

Reinhold Environmental Ltd.



***2007 APC Round Table & Expo
Presentation***

***July 8-10, 2007
Chattanooga, TN
Hosted by TVA***

**Welcome
&
Good Morning!**

Please take a moment to give your pagers and cell phones a rest; either shut them off or switch to vibrate mode



"Science of Fossil Fuels"

2007 APC Conference

10 July 2007

Marriott-Chattanooga Hotel
Chattanooga, TN

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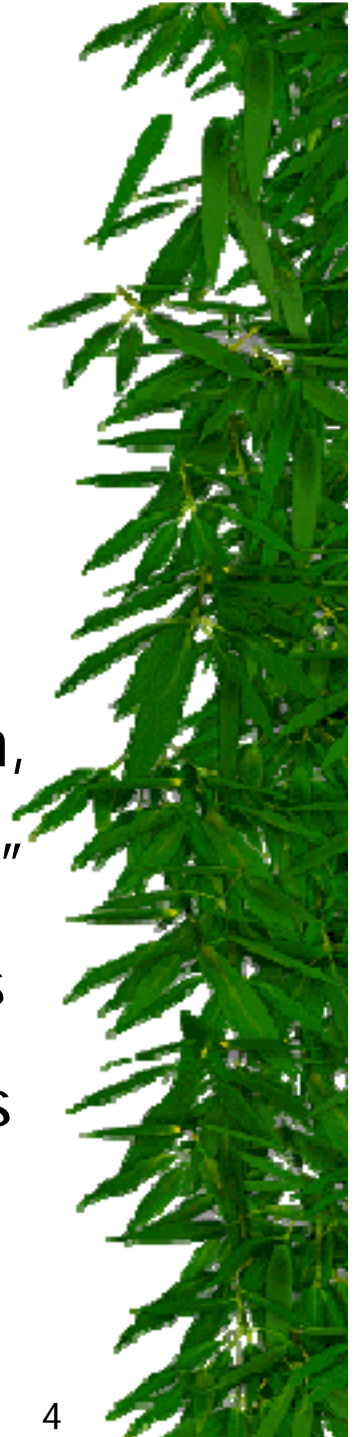
Special thanks to
Susan Reinhold

for her persuasive encouragement at
Electric Power-Chicago
for me to speak this morning



Thanks to
Bob Taylor
GE Energy

for his excellent Monday afternoon presentation,
"Impact of Combustion on Particulate Collection."
His presentation was the perfect lead-in to this
presentation. Make sure you get a copy of Bob's
presentation before you leave the conference



Objective

To present a brief tutorial
on the environmental
impacts of coal



What is coal?

It's definitely not just
black and burns

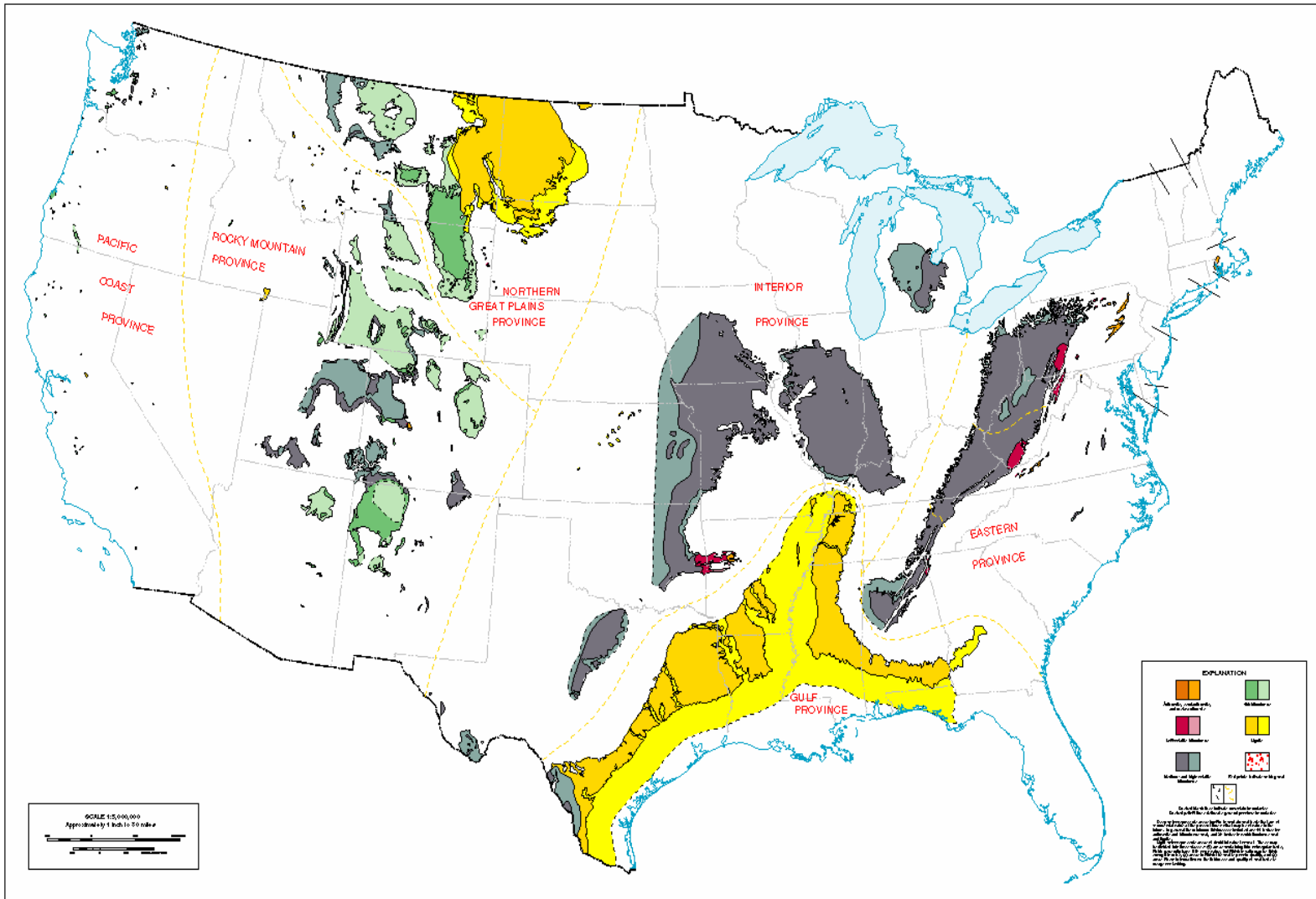


Definitions of Coal

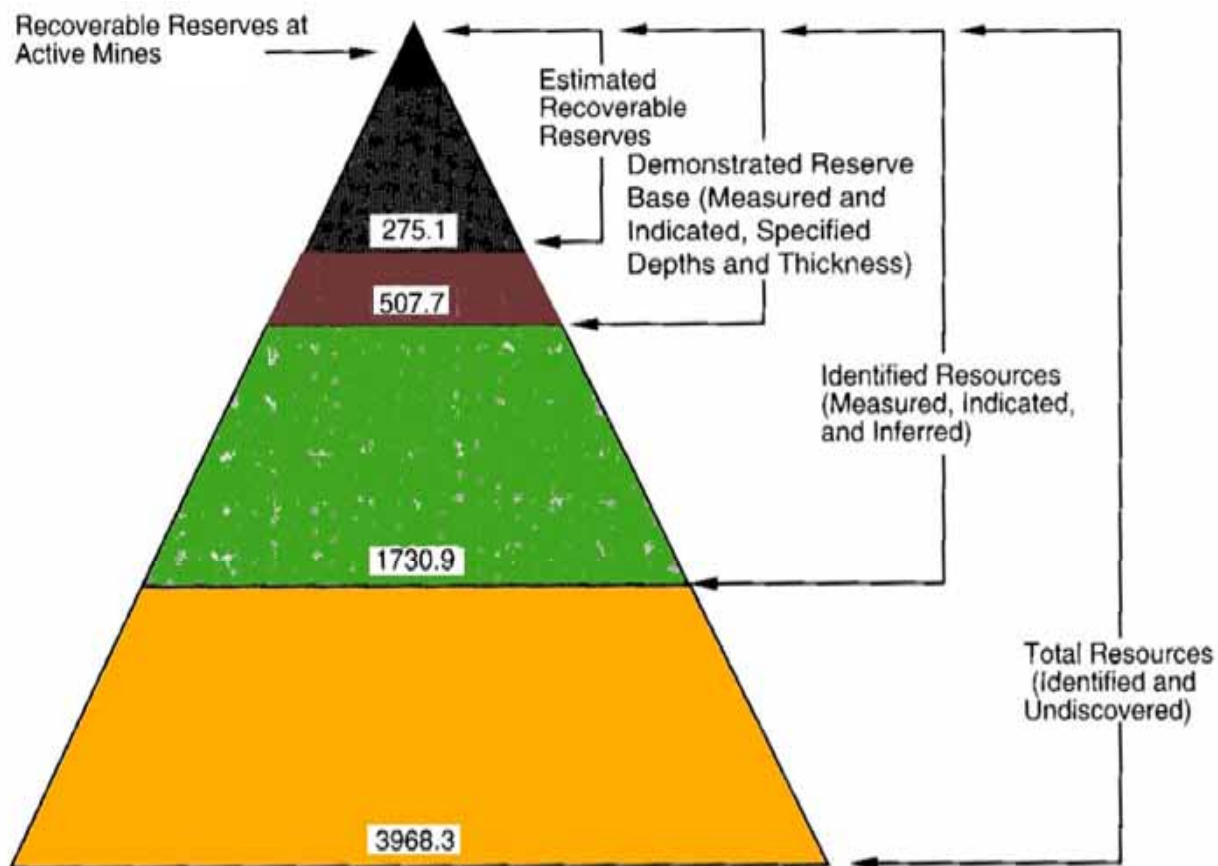
- A brown or black combustible sedimentary rock (in the geological sense) composed principally of consolidated and chemically altered plant remains. (ASTM D121)
- Coal is a rock, a sediment, a conglomerate, a biological fossil, a complex colloidal system, an enigma in solid-state physics and an intriguing object for chemical and physical analyses (*van Krevelen*)
- A solid, brittle, more or less distinctly stratified **combustible, carbonaceous rock**
- A black, **inhomogeneous**, organic fuel formed largely from partially **decomposed** and **metamorphosed plant materials**
- The natural, rocklike, brown or black derivative of **forest-type plant material**, usually accumulated in peat beds and progressively compressed and indurated until it is finally altered in graphite or graphite-like material
- **Coal is a chemically and physically heterogeneous, "combustible," sedimentary rock consisting of both organic and inorganic material** (Miller)



Coal Deposits in the USA



US Coal Resources & Reserves



United States coal resources and reserves in billion short tons.
(From EIA, *U.S. Coal Reserves: 1997 Update*, U.S. Department of Energy, Energy Information Administration, Washington, D.C., February 1999, p. 5, Appendix A.)



Coal

Mechanical combination of coal + mineral matter

Coal Maceral (bark, sap, leaves)

- Sorry, no dinosaurs
- Complex aromatic hydrocarbon
- Volatile & Fixed Carbon — energy source
- Hydrophobic (rejects water)

Mineral Matter (ash)

- Combustible & non-combustible minerals — energy sink
- Mostly minerals of the following oxides
 - Si, Al, Ti, Fe, Ca, Mg, K, Na, S, P, Ba, Sr, Mn, Cl, + ...
 - 76 of the first 92 elements
- Hydrophilic (accepts water)

Moisture

- Inherent (Equilibrium, Bed) & Surface — energy sink



Coalification Process

Materials	Partial Processes	Main Chemical Reactions
Decaying Vegetation ↓ <i>Peat</i> ↓ <i>Lignite</i> ↓ <i>Bituminous coal</i> ↓ <i>Semianthracite</i> ↓ <i>Anthracite</i>	Peatification Lignitification Bituminization Preanthracitization Anthracitization Graphitization	Bacterial and fungal life cycles Air oxidation, followed by decarboxylation and dehydration Decarboxylation and hydrogen disproportioning Condensation to small aromatic ring systems Condensation of small aromatic ring systems to larger ones; dehydrogenation Complete carbonification

FIGURE 1-2. The coalification process. (From Van Krevelen, D. W., *Coal: Typology-Physics-Chemistry-Constitution*, Third ed., Elsevier Science, Amsterdam, 1993. With permission).



Composition

(wt% DMMF Basis)

	C	H	O
Wood	49	7	44
Peat	60	6	34
Lignite	70	5	25
Subbituminous	75	5	20
Bituminous	85	5	10
Anthracite	94	3	3

- Increasing Aromatization & Loss of Oxygen with Time



Hypothesized Coal Structures

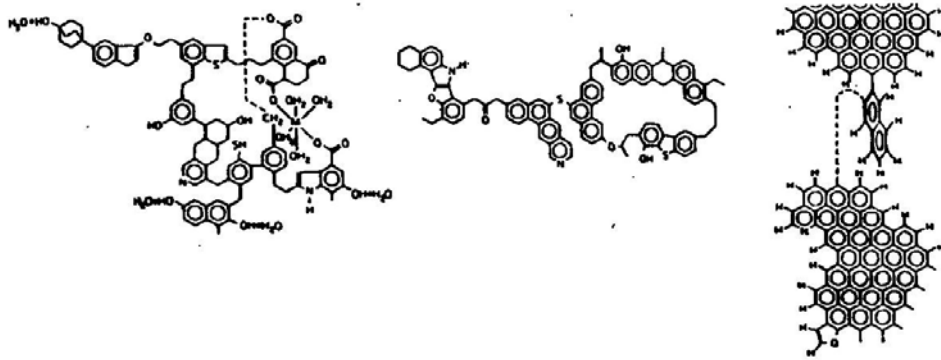


Figure 13. Spiro and Kosky (1982) models for a low-, intermediate-, and high-rank coal.

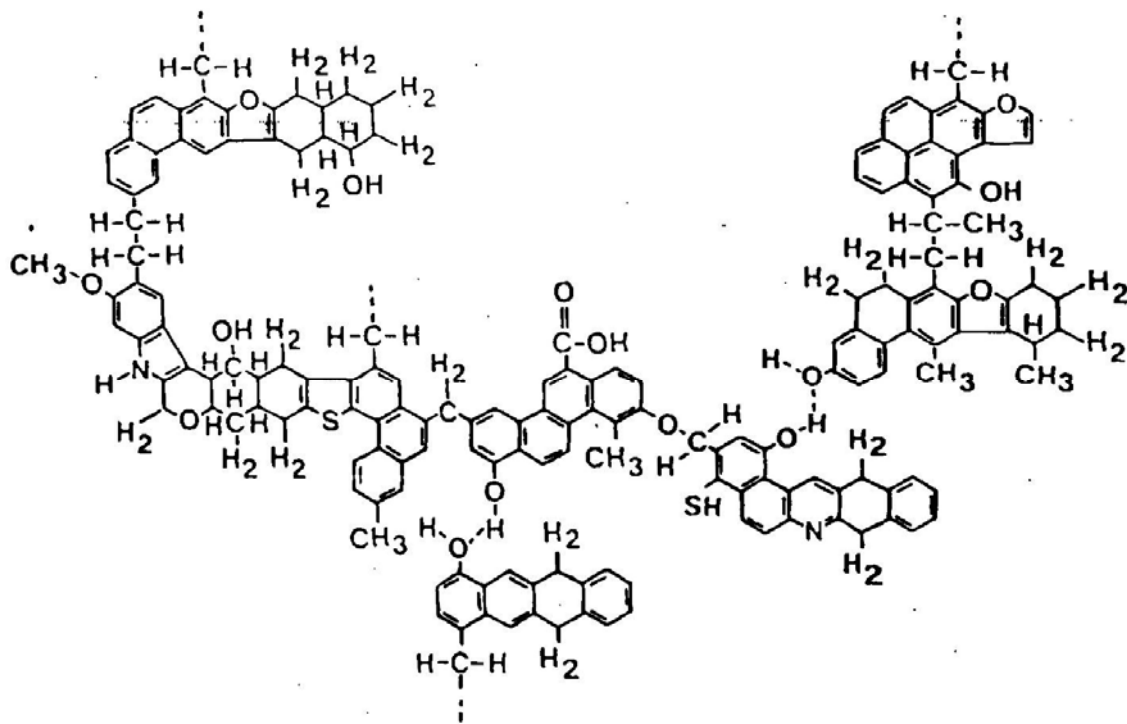


Figure 12. The Solomon (1981) model of a Pittsburgh high-volatile bituminous coal.



Coal Structural Characterization

Polycyclic Aromatic Hydrocarbons Identified in the A-2 Fractions of
Upper Freeport, Wyodak, Illinois #6, Pittsburgh, Pocahontas #3, and Beulah-Zap

Peak no.	Proposed structure	Peak no.	Proposed structure
1.	Naphthalene	24.	<i>tert</i> -Butyl-C ₁ -biphenyl
2.	2-Methylnaphthalene	25.	2-Phenylnaphthalene
3.	1-Methylnaphthalene	26.	C ₂ -phenanthrenes
4.	Biphenyl	27.	Fluoranthene
5.	C ₂ -naphthalenes	28.	C ₁ -phenylnaphthalenes
6.	C ₁ -biphenyls	29.	Pyrene
7.	C ₂ -naphthalenes	30.	C ₂ -phenanthrenes
8.	Fluorene	31.	Benzo[a]fluorene
9.	3-Methylfluorene	32.	Benzo[b]fluorene and/or benzo[c]fluorene
10.	C ₂ -biphenyls	33.	Retene (7-isopropyl-1- methylphenanthrene)
11.	C ₄ -naphthalenes	34.	Methyl-9,10-dihdropyrene
12.	2-Methylfluorene	35.	C ₁ -benzofluorenes
13.	1-Methylfluorene	36.	Chrysene
14.	C ₂ -naphthalenes	37.	C ₂ -benzofluorenes
15.	Phenanthrene	38.	C ₁ -chrysenes
16.	C ₂ -fluorenes	39.	C ₁ -benzofluorene
17.	C ₁ -biphenyls	40.	C ₂ -chrysenes
18.	C ₄ -naphthalenes	41.	Benzo[fluoranthene]
19.	2-Methylphenanthrene	42.	Benzo[e]pyrene
20.	3-Methylphenanthrene	43.	Benzo[a]pyrene
21.	4-Methylphenanthrene and/or 9-methylphenanthrene	44.	C ₁ -252
22.	1-Methylphenanthrene		
23.	<i>tert</i> -Octyl-C ₂ -naphthalene		



Coal Mineral Types

TABLE 51. Mineral Types Observed in the Recommended Coals by CCSEM

Mineral type	Chemical formula ^a
Quartz	SiO ₂
Al-silicate (kaolinite)	Al ₄ Si ₄ O ₁₀ (OH) ₈
Fe-aluminosilicate	Fe _x Al _y Si _z
K-aluminosilicate (illite)	K(Al, Fe) ₄ (Si, Al) ₈ O ₂₀ (OH) ₄
Ca-aluminosilicate	Ca _x Al _y Si _z
Iron oxide	Fe ₂ O ₃
Pyrite	FeS ₂
Gypsum	CaSO ₄ · 2H ₂ O
Calcite	CaCO ₃
Rutile	TiO ₂
Barite	BaSO ₄
Ankerite	Ca(Mg, Fe, Mn) (CO ₃) ₂
Siderite	FeCO ₃
Crandallite	CaAl ₃ (PO ₄) ₂ (OH) ₅ · H ₂ O
Dolomite	CaMg(CO ₃) ₂
Calcium aluminate	Ca ₃ Al ₂ O ₆
Apatite	Ca ₅ F(PO ₄) ₃
Spinel	(Fe, Al, Mg)O ₄
Calcium silicate	CaSiO ₃
Pyrrhotite/iron sulfate	FeS
Ca-rich	—
Si-rich	—

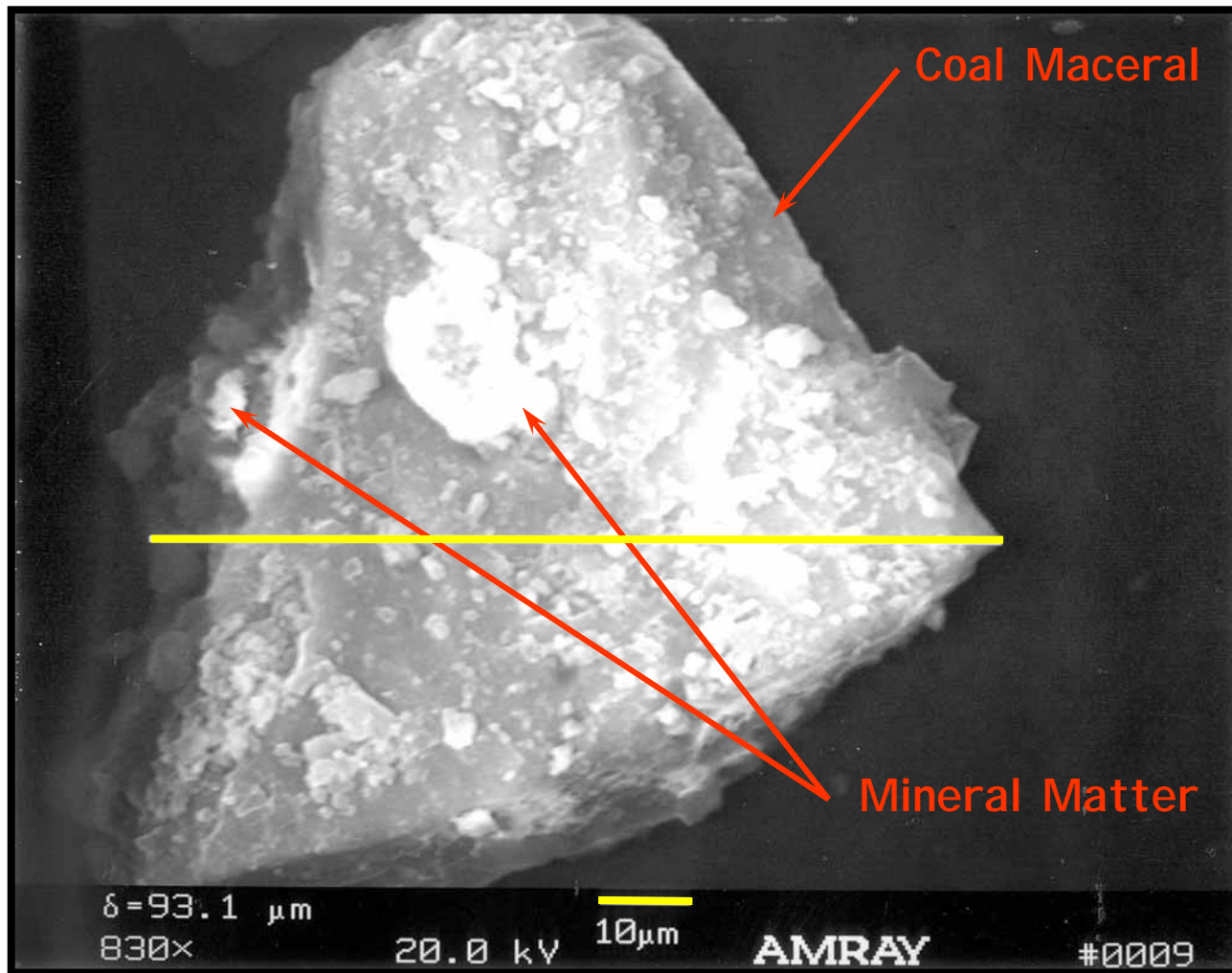
^a Actual molar ratios will vary due to limits of the CCSEM technique.
 Source: Zygarrlicke *et al.* (1990a).



Coal Seam — Pittsburgh (Northern Appalachia)



SEM Photomicrograph of Coal Particle



Sub-bituminous coal particle, about 93- μm across.
Note the defined edges, the shape and texture of the particle



Coal Characteristics

Its Properties & Effects



**Knowing just a coal's short prox
is no longer sufficient;
not enough information,**

&

**results not sufficiently timely
to make accurate operating
decisions**



What does the short proximate tell you?

- Moisture
 - Ash
 - Sulfur
- Heating Value



Now, what do these values tell you?

- Moisture
- Ash
- Volatile
- Fixed Carbon
- Sulfur
- Heating Value
- MAF Heating Value
- Moisture Load
- Ash Load
- SO₂
- Volatile/Fixed Carbon



Coal Comparisons

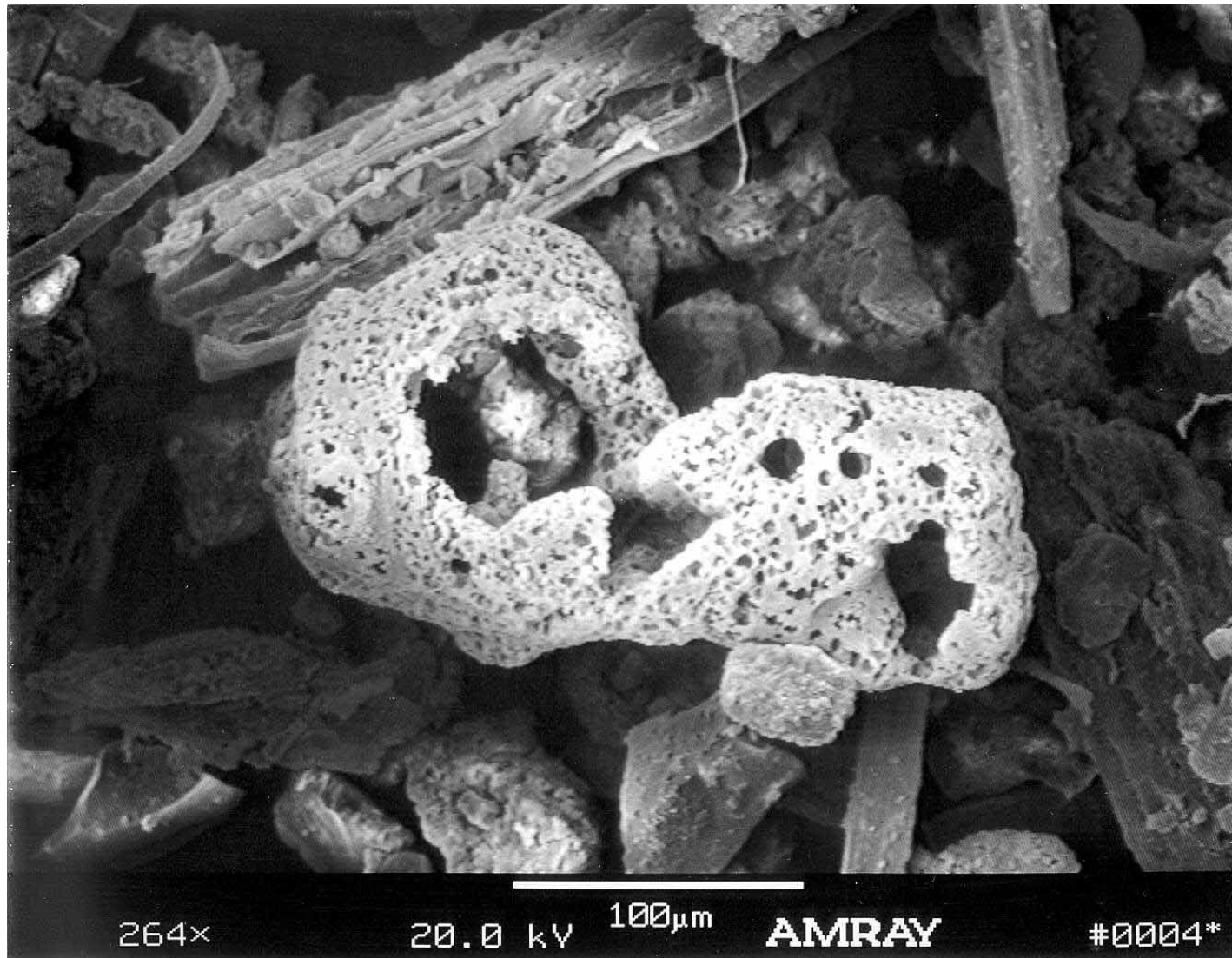
	Bituminous		Sub-Bituminous	
<u>Proximate</u>	Pitt (S<1.7)	Pitt (S>1.7)	PRB (Na<4)	PRB (Na>4)
Moisture (%)	6.24	4.52	23.13	24.60
Ash (%)	6.70	6.78	4.22	3.60
Volatile (%)	31.89	34.31	32.97	31.57
Fixed Carbon (%)	54.75	54.39	39.68	40.23
Sulfur (%)	1.42	2.05	0.29	0.25
HHV (Btu/lb)	13,061	13,376	9,554	9,507
<u>MAF (Btu/lb)</u>	15,002	15,080	13,152	13,241
Moisture Load (lbs/MBtu)	4.78	3.38	24.21	25.88
Ash Load (lbs/MBtu)	5.13	5.04	4.41	3.79
SO ₂ (lbs/MBtu)	2.17	3.07	0.62	0.53
V/FC (%/%)	0.58	0.63	0.83	0.78



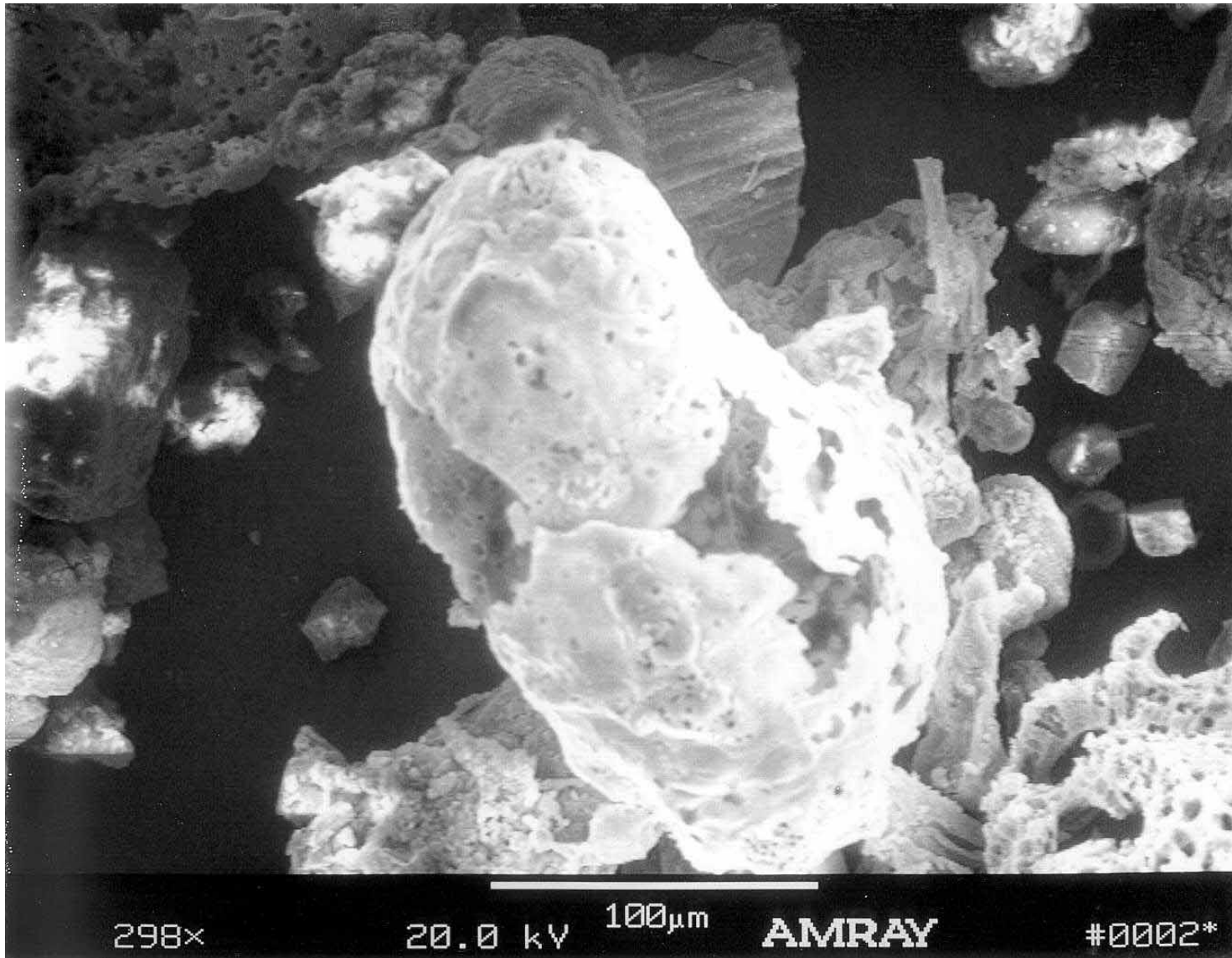
Ash With Your Coal? — No Thank You



Coal Char



Coal Char



How about these values?

- Carbon
 - Hydrogen
 - Nitrogen
 - *Chlorine*
 - Oxygen
- Atomic Ratios
- H:C
 - O:C



Coal Comparisons

<u>Ultimate</u>	Pitt (S<1.7)	Pitt (S>1.7)	PRB (Na<4)	PRB (Na>4)
Carbon	79.36	78.82	68.65	71.47
Hydrogen	5.14	5.24	4.48	5.03
Nitrogen	1.57	1.52	0.93	1.14
Chlorine	0.095	0.103	0.013	0.010
Oxygen	5.27	5.17	20.06	17.25
Atomic Ratios				
H:C	0.772	0.792	0.778	0.838
O:C	0.050	0.049	0.219	0.181



Ash Mineral

- Acids (SiO_2 , Al_2O_3 , TiO_2)
- Bases (Fe_2O_3 , CaO , MgO , K_2O , Na_2O)
- Minor Elements (SO_3 , P_2O_5 , BaO , MnO_2)

Calculated Values

- Base/Acid
- Slagging & Fouling Indexes
 - High Rank Coals
 - Low Rank Coals
- Fe, Ca, Na, Alkali Loads, "Sticky Alkali" Loads
- Fe/Ca
- ESP Index



Coal Comparisons

<u>Ash Mineral</u>	Pitt (S<1.7)	Pitt (S>1.7)	PRB (Na<4)	PRB (Na>4)
SiO ₂	53.31	51.57	38.34	35.96
Al ₂ O ₃	24.98	23.58	17.83	20.08
TiO ₂	1.04	0.95	1.29	1.67
Fe ₂ O ₃	11.84	15.95	5.03	5.20
CaO	3.07	2.69	14.23	20.19
MgO	0.86	0.80	4.63	4.89
K ₂ O	2.01	1.98	0.82	0.42
Na ₂ O	0.61	0.57	2.58	11.58
% Acid	81.18	77.58	67.80	57.71
% Base	18.82	22.42	32.20	42.29
Base / Acid	0.23	0.29	0.47	0.73
Slagging Type	Low	Severe	High	High
Fouling Type	Low	Low	Low-Medium	Severe



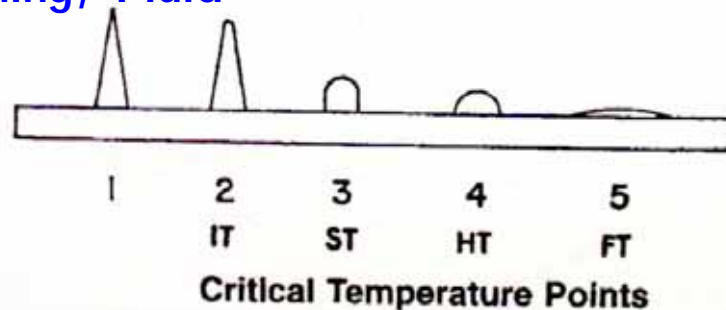
Coal Comparisons

<u>Ash Mineral</u>	Pitt (S<1.7)	Pitt (S>1.7)	PRB (Na<4)	PRB (Na>4)
Si Ratio	73	77	62	54
Si/Al	2.19	2.13	2.15	1.79
Fe/Ca	5.92	3.85	0.35	0.26
Si/Na	90.21	84.03	14.87	3.11
Dolomite %	15.87	21.37	69.09	59.32
Dolomite/Fe	0.99	1.82	13.73	11.40
Fe Index	4.61	2.75	2.39	3.81
Fe + Ca	18.65	14.91	19.26	25.40
Fe Load	0.81	0.61	0.22	0.20
Ca Load	0.14	0.16	0.63	0.76
Na Load	0.03	0.03	0.11	0.44
"Sticky" Alkali Load	0.21	0.23	0.95	1.39
ESP Index	75	78	54	56



Ash Fusion

- Slagging & Fouling Predictors
- Eutectic Predictor
- Oxidizing & Reducing Atmospheres
- Initial Deformation, Spherical Softening, Hemispherical Softening, Fluid
- Plastic Range
- TMA may replace this technique

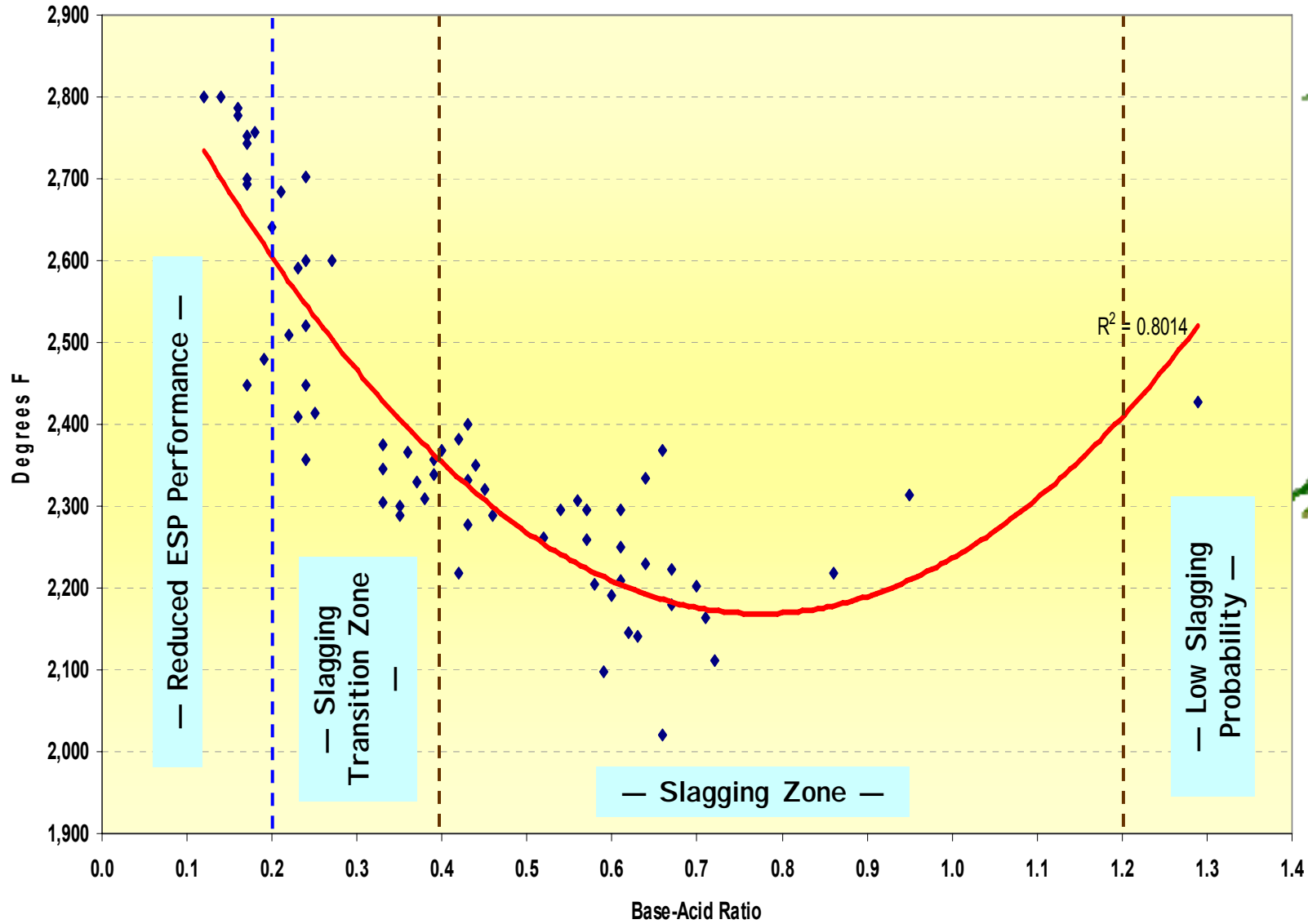


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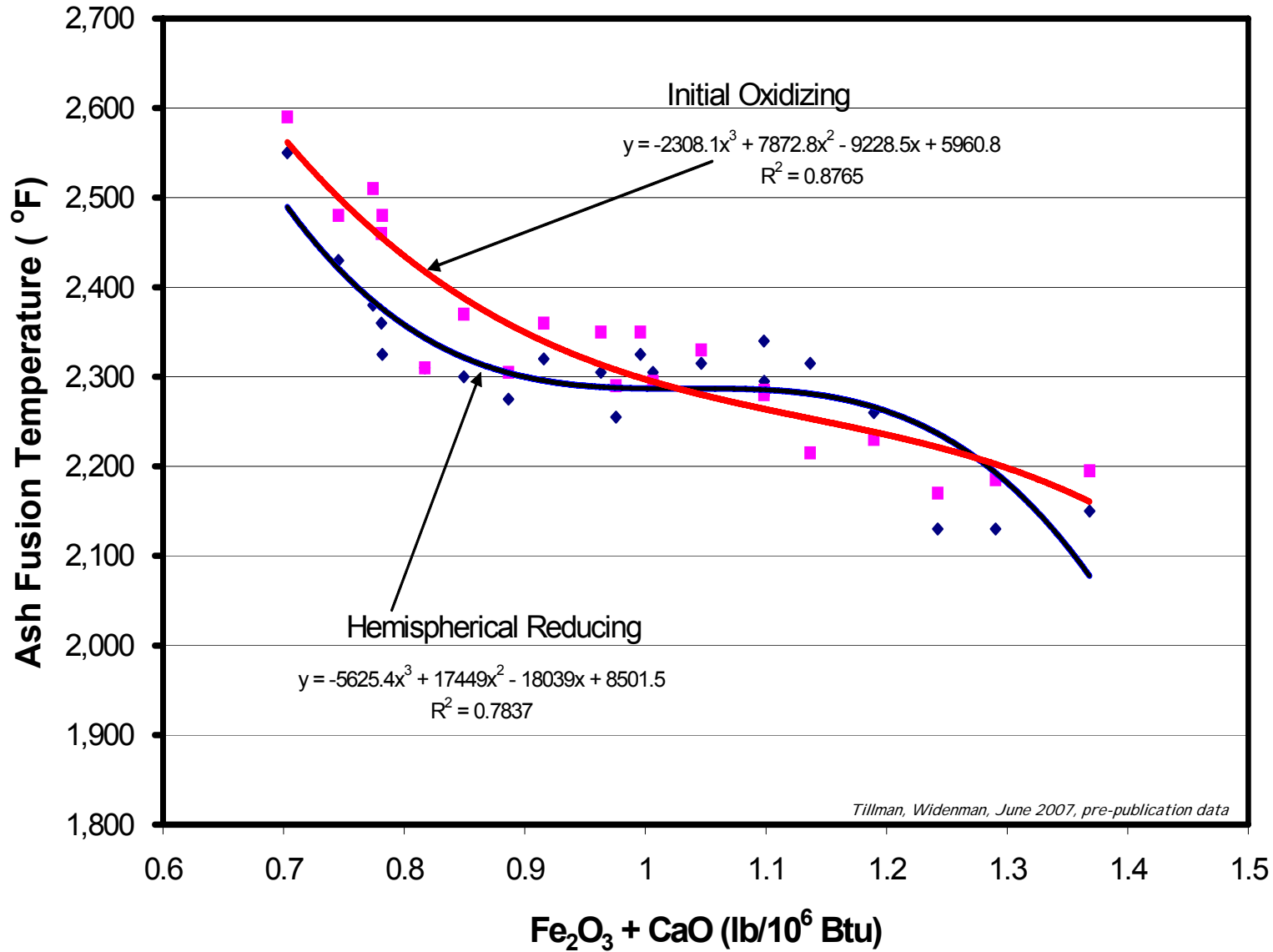
Ash Fusion	Pitt (S<1.7)	Pitt (S>1.7)	PRB (Na<4)	PRB (Na>4)
Reducing Atmosphere (° F)				
Initial Deformation	2,472	2,209	2,135	2,066
Spherical Softening	2,499	2,280	2,150	2,150
Hemispherical Softening	2,530	2,372	2,160	2,161
Fluid	2,585	2,460	2,249	2,177
Plastic	113	251	105	111
Oxidizing Atmosphere (° F)				
Initial Deformation	2,550	2,535	2,225	2,348
Spherical Softening	2,590	2,575	2,390	2,412
Hemispherical Softening	2,625	2,595	2,428	2,422
Fluid	2,670	2,665	2,450	2,438
Plastic	120	130	225	90



B:A vs Fusion-Hemispherical



Ash Fusion Temperature Prediction Using Coal Fe+Ca



These values?

	Pitt (S<1.7)	Pitt (S>1.7)	PRB (Na<4)	PRB (Na>4)
<u>Sulfur Forms</u>				
Organic S	0.80	1.10	0.27	0.29
Pyritic S	0.70	1.02	0.08	0.05
Sulfate	0.01	0.03	0.01	0.01
<u>Equilibrium Moisture</u>				
EQ Moisture	4.0	3.7	23.5	23.1
<u>Hardgrove Grindability Index</u>				
HGI	51	53	47	51
@ Moisture	1.52	1.64	11.10	11.60



HGI (Hardgrove Grindability Index)

- At x% moisture
 - ◆ Higher moisture, higher apparent HGI ; coal less friable
 - ◆ Lower moisture, lower apparent HGI ; coal more friable
- Typical utility range, 40-65 (harder \Rightarrow softer)
 - PRB ~ 47; Pittsburgh Seam ~ 50-54
- Mill throughput
 - $f(\text{coal moisture, coal recirculation, pyrite concentration})$
- Fineness
 - ◆ **One of the most important factors for proper combustion & burner line distribution; everything downstream is effected by coal particle size and particle distribution across the boiler**
 - ◆ **Coarse** — Delayed combustion, combustion higher in furnace, increased slagging, fouling & unburned C (UBC), higher CO, increased O₂ requirements, larger burner bias (particle momentum vs. particle density), increased mill throughput
 - ◆ **Fine** — Rapid combustion, combustion lower in furnace, reduced slagging, fouling & unburned C (UBC), lower CO, reduced O₂ requirements, reduced mill throughput, increased mill maintenance



To Do the Above

**You Must Control Your
Processes**

How Is This Done?



Representative Sampling

&

Accurate Weighing

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

NOT

What number do you want?



Define Heat Rate

Heat Rate \equiv Btu/kWh

Where:

Btu = Total Btu for 1 hour
 \approx **Btu/lb** * **Tons** for 1 hour

Where:

- **Btu/lb** = Heating value determined in laboratory from the sample provided by the customer representing 1 hours burn
- **Tons** = total coal consumed in 1 hr

Where:

- **kWh** = Power output for 1 hour



Scales & Samplers

Cost Justify via PV/C?

- f (bias relative to zero)
- Seldom works out
- Then why bother
 - Do you buy food or gasoline on approximate uncertified values?
 - What is the accuracy & calibration status of the MWh readout for each unit? I bet it is within the instruments limits of precision & is routinely calibrated
 - Cost of doing business
 - Good business practice



Sampling

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

- **Representative Sampling — MOST CRITICAL!**
 - Results based on sample received by laboratory
 - Critical for both gross and laboratory samples
 - Coal characteristics vary by particle size
 - $\Delta 1\%$ Moisture or Ash ~130-150 Btu/lb, ~100 Btu/kWh
 - Want to lower your plant's reported heat rate and your coal sample is not collected by ASTM procedures?
 - Double the as-fired sample size
 - Most coal quality parameters follow normal distribution
 - Sample reports represent the average of the lot size sampled
 - Both tails of the distribution exist
- **Causes of errors**
 - Laboratory.5%
 - Sample Preparation.15%
 - **Sampling. 80%**



- **Sampling Techniques**

- Stop-Belt (reference standard)
- **Mechanical (best commercial method)**
- Grab (continuous), Auger, Car-Top, Grab (one-time), Stockpile Core Drill, Stockpile Auger, Stockpile Manual

- **Effects**

- Corporate, Regulatory, Government
- Industry Statistics & Records
- Production Cost, Dispatch Order, Sales
- Performance Measurement & Accurate Cost Accounting (Along With Scales)
- Problem Solving

Coal is purchased by the heat requirement, not tons

- Tons are used for commercial exchange
- Boilers require x -Btus to make y -Lbs of steam, not x -tons to make y -Lbs of steam
- To determine accurate Total Btus, a representative sample must be collected



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



One Lump or Two?

Coal Quality by
Density or Particle Size

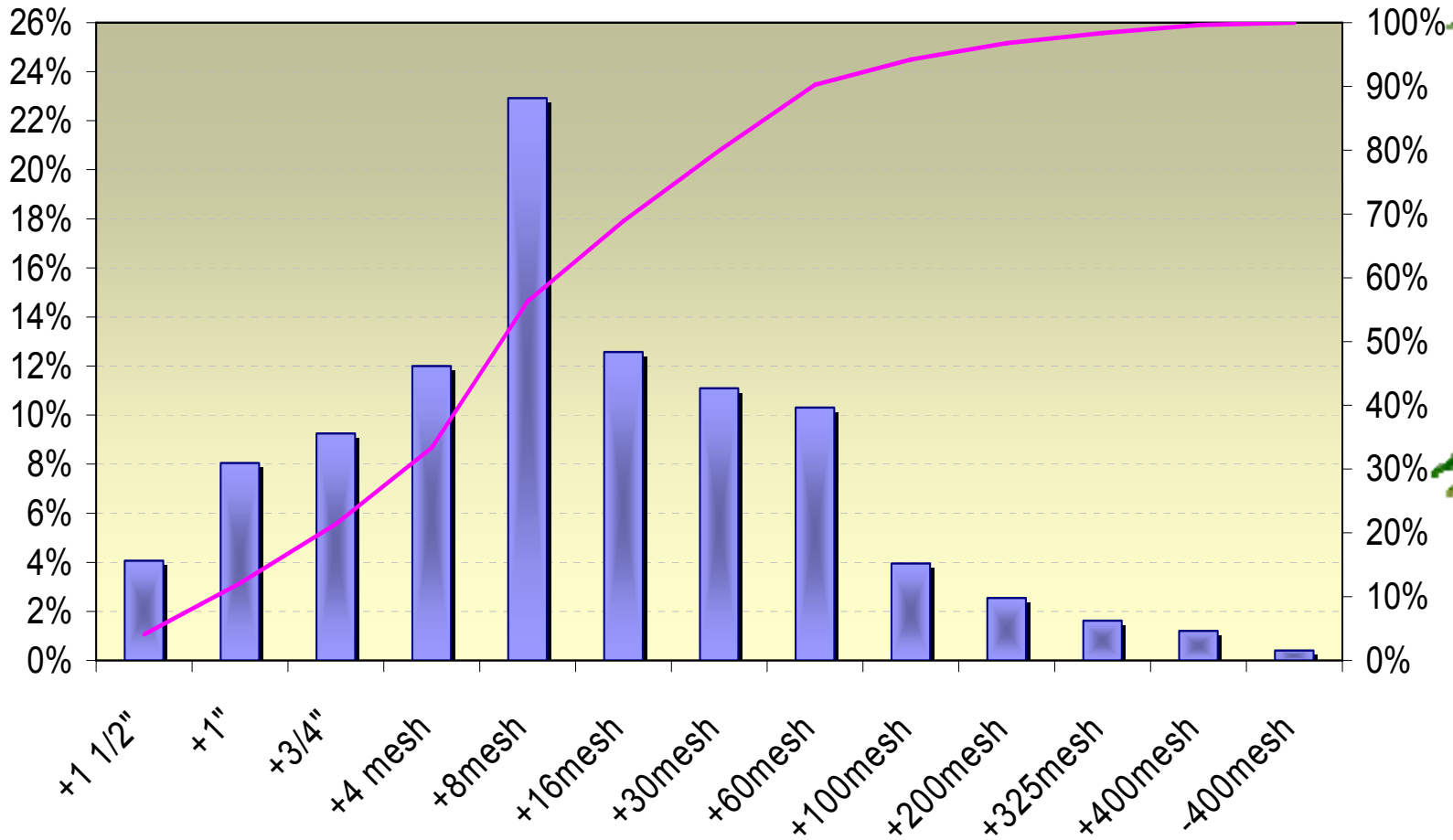
OR

What Number Do You Want?

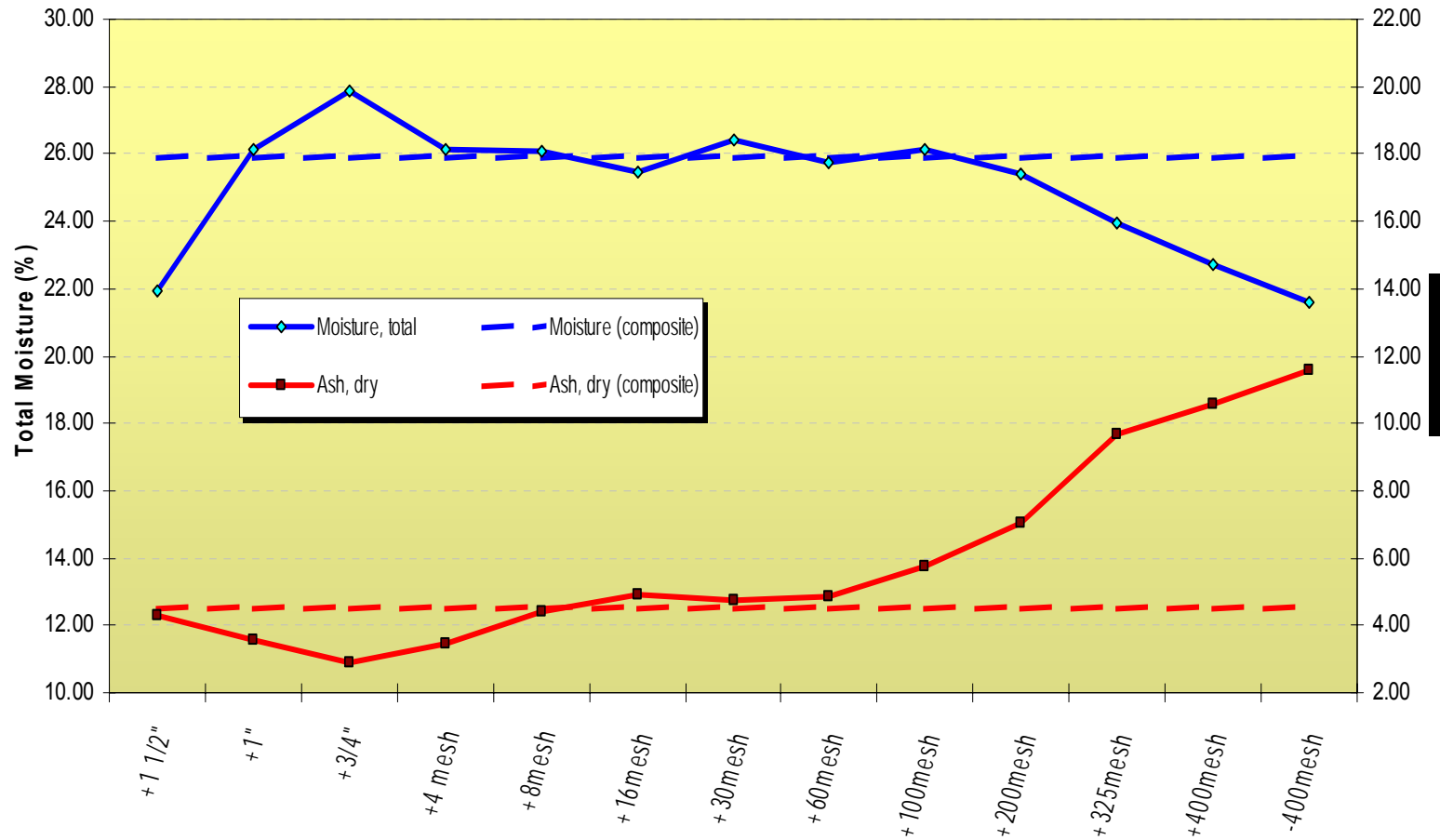
Representative Sampling is Your Only Answer



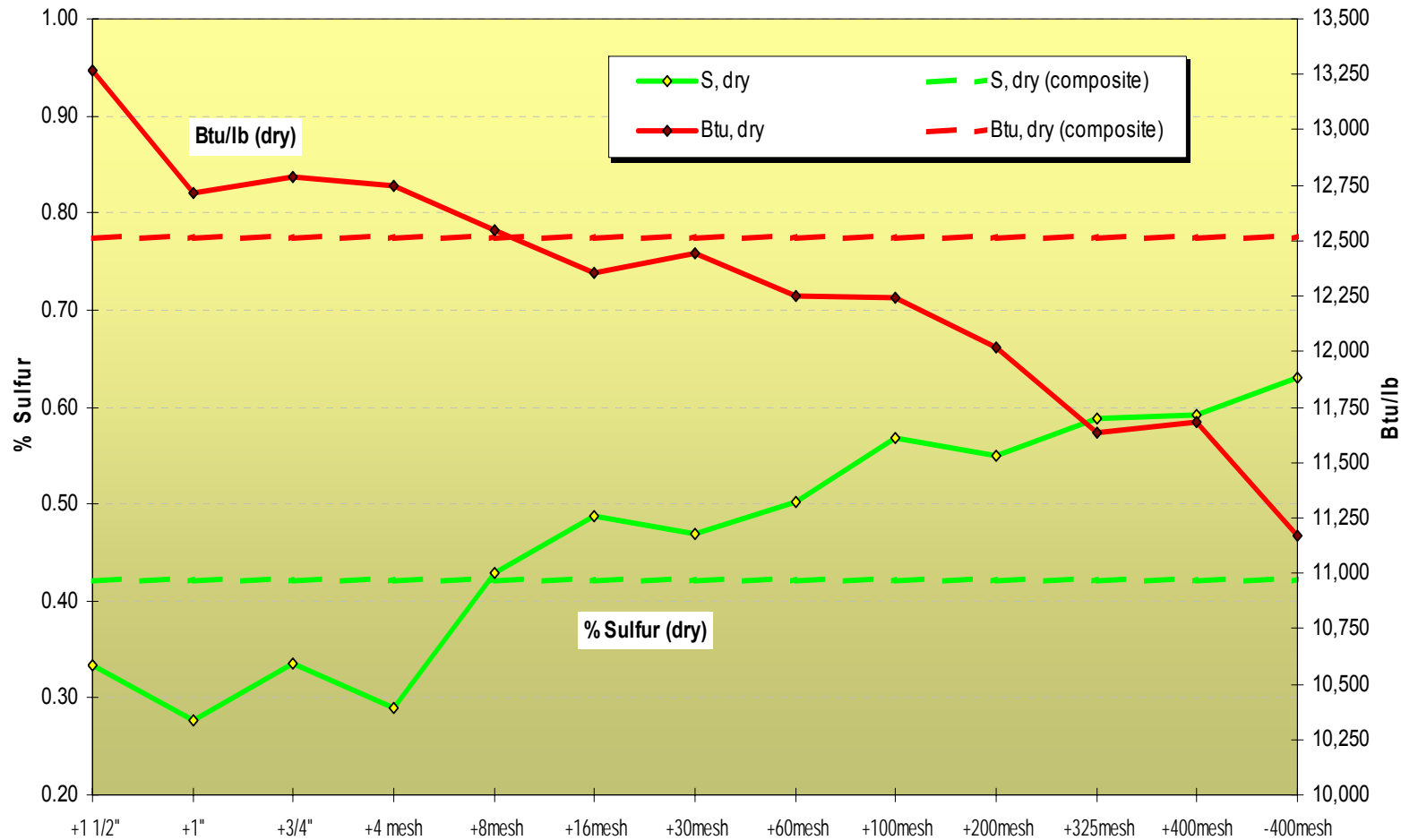
PRB-MT CROM Size Distribution



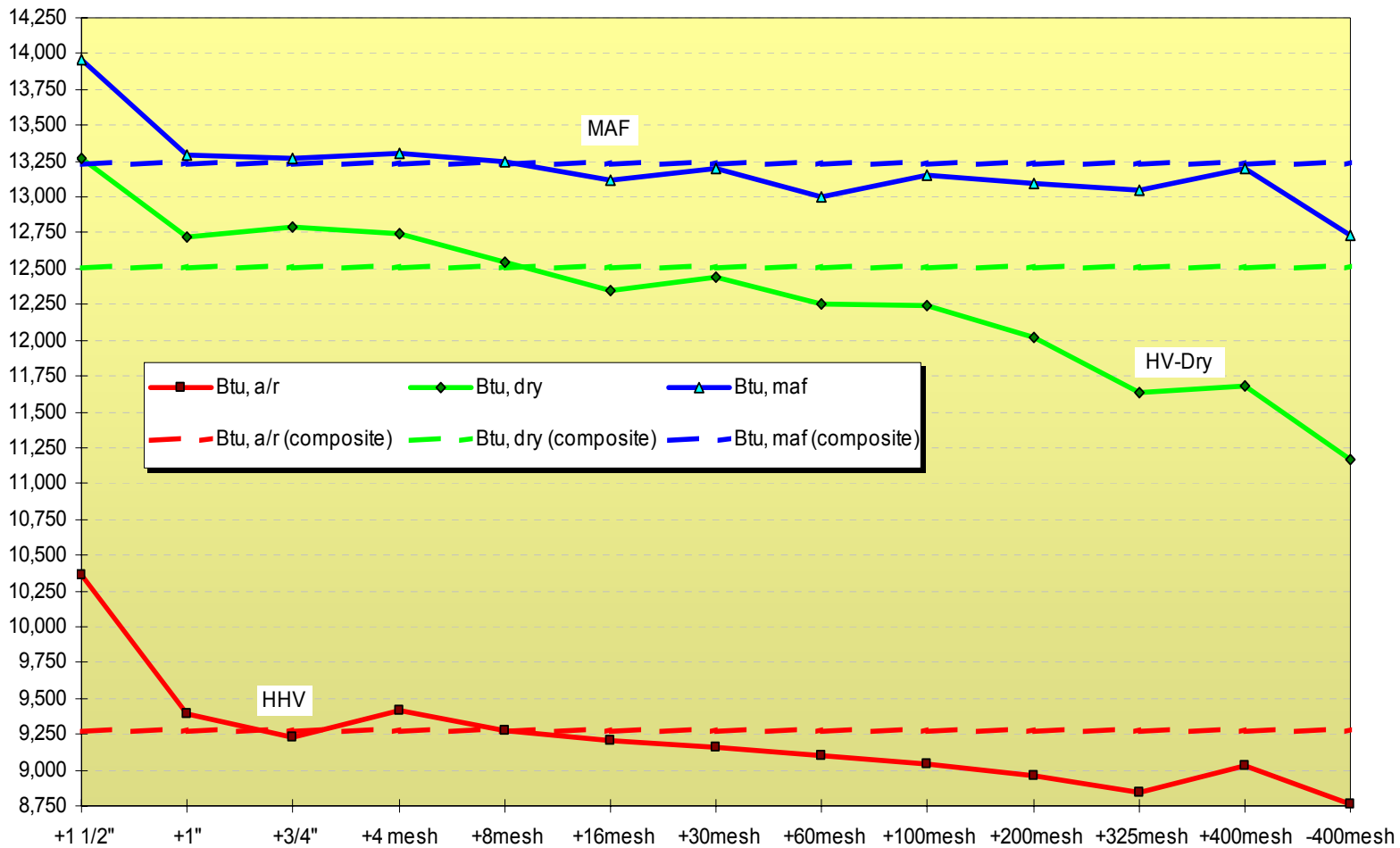
PRB-MT Coal Quality by Size (Moisture, Dry Ash)



PRB-MT Coal Quality by Size (Dry Sulfur, Dry Btu)



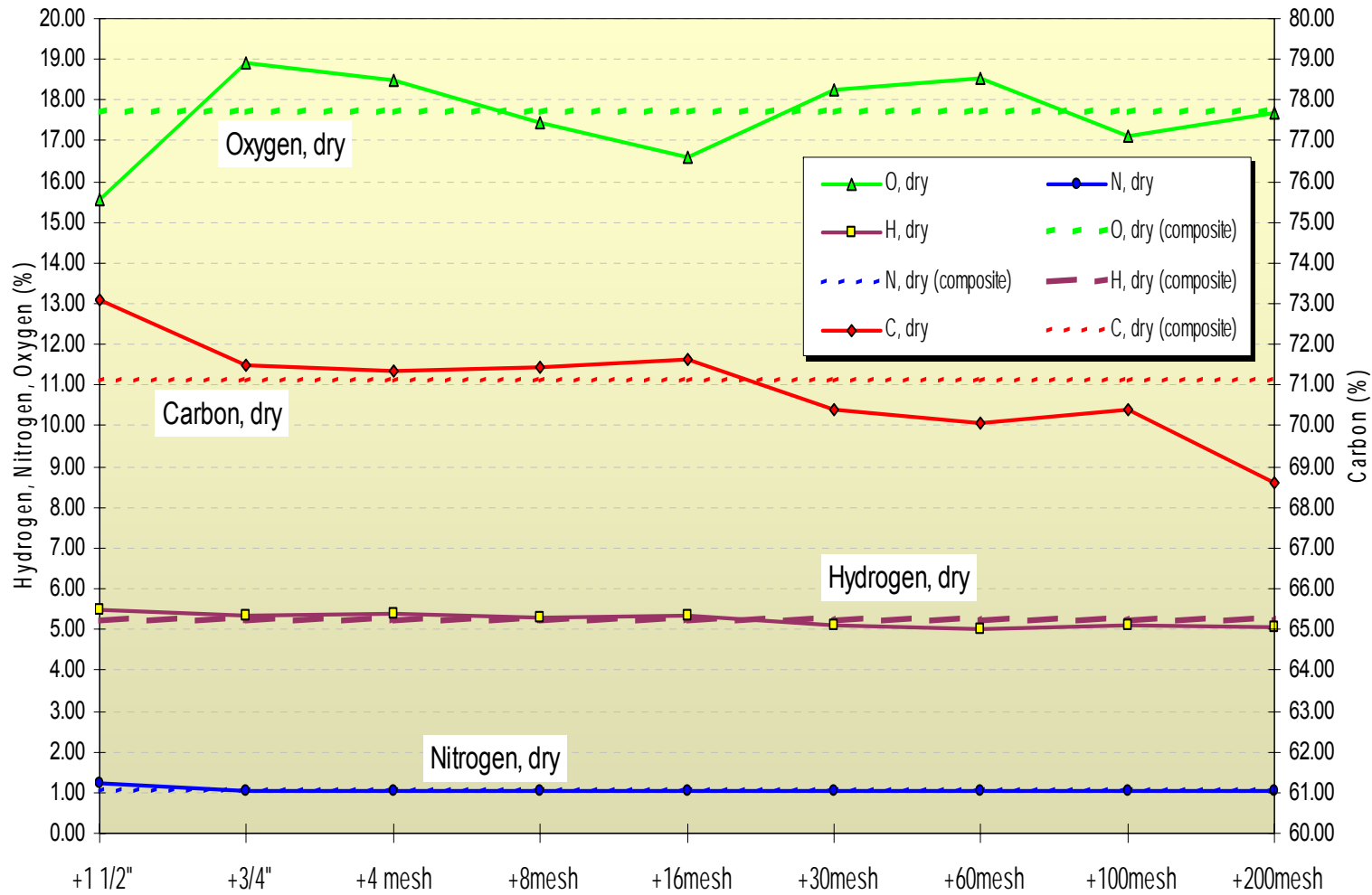
PRB-MT Coal Quality by Size
(As-Received Btu, Dry Btu, MAF Btu)



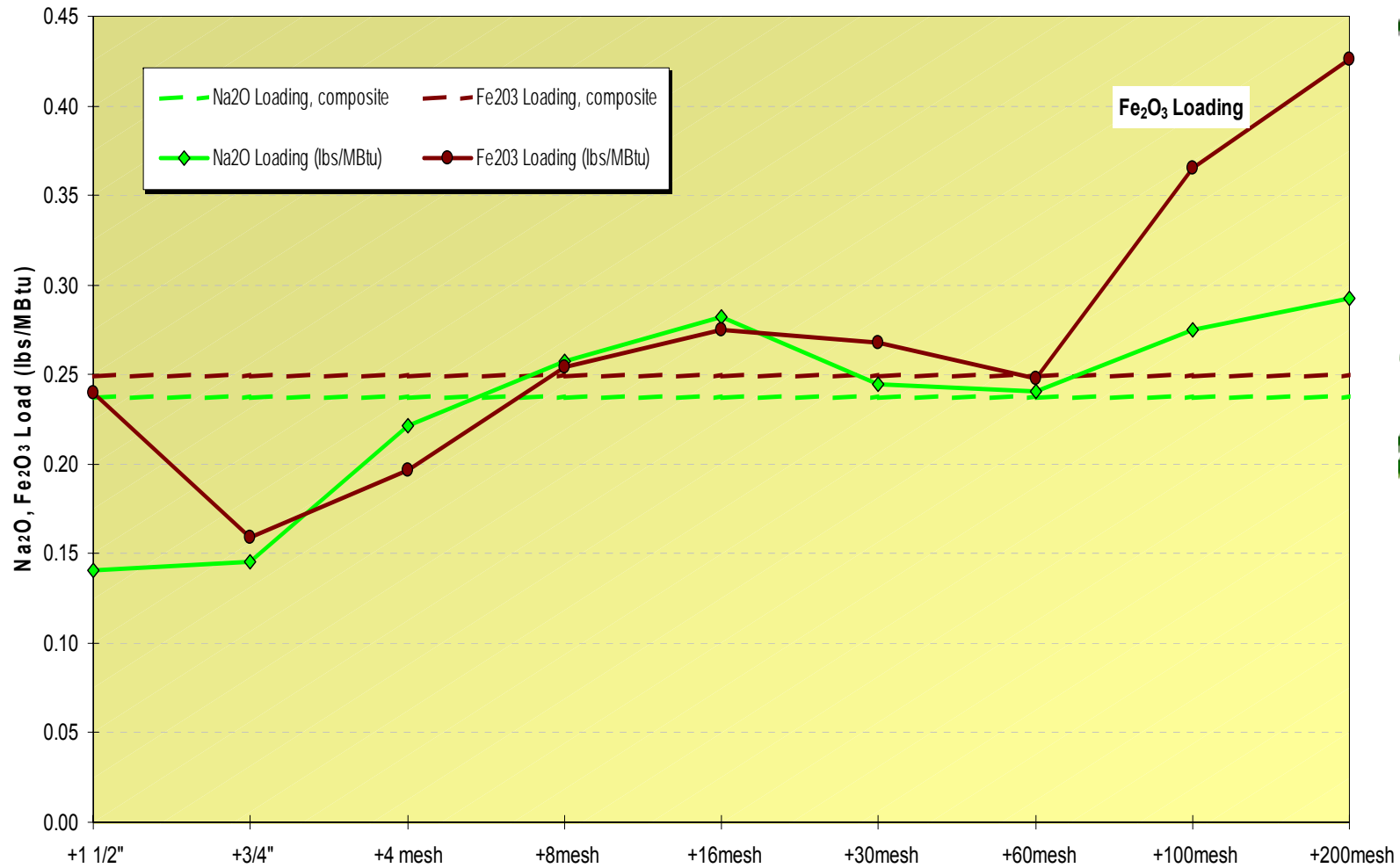
PRB-MT Coal Quality by Size (SO₂, Ash Loading)



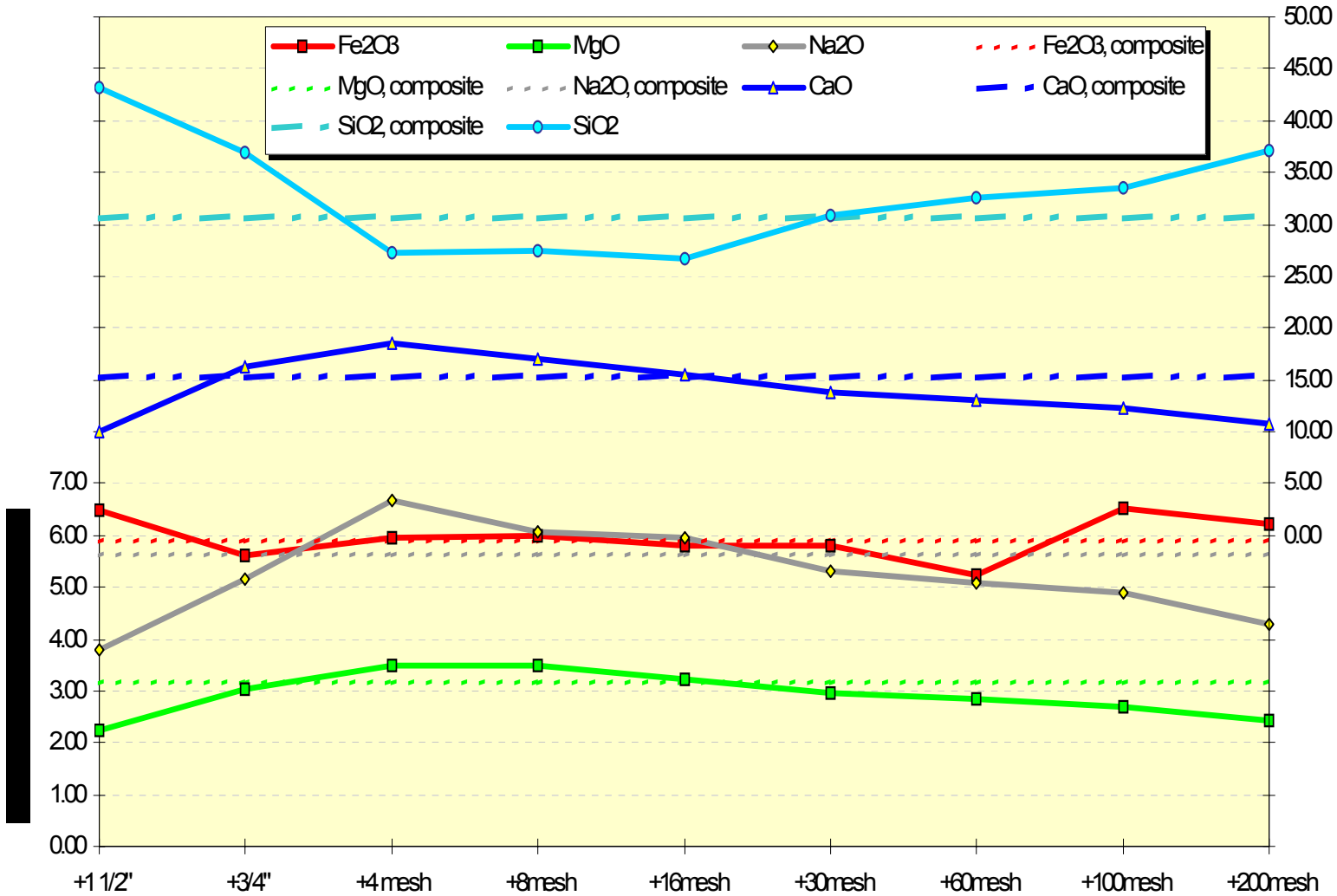
PRB-MT Coal Quality by Size (Ultimate, Dry Basis)



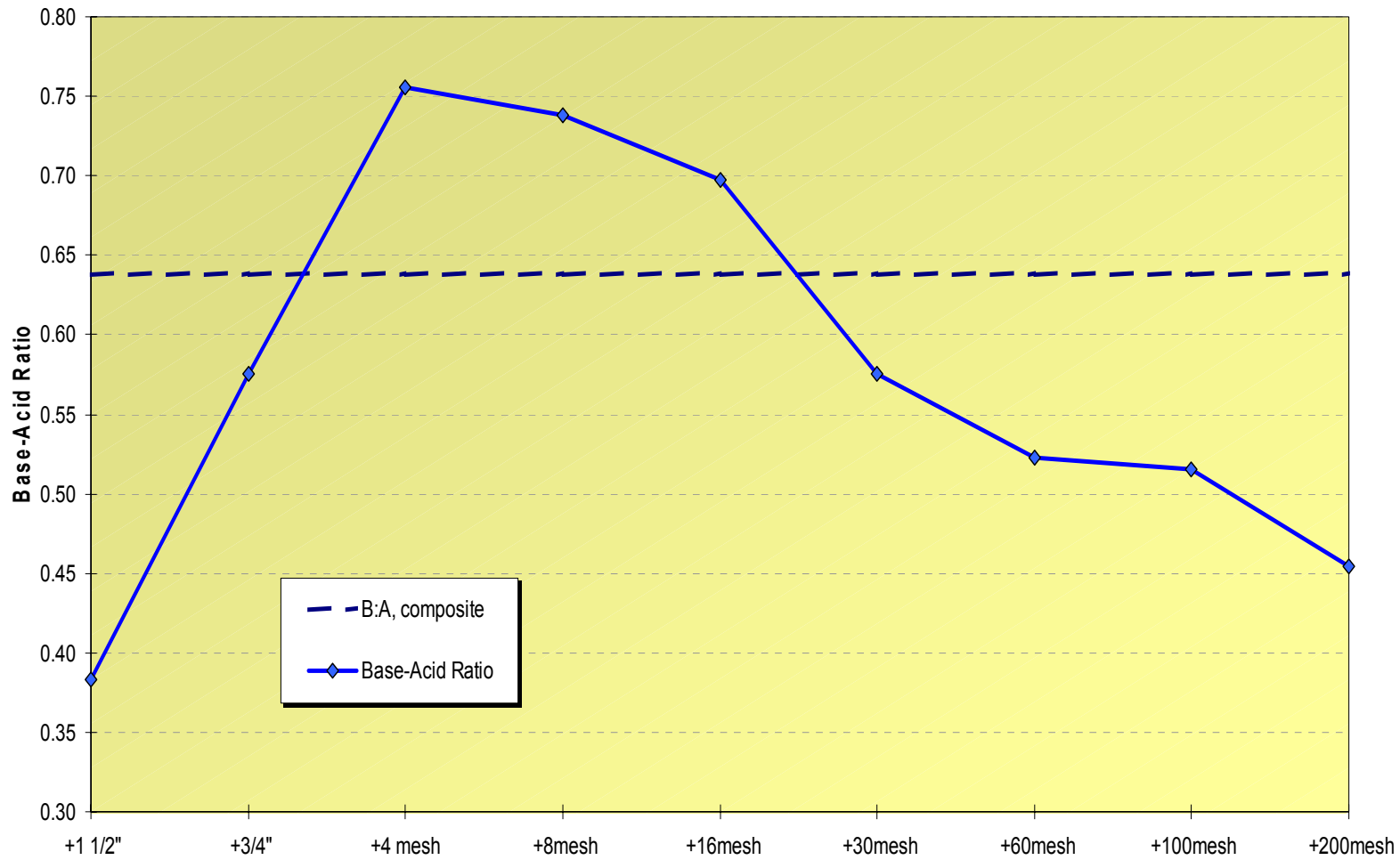
**PRB-MT Coal Quality by Size
(Na₂O, Fe₂O₃ Loading)**



PRB-MT Coal Quality by Particle Size
Ash Mineral (Si, Fe, Ca, Mg, Na) as Oxides



**PRB-MT Coal Quality by Size
(Base-Acid Ratio)**



Particle Size
Segregation



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 0
- 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



Float-Sink Coal Quality

06/11/84

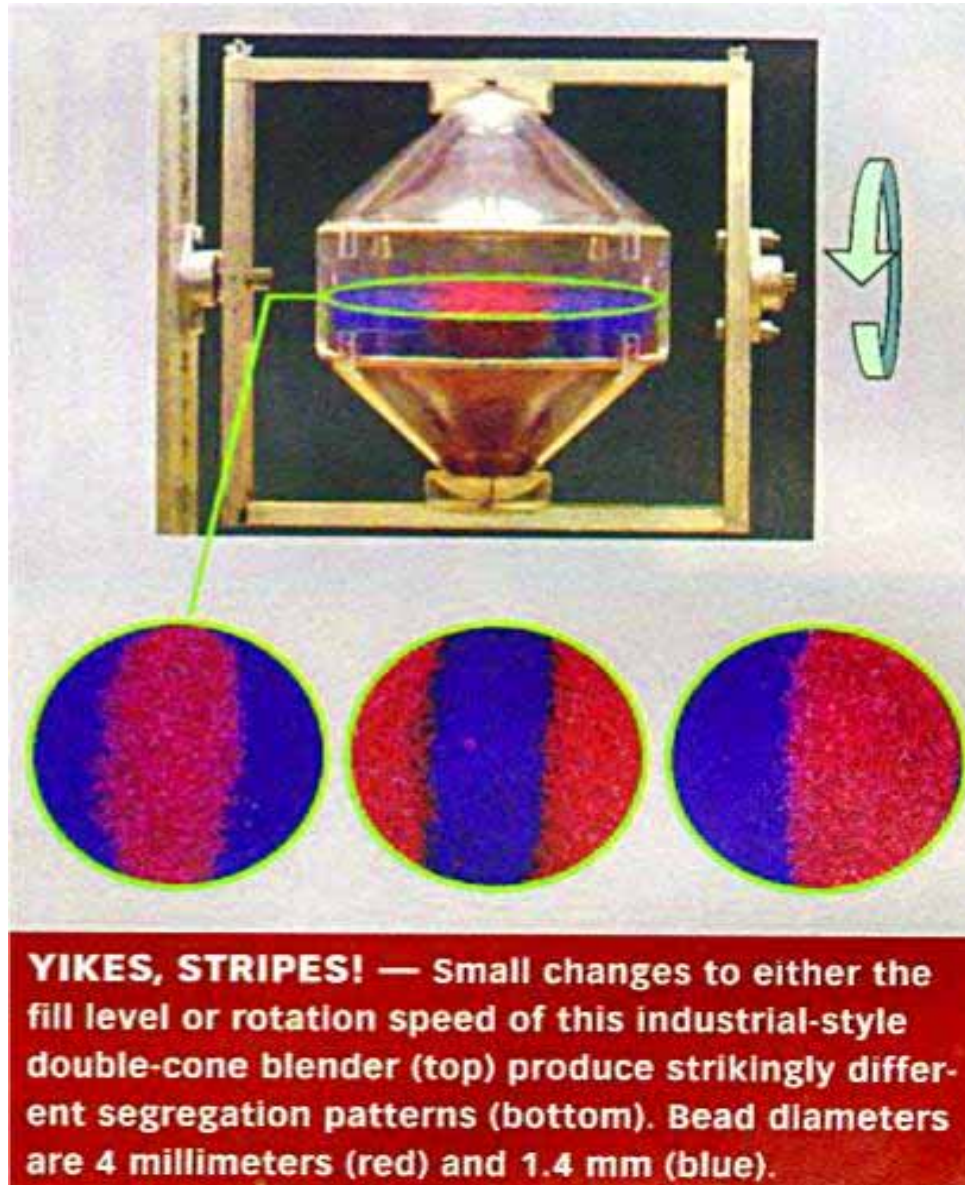
RAW COAL - SAMPLED AFTER BREAKER FEEDER - 5/9-10/84

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

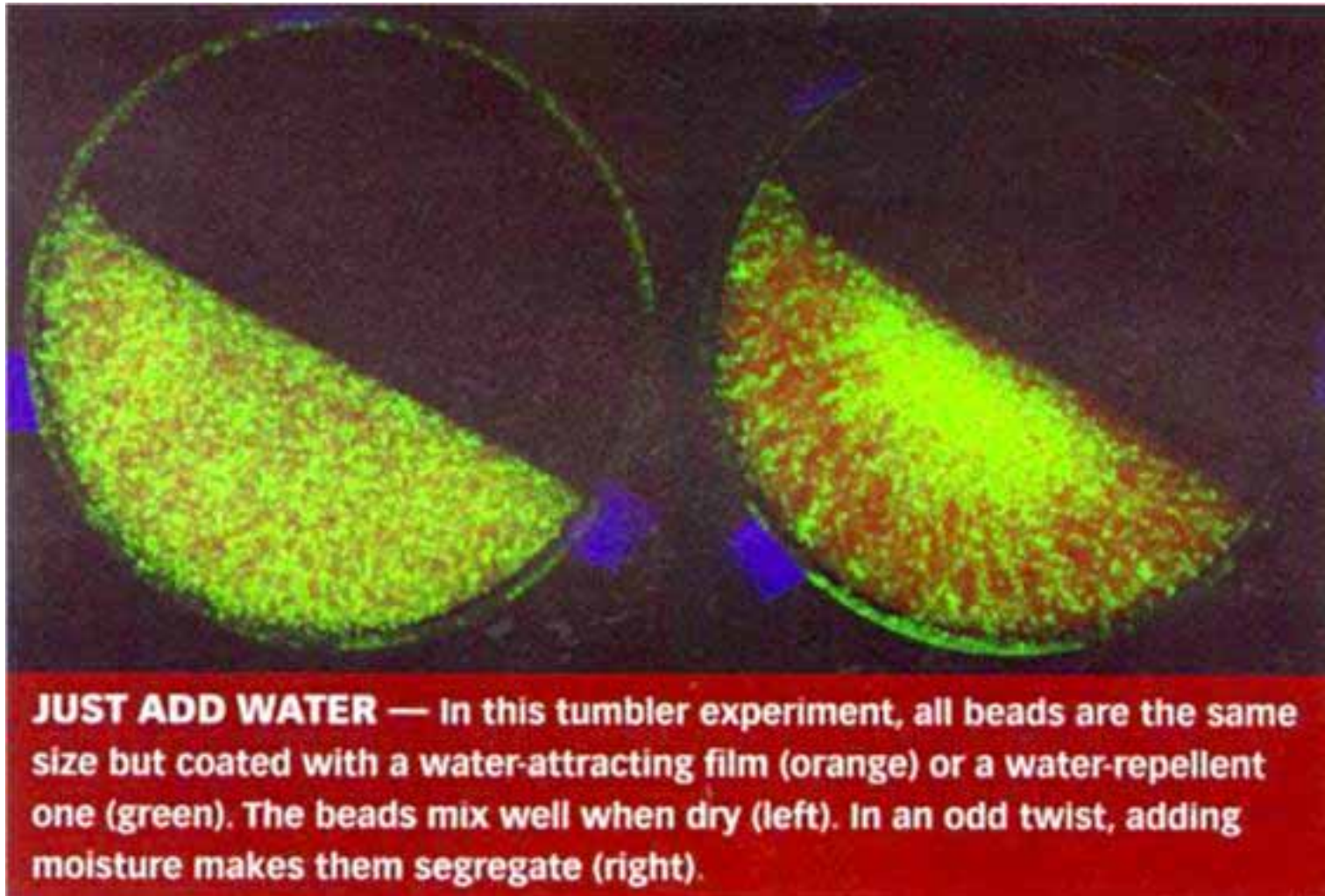




Science News



"Science of Fossil Fuels" — 2007 APC Conference

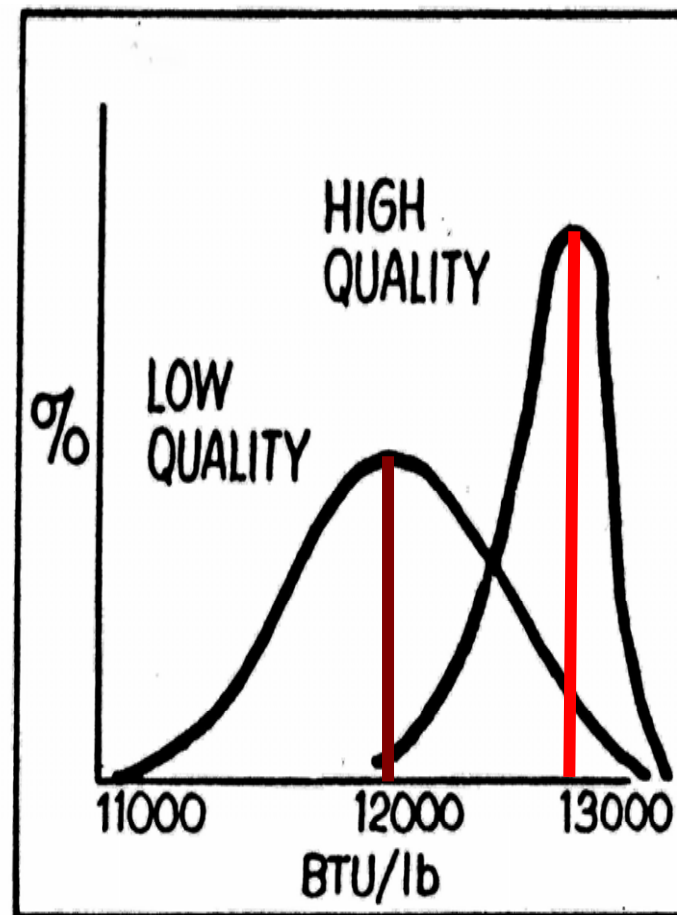
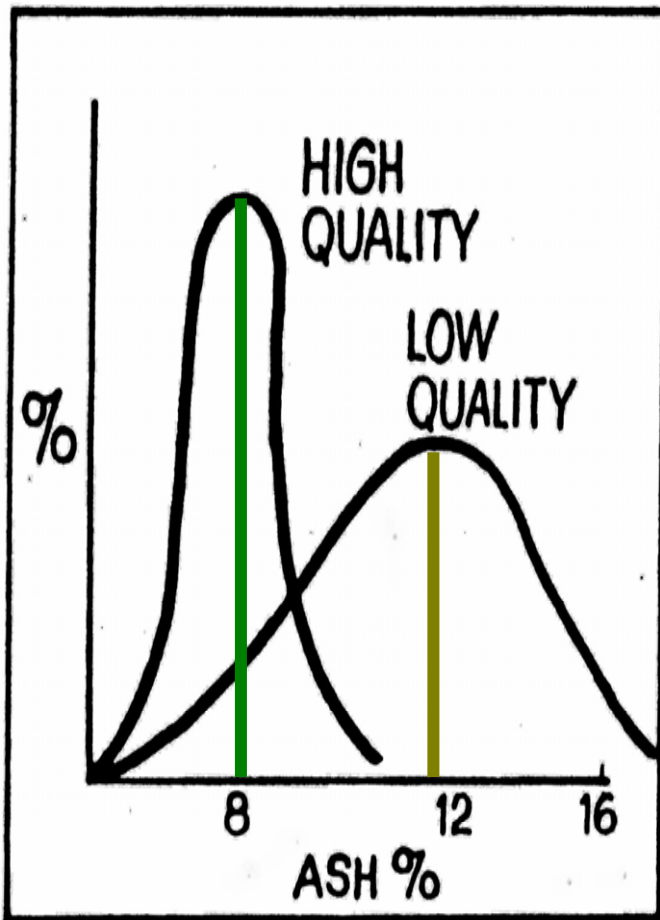


Science News



Coal Washing (Physical Coal Cleaning)

Ash Reduction Increases Heating Value



Bob Buckler, Detroit Edison, 1980



Slag Deposit Characteristics



Proportions of Liquid @2552°F (1400°C) in Slag

4-Parameter Model (SiO_2 , Al_2O_3 , Fe_2O_3 , CaO)

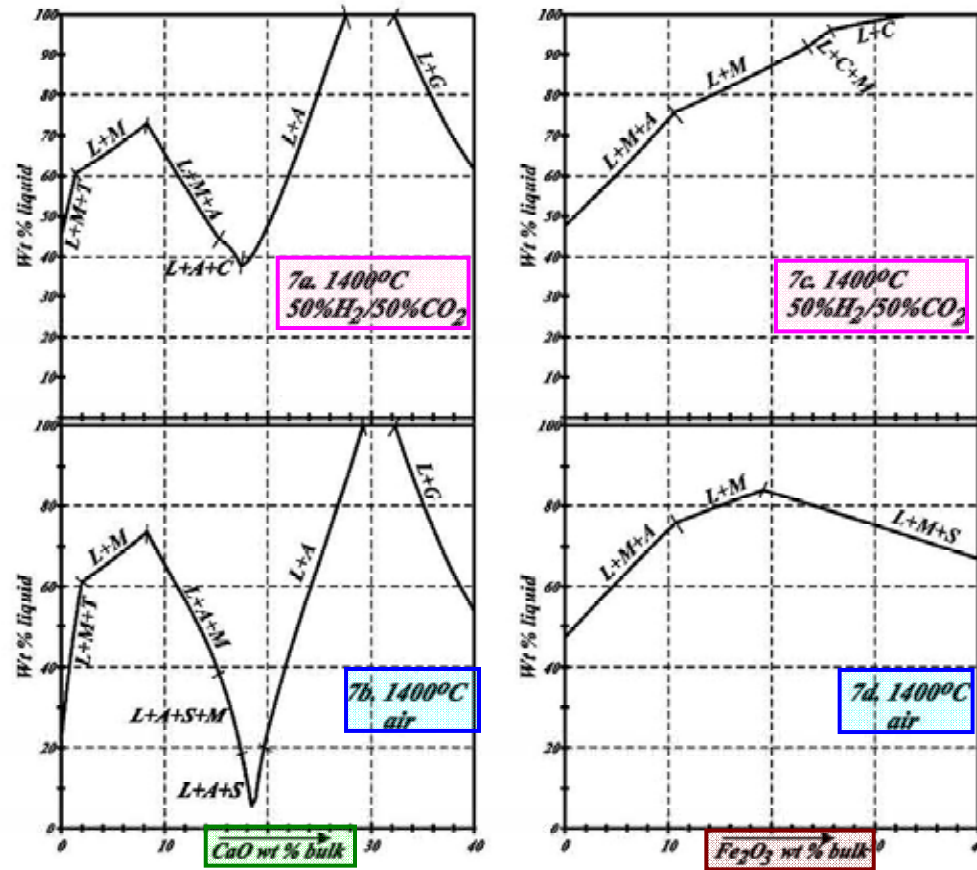
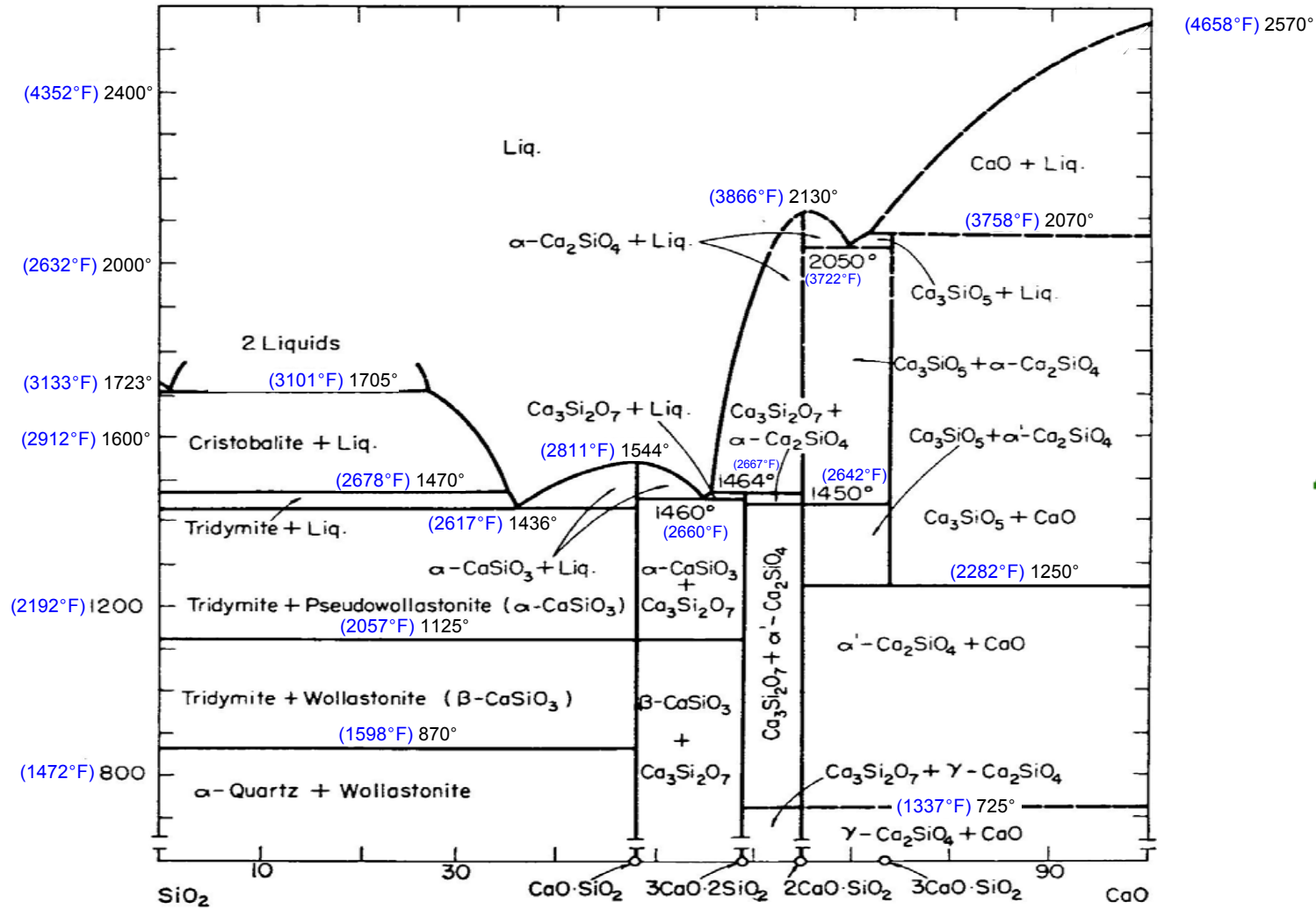


Fig. 7. Proportions of liquid at 1400 °C for slags with weight ratios of $\text{SiO}_2/\text{Al}_2\text{O}_3 = 1.20$ and $(\text{SiO}_2 + \text{Al}_2\text{O}_3)/\text{Fe}_2\text{O}_3 = 9.0$ in 50% H_2 /50% CO_2 gas (a) and in air (b) and $(\text{SiO}_2 + \text{Al}_2\text{O}_3)/\text{CaO} = 9.5$ in 50% H_2 /50% CO_2 gas (c) and in air (d); phase names are: L: liquid, M: mullite, A: anorthite, G: gehlenite, S: spinel, C: corundum.



CaO and SiO₂ Phase Diagram



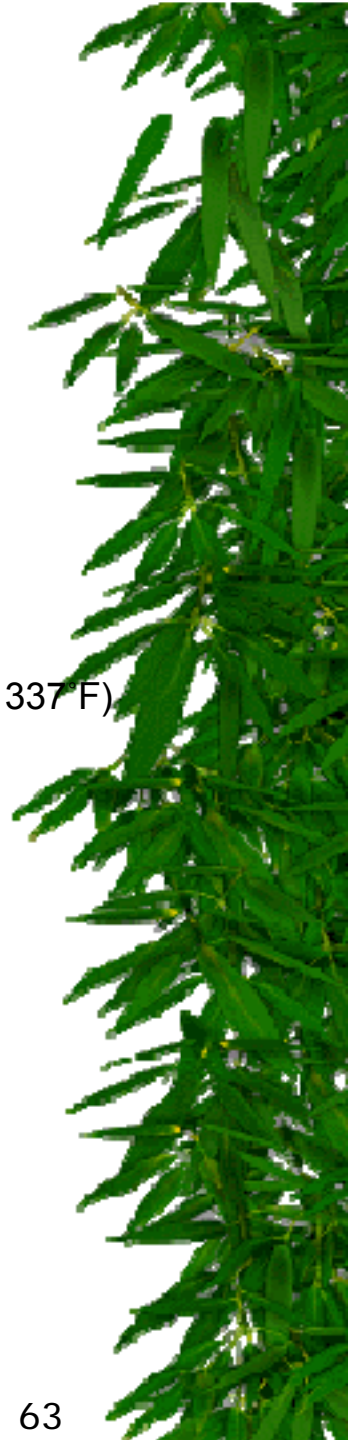
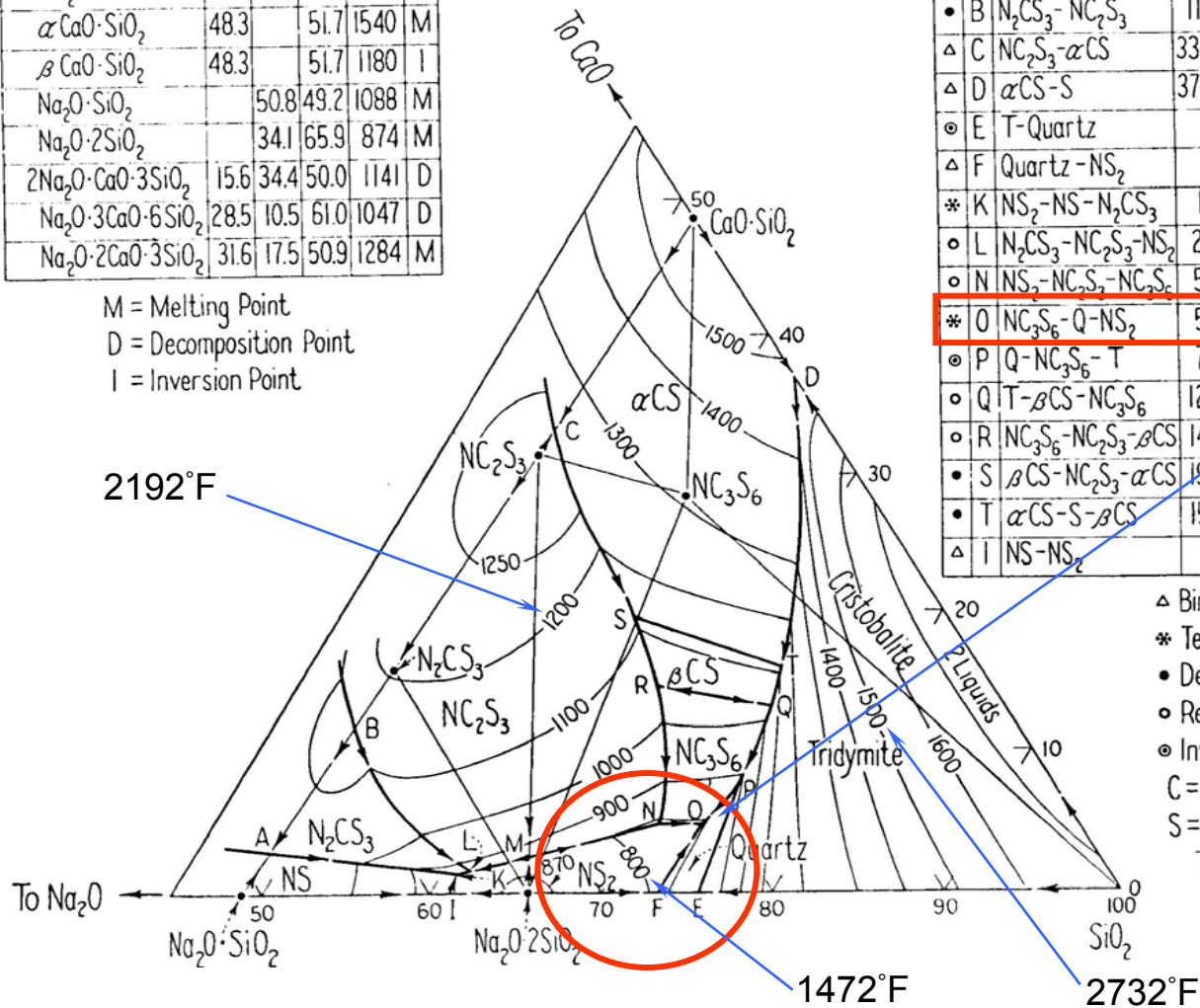
CaO and SiO₂ with Na₂O Phase Diagram

Compounds	CaO	Na ₂ O	SiO ₂	Temp.	
SiO ₂			100.0	1710	M
αCaO·SiO ₂	48.3		51.7	1540	M
βCaO·SiO ₂	48.3		51.7	1180	I
Na ₂ O·SiO ₂		50.8	49.2	1088	M
Na ₂ O·2SiO ₂		34.1	65.9	874	M
2Na ₂ O·CaO·3SiO ₂	15.6	34.4	50.0	1141	D
Na ₂ O·3CaO·6SiO ₂	28.5	10.5	61.0	1047	D
Na ₂ O·2CaO·3SiO ₂	31.6	17.5	50.9	1284	M

M = Melting Point
 D = Decomposition Point
 I = Inversion Point

Point	Crystal Phases	CaO	Na ₂ O	SiO ₂	Temp.
△ A	NS-N ₂ CS ₃	3.0			1060
• B	N ₂ CS ₃ -NC ₂ S ₃	11.5			1141
△ C	NC ₂ S ₃ -αCS	33.0			1280
△ D	αCS-S	37.0		63.0	1436
⊙ E	T-Quartz		24.3	75.7	870
△ F	Quartz-NS ₂		26.4	73.6	790
* K	NS ₂ -NS-N ₂ CS ₃	18	37.5	60.7	821
⊙ L	N ₂ CS ₃ -NC ₂ S ₃ -NS ₂	2.0	36.6	61.4	827
⊙ N	NS ₂ -NC ₂ S ₃ -NC ₃ S ₆	5.2	24.1	70.7	740
* O	NC ₃ S ₆ -Q-NS ₂	5.2	21.3	73.5	725 (1337 F)
⊙ P	Q-NC ₃ S ₆ -T	7.0	18.7	74.3	870
⊙ Q	T-βCS-NC ₃ S ₆	12.9	13.7	73.4	1035
⊙ R	NC ₃ S ₆ -NC ₂ S ₃ -βCS	14.5	19.0	66.5	1030
• S	βCS-NC ₂ S ₃ -αCS	18.5	17.7	62.8	1110
• T	αCS-S-βCS	15.6	11.4	73.0	1110
△ I	NS-NS ₂		38.0		840

△ Binary Eutectic
 * Ternary Eutectic
 • Decomposition Point
 ⊙ Reaction Point
 ⊙ Inversion Point
 C = CaO N = Na₂O
 S = SiO₂ Q = Quartz
 T = Tridymite



Fly Ash Collection

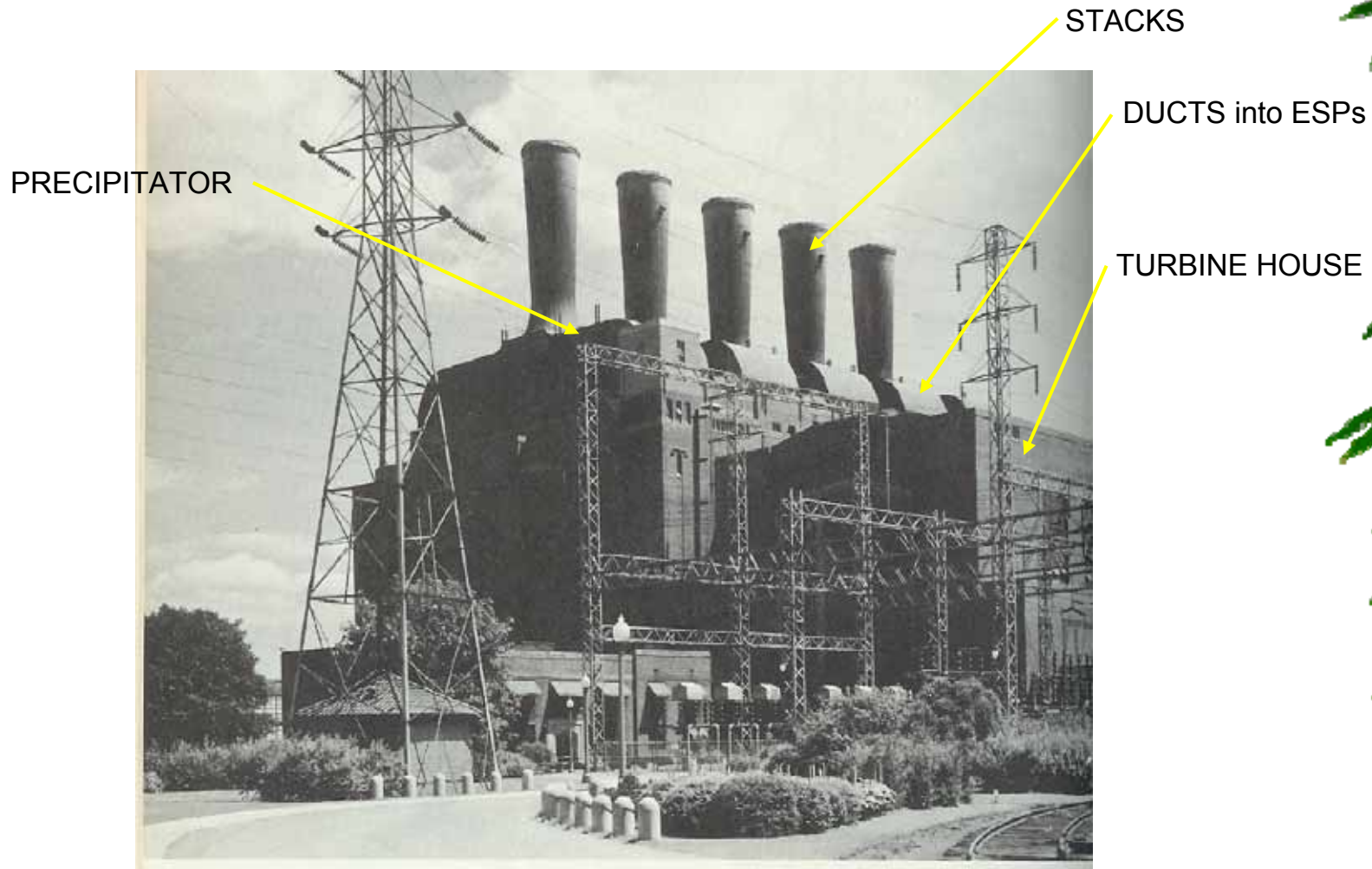
&

Ash Resistivity



"Science of Fossil Fuels" — 2007 APC Conference

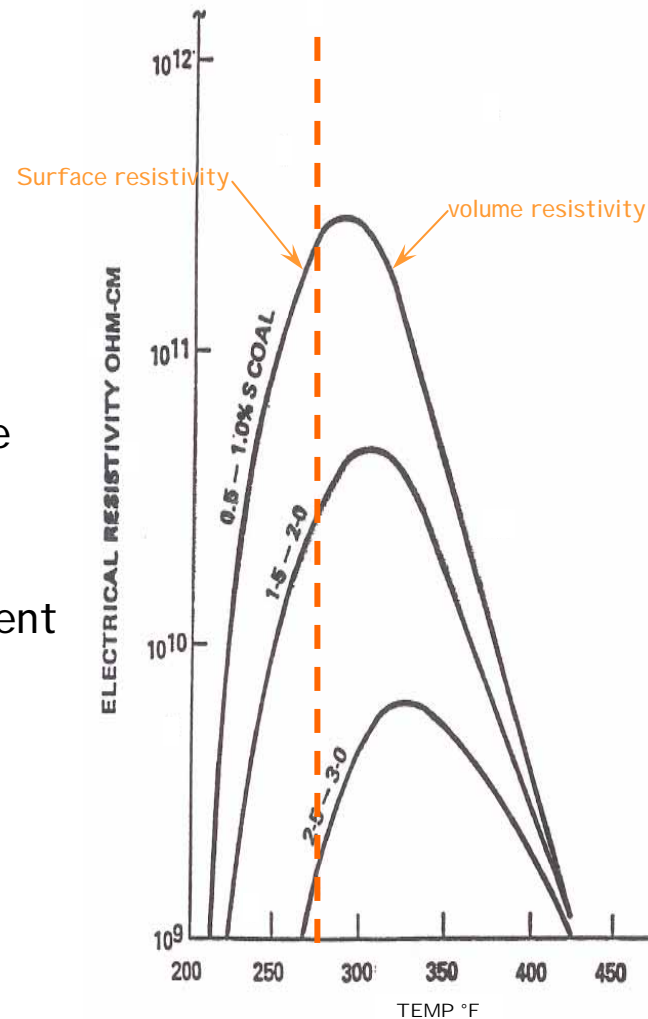
TRENTON CHANNEL POWER PLANT LOW PRESSURE
FIRST UTILITY BOILER w/PRECIPITATOR — 1923

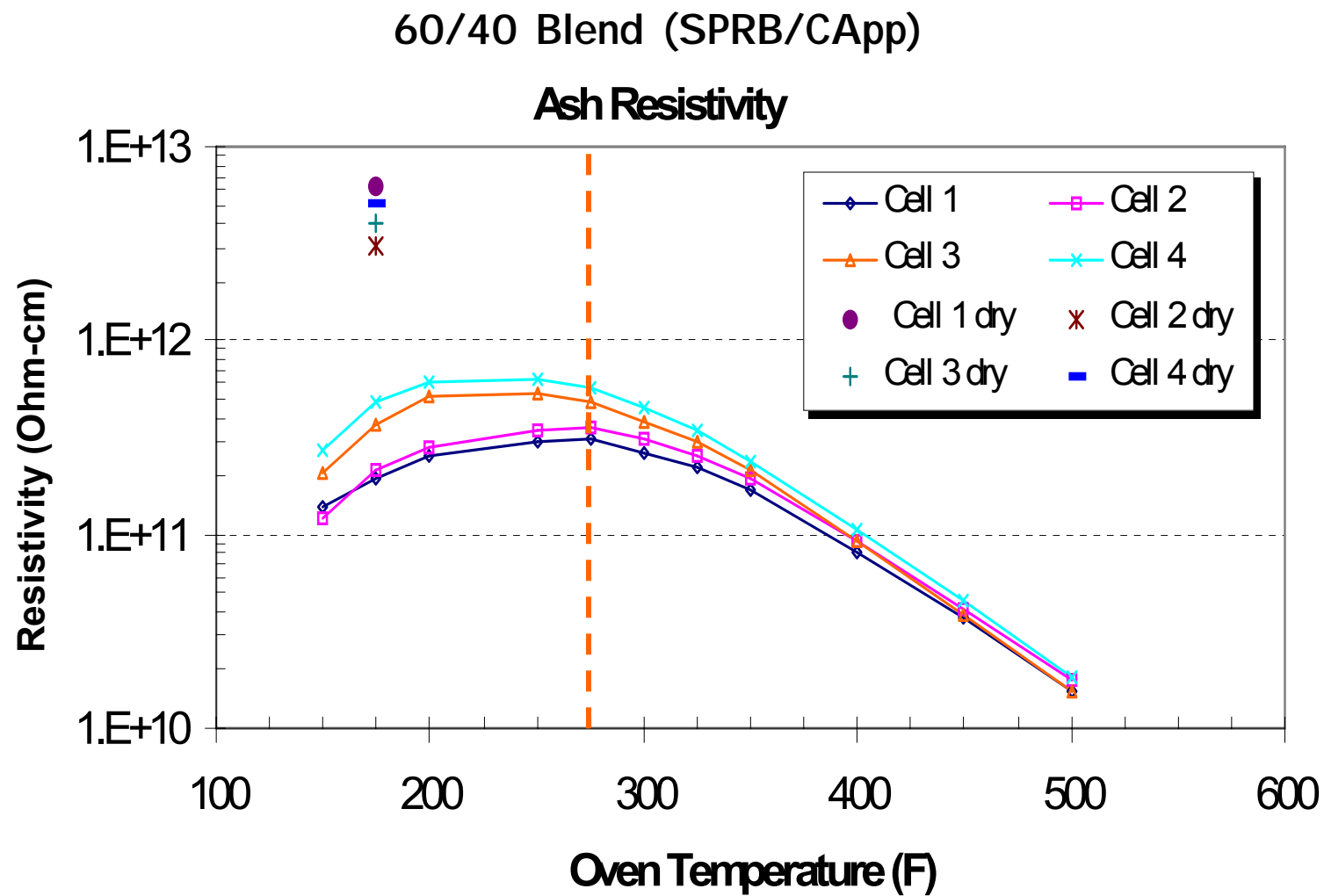


Electrostatic Precipitation

● 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
- $SiO_2 + Al_2O_3 < \sim 80\%$ (ESP Index)
 - Ash resistivity too high for efficient collection
 - "glass"
- $SiO_2 + Al_2O_3 + Fe_2O_3 < \sim 98\%$,
 - Ash resistivity too low
 - Difficult to remove from rappers, re-entrainment





On-Line Fuel Analysis

*Don't Do It Unless You're
Ready to Own It!*

AND

*When You Do It, You
Better Be Ready to Own
It!*



Opportunities Missed

w/o

On-Line Analysis

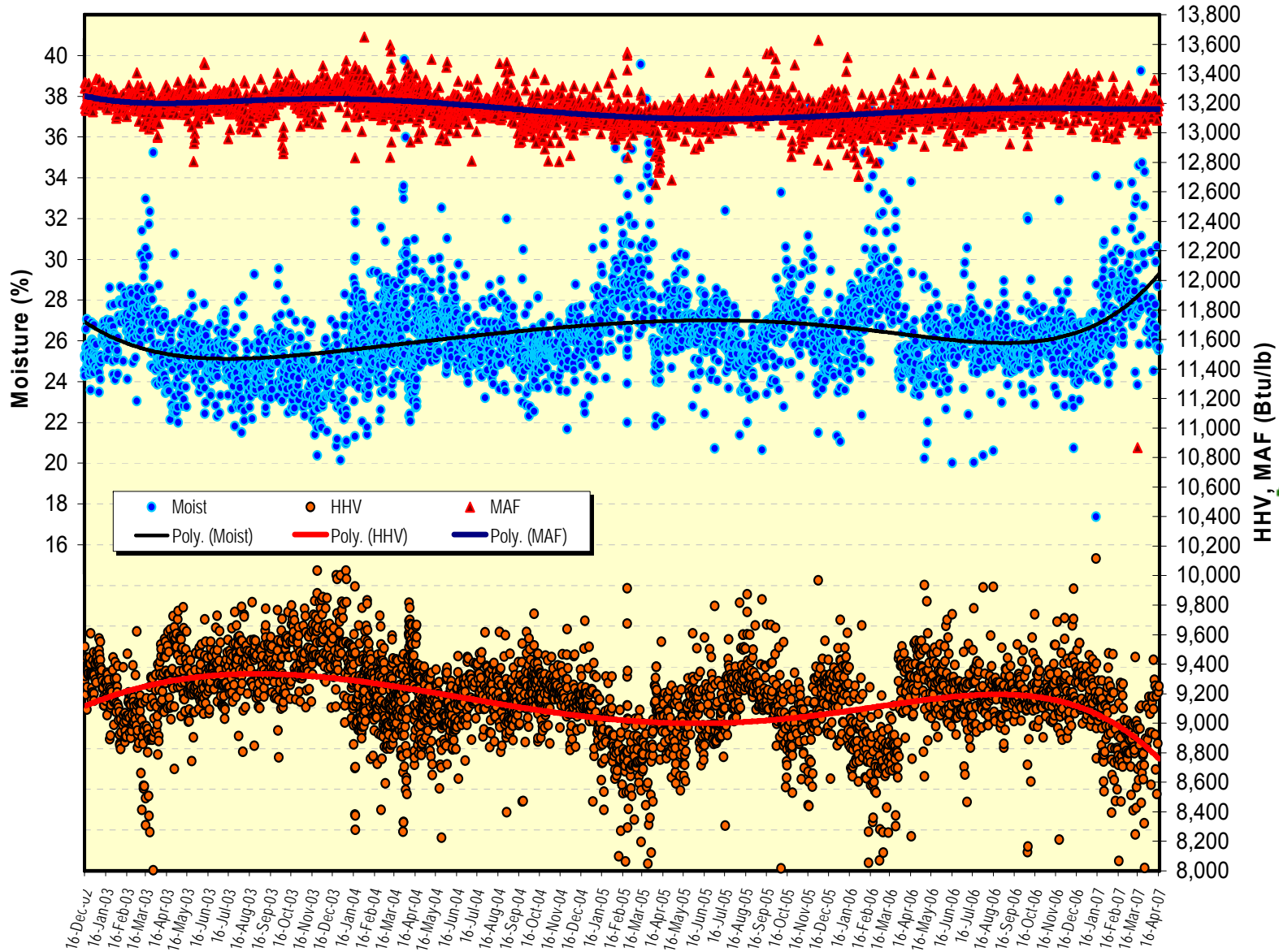
(Be Proactive Instead of Reactive)

Following charts illustrate (after-the-fact):

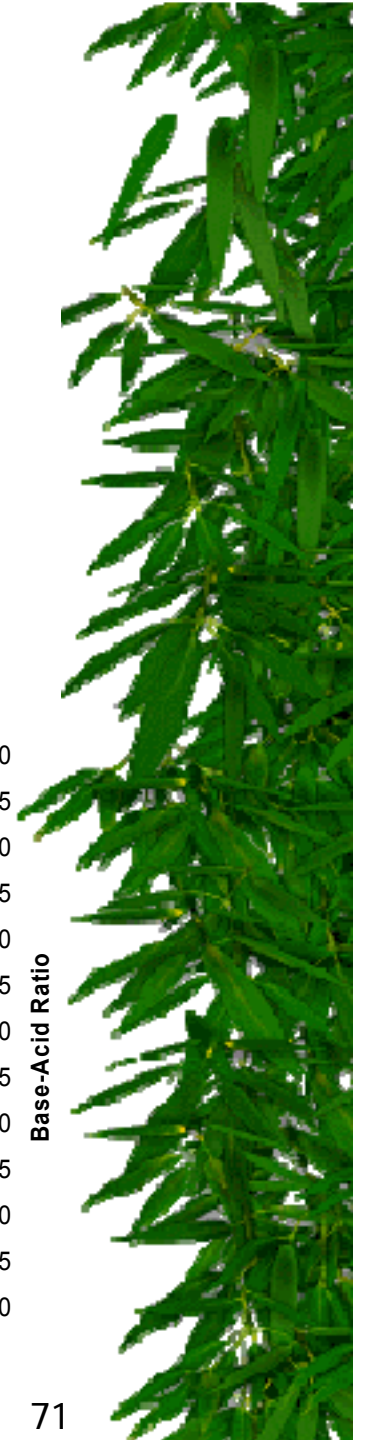
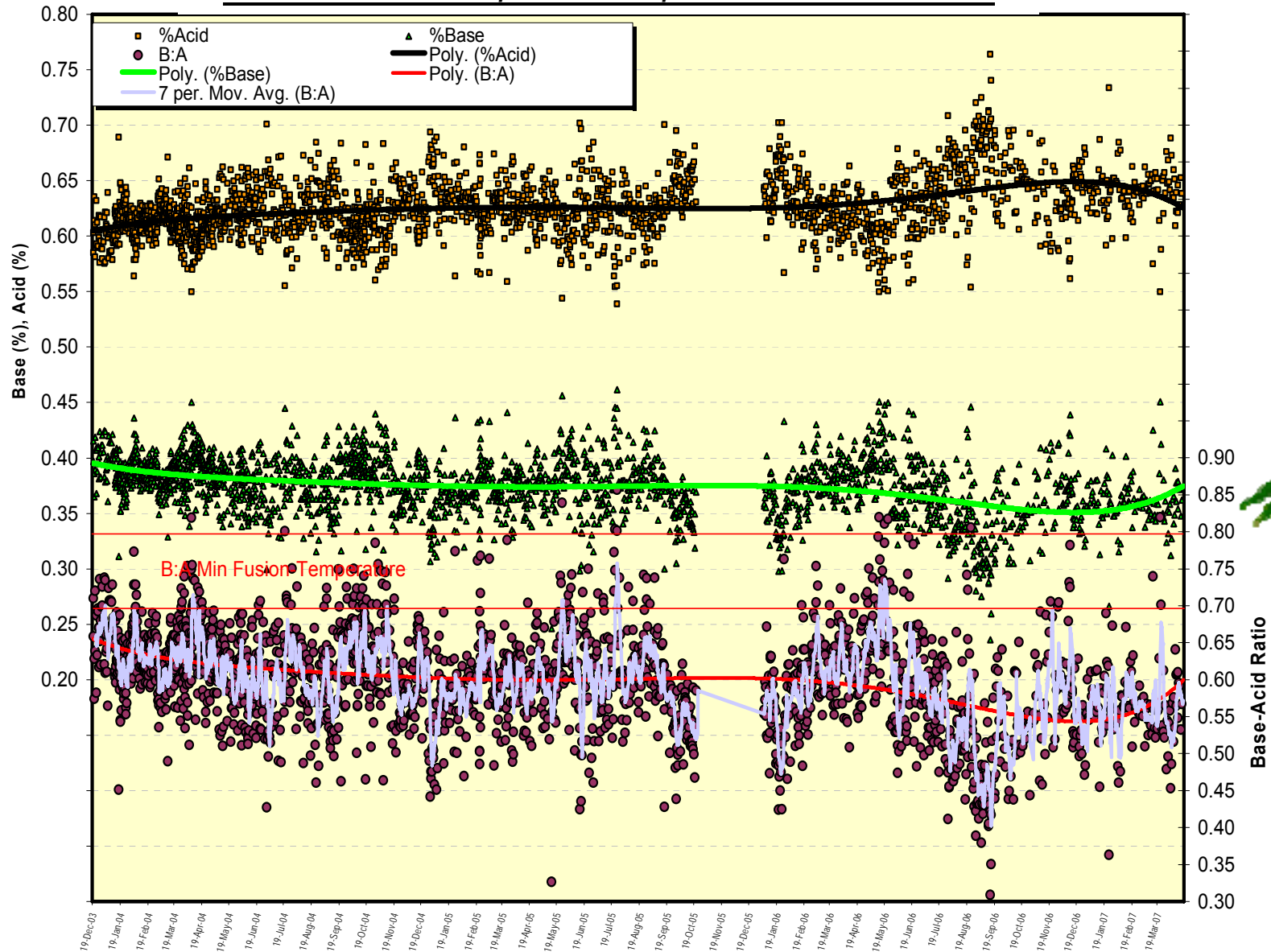
- Coal characteristic changes
- Slagging, fouling & opacity problems
- Blend changes
- Seasonal or weather related quality changes



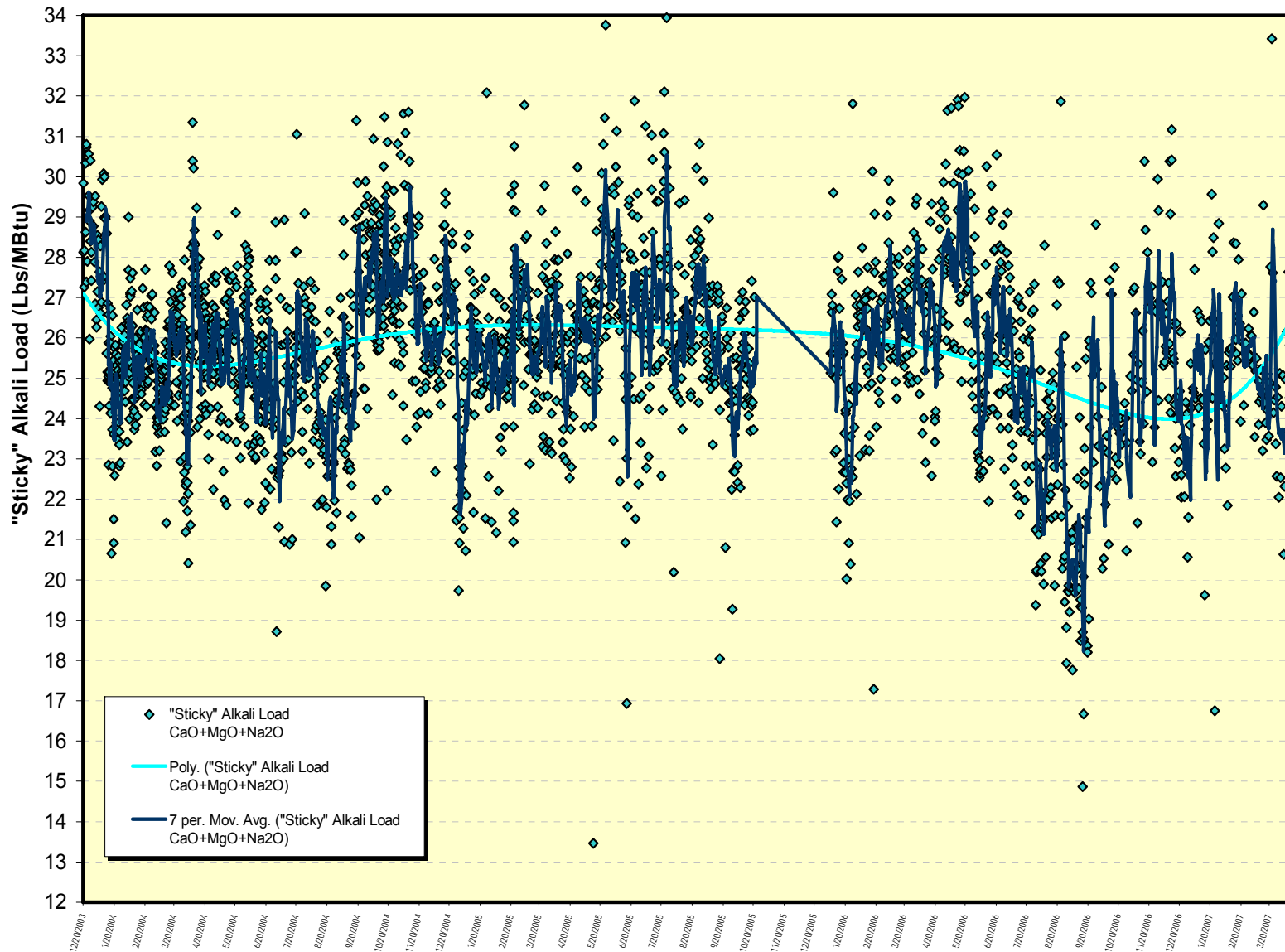
PRB — Moisture, HHV, MAF



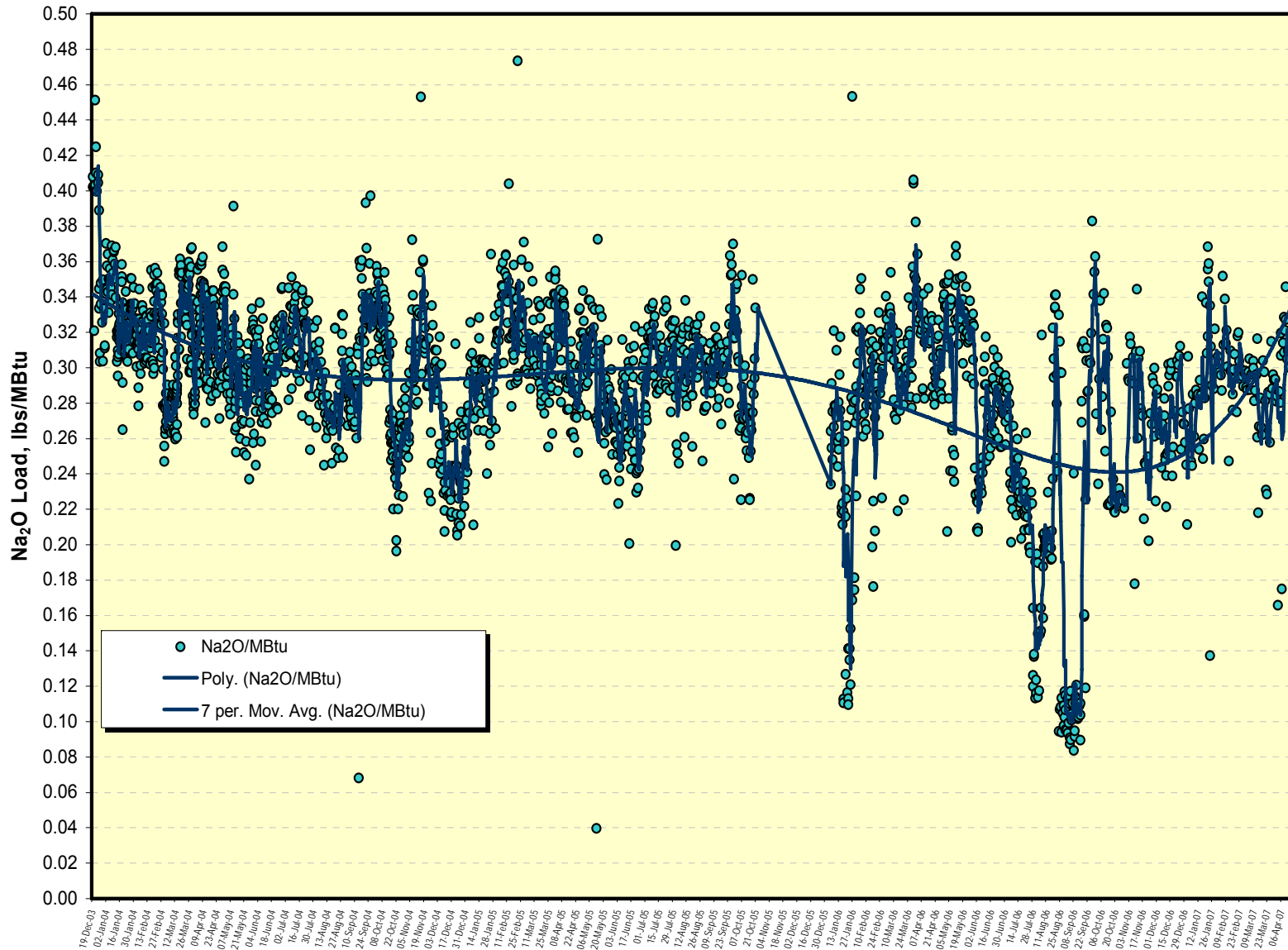
PRB — % Base, % Acid, Base-Acid Ratio



PRB — "Sticky" Alkali (CaO+MgO+Na₂O) Load



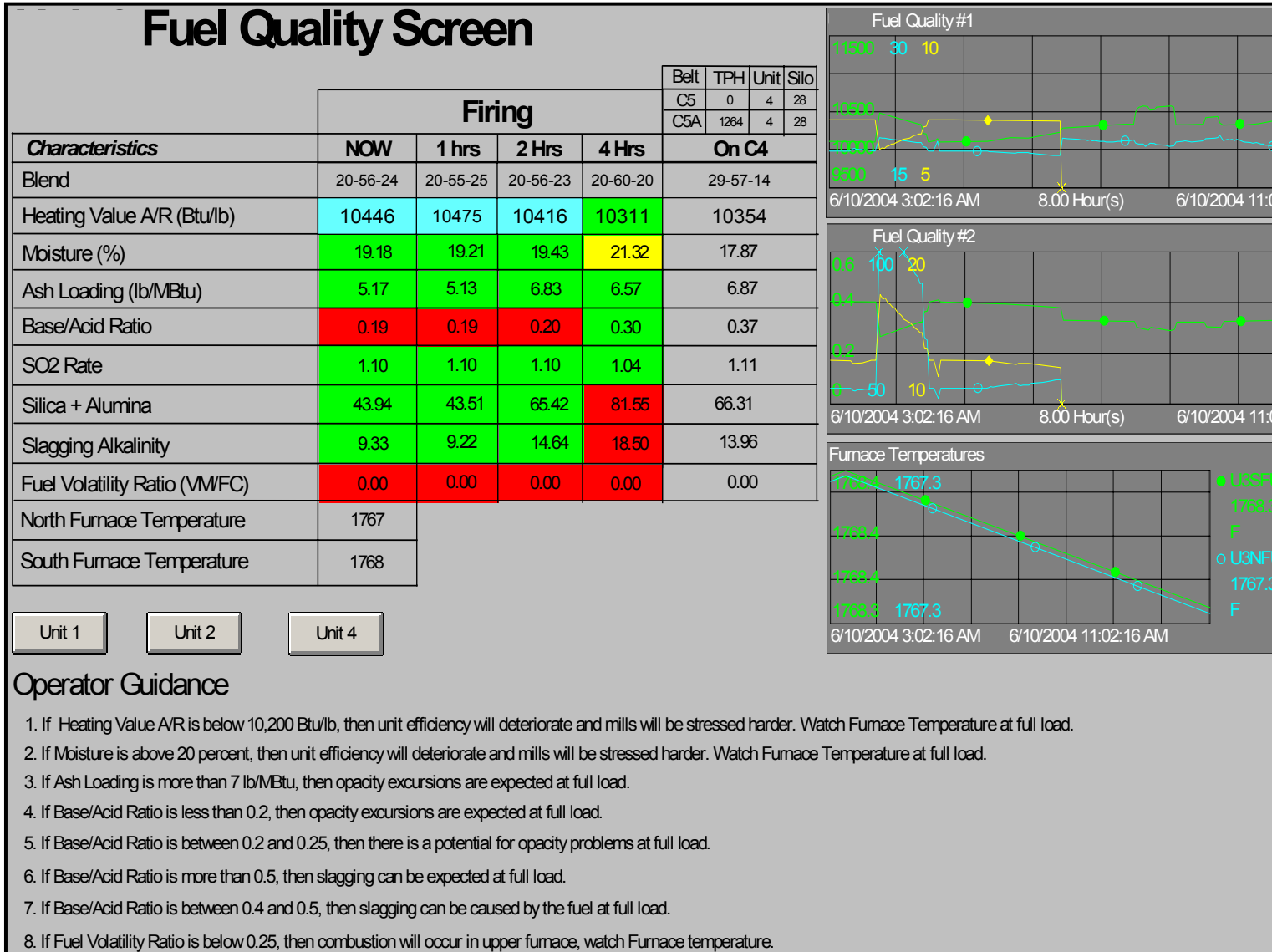
PRB — Na Load



**On-Line Analysis
&
Digital Fuel Tracking**



DFT Predictive Output



Operator Guidance

1. If Heating Value A/R is below 10,200 Btu/lb, then unit efficiency will deteriorate and mills will be stressed harder. Watch Furnace Temperature at full load.
2. If Moisture is above 20 percent, then unit efficiency will deteriorate and mills will be stressed harder. Watch Furnace Temperature at full load.
3. If Ash Loading is more than 7 lb/MBtu, then opacity excursions are expected at full load.
4. If Base/Acid Ratio is less than 0.2, then opacity excursions are expected at full load.
5. If Base/Acid Ratio is between 0.2 and 0.25, then there is a potential for opacity problems at full load.
6. If Base/Acid Ratio is more than 0.5, then slagging can be expected at full load.
7. If Base/Acid Ratio is between 0.4 and 0.5, then slagging can be caused by the fuel at full load.
8. If Fuel Volatility Ratio is below 0.25, then combustion will occur in upper furnace, watch Furnace temperature.

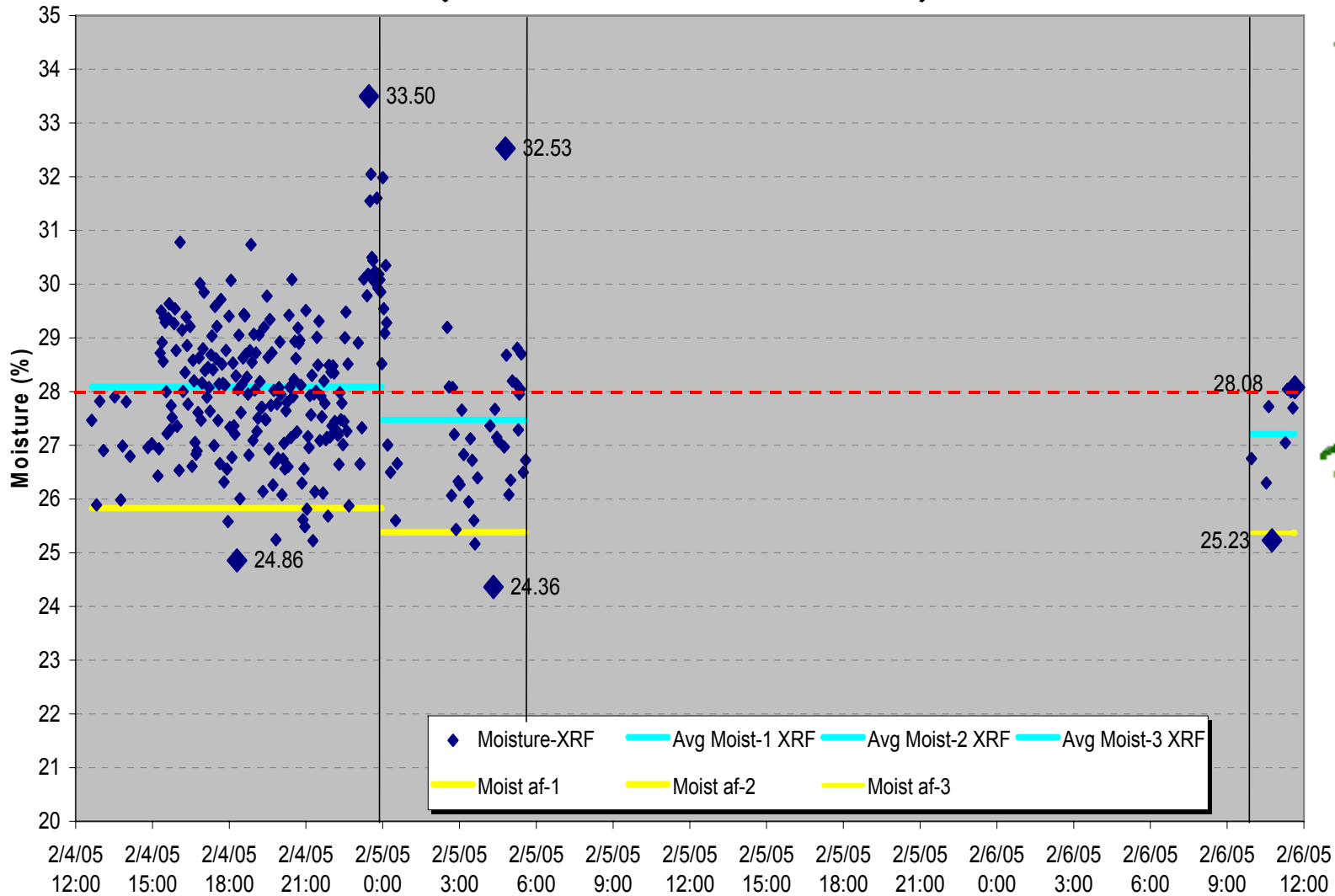


**On-Line Analysis
vs.
Laboratory**

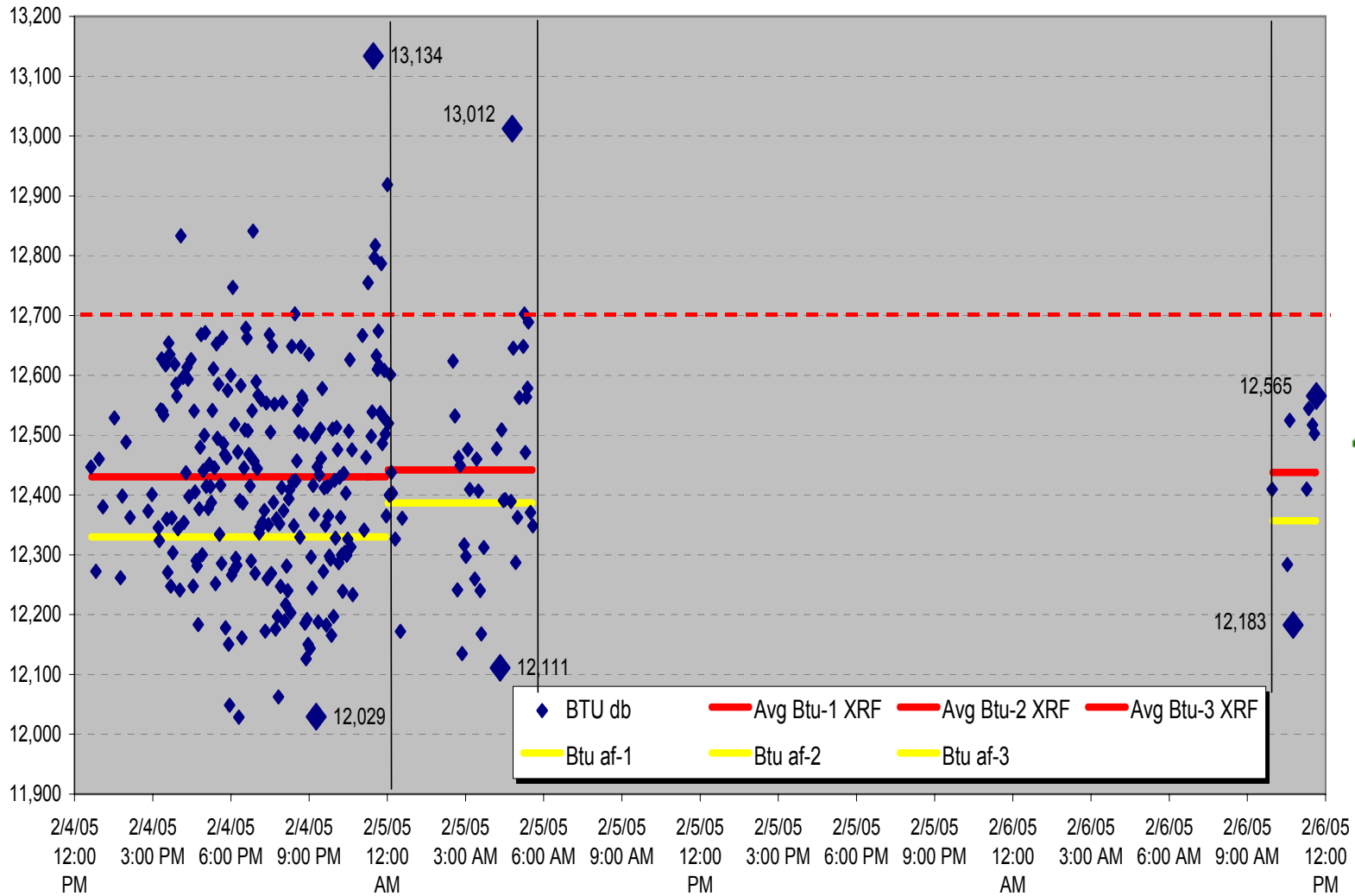


Moisture — Lab vs. On-Line Analyzer

(After Initial Calibration)

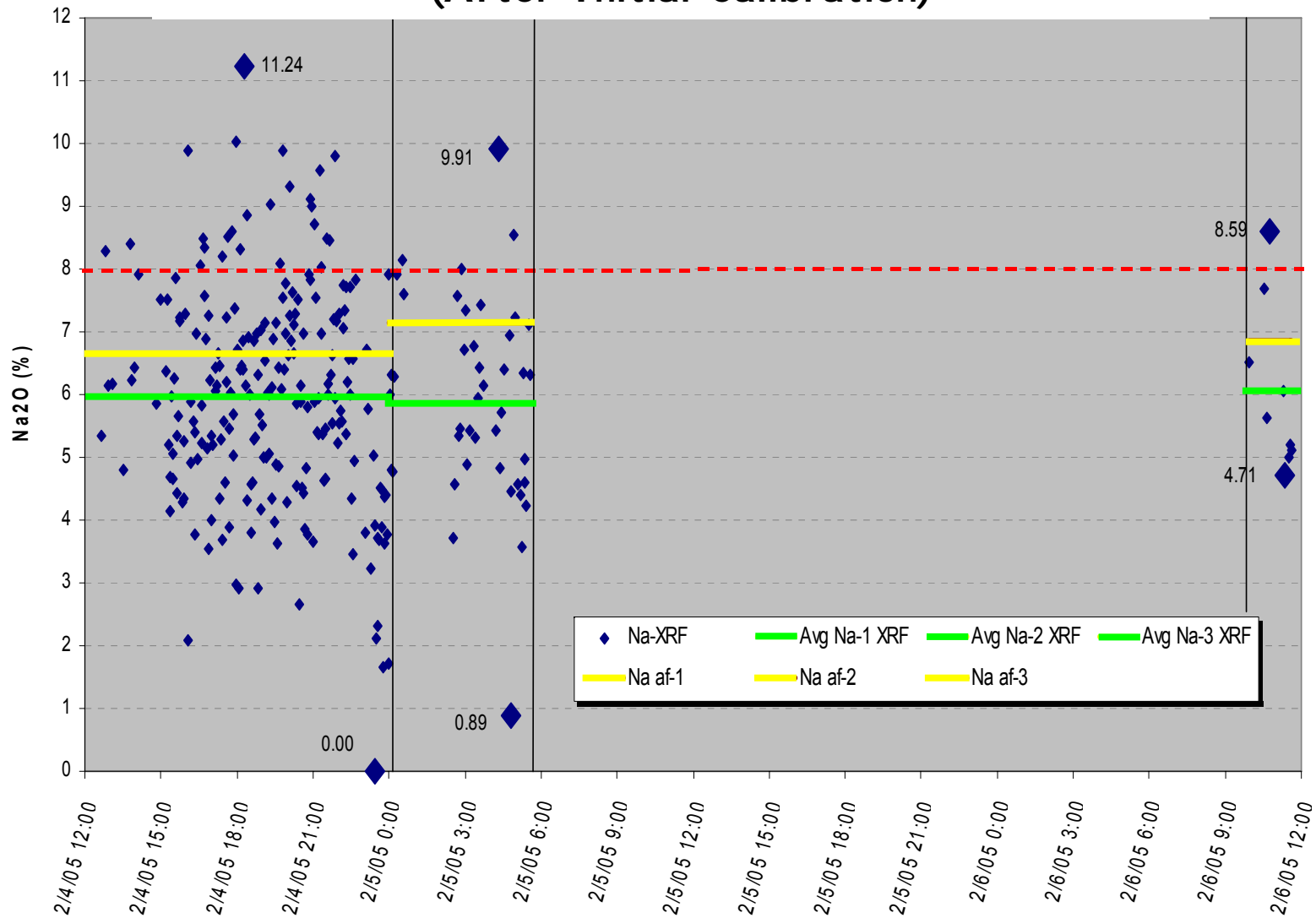


Heating Value — Lab vs. On-Line Analyzer (After Initial Calibration)

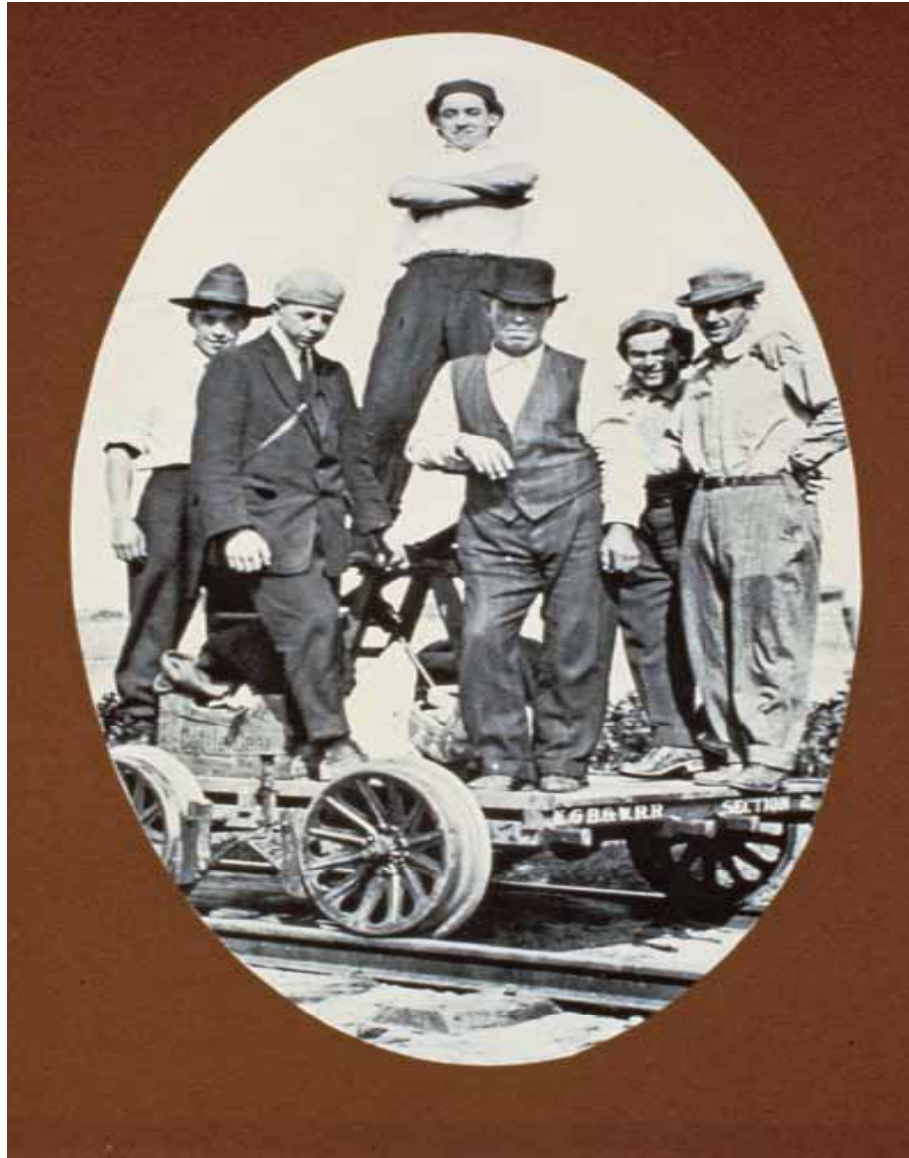


Sodium — Lab vs. On-Line Analyzer

(After Initial Calibration)



Thank You!



**Thank You
&
Enjoy the Rest of Your
Stay in Chattanooga!**

