for testing
  - Mineral analysis performed on coal to determine if oxidation of minerals occurred during storage
- Proximate (left) and ash (right) analysis on a dry basis:

	Mine 1	Mine 2
Ash	9.5	11.2
Volatile	44.9	43.6
Fixed Carbon	45.6	45.2
BTU/lb	11,016	10,979
Total Sulfur	0.8	1.3

	Mine 1	Mine 2
Na_2O	9.7	9.13
K_2O	0.72	0.79
SiO_2	21.8	22.8
Fe_2O_3	6.54	12.00
CaO	20.6	15.3
Al_2O_3	12.97	10.25
SO_3	19.5	23.3
Base/Acid	1.23	1.25

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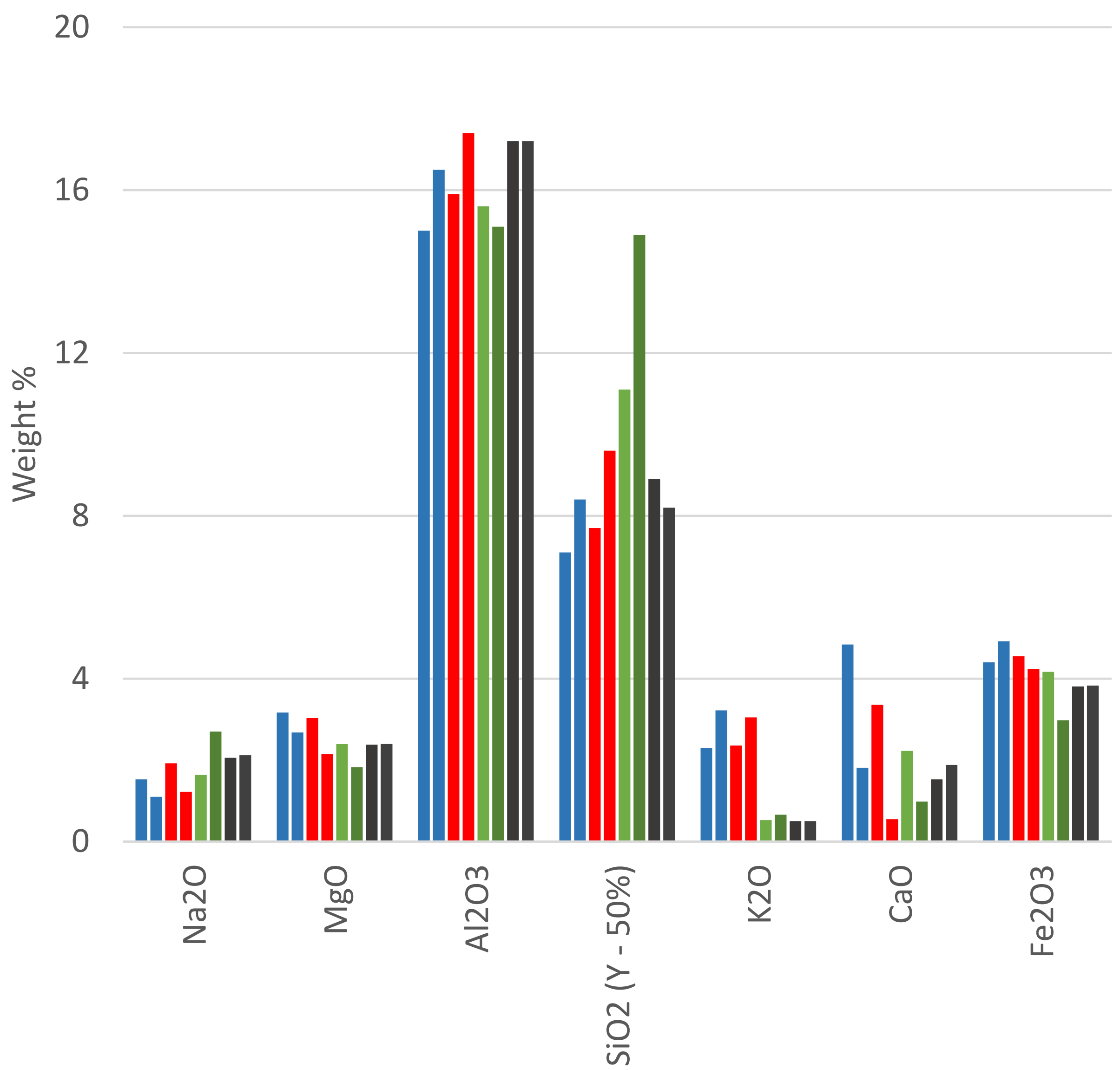
Lab Testing (Task 2) – Gather/Characterization: Sorbent

- Developed screening method based on composition and particle size
- Performed XRD / XRF analysis on sorbents
- Performed CCSEM analysis on sorbents
- XRF provides oxide composition
- Evaluated grindability
- Selected optimal sorbents for testing
- Processed sorbents at desired size for testing.



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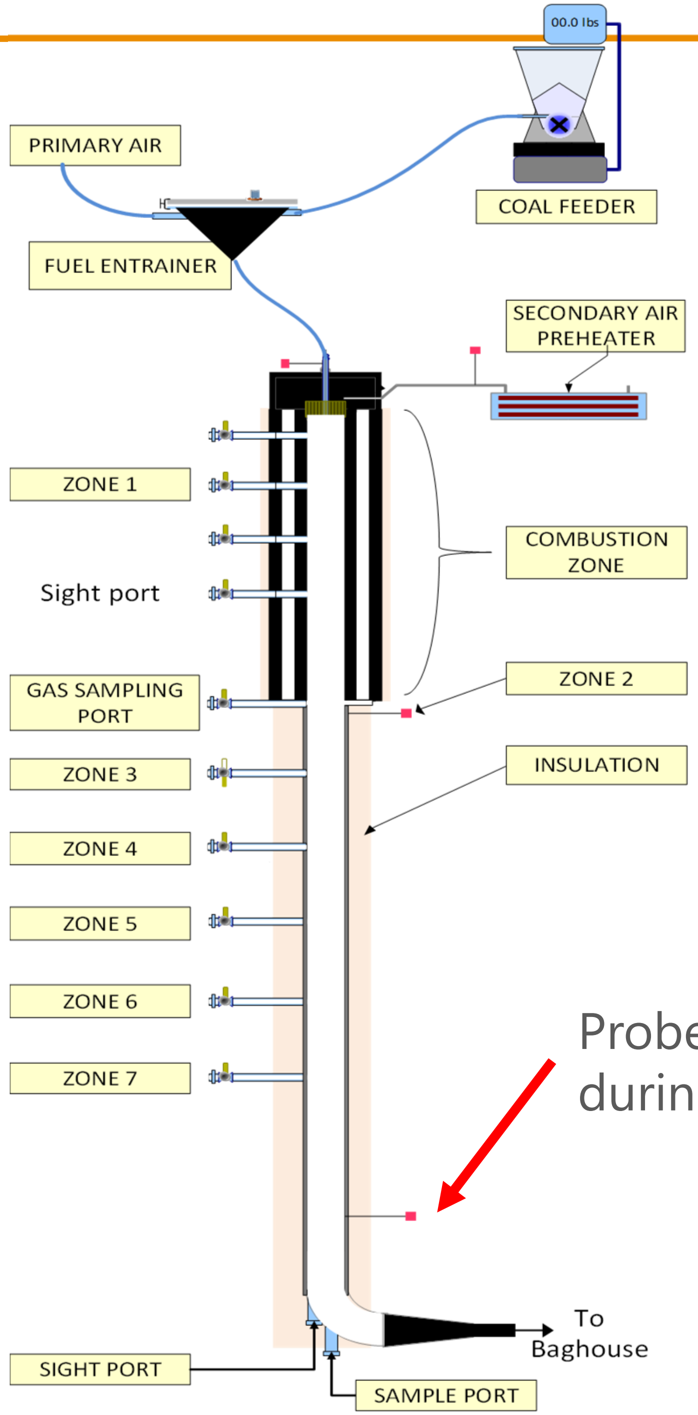
Lab Testing (Task 2) – Equipment Setup at UND



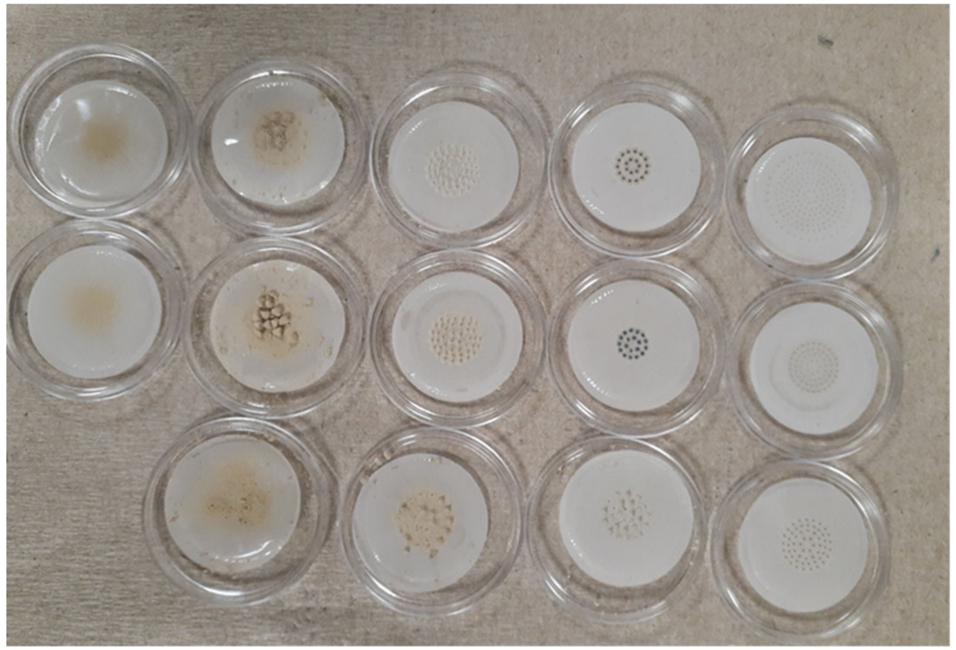
Probe position during sampling

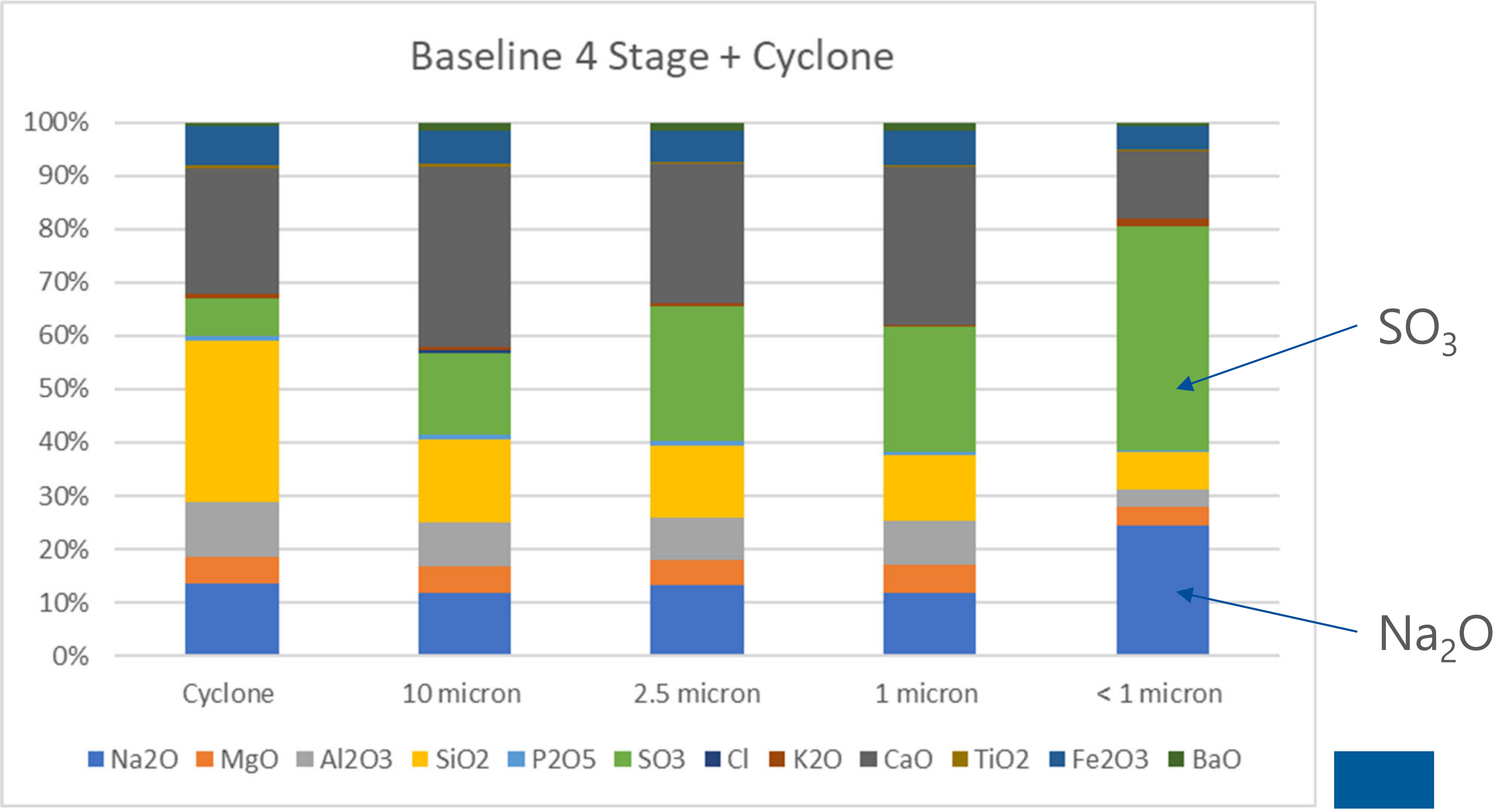
Lab Testing (Task 2) – Test Matrix

Phase	Coal	Sorbent	Particle Size	Status
1	Mine #1	None / Baseline	N/A	Completed in October 2020
		Commercial Sorbent #1	Fine	Completed in December 2020
		Commercial Sorbent #1	Coarse	
		Commercial Sorbent #2	Fine	
		Commercial Sorbent #1 Demonstration Grind Test Vendor #1	Coarse	
		Commercial Sorbent #1 Demonstration Grind Test Vendor #2	Coarse	Completed in March 2021
2	Mine #1	Mine #1 Local (1)	Fine	Completed in December 2020
		Mine #1 Local (2)	Fine	
		Mine #1 Local (5)	Fine	
3	Mine #2	None / Baseline	N/A	Completed in January 2021
		Mine #2 Local (10)	Fine	Completed in March 2021
		Mine #2 Local (11)	Fine	
		Mine #2 Local (12)	Fine & Coarse	

Lab Testing (Task 2) – Establish Baseline Results Phase 1 & 2

- Composition of 4-stage impactor for baseline and the addition of sorbents





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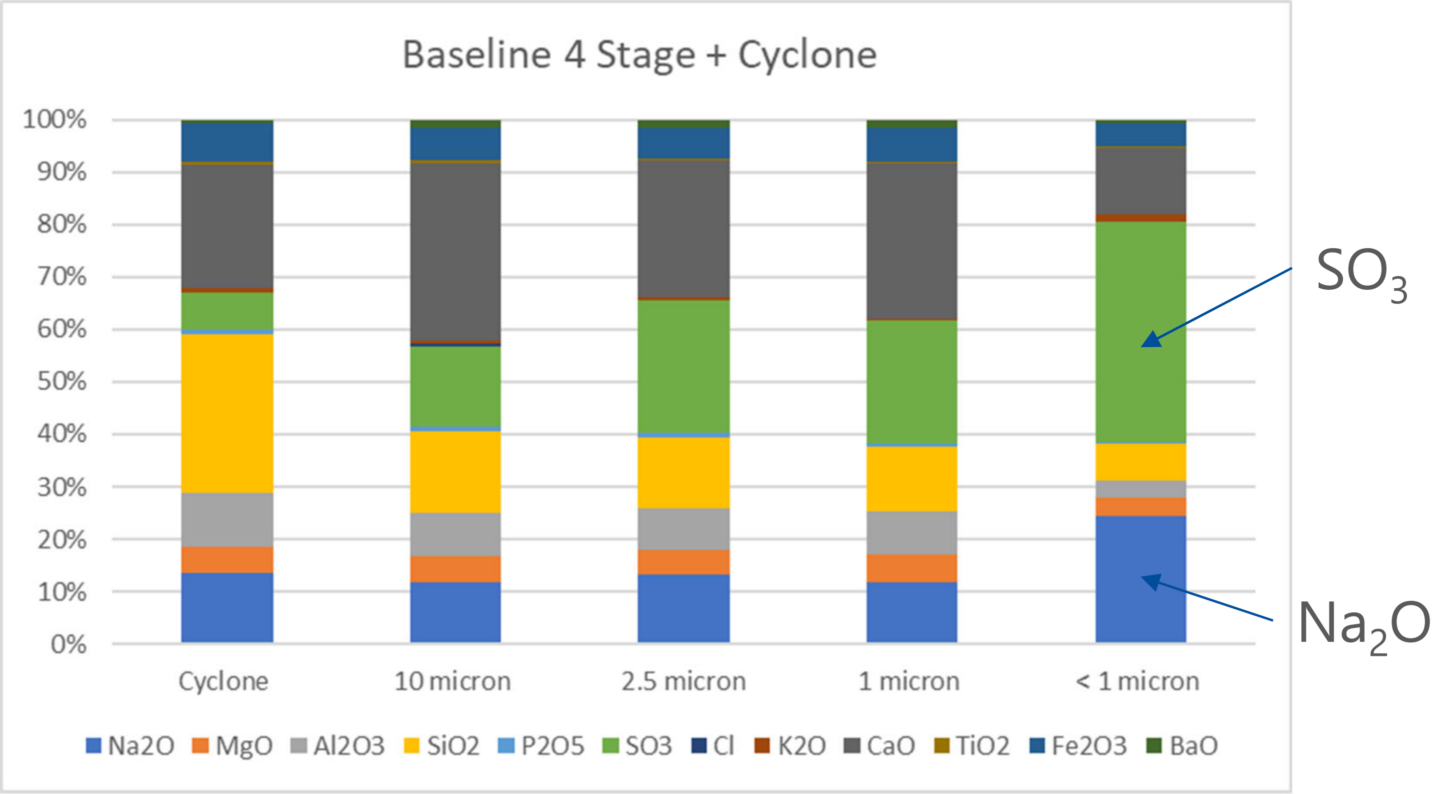
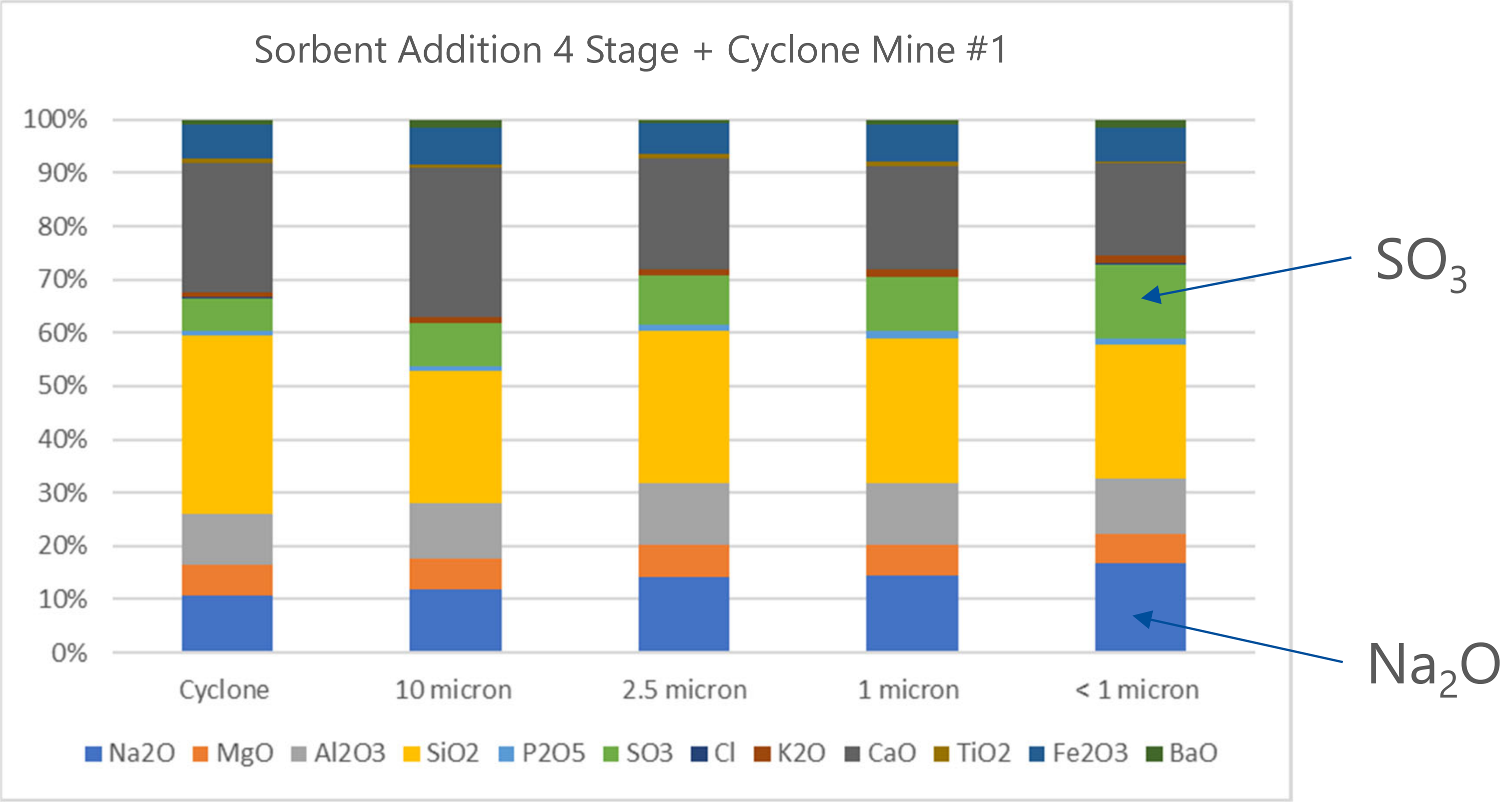
Lab Testing (Task 2) – Baseline vs. Sorbent Injection Mine #1 Results Phase 1 & 2





Reduction in sulfur levels in the <1μm ~66%
Reduction in sodium levels in the <1μm ~32%

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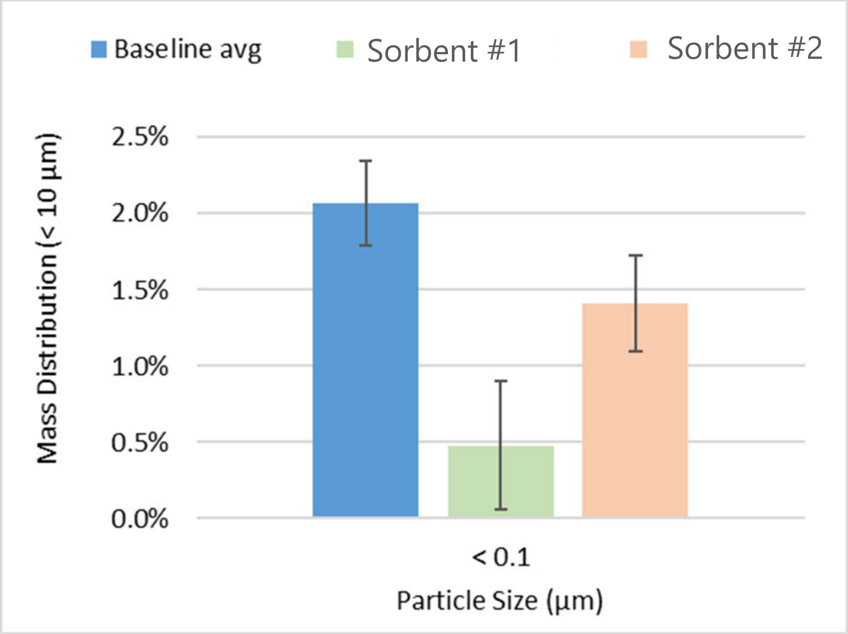
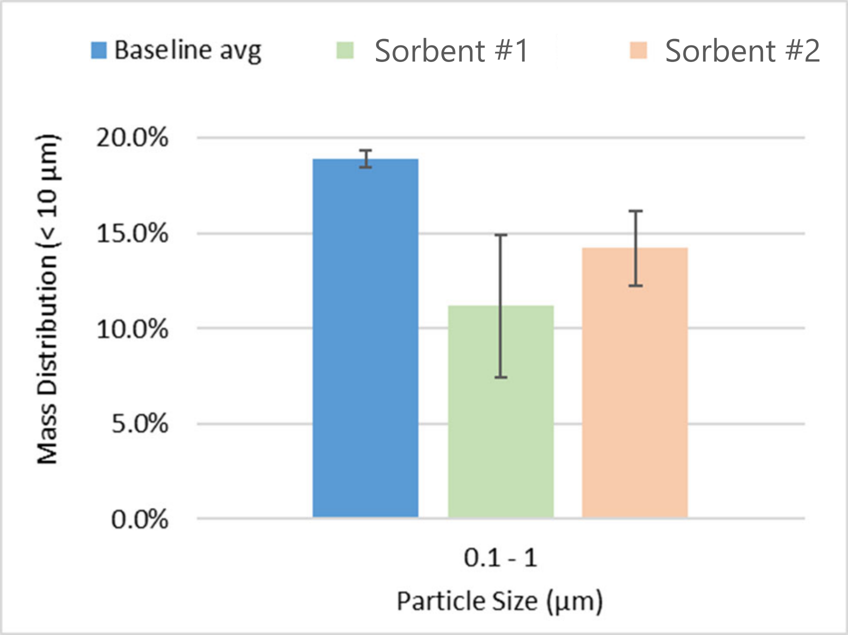
Lab Testing (Task 2) – Mine #1 Results Na & Ash PSD Phase 1 & 2

Sodium Distribution

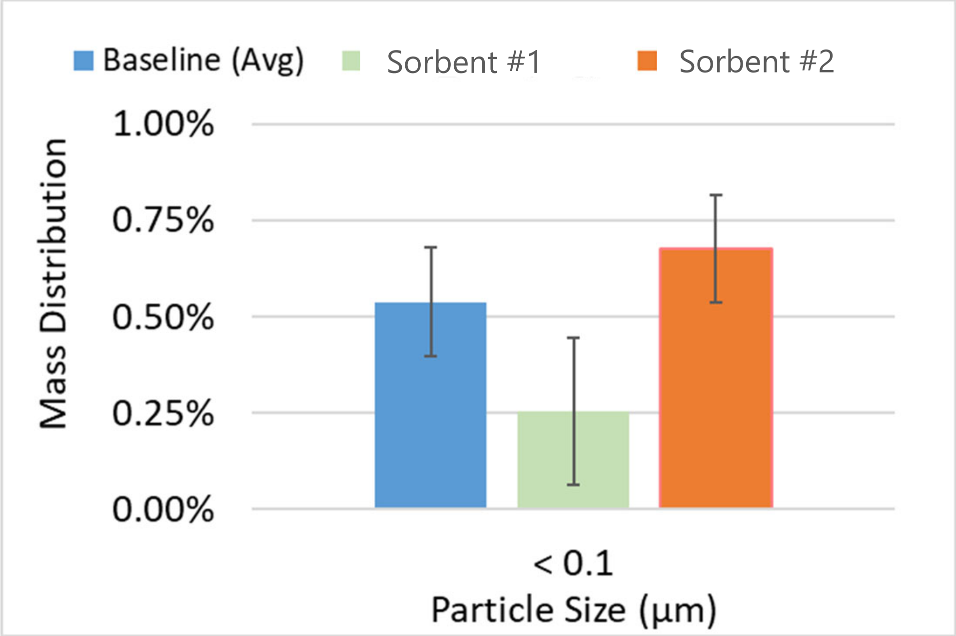


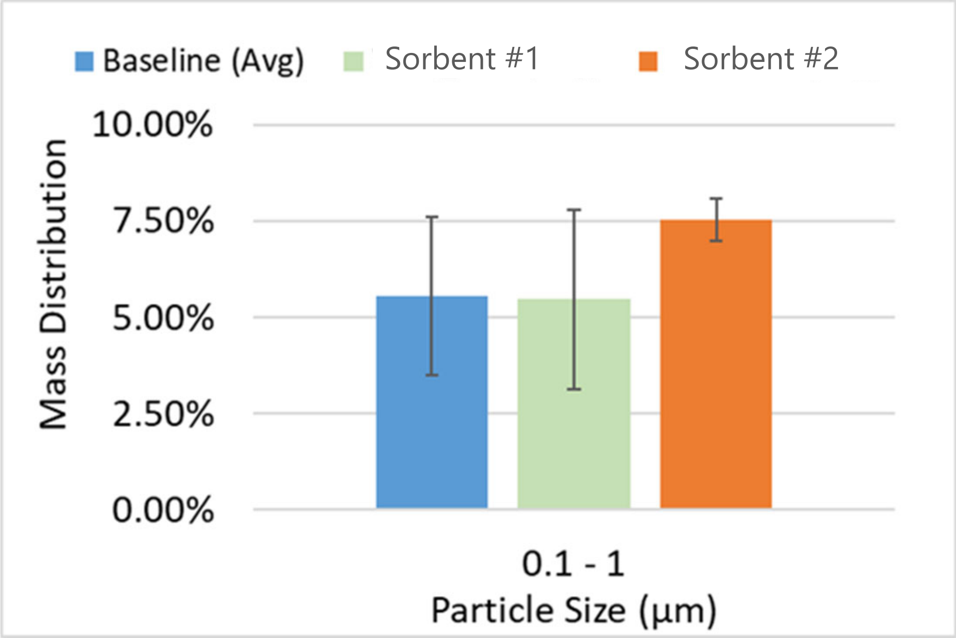


Key Observations:

- PSD between Sorbent #1 & 2 is similar (Table)
- Sorbent #1 reduction 41 – 77%
- Sorbent #2 reduction less than 20%
- **Sorbent #1 Selected for Demonstration**

Ash Distribution



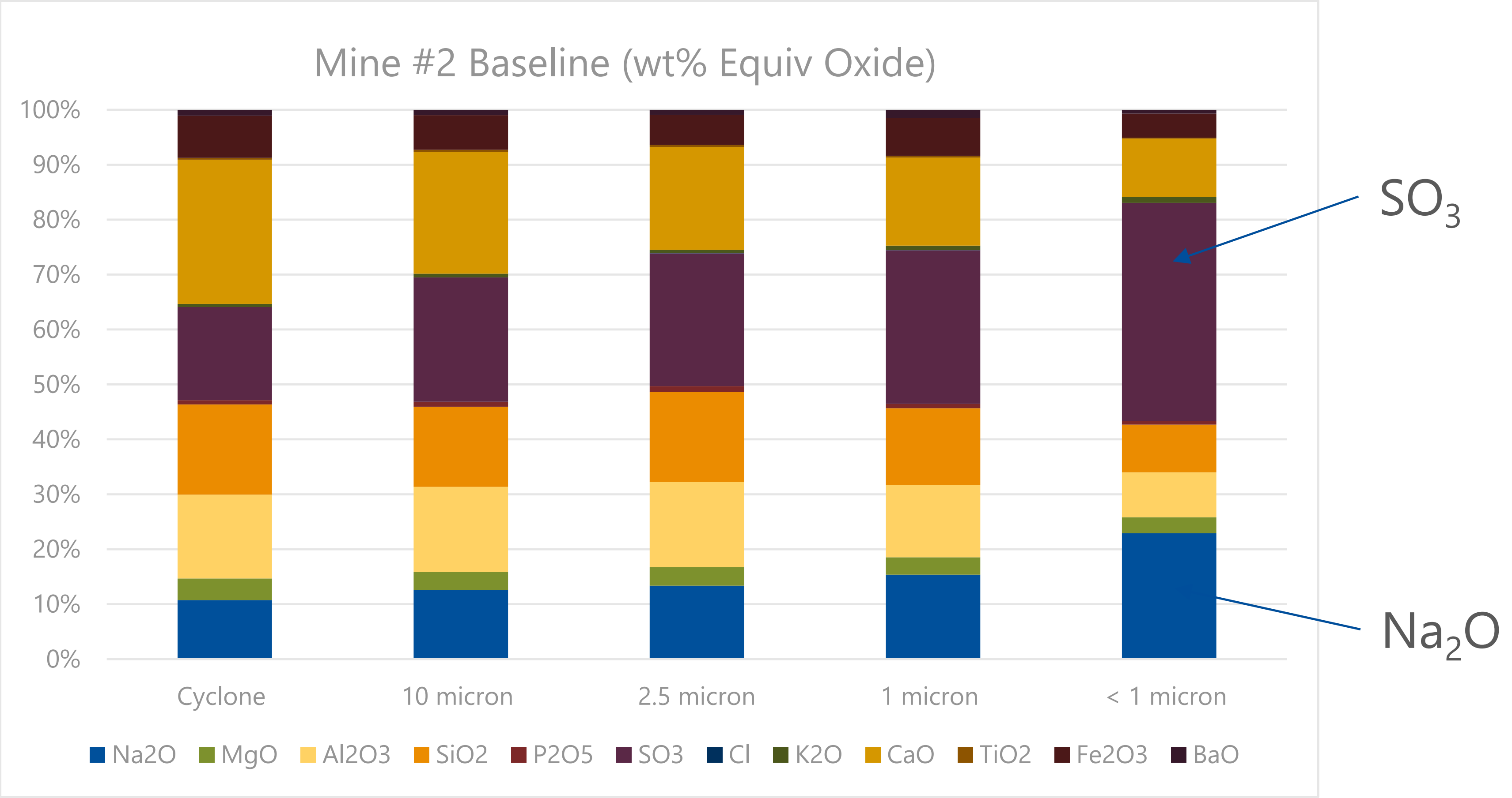


Lab Testing (Task 2) – Phase 1 & 2 Conclusions

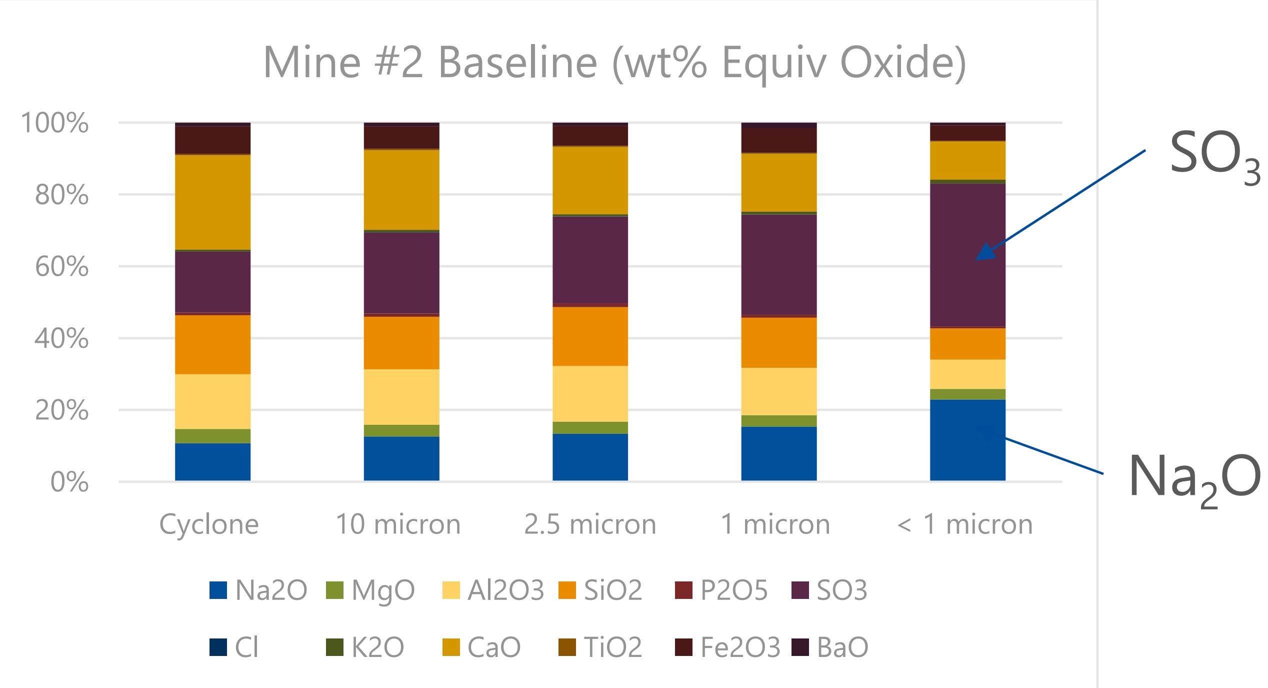
- Reduction of sodium in the submicron size fraction
  - Most sorbents show >40% reduction of Na in <1 µm
    - Composition (quartz) likely an issue for poor performing sorbents
    - Performance of fine vs. coarse particle size inconclusive
- Suggests
  - Sodium and calcium are incorporated into sorbent melt phase
  - Decreased availability to form sulfate
- Optimal sorbent selected for demonstration based on availability and accessibility and demonstration flow rates confirmed
- Other sorbents that may be more cost effective recommended for further testing

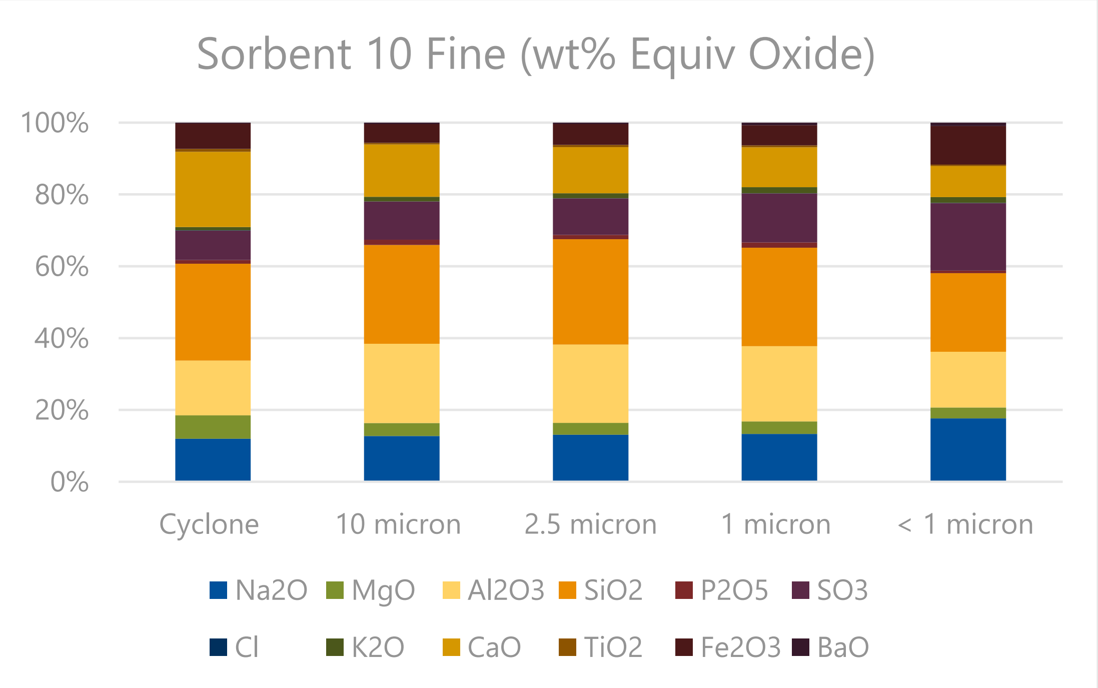
Lab Testing (Task 2) – Establish Baseline Results Phase 3

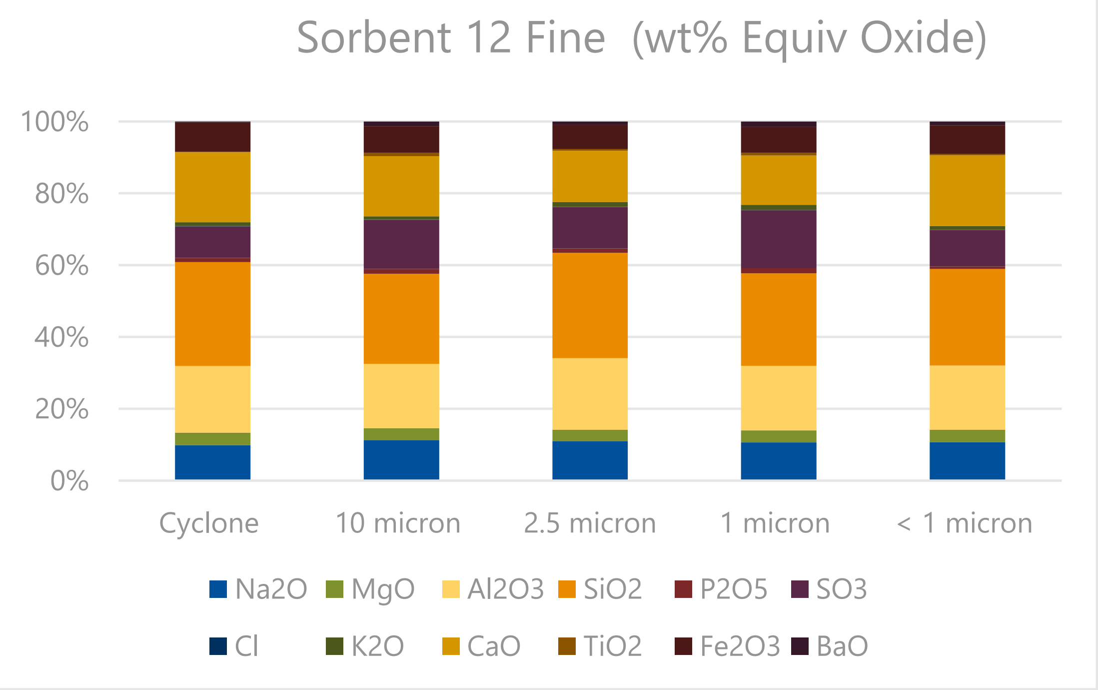
- Composition of 4-stage impactor for baseline and the addition of sorbents

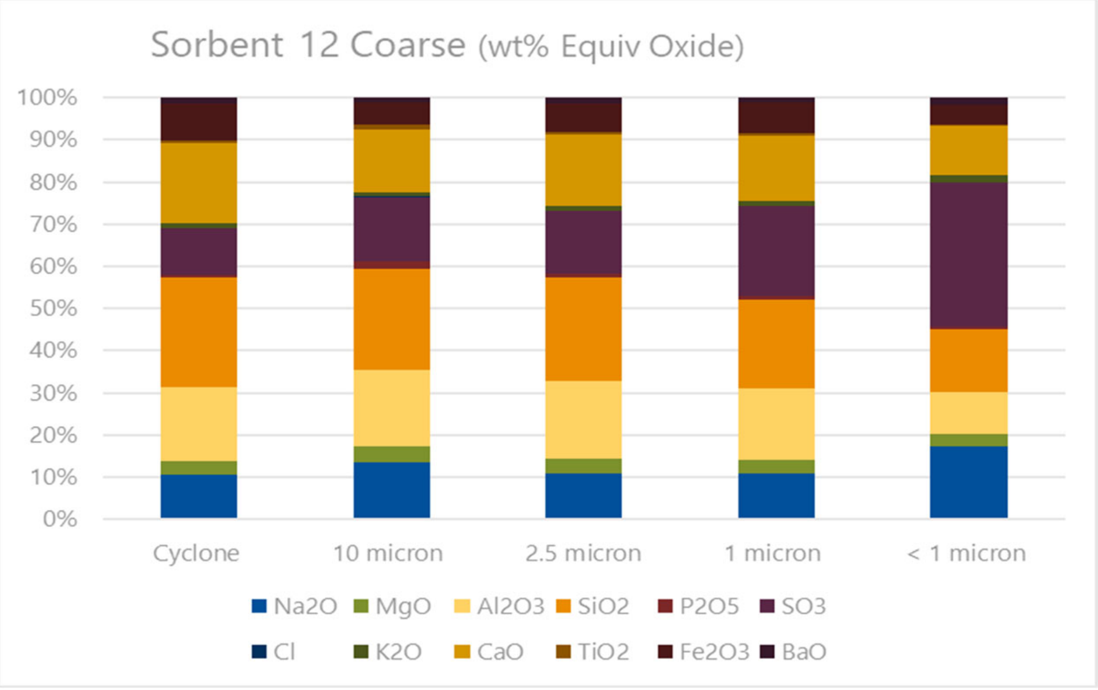


Lab Testing (Task 2) – Baseline vs. Sorbent Injection Mine #2 Results Phase 3





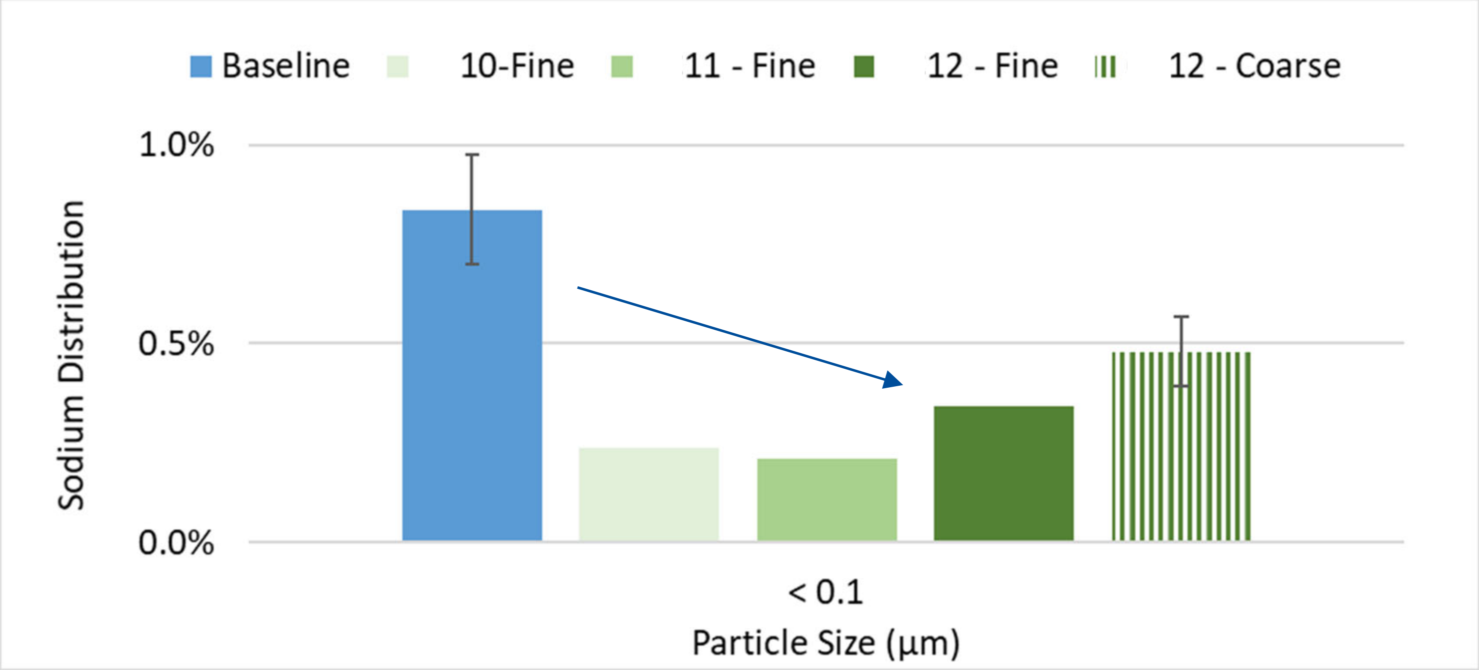


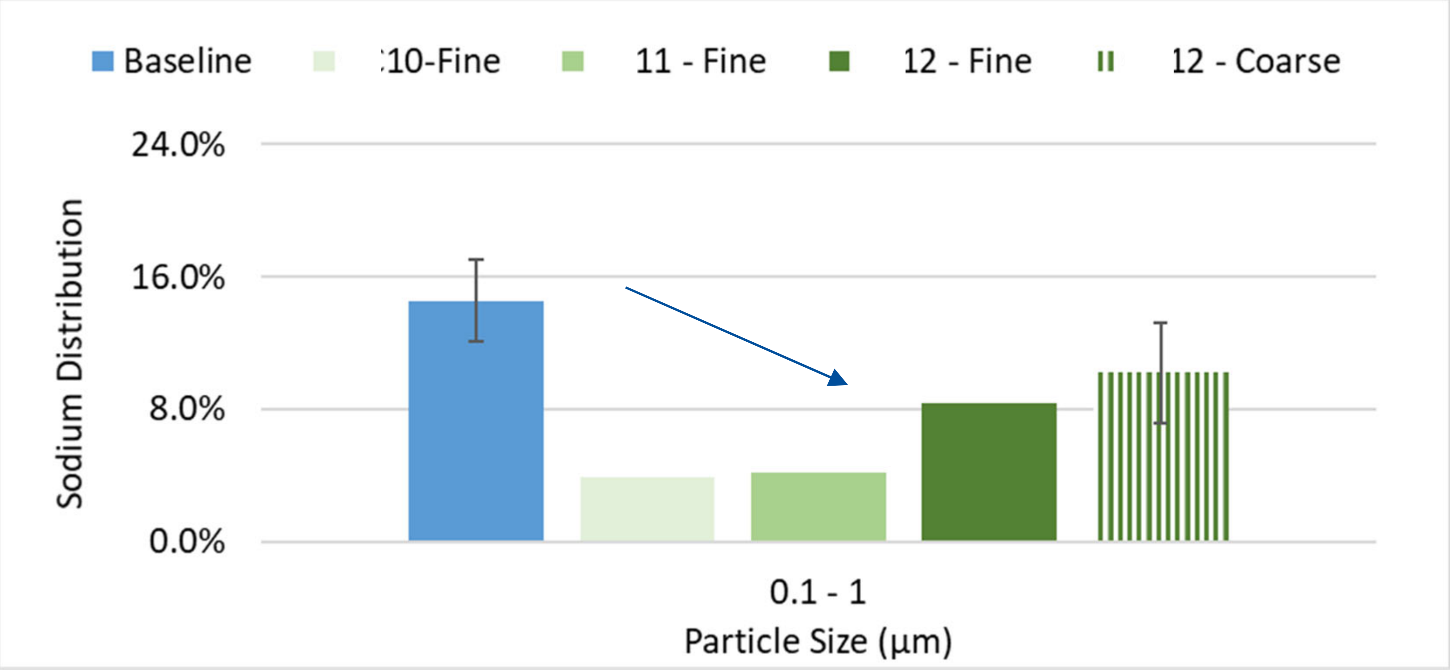


Lab Testing (Task 2) – Phase 3

- Reduction observed for sodium at the sub-micron level

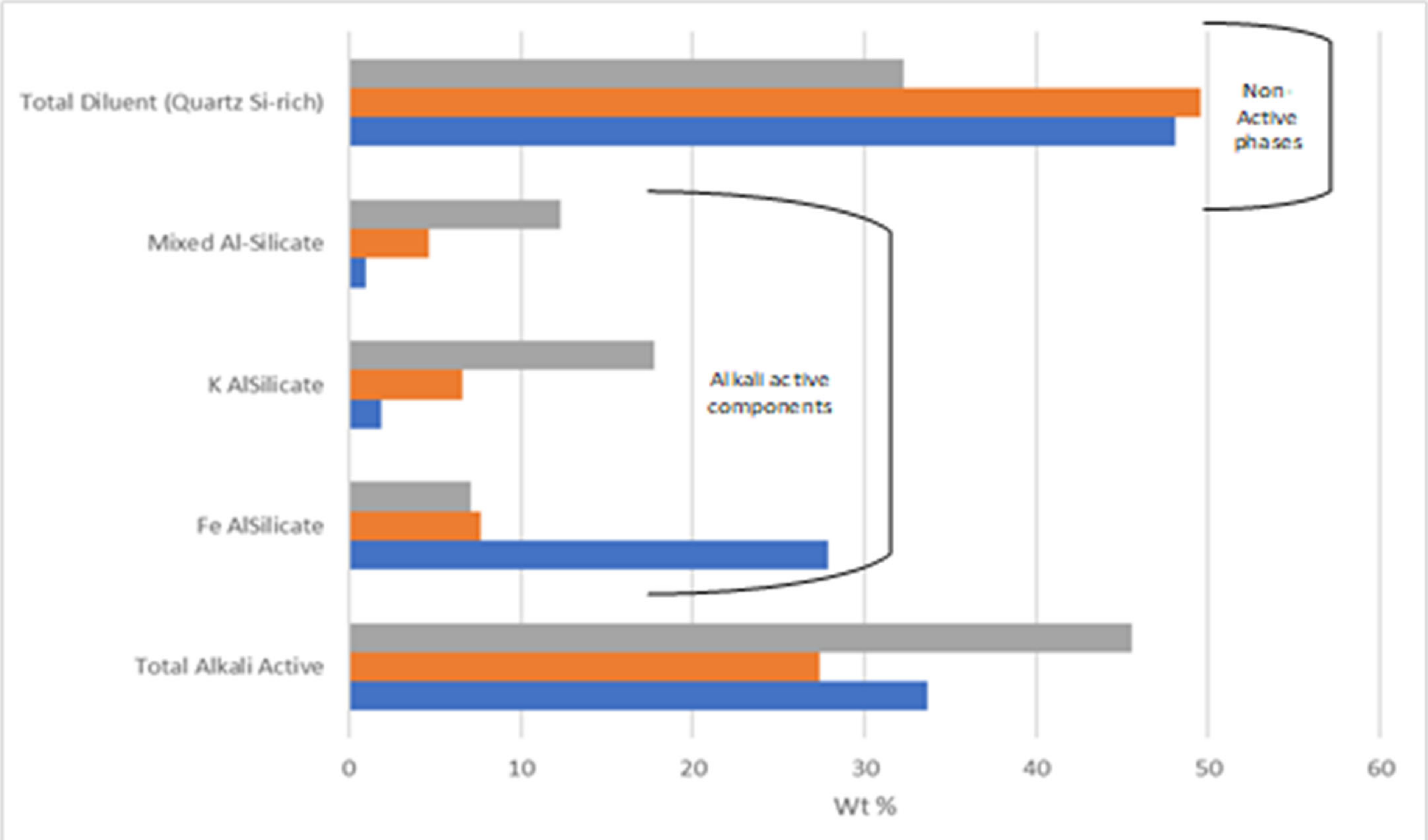
Percent Reduction	< 0.1 µm	0.1 – 1 µm	Total
Mine #2 Sorbent 10 Fine	71%	73%	73%
Mine #2 Sorbent 11 Fine	75%	71%	72%
Mine #2 Sorbent 12 Fine	59%	43%	44%
Mine #2 Sorbent 12 Coarse	43%	30%	31%





Abundance of non-active and active materials for sodium capture

1. Gray bar is the best sorbent
2. Blue bar is the next best
3. Orange bar is the poorest



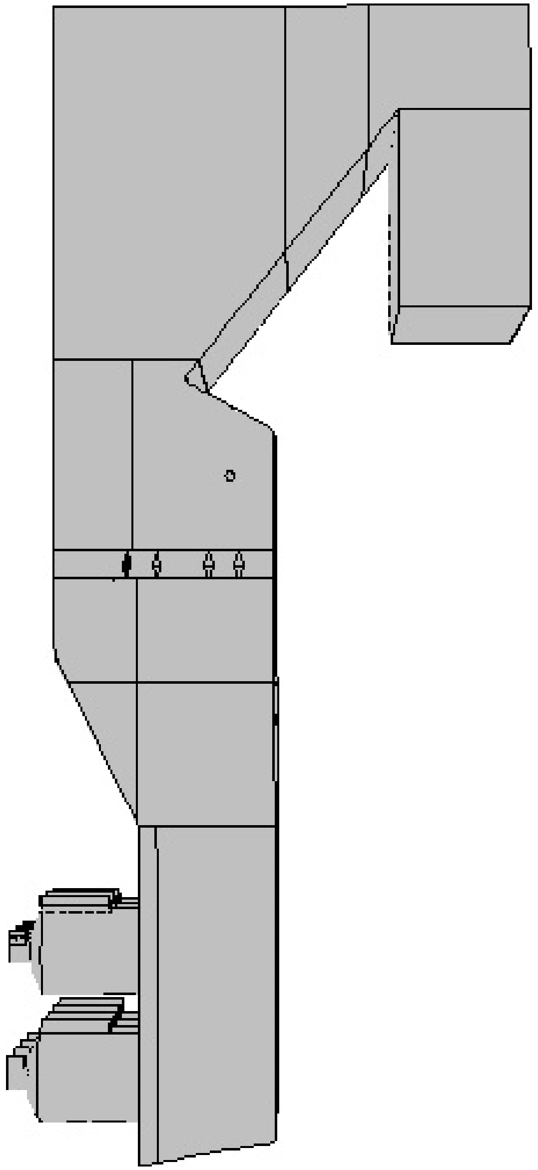
Lab Testing (Task 2) – Phase 3 Conclusions

- Reduction of sodium in the submicron size fraction
  - Most sorbents show >40% reduction of Na in <1 μm
    - Performance of fine vs. coarse particle size shows finer sorbent may have better sodium and sulfur capture but results still not clear
    - Sorbents with higher alkali active elements and lower quartz present a higher reduction in Na.
- Performance similar to Phase 1 & 2 testing with Mine #1 coal
- Other sorbents that may be more cost effective recommended for further testing

Task 3: Demonstration Plant Boiler Injection Modeling

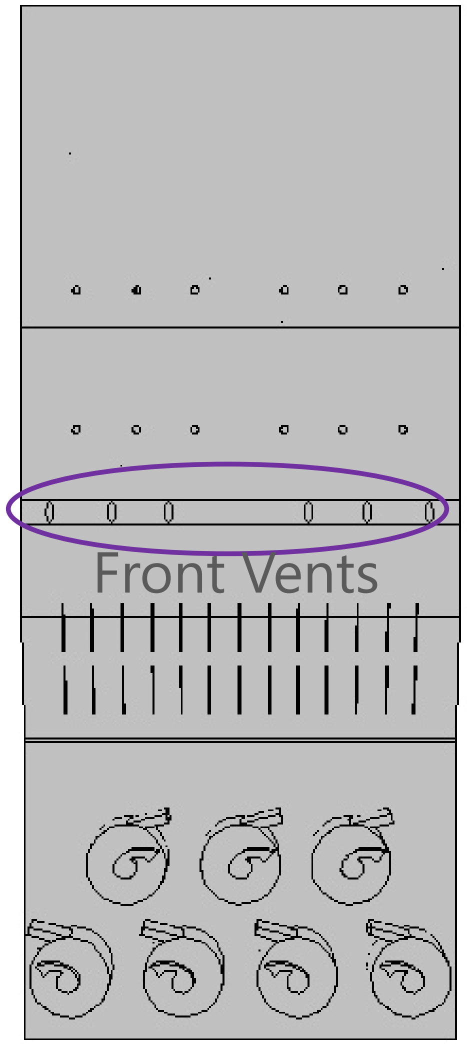
CFD Model Objective and Approach (Task 3)

- Capture sodium vapor species by reacting with fine sorbent (aluminosilicates) particles
- Dispersion of sorbent particles
  - Injected at boiler walls
  - Challenge is to mix sorbent in entire flow field
- Temperature range for reaction
  - High temperature range for fast kinetics while limiting sintering deactivation
- CFD model for flow and temperature field calculations

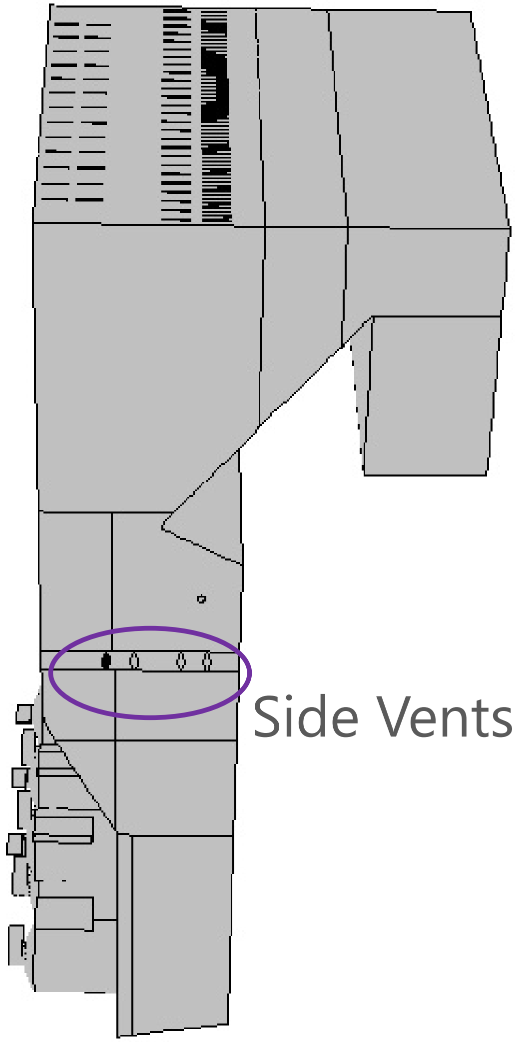


Demonstration Model (Task 3) Conclusion

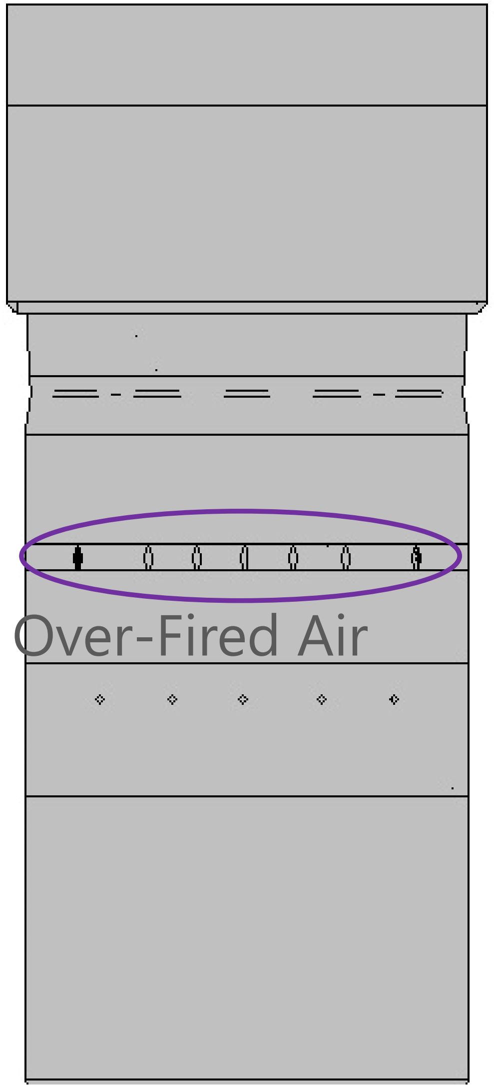
- RSD of sorbent to flue gas flux ratio – for different injection combinations with ranges of 1.0 – 3.0
- At a minimum, good sorbent distribution requires use of front vents <u>and</u> over-fired air ports
- Sorbent injected into front vents in desired 900-1200°C range
- Injection locations identified and specified for injection demonstration equipment



Front View (East)



Side View (North)



Back View (West)

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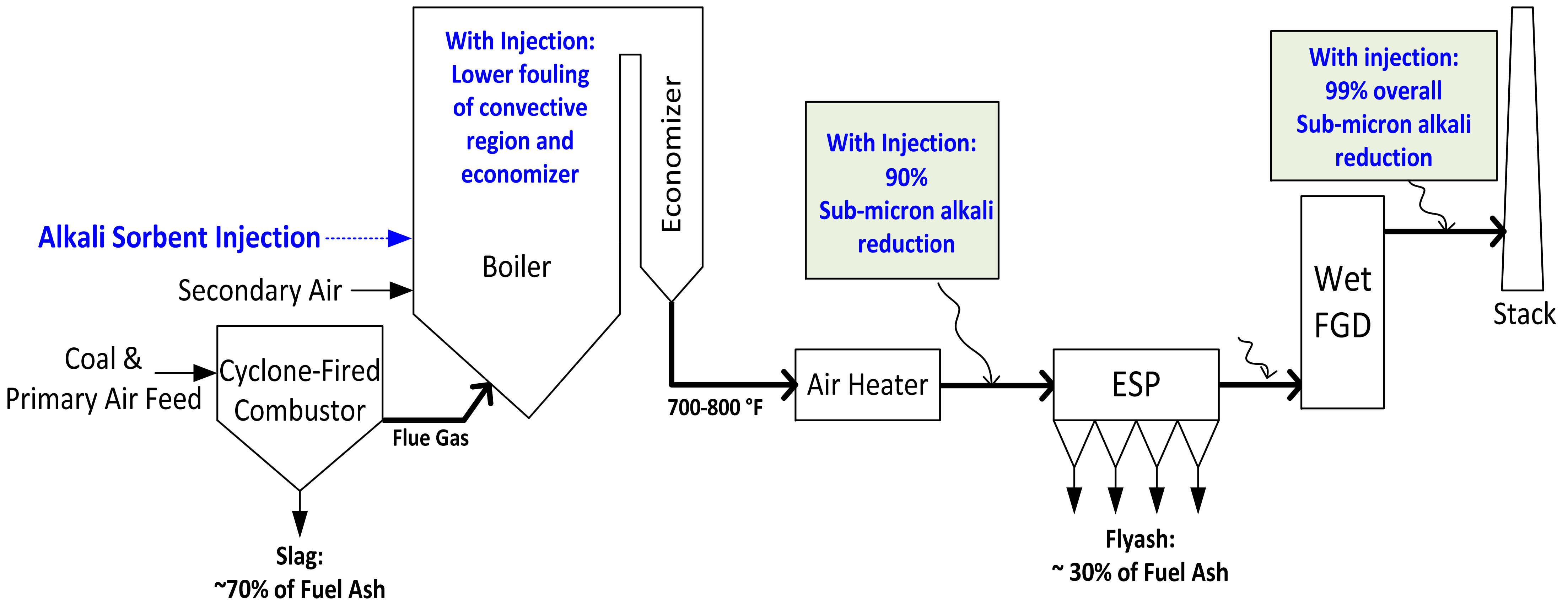
Task 4: Preliminary Design for Demonstration

Prepare for Demonstration Preliminary Design(Task 4)

- Gather preliminary testing from two demonstration vendors
- Selected field demonstration dates in August (Test 1) and November (Test 2) 2021
- Obtained quotes from injection demonstration vendors and selected vendor



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Budget Period 1 Success Criteria / Results

- Task 2 showed a commercial sorbent can remove sodium-based aerosols at a significant rate (40 – 77%); other sorbents can perform equal or better.
- The CFD modeling in Task 3 showed good flow dispersion at injection points.
- Task 4: feasible sorbent size reduction and injection vendor procured/contracted; cost compliant test plan developed
- Planning for field demonstration is underway (safety, mechanical, sorbent supply, environmental considerations)

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Objectives – Budget Period 2

Budget Period 2 (April 2021 – September 2022)

- Task 5 – Demonstration Test Planning, Design, and Construction
  - Mechanical, Structural, Electrical Tie-In, Permitting
- Task 6 – Parametric Testing
  - Five-day test, 24/7 Operation (August 2021)
- Task 7 – Data Reduction Determine Recommendations for Extended Testing
  - August – November
  - Testing equipment left onsite between tests
- Task 8 – Extended Testing (November 2022)
- Task 9 – Data Reduction, Technoeconomic Analysis, and Final Reporting

Success Criteria-BP2

- Budget Period 2 success criteria:
  - Successful installation and operation of equipment at the field test site within the proposed budget and schedule
  - Parametric testing demonstrates the effectiveness of the sorbent application and identifies the optimal parameters to maximize the benefits
  - Long-term testing demonstrates that the technology is effective
  - Positive business case
  - Advancement of the technology to a TRL 7 (system prototype validated in operational environment) and commercial demonstration

Acknowledgement and Disclaimer

Acknowledgment: This material is based upon work supported by the Department of Energy Award Number DE-FE0031756.

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Questions?