Physical and Chemical Property Variations of Segregated Coal Fractions for Modeling Entrained Flow Slagging Gasifier

Nari Soundarrajan, Nandakumar K., Latosha Gibson, Sarma Pisupati

Department of Energy and Mineral Engineering and EMS Energy Institute
Penn State University

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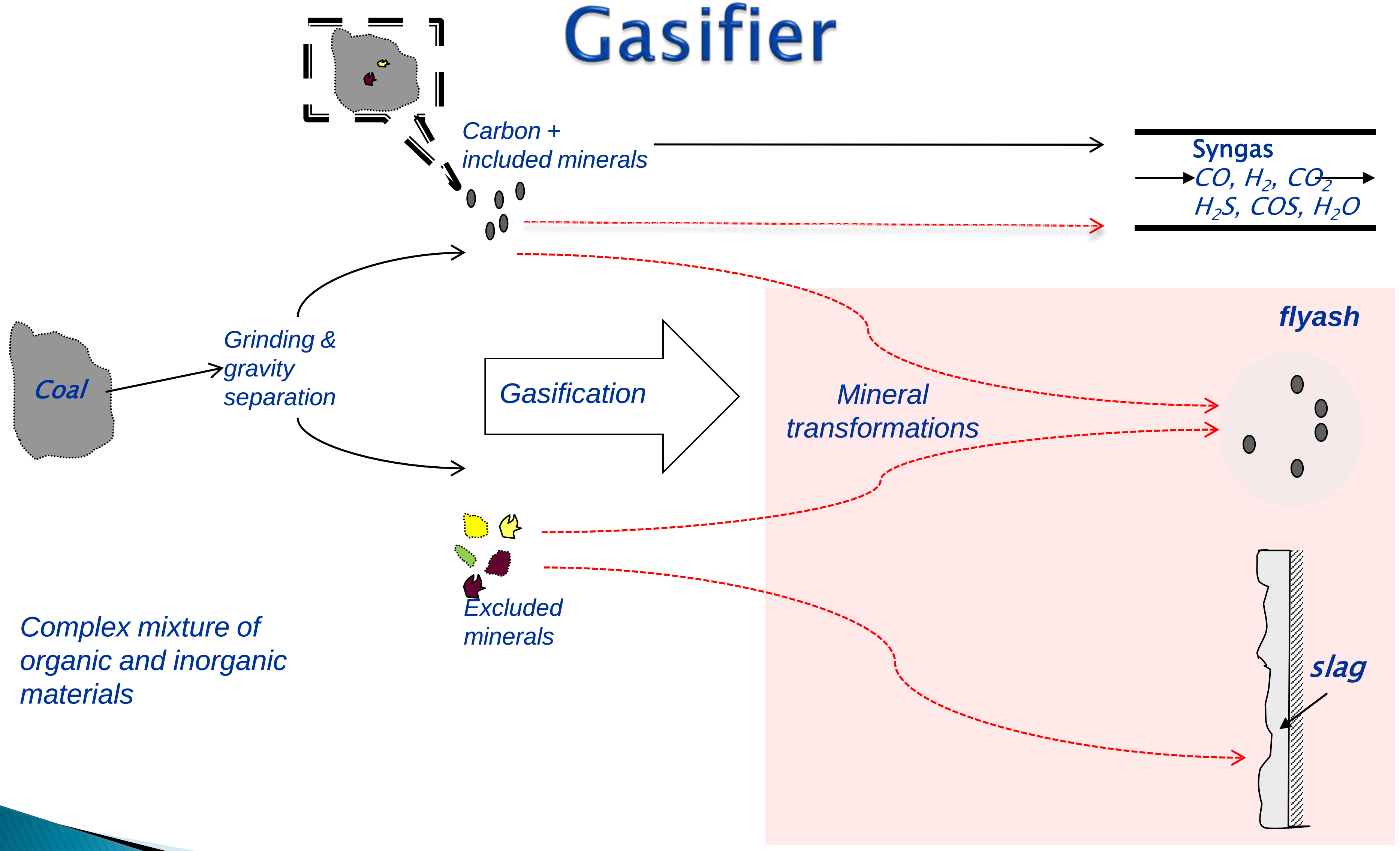
Background – Coal Conversion in Gasifier



Complex mixture of organic and inorganic materials

Assumed Particle Transformation in an Entrained Flow Gasifier

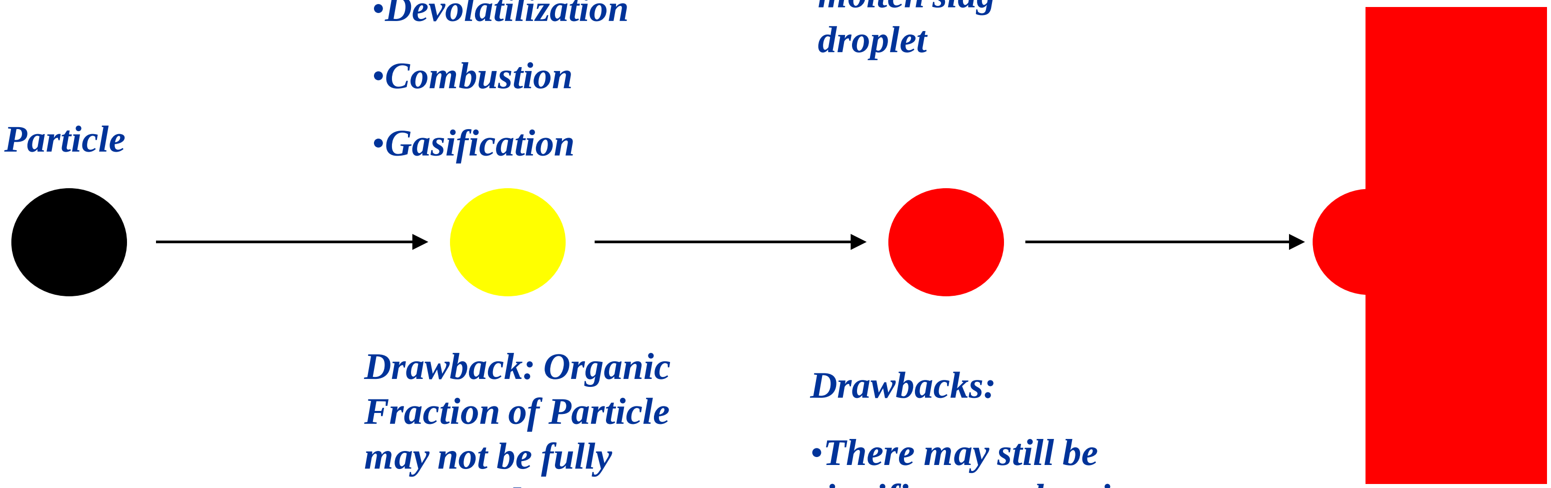
Feed Particle

Organic fraction is consumed by reactions:

- *Devolatilization*
- *Combustion*
- *Gasification*

It turns into a molten slag droplet

And gets absorbed into the slag layer on the wall



Drawback: Organic Fraction of Particle may not be fully consumed

- *Particle size effect*
- *Ash in particle may slow down heterogeneous reactions*

Drawbacks:

- *There may still be significant carbon in the particle*
- *The ash melting temperature may be above the particle temperature*

Drawback: If there is appreciable carbon in the particle, it may not be wetted by slag (contact angle >90^0)

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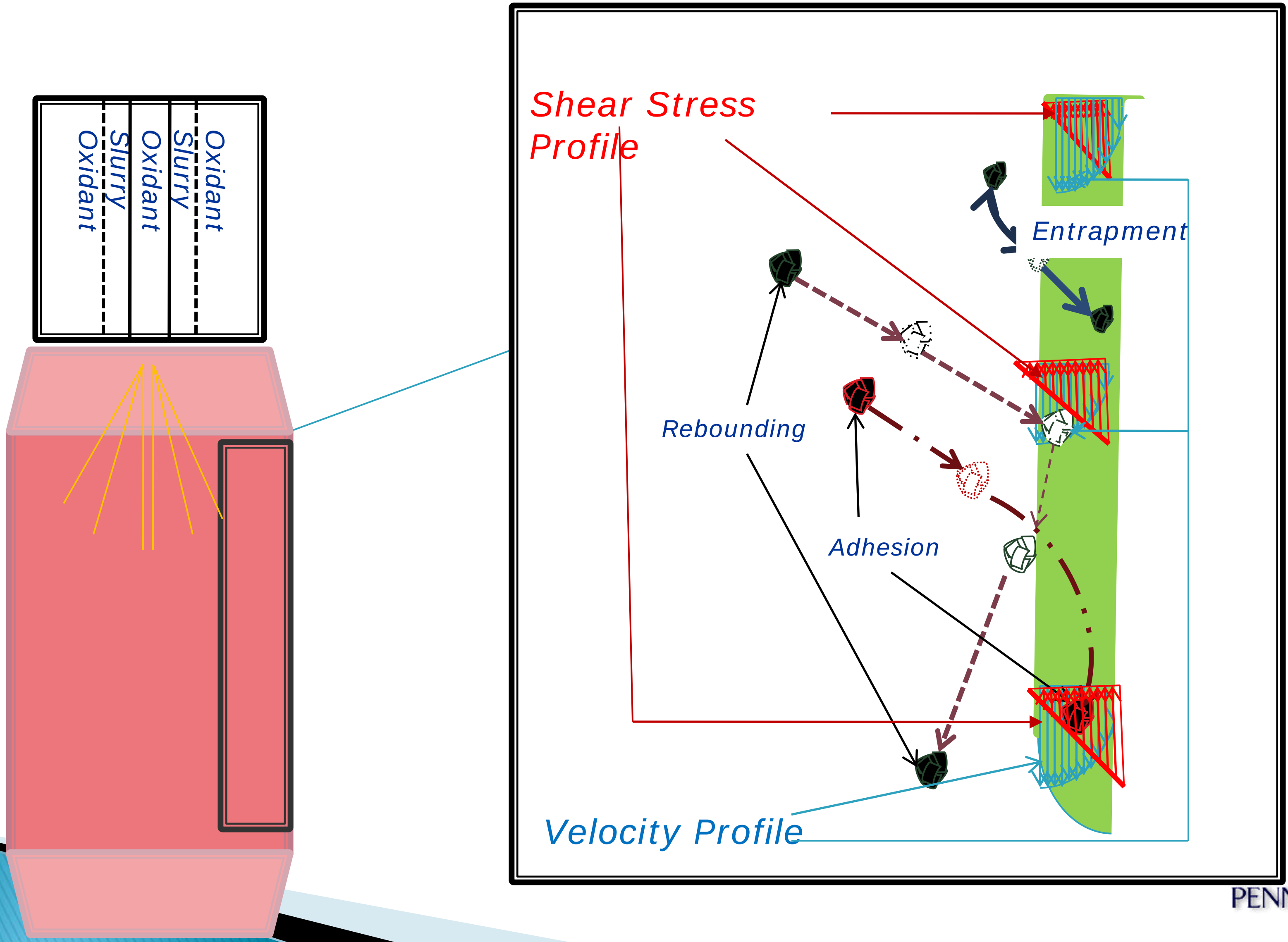
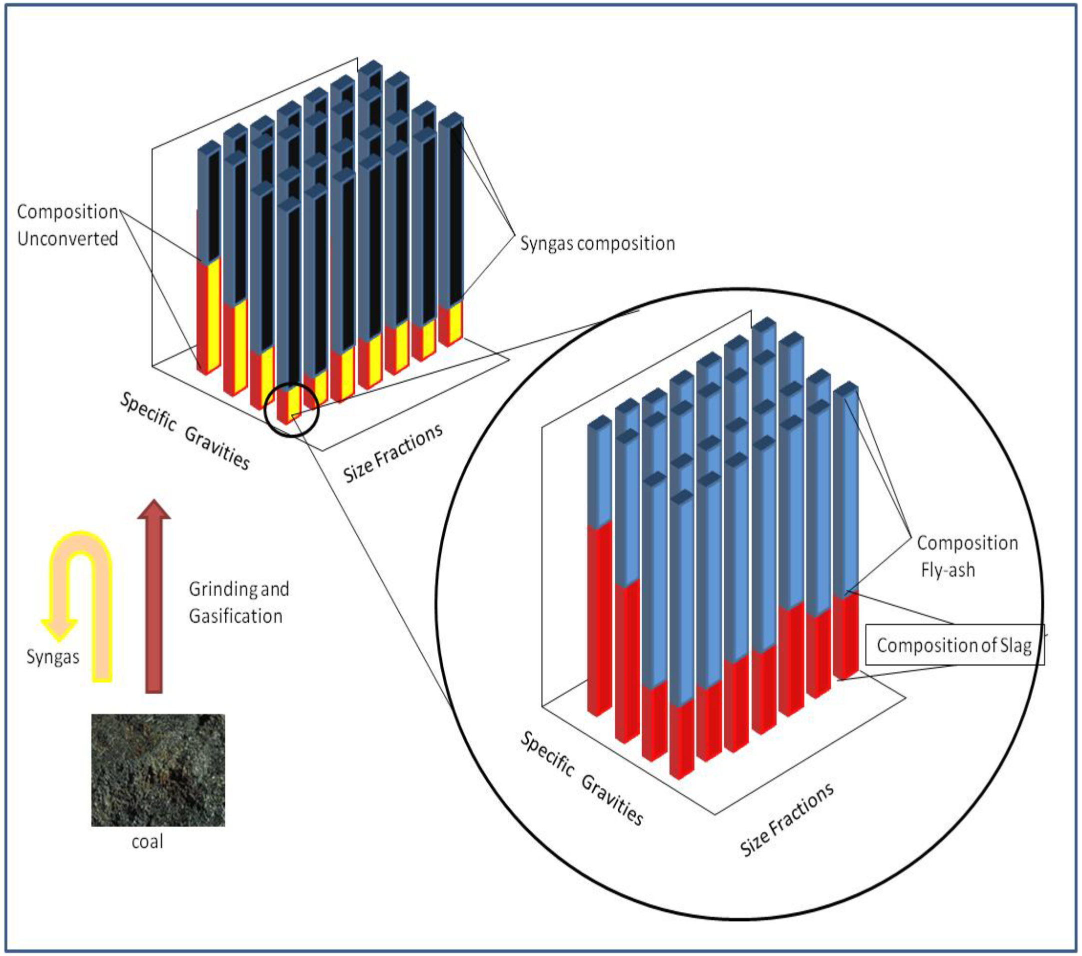
Char and Slag Interaction



Particle Population Model for Lab Scale



Particle Partitioning

Overall Goal

To determine whether an analysis based on the fuel PSD, mineral compositions, carbon conversion, and capture efficiencies of the slag layer can interpret the historical backlog of entrained gasifier's syngas cooler’s fouling problems for different fuels.

Based on particle size and specific gravity distributions, to quantify key fuel parameter distributions that can contribute to flyash formation

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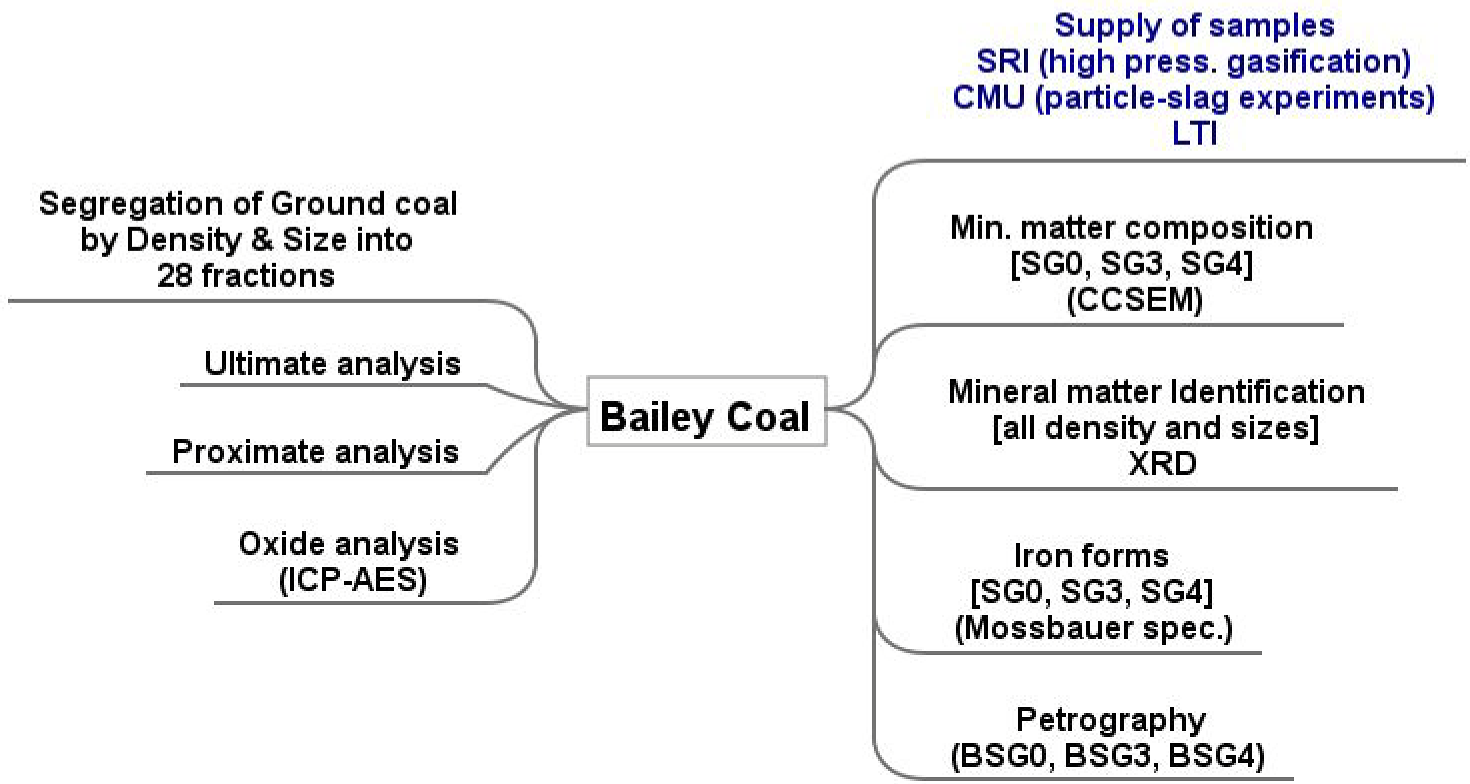
Methodology for Evaluating Heterogeneity



Heterogeneity in coal samples was determined with respect to organic and inorganic components

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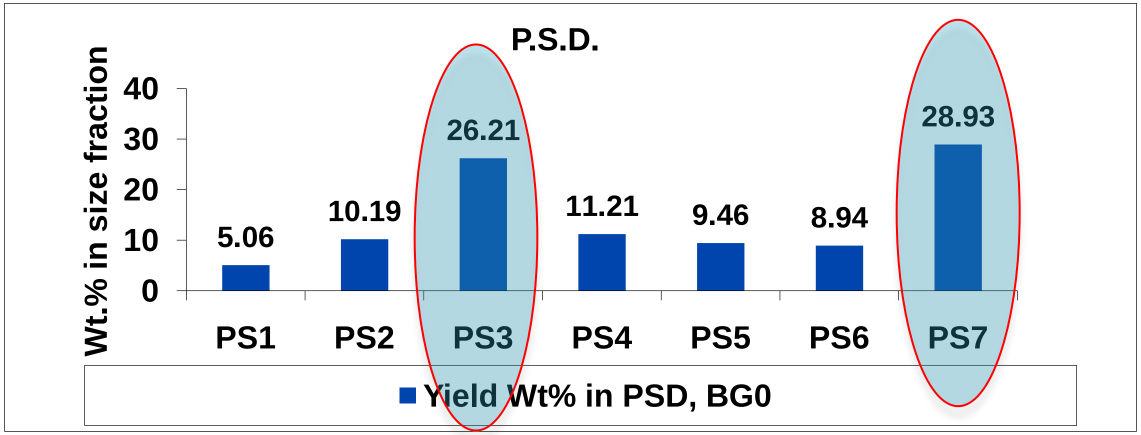
Yield and HHV Segregation

Property Unit	Whole Coal	SG1 < 1.3	SG2 1.3 -1.6	SG3 1.6-2.6	SG4 > 2.6 g/cc
Yield, %	100 %	47.8	47.6	3.5	1.1
HHV MJ/kg	33.79	17.35	15.65	0.45	0.08
HHV in fractions %	100%	52.1	46.3	1.3	0.3

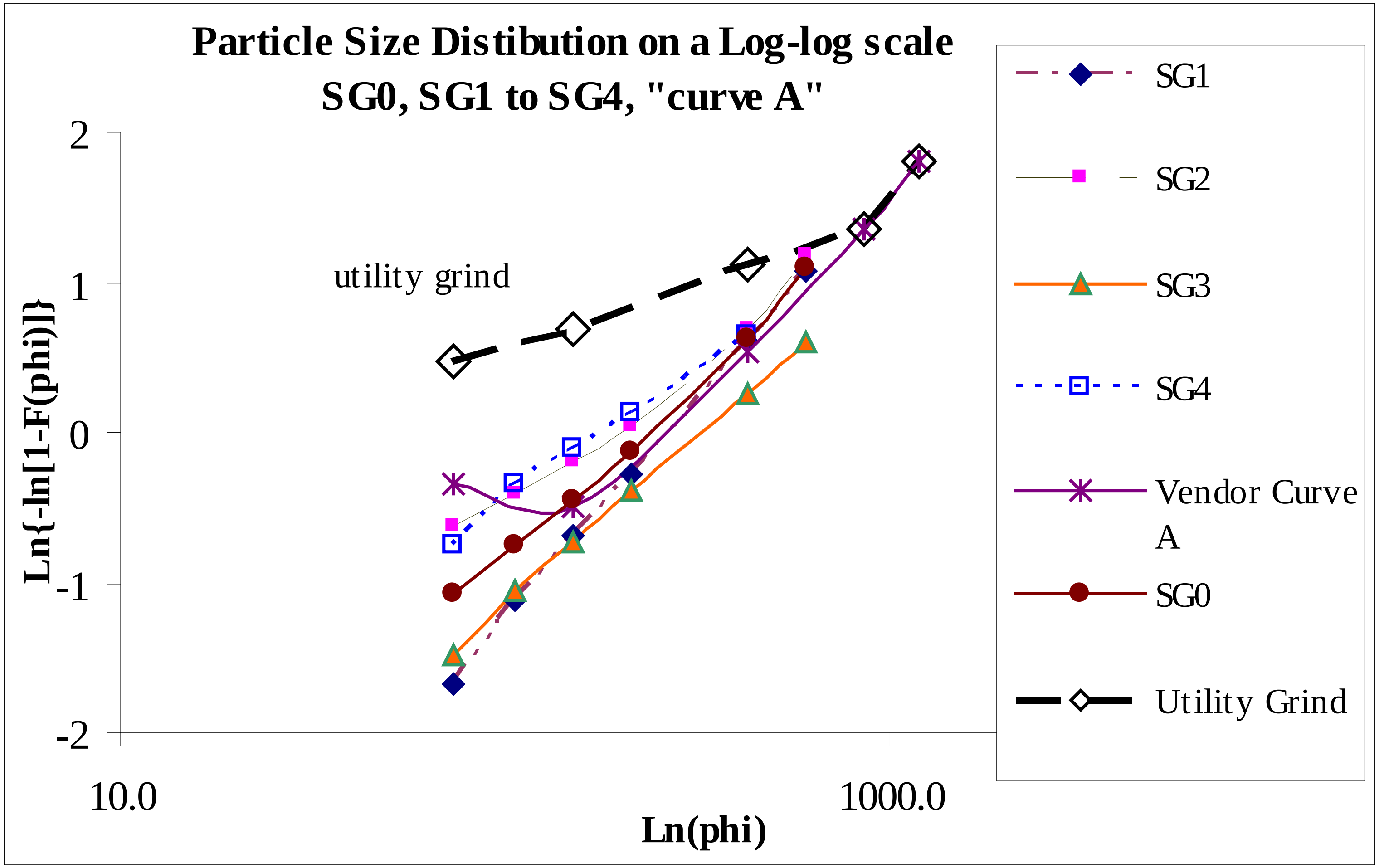


Sample Array Showing Yield

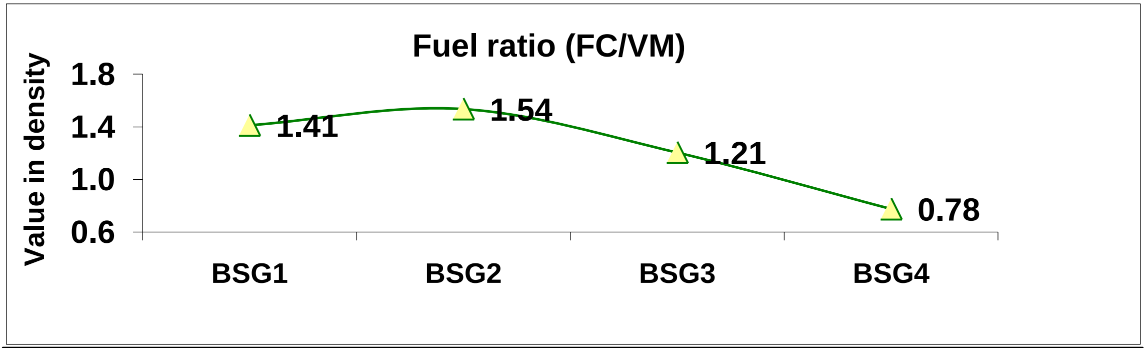
		+600 micron	-600 to +425	-425 to +212	-212 to +150	-150 to +106	-106 to +75	-75 to 0 micron
		PS1	**PS2**	**PS3**	**PS4**	**PS5**	**PS6**	**PS7**
1.3 < ρ	**SG1**	2.54	5.19	14.90	6.39	5.54	5.16	8.12
1.3 to 1.6	**SG2**	1.86	4.53	10.31	4.35	3.51	3.32	19.69
1.6 to 2.6	**SG3**	0.56	0.40	0.81	0.37	0.32	0.30	0.71
ρ > 2.6	**SG4**	0.10	0.07	0.20	0.09	0.10	0.15	0.42

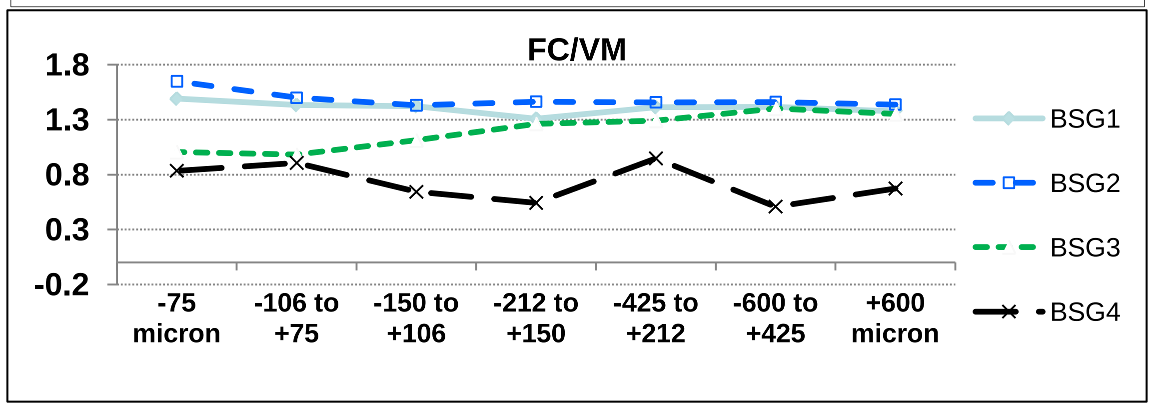
These samples were investigated by by SRI and CMU

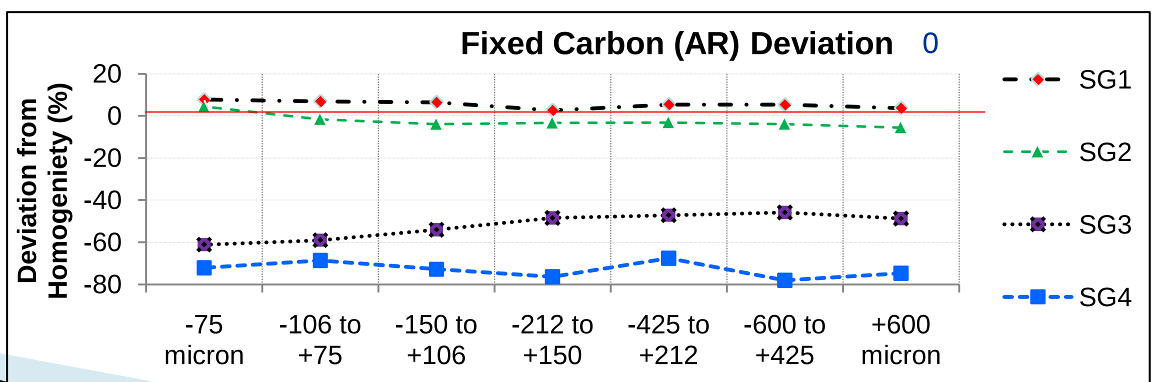
PSD comparison with Utility Grind



Heterogeneity in Fixed Carbon and Volatiles







Maceral Segregation

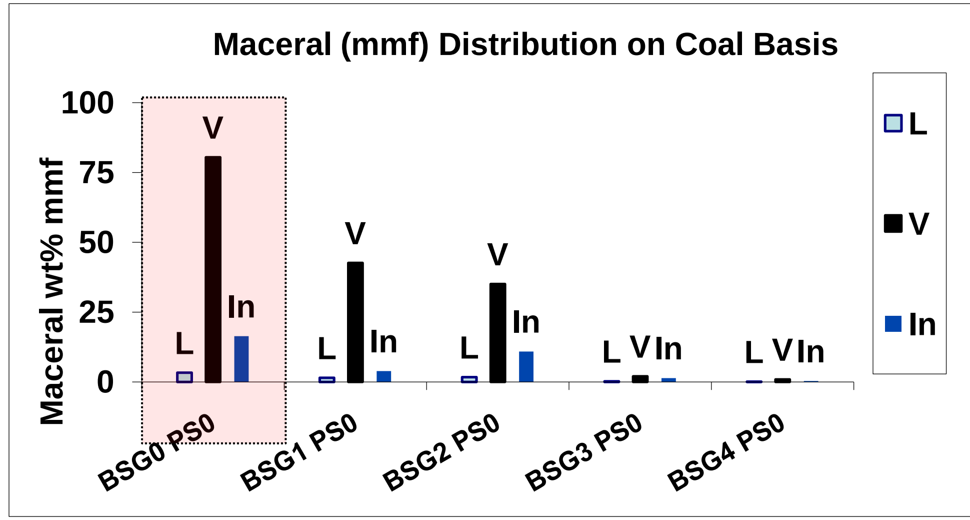
SG1 SG2 SG3 SG 4

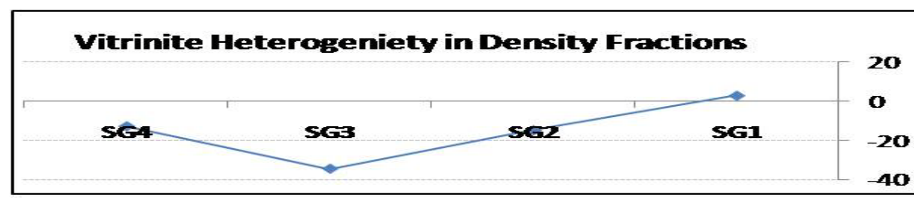
max. V V/I L& I MM

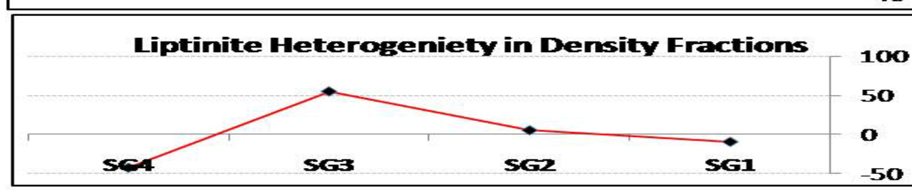
Maceral mmf	BSG0 PS0	BSG1 PS0	BSG2 PS0	BSG3 PS0	*BSG4 PS0
Vitrinite	83.7	87.2	70.5	53.1	75.2
Liptinite	3.3	3.0	3.4	5.0	1.9
Inertinite	13.0	9.9	26.0	41.8	23.4
Vitrinite/ Inertinite	*6.4*	*8.8*	*2.7*	*1.3*	*3.2*

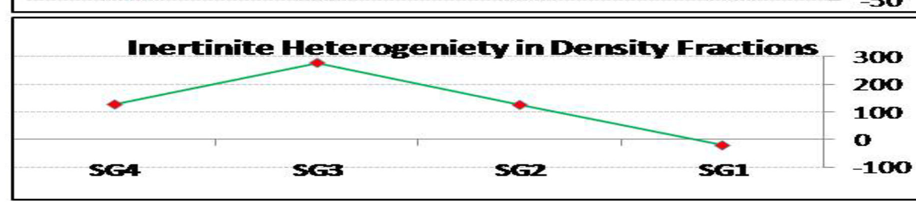
- SG4 data is out of 360 counts vs. the normal 1000 count
- Based on literature*, reactivities of chars of fractions are expected to reflect respective heterogeneity in macerals
- Vitrinites form porous char

** Wall,T. et al. The Effect of Pressure on Char Characteristics, Burnout and Ash Formation in Entrained Flow Gasifiers, IFRF Combustion Journal, Art. # 200105, May 20*









Burnout differences in Macerals: Observations

- Reactivity of Lab chars of BSG1, BSG2 (in TGA at atmospheric pressure) are slower to start burning (confirmed from reactivity plots) but achieve higher Rmax.
- BSG3 is very quick to burn compared to others. This could be explained by the presence of fast burning Liptinites and lower overall fixed carbon.
- Anomaly: BSG4, as it is found to start burning quite late (after BSG1) but burnout is quicker. This could be due to lower fixed carbon which in combustion reactivity settings reacts away quickly.

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Ash yield variation

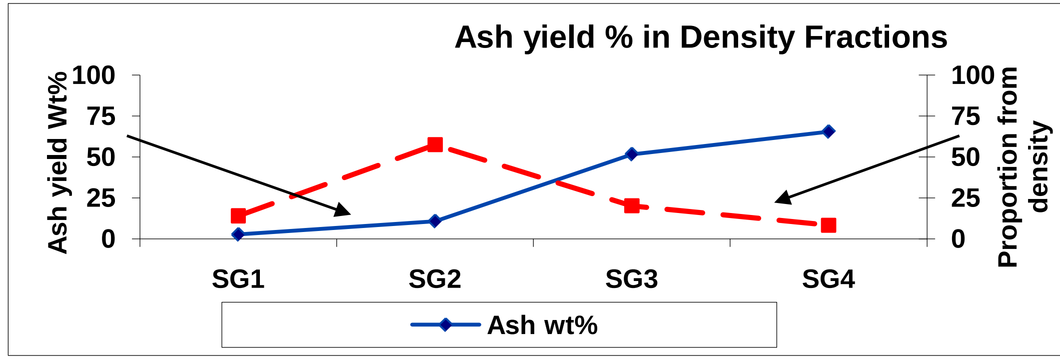
Ash yield varies widely with density

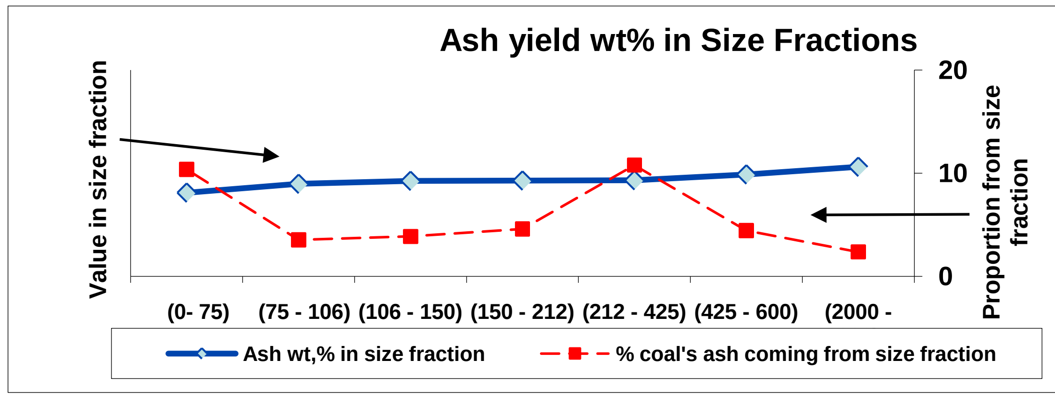
Contribution to total ash yield of coal is highest from SG2 (included nature of minerals)

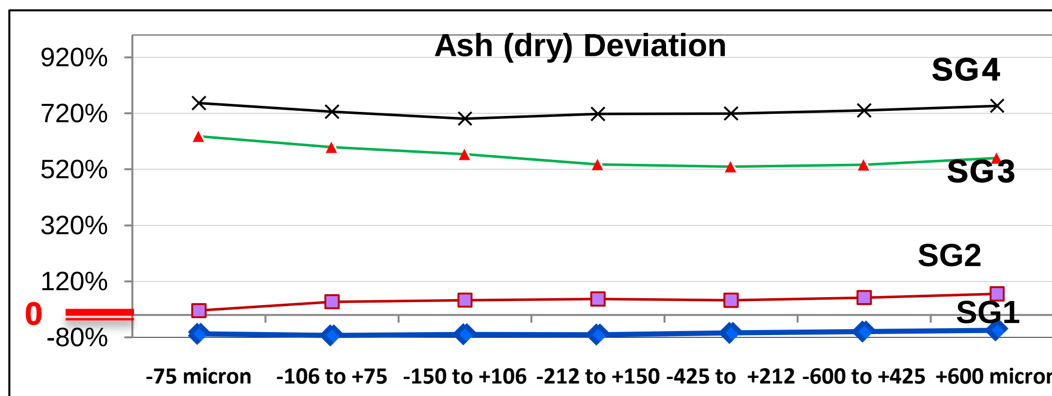
Size fractions 0-75 µm and 212-425 µm contribute max towards the whole coal ash yield

Ash yield variation with size fraction in not significant

Heterogeniety in ash yield(about)
SG1 - 80 %, SG2 + 80 %
SG3 + 570 %, SG4 + 720 %







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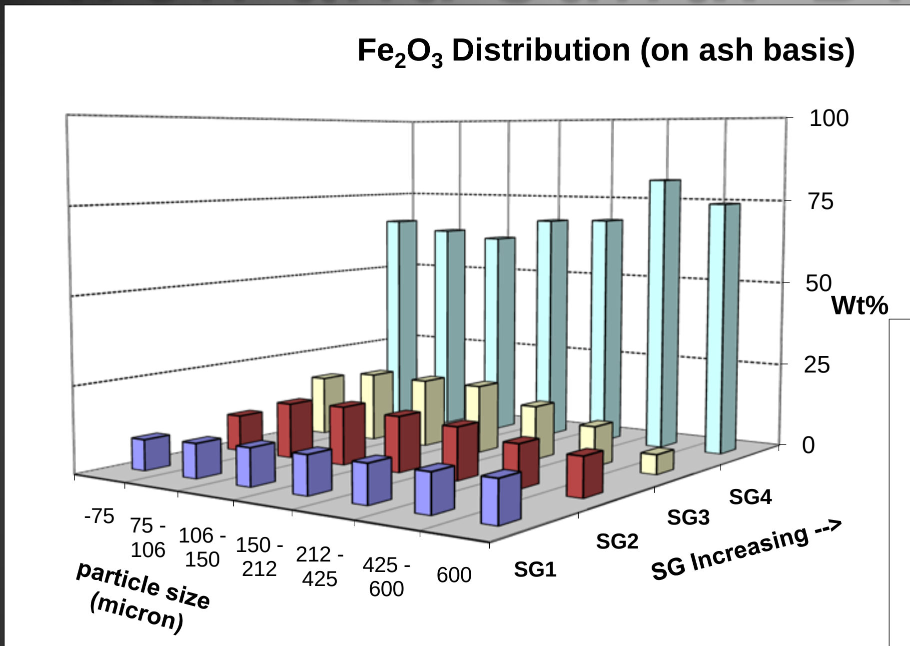
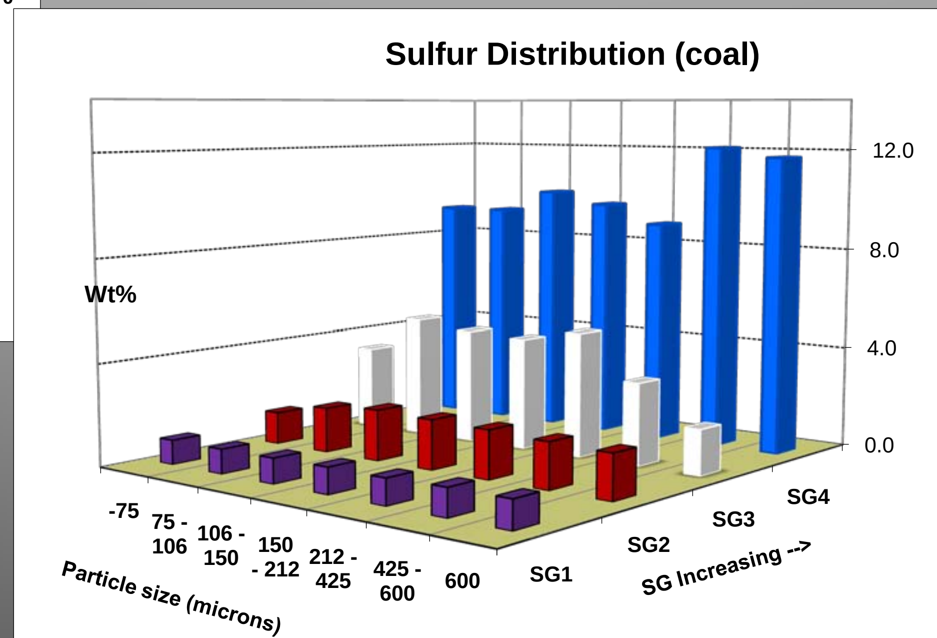
Iron and Sulfur Distibution in Coal





Mineral Matter Makeup SG0, SG3 & SG4

SG4 (84.23 wt.% MM)	TOTALS (%)	EXCLUDED
PYRITE (2)	90.4	88
IRON OXIDE	5.4	87.1
OXIDIZED Pyrrhotite	2.1	86.8
UNCLASSIFIED	1.9	66.8
PYRITE (1)	0.1	100
SG3 (60.04 wt.% MM)	TOTALS (%)	EXCLUDED
PYRITE (2)	33.4	80.8
UNCLASSIFIED	17.7	69
K Al Silicate	12.6	52.7
QUARTZ	8.6	59.7
KAOLINITE	4.6	29.9
MONTMORILLONITE	4	26.3
MIXED Al Silicate	3.5	37.7
CALCITE	3.1	49.2
FE Al Silicate	2.9	59
SI-RICH	2.5	42.9
GYPSUM	1.7	82.7
ALUMINOSILICATE	1.6	37
PYRITE	1.5	80

PYRITE (2) – reported as pyrrhotite by UND CCSEM software

Parent Coal (non segregated)		
SG0 (5.76 wt.% MM)	TOTALS (%)	EXCLUDED
PYRITE (2)	30.8	44.2
UNCLASSIFIED	17.9	14.2
K Al Silicate	11.7	11.1
KAOLINITE	8	14.4
QUARTZ	7.4	26.9
MONTMORILLONITE	4.5	34.6
PYRITE	3.9	25.6
SI-RICH	3.3	35.1
FE Al Silicate	3.1	11.5
MIXED Al Silicate	2.1	22.6
OXIDIZED Pyrrhotite	1.5	33.5
CALCITE	1.3	38.9
GYPSUM	1.2	70.3
IRON OXIDE	1	40.3

CCSEM work done at UND

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CCSEM Analysis: Mineral matter Composition

Major Minerals
CCSEM * **(on coal basis)**

Pyrites:
37 %

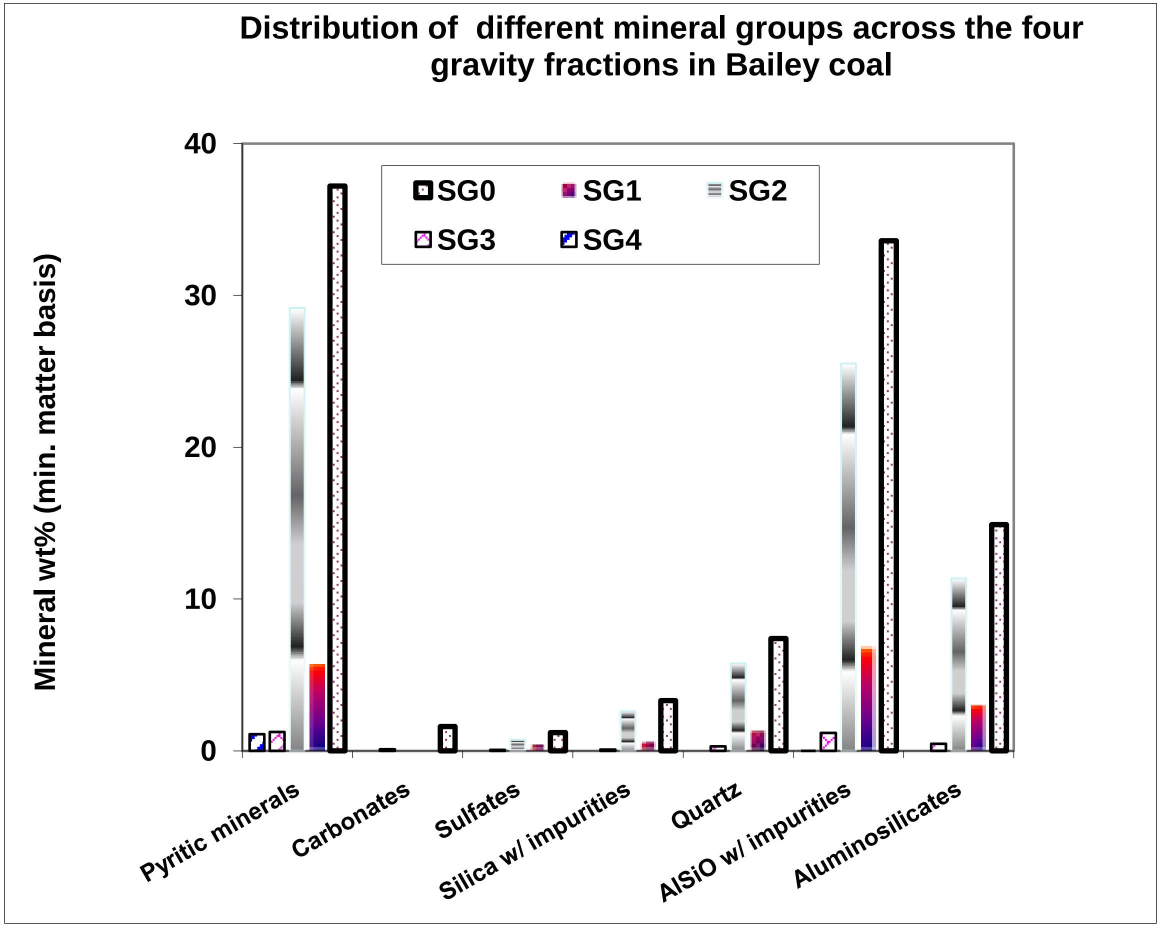
Carbonates and sulphates: 3 %

Silica (with impurities): 3 %

Quartz:
7 %

Aluminosilicates (with impurities): 35 %

Aluminosilicates:
15 %



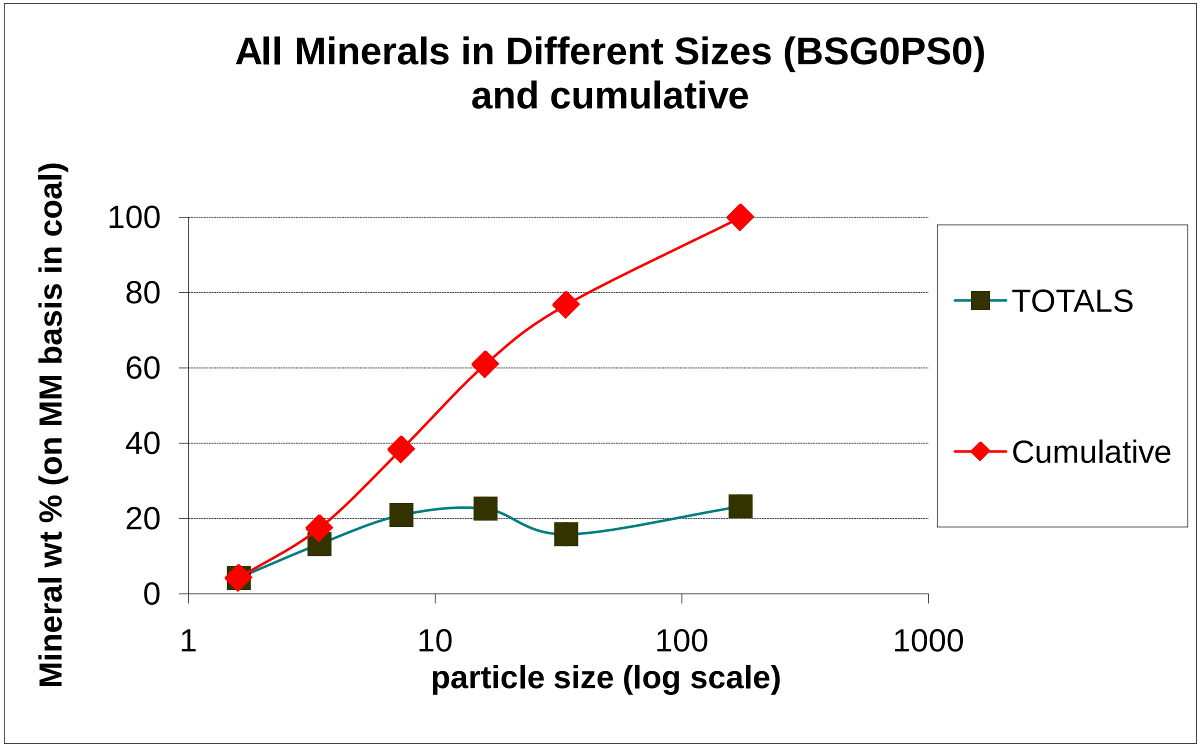
From left to right: SG4, SG3, SG2, SG1 and SG0 (whole coal)

Preparation Limitation: *particles > 300 µm were crushed and added*

Significant presence of Al-silicates and silica with impurities

Iron, as impurity helps melting
Potassium, as impurity

Mineral matter by Size



Minerals present in extremely fine form

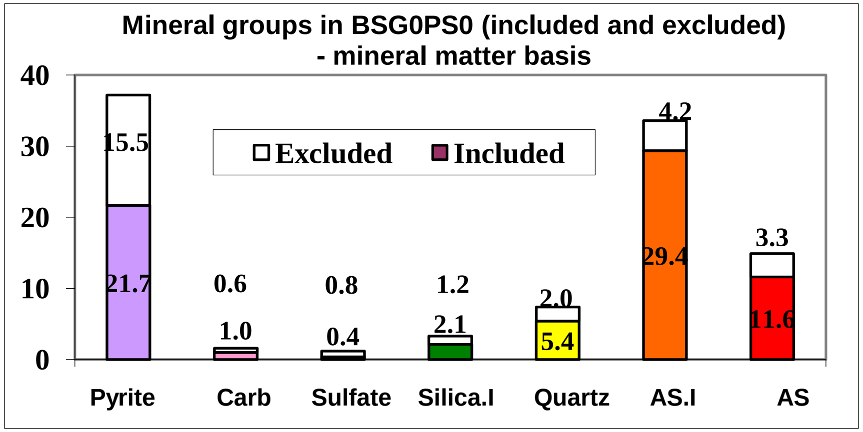
- 76% minerals are less than 46 µm
- 60% less than 22 µm
- 38% less than 10 µm

CCSEM: Included *vs* Excluded Minerals

In whole coal, over 72% (v/v) minerals present as included;

<u>Proportion present in the included form</u>

- Aluminosilicates: 78 %
- Aluminosilicates (with impurities) at 87%
- Quartz: 73 %
- Silica (with impurities): 65%
- Sulfates: 30 %
- Carbonates:62%
- Iron minerals (pyrites) 58%



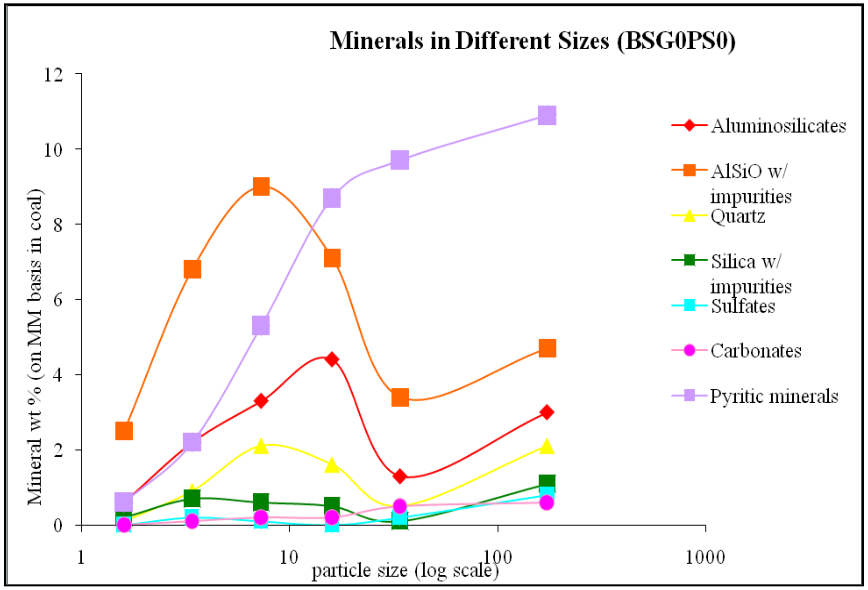
Carb: carbonates; AS: aluminosilicate; .I = with impurities

Size wise distribution of minerals

Over 42% clay particles, d <10 µm
~ 71.6% of clay particles, d < 22 µm

Maximum amount of aluminosilicates are present in 4.6 to 10 µm size fraction

Fine sized minerals present as inclusions → higher propensity to convert to fly ash particles



[*Barroso et al. 2006, Study of coal ash deposition in an entrained flow reactor : Influence of coal type, blend composition and operating conditions, Fuel Proc. Technology, 87, p. 737*]

NB: Preparation: particles > 300 µm were crushed

Technical Approach- Future Work

- Perform gasification tests on specific sizes SG2, SG3 and SG4 fractions to obtain reactivity parameters
- Perform kinetic studies on chars obtained at different conversions to study the kinetics of char conversion as a function of starting mineral matter composition
- Modification of mineral processing circuit based on the identification of the “Bad Actors”

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Summary

Partitioning of coal by density & size distribution is a magnifying lens to select samples widely varying in constituents to identify the outliers that cause problems in entrained flow gasifiers

Three density fractions show varying macerals

- Vitrinite to inert ratios of SG1 and SG2 significantly different
- SG3 has maximum amount of liptinites (relative basis)

Minerals are predominantly aluminosilicates, pyrites and quartz

Majority of minerals present as very fine particles ($d < 22$ μm)
Bulk of fine minerals are present as included mineral matter

Feed particle size distribution into a slurry fed gasifier does not follow Rosin Rammer function.

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Acknowledgements

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