Reinhold Environmental Ltd.

2008 APC Round Table
& Expo Presentation

July 13-15, 2008, in Savannah, GA

Scales

You Can't Control What You Can't Measure!

- Scale types:
  - Belt (electronic, mechanical), precision: 1%-0.25%
  - Bin, precision: 0.1%
  - Truck (static), precision: 0.1%
  - Rail (weigh-in-motion), precision: 0.25%
- Methods of Calibration
  - Weighed Material Test (also certification)
  - Static Weights, Stacked Weights (also certification)
  - Belt Weights (approximate, but not certifiable)
  - Chains (approximate, 1-5%)
- All weights must be traceable to NIST reference weights
  - NIST Handbook 44

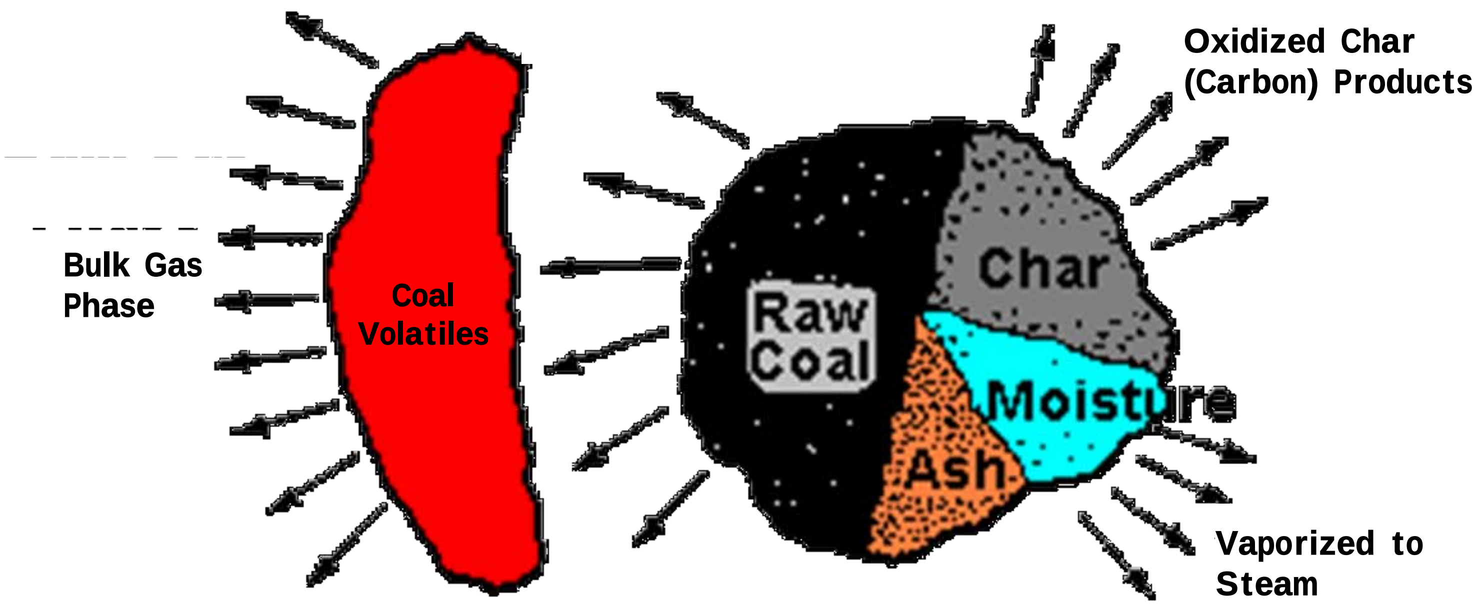
  (http://ts.nist.gov/WeightsAndMeasures/h44-07.cfm)

Remember, coal is purchased by the heat requirement, not tons

- Tons are just for commercial exchange
- Boilers require *x*-Btus to make *y*-MWs, not x-tons to make Y-MWs
- To determine total Btus, accurate total tons is required

Coal Combustion

Generalized Combustion Depiction



Lump of Coal

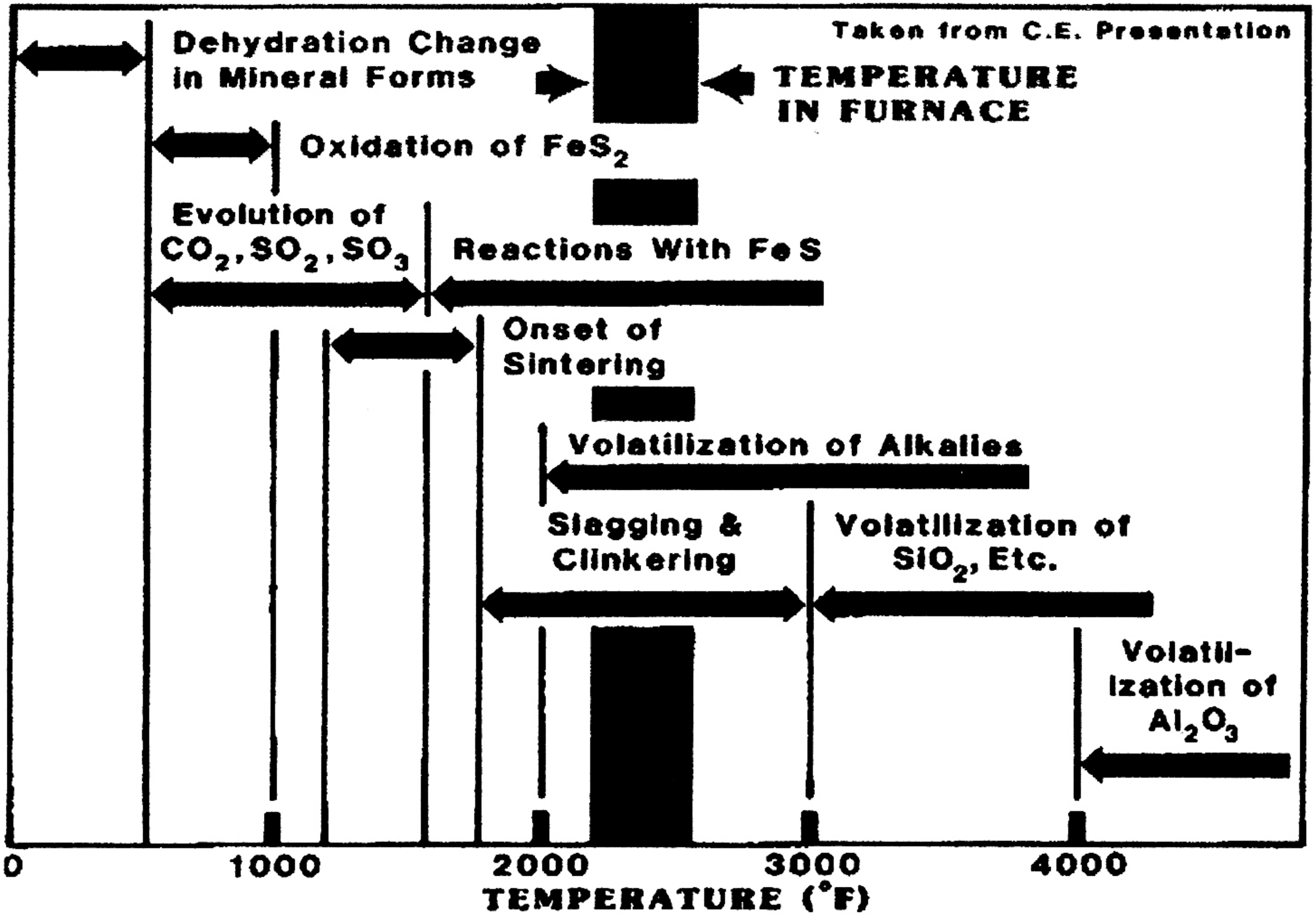
David Tillman, Fundamentals of Combustion Tutorial

Chemistry of Coal Combustion

- **Particle size is the most important parameter** for the dominant reaction mechanism and other thermal behavior (rate of heating, which controls volatile yield and composition)

- Combustion consists of several steps
  - Moisture driven off as particle is heated
  - Particles undergo devolatilization & release volatile organics
    - Volatile matter combusted in gas phase (homogenous reaction)
  - Prior to or simultaneously w/combustion of char
    - Char is surface (heterogeneous) reaction
    - These reactions are mostly sequential and slowest will determine rate of overall process

Chemical Changes in Coal Ash as a Function of Temperature



Source: *Routine Coal & Coke Analysis,* Dr John Riley, *pg 75, ASTM, 2007*

Combustion Characteristics for Pulverized Coal Furnaces

Particle size

~Top size	180 μm
Average size	45 μm
Furnace temperature	>2200°F
Particle heating rate	10^3–10^6 °F/sec

Reaction times

Volatiles	<0.1 sec
Char	<1 sec
Reactive element	Chemically controlled combustion

Particle Size Segregation

CROM Coal

One Lump or Two?

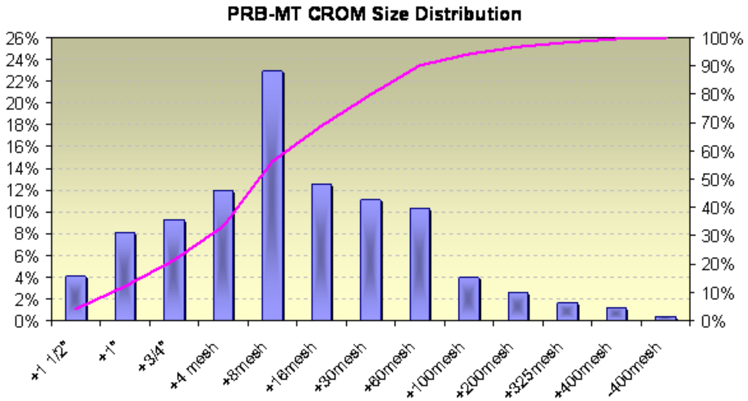
Coal Quality by
Density or Particle Size

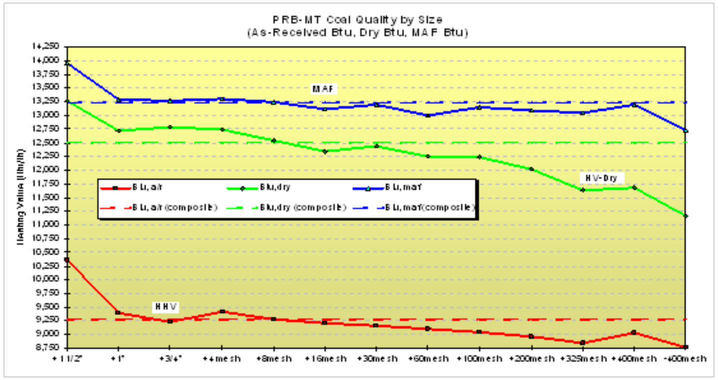
OR

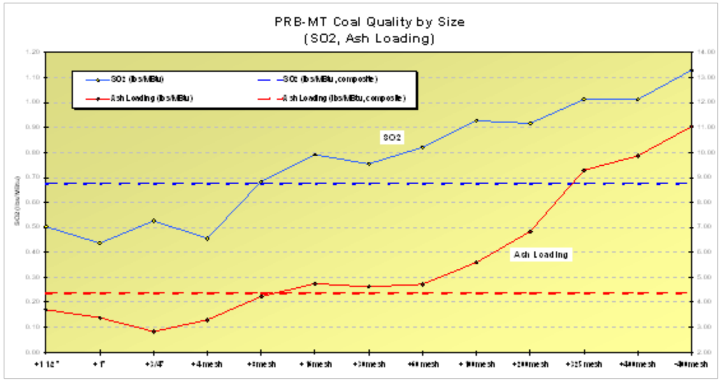
What Number Do You Want?

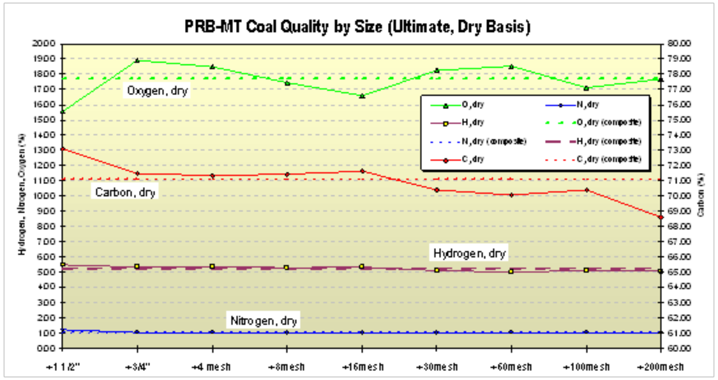
Representative Sampling is Your Only Answer

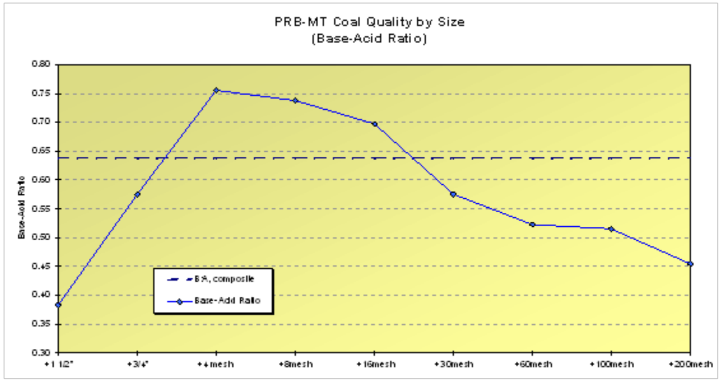
"Fuels" — 2008 APC-Savannah











Mine Size Consist

- Raw vs. CROM vs. washed (full vs. partial)
  - Washing removes ash (e.g., pyrites, roof, floor, slate, bone, sulfur balls, partings)
  - Tightens σ vs. mean
- Washed coals generally spec at 2” x 0; in reality 1½” x 0
- CROM Appalachian coals generally spec at 2” x O
- CROM PRB coals generally spec at 2” x 0…

WHY IS THIS PRACTICE CONTINUING?

  - Increased coal oxidation, increased moisture, accelerated breakage, increased fugitive dust, reduced as-fired heating value
  - Spec at 4” x 0
    - Relative to 2” x 0, reduced oxidation, reduced moisture adsorption, reduced fugitive dust, increased as-fired heating value

Pulverized 60-Mesh Coal

One Spoon or Two?

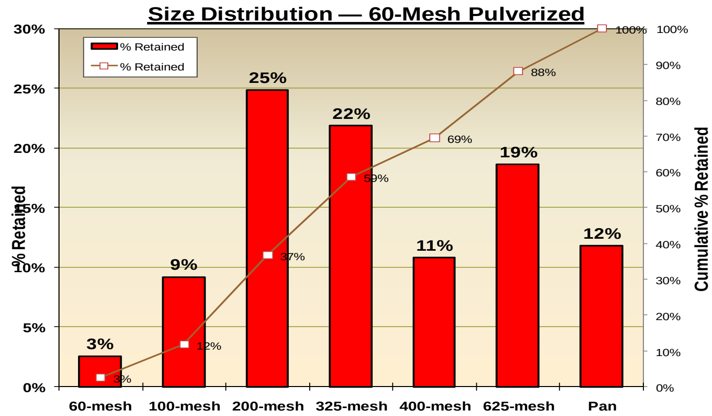
Coal Quality by
Particle Size

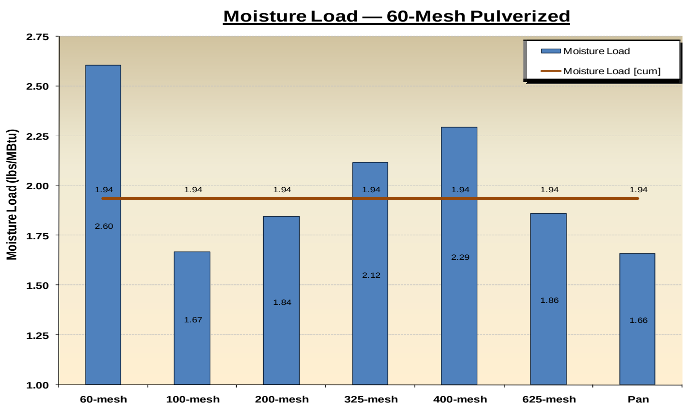
OR

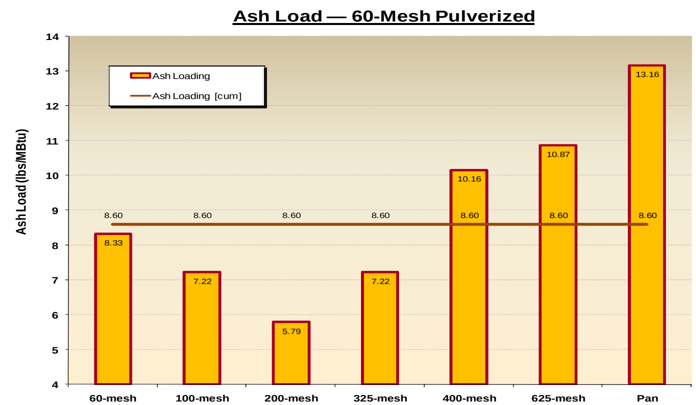
What Number Do You Want?

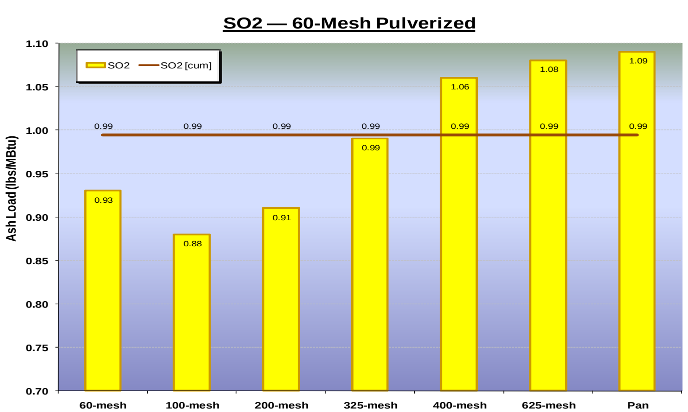
Representative Sampling is Your Only Answer

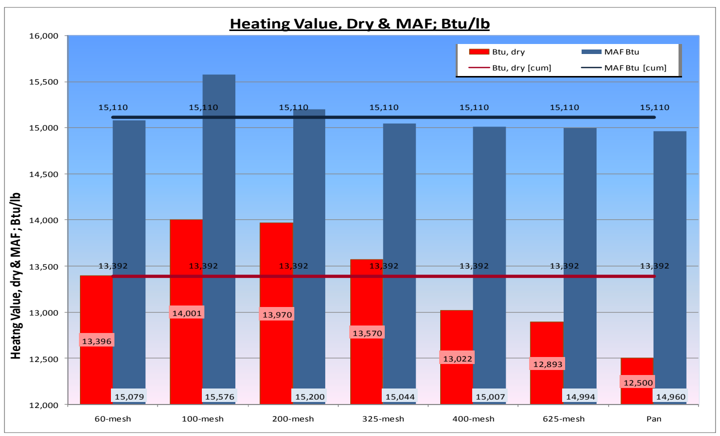
“Fuels” — 2008 APC-Savannah





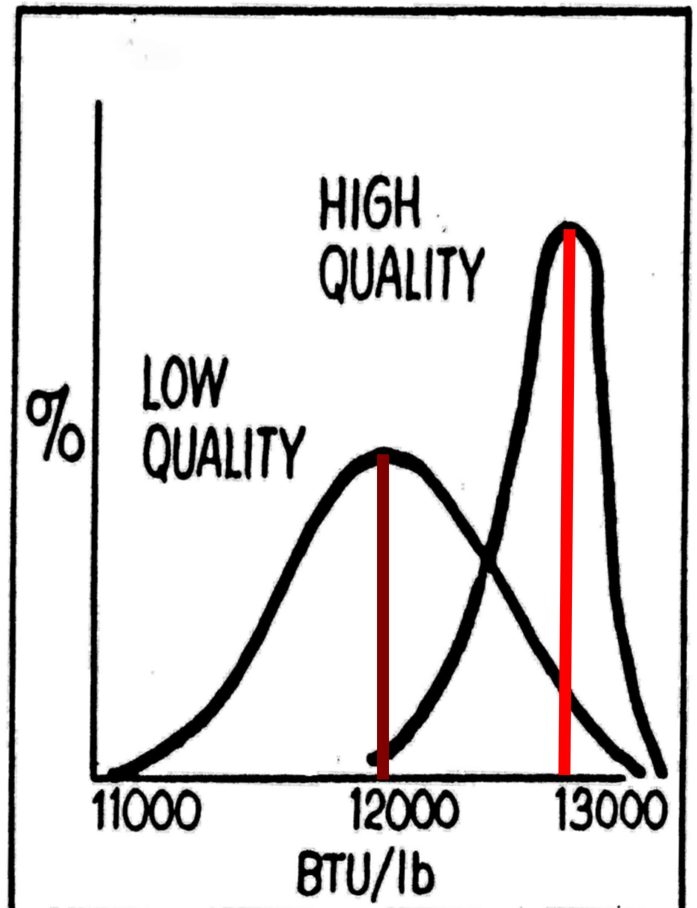






Coal Washing (Physical Coal Cleaning)

Ash Reduction Increases Heating Value



Bob Buckler, Detroit Edison, 1980

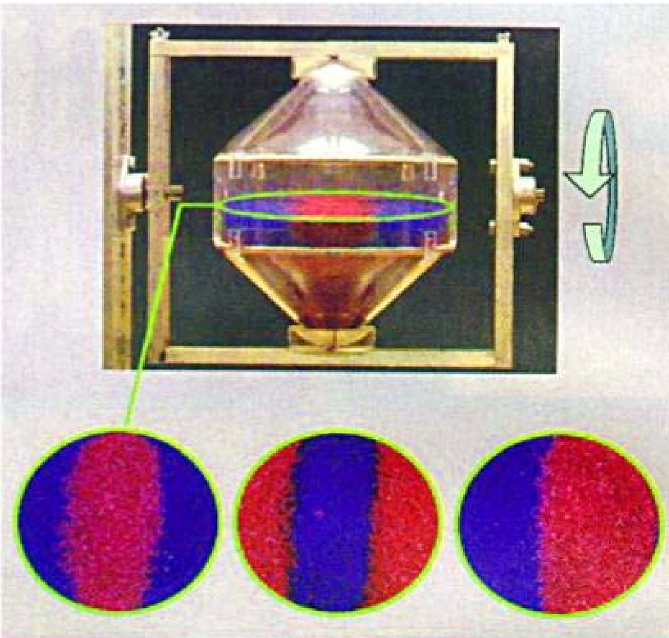
Float-Sink Coal Quality

06/11/84 RAW COAL - SAMPLED AFTER BREAKER FEEDER - 5/9-10/84

SIZE 4" X 3/8" SIZE PCT: 58.28

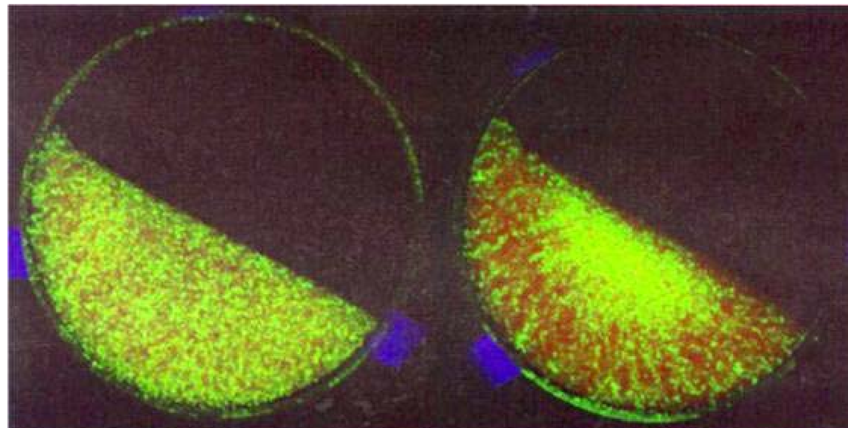
SPEC GRAV		ELEMENTARY DATA				CUMULATIVE FLOAT				CUMULATIVE SINK			
SINK	FLOAT	WT%	ASH	SUL	BTU	WT%	ASH	SUL	BTU	WT%	ASH	SUL	BTU
0.00	1.30	43.62	3.65	0.97	14504	43.62	3.65	0.97	14504	100.00	34.81	1.50	9336
1.30	1.40	14.63	8.97	2.12	13639	58.25	4.99	1.26	14287	56.38	58.92	1.91	5339
1.40	1.50	4.01	18.93	3.49	12001	62.26	5.88	1.40	14140	41.75	76.42	1.83	2430
1.50	1.60	1.37	29.45	3.49	10313	63.63	6.39	1.45	14057	37.74	82.53	1.66	1413
1.60	1.80	2.13	40.60	3.94	8515	65.76	7.50	1.53	13878	36.37	84.53	1.59	1078
1.80	OVER	34.24	87.26	1.44	615	100.00	34.81	1.50	9336	34.24	87.26	1.44	615

Consolidation Coal-1984



YIKES, STRIPES! — Small changes to either the fill level or rotation speed of this industrial-style double-cone blender (top) produce strikingly different segregation patterns (bottom). Bead diameters are 4 millimeters (red) and 1.4 mm (blue).

Science News



JUST ADD WATER — In this tumbler experiment, all beads are the same size but coated with a water-attracting film (orange) or a water-repellent one (green). The beads mix well when dry (left). In an odd twist, adding moisture makes them segregate (right).

Science News

Characteristics of Various US Coals

Proximates of Various US Coals

Type	Moisture	Ash, a/r	Volatile, a/r	FC, a/r	S, a/r	HHV, a/r	Btu, MAF	MoistureLoad	AshLoad	SO2	V/FC
PRB-MT-1a	24.95	3.94	30.72	40.39	0.35	9,340	13,134	26.71	4.22	0.75	0.76
PRB-MT-1b	24.67	3.90	32.62	38.81	0.35	9,476	13,135	26.03	4.12	0.74	0.84
PRB-MT-1c	22.45	4.59	31.83	41.14	0.33	9,569	13,136	23.46	4.80	0.69	0.77
PRB-MT-2	23.45	4.56	30.76	41.19	0.36	9,516	13,137	24.65	4.79	0.75	0.75
PRB-WY-1	26.55	5.01	32.10	36.35	0.25	8,855	13,139	29.98	5.66	0.56	0.88
PRB-WY-2	24.93	5.79	31.97	37.33	0.35	8,985	13,140	27.74	6.45	0.78	0.86
CApp-1	5.55	6.40	34.17	53.89	0.91	13,211	13,142	4.20	4.84	1.37	0.63
CApp-2	7.56	6.35	30.17	55.92	0.68	13,068	13,143	5.79	4.86	1.05	0.54
CApp-3	5.79	8.68	32.78	52.76	0.82	12,768	13,144	4.53	6.80	1.28	0.62
CApp-4	7.95	5.87	29.52	56.66	0.88	13,288	13,145	5.98	4.42	1.32	0.52
Pitt-1 <1.70S	6.24	6.70	31.89	54.75	1.42	13,061	13,147	4.78	5.13	2.17	0.58
Pitt-1 >1.70S	4.52	6.78	34.31	54.39	2.05	13,376	13,148	3.38	5.07	3.07	0.63
Pitt-2	5.28	6.99	34.11	53.61	1.58	13,268	13,149	3.98	5.27	2.38	0.64
Pitt-HSE-1	6.20	6.40	37.10	50.30	2.25	13,288	13,151	4.67	4.82	3.39	0.74
Pitt-HSE-2	5.50	7.59	36.31	50.60	2.43	13,215	13,152	4.16	5.74	3.68	0.72

Ultimates, dry & HGIs of Various US Coals

Type	C, dry	H, dry	N, dry	O, dry	H:C	O:C	HGI
PRB-MT-1a	74.50	4.77	0.92	14.10	0.76	0.14	
PRB-MT-1b	72.04	5.42	1.08	15.80	0.90	0.16	47
PRB-MT-1c	70.80	5.34	0.86	16.66	0.90	0.18	46
PRB-MT-2	71.35	4.88	1.01	16.31	0.81	0.17	47
PRB-WY-1	68.58	5.24	1.08	17.92	0.91	0.20	46
PRB-WY-2	71.64	4.65	0.93	15.82	0.77	0.17	48
CApp-1	80.48	5.18	1.37	5.24	0.77	0.05	48
CApp-2	82.07	5.06	1.48	3.78	0.73	0.03	53
CApp-3	78.13	5.12	1.69	4.98	0.78	0.05	49
CApp-4	82.60	5.17	1.62	3.17	0.75	0.03	54
Pitt-1 <1.70S	79.36	5.14	1.57	5.27	0.77	0.05	52
Pitt-1 >1.70S	78.82	5.24	1.52	5.17	0.79	0.05	51
Pitt-2	77.77	5.22	1.54	6.42	0.80	0.06	54
Pitt-HSE-1	79.10	5.30	1.50	4.78	0.80	0.05	54
Pitt-HSE-2	78.00	5.08	1.52	4.71	0.78	0.05	55

Ash Mineral of Various US Coals

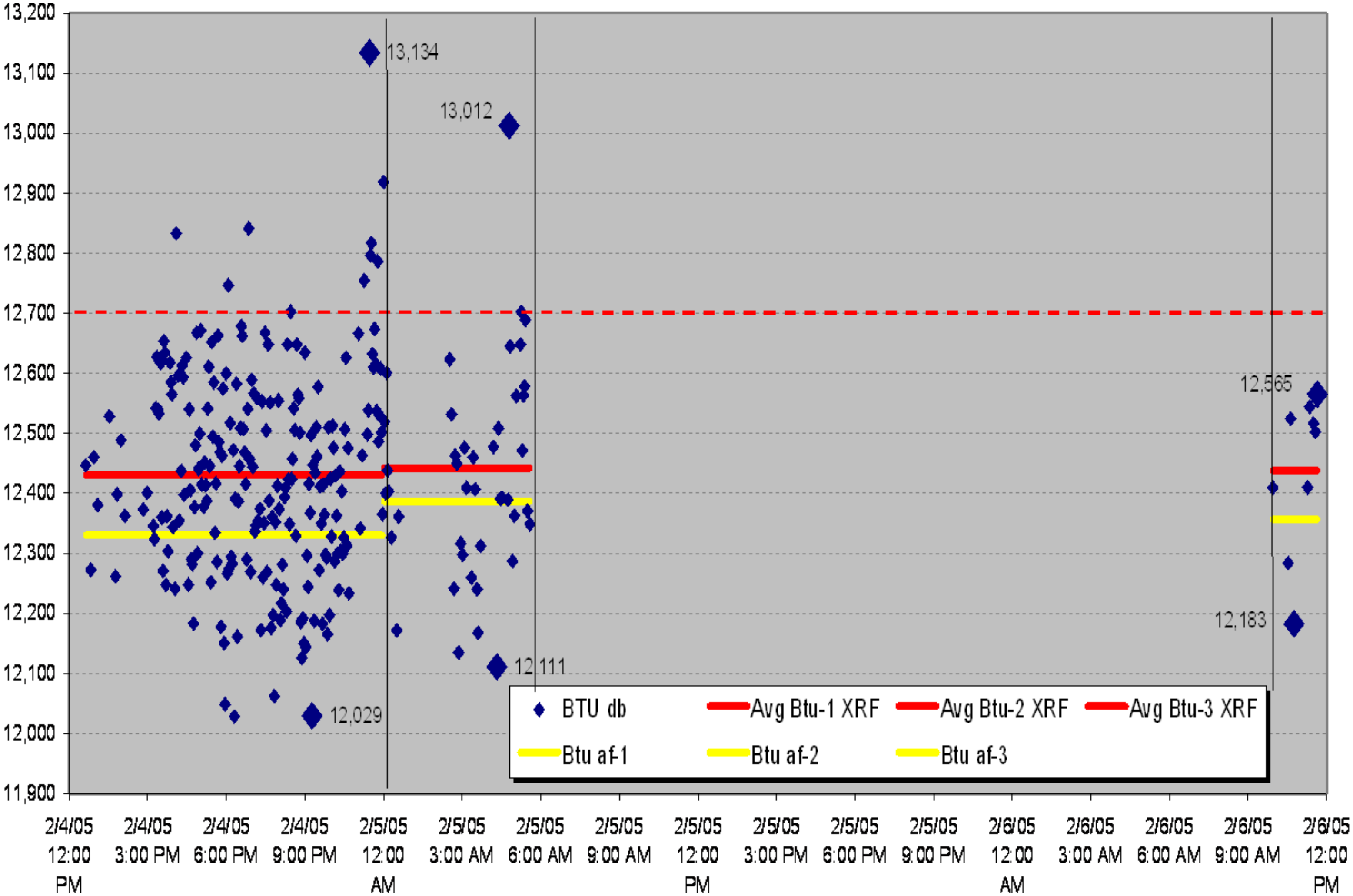
Type	SiO2	Al2O3	TiO2	Fe2O3	CaO	MgO	K2O	Na2O	SO3	P2O5	BaO	MnO2	ba_ratio
PRB-MT-1a	29.29	16.53	1.20	3.88	15.36	4.28	0.43	7.43	16.50	0.27	0.95	0.04	0.67
PRB-MT-1b	28.90	16.20	1.24	5.37	16.70	3.63	1.20	10.40	14.30	0.10	0.92	0.04	0.80
PRB-MT-1c	38.40	18.40	0.93	6.24	14.00	6.14	0.50	3.42	15.00	0.12	0.77	0.04	0.52
PRB-MT-2	35.34	16.89	1.11	4.89	13.86	3.40	0.64	6.02	13.88	1.01	1.12	0.03	0.54
PRB-WY-1	29.90	14.90	0.88	4.55	23.10	6.47	1.60	1.30	11.70	3.24	0.74	0.01	0.81
PRB-WY-2	35.90	15.89	1.24	5.32	18.95	3.95	0.52	1.46	12.89	0.74	0.48	0.02	0.57
CApp-1	52.72	29.81	1.27	7.19	1.64	1.23	3.55	0.57	1.11	0.14	0.17	0.02	0.17
CApp-2	53.70	31.54	1.36	4.38	1.64	0.91	1.43	0.68	0.08	0.65	0.16	0.02	0.10
CApp-3	54.60	29.62	1.14	4.20	2.05	0.80	1.91	0.98	1.70	0.42	0.11	0.01	0.12
CApp-4	53.13	33.20	1.63	7.51	1.27	0.60	1.31	0.75	0.78	0.56	0.17	0.01	0.13
Pitt-1 <1.70S	52.22	24.47	1.02	11.60	3.01	0.84	1.97	0.60	1.45	0.48	0.28	0.02	0.23
Pitt-1 >1.70S	50.52	23.10	0.93	15.63	2.64	0.78	1.94	0.56	1.25	0.35	0.26	0.01	0.29
Pitt-2	50.94	23.93	0.86	12.26	2.99	0.70	2.05	0.60	2.01	0.26	0.08	0.02	0.25
Pitt-HSE-1	43.40	22.80	1.10	19.50	4.40	1.00	1.24	1.33	4.60	0.30	0.13	0.03	0.41
Pitt-HSE-2	44.06	22.28	0.93	18.17	5.47	0.95	1.54	0.95	4.67	0.51	0.19	0.04	0.40

Ash Fusion of Various US Coals

Type	Red,Initial	Red,Soften	Red,Hemi	Red,Fluid	Red,Plastic	Ox,Initial	Ox,Soften	Ox,Hemi	Ox,Fluid	Ox,Plastic
PRB-MT-1a	2,095	2,150	2,185	2,225	130	2,260	2,375	2,445	2,490	230
PRB-MT-1b	2,083	2,151	2,155	2,170	87	2,233	2,415	2,448	2,468	235
PRB-MT-1c	2,018	2,077	2,107	2,167	149	2,140	2,227	2,240	2,285	145
PRB-MT-2	2,073	2,102	2,127	2,182	109	2,219	2,331	2,362	2,401	181
PRB-WY-1	2,042	2,098	2,123	2,165	123	2,094	2,184	2,200	2,249	155
PRB-WY-2	2,110	2,171	2,190	2,237	127	2,177	2,188	2,205	2,258	81
CApp-1	2,760	2,770	2,785	>2800	>40	>2800	>2800	>2800	>2800	>0
CApp-2	>2800	>2800	>2800	>2800	>0	>2800	>2800	>2800	>2800	>0
CApp-3	>2800	>2800	>2800	>2800	>0	>2800	>2800	>2800	>2800	>0
CApp-4	>2800	>2800	>2800	>2800	>0	>2800	>2800	>2800	>2800	>0
Pitt-1 <1.70S	2,472	2,499	2,530	2,585	113	2,550	2,590	2,625	2,670	120
Pitt-1 >1.70S	2,209	2,280	2,372	2,460	251	2,535	2,575	2,595	2,665	130
Pitt-2	2,145	2,195	2,355	2,435	290	2,350	2,385	2,415	2,490	140
Pitt-HSE-1	2,115	2,165	2,220	2,395	280	2,450	2,495	2,525	2,560	110
Pitt-HSE-2	2,118	2,181	2,249	2,329	211	2,406	2,449	2,497	2,540	134

Heating Value — Lab vs. On-Line Analyzer

(After Initial Calibration)



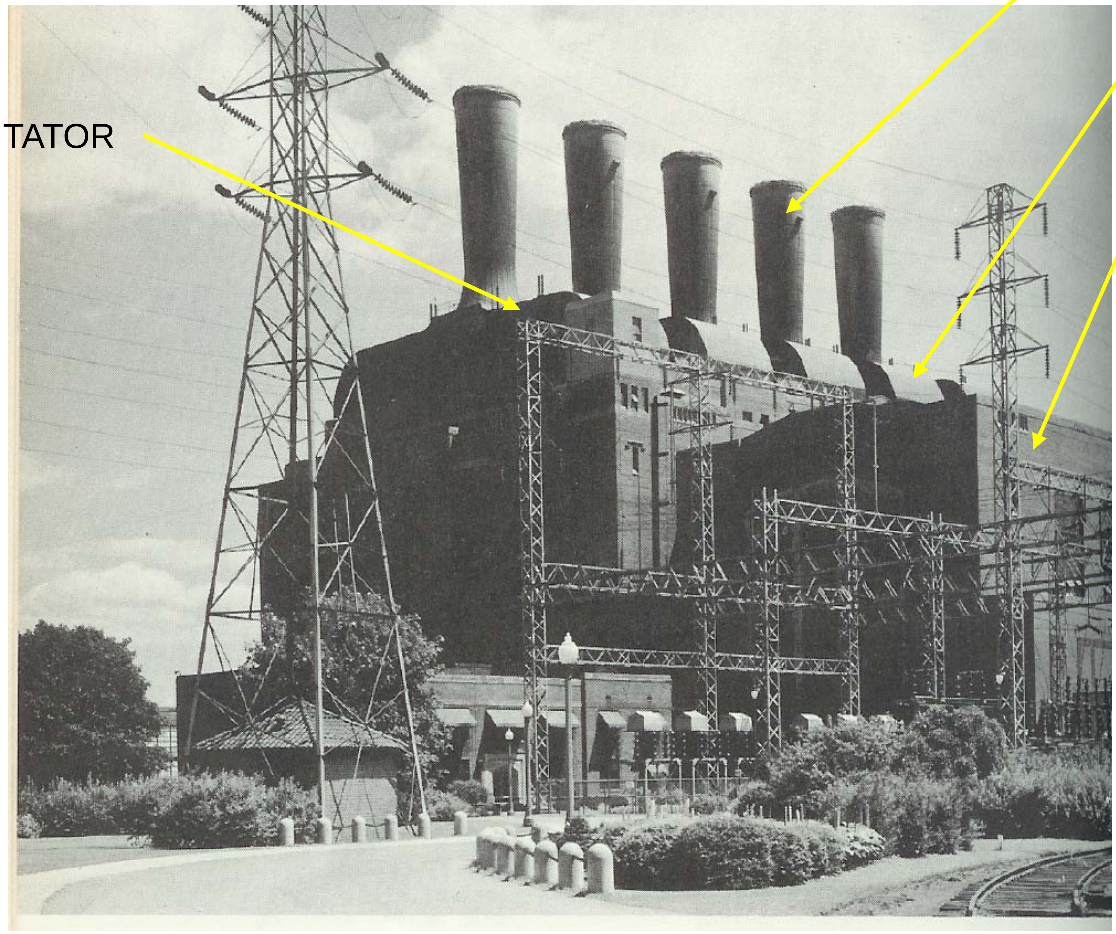
Fly Ash Collection

ESPs

&

Ash Resistivity

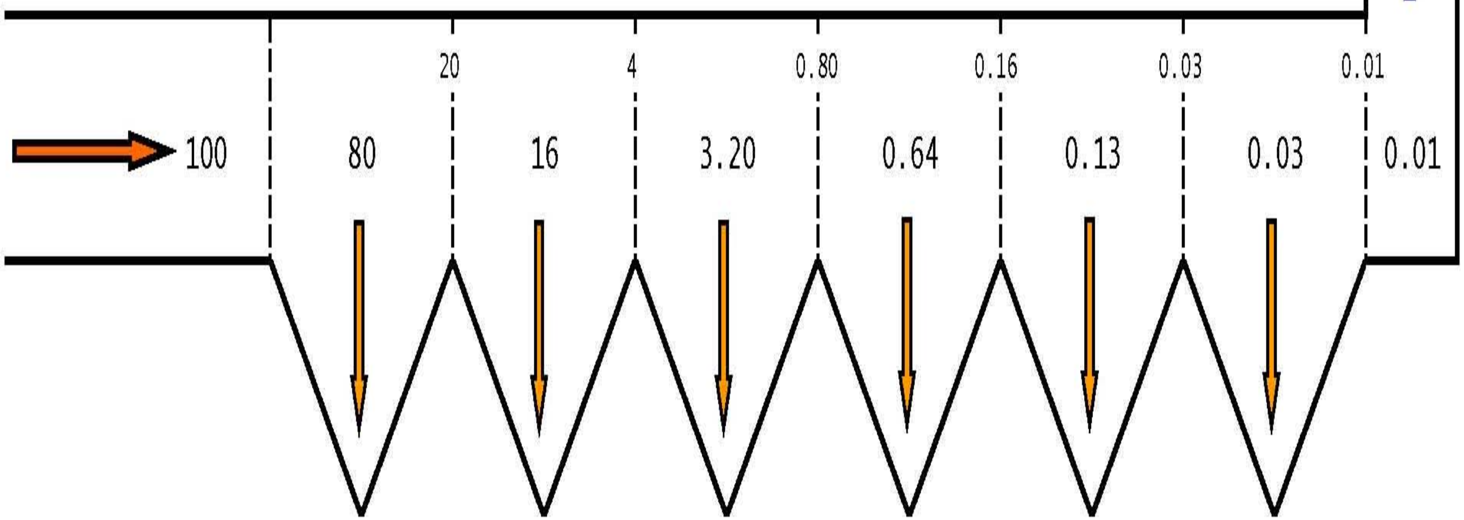
TRENTON CHANNEL POWER PLANT LOW PRESSURE FIRST UTILITY BOILER w/PRECIPITATOR — 1923



Electrostatic Precipitator Operation

Field #	Lbs Collected	Lbs By-Passed	Collection Efficiency
Entering Ash	100		
1	80	20	80.00%
2	16	4	96.00%
3	3.20	0.80	99.20%
4	0.64	0.16	99.84%
5	0.13	0.03	99.97%
6	0.03	0.01	99.99%

Assumed Collection Efficiency/Field = 80%

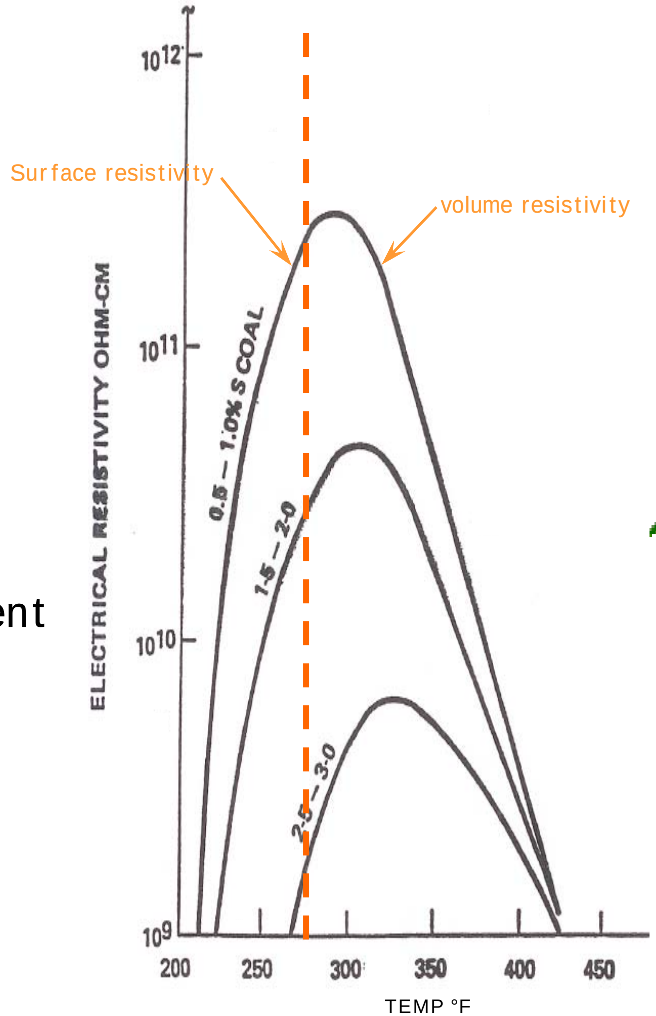


Ash ESP Parameters

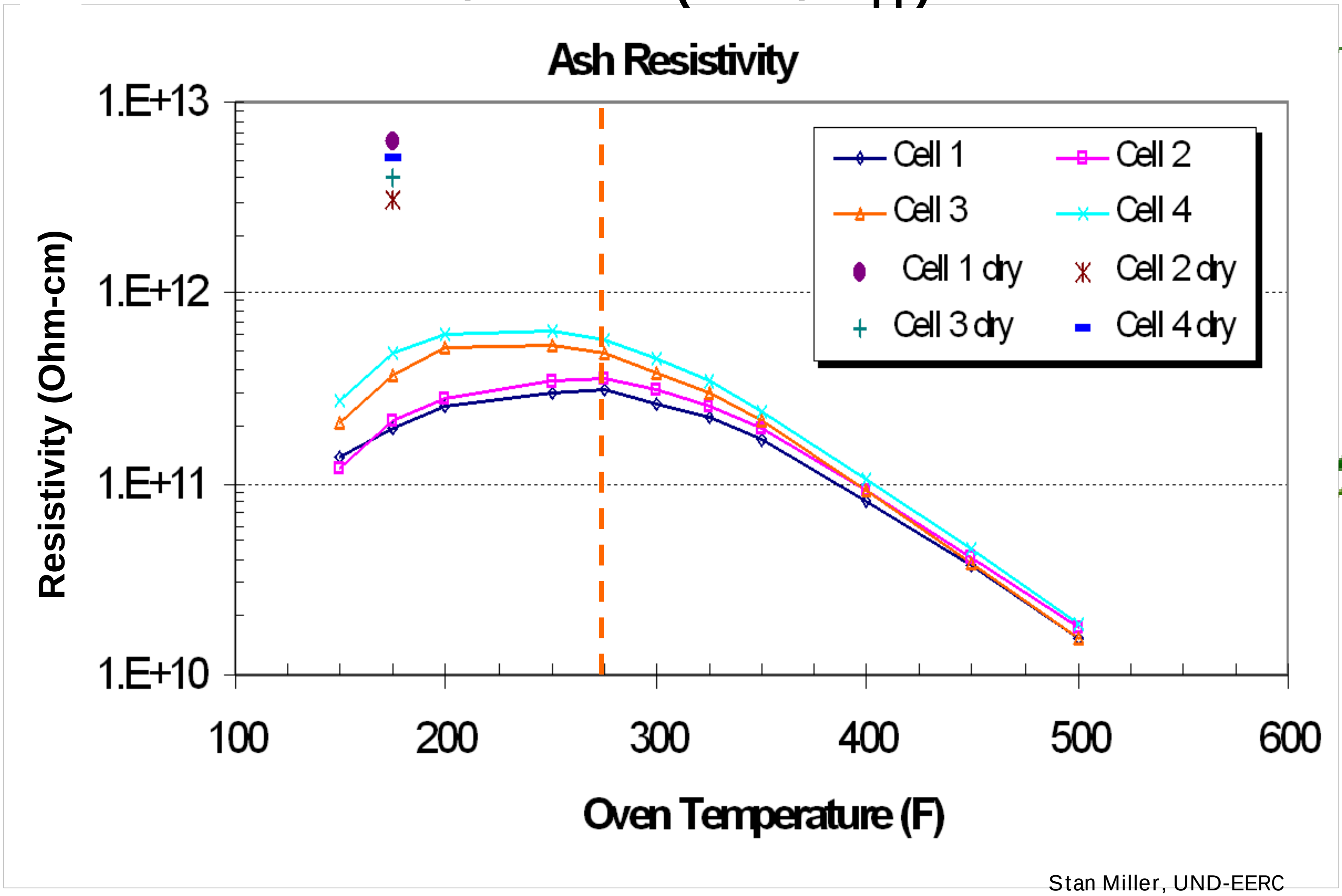
- **Ash Load (Grain Loading)**
  - Lbs Ash/MBtu ≡
    Ash% * 10,000 / Heating Value (Btu/lb)
  - Not all ash travels to ESP
    - *ƒ*(ash viscosity, ash fusion temperatures, furnace atmosphere)
    - High fusion temperature moves more ash to back pass and ESPs as economizer ash & fly ash
    - Low fusion temperature holds more ash in furnace and pendants in the form of slag & fouling deposits

Electrostatic Precipitation

- **Ash Resistivity (Ω-cm)**
  - Highly dependent on flue gas temperature and relative humidity
  - **S *[SO_3]*, Na, Fe, Li** (> improves collection efficiency)
    - Metals that act as conductors
    - High voltage field easily strips the metal of electrons
  - **SiO_2+Al_2O_3** < ~80% (ESP Index)
    - Ash resistivity too high for efficient collection
    - "glass"
  - **SiO_2+Al_2O_3+Fe_2O_3** <~98%,
    - Ash resistivity too low
    - Difficult to remove from rappers, re-entrainment



60/40 Blend (SPRB/CApp)



Stan Miller, UND-EERC

Now, let’s go over the fuel analysis shown at the start of today’s tutorial

Coal Analysis

Mine/Supplier:	Pittsburgh Seam	Sampling Method:	Mechanical
Sample #:	99F-00852	Sample Date:	2/25/1999
Sample Description:	S> 1.7%	Sample Receipt:	2/26/1999

Proximate	As=Received	Dry	MAF
Moisture (-)	4.52		
Ash (-)	6.78	7.10	
Volatile (+)	34.31	35.95	38.68
Fixed Carbon (+)	54.39	56.99	61.32
Sulfur	2.05	2.14	
Heating Value	13,376	14,010	15,080

ADL	2.30
Residual Moisure	2.27

Moisture Load	3.38
Ash Load	5.07
SO2	3.07
V/FC	0.63

Ultimate	As=Received	Dry	MAF
Carbon	75.23	78.82	84.84
Hydrogen	5.00	5.24	5.64
Nitrogen	1.45	1.52	1.64
Oxygen	4.97	5.21	5.61

Hardgrove Grindability Index

HGI	**50.8 @2.89% Moisture**

Coal Analysis

Mine/Supplier:	Pittsburgh Seam	Sampling Method:	Mechanical
Sample #:	99F-00852	Sample Date:	2/25/1999
Sample Description:	S> 1.7%	Sample Receipt:	2/26/1999

Ash Fusion - 8 point

	Reducing	Oxidizing
Initial	2,209	2,535
Spherical	2,280	2,575
Hemispherical	2,372	2,595
Fluid	2,460	2,665
Plastic Range	251	130

Ash Mineral

SiO2	50.52
Al2O3	23.10
TiO2	0.93
Fe2O3	15.63
CaO	2.64
MgO	0.78
K2O	1.94
Na2O	0.56
SO3	1.25
P2O5	0.35
BaO	0.26
SrO	0.81
MnO2	0.01
Undetermined	1.22

B/A	0.29
Ash Ratio	0.22
Ash Type	Bituminous
Slagging Index	1
Slagging Type	Medium
Fouling Index	0.16
Fouling Type	Low
Silica Ratio	0.73
Si/Al	2.19
Fe/Ca	5.92
Dolomite %	15.87

Trace Elements	*Units*	*Value*		*Units*	*Value*		*Units*	*Value*
Sb, Antimony	ppm	0.11	Pb, Lead	ppm	8.24	Ag, Silver	ppm	0.067
As, Arsenic	ppm	11.97	Mn, Manganese	ppm	18.9	Tl, Thalium	ppm	0.62
Ba, Barium	ppm	104	Hg, Mercury	ppm	0.082	V, Vanadium	ppm	30.1
Be, Beryllium	ppm	2.2	Mo, Molybdenum	ppm	1.12	Zn, Zinc	ppm	14.5
Cd, Cadmium	ppm	0.061	Ni, Nickel	ppm	13.61			
Cl, Chlorine	ppm	957.28	Se, Selenium	ppm	3.22			
Cr, Chromium	ppm	12.4						
Co, Cobalt	ppm	6.21						
Cu, Copper	ppm	15.8						
F, Fluorine	ppm	<10						

Make sure you attend tomorrow's

Impact of Combustion on Particulate Collection

Presented by Bob Taylor

GE Energy

His presentation is the perfect successor to this presentation

Thank You!