REINHOLD ENVIRONMENTAL Ltd.

2013 APC Round Table & Expo Presentation

July 8-9, 2013, in St. Louis, MO / Hosted by Ameren

Welcome

&

Good Morning!

First get more coffee, a pen/pencil and a buddy to keep you awake.

Also, please turn-off or set to vibrate all pagers and cell phones

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"Such-a-Deal I Have For You"
or
"There Ain't No Such Thing As A Free Lunch*"

Coal Quality Impacts

* Dr. Milton Freedman,
Harvard Business Review, 1975,
et. al.

Such-a-Deal — The Coal Buyer

Your Coal Buyer has been offered 50k tons of coal at a significantly reduced price. With the exception of a little higher ash and sulfur than normal, the short prox values are within the coal specifications of the existing contract.

Knowing that the fuel savings will be about $500k and not too concerned with a little extra ash and sulfur, the 50k tons was purchased and delivered to the plant’s stockpile.

Such-a-Deal — The Plant

After receiving the short prox report from the coal buyer, the plant readily accepted the coal knowing the reduced fuel cost would put the plant higher on the dispatch table. This would allow the plant to generate more MWhs at a lower cost.

Plant engineers felt that the ESPs could handle extra ash and the higher sulfur would help collection efficiency.

Such-a-Deal — The System Supervisor

What the h..l is going on? Output is down 200 MWs. You were dispatched higher because of your reduced fuel cost, now you can't make your bid load. The ISO charge will likely wipe out most of the fuel savings.

The morning report didn't say anything about the effects of ash and sulfur on the ESPs, which you thought might be a problem, and could handle.

All that is reported is a derate due to slagging and furnace pluggage. Now you want a furnace cleaning outage for this weekend. I want some answers!

Such-a-Deal — Downtown

To plant: What the h..l is happening? The $500k saved in fuel cost has been canceled by increased boiler O&M, lost MWs and ISO charges. Fix it now!!

To coal buyer: What junk did you buy? That coal is slagging the boilers. This is causing a plant derate, an upcoming forced outage and ISO charges. Too bad these charges couldn't be charged against your budget. Better figure a way to get us out of this, now!

Such-a-Deal — Plant Shift Supervisor

All we know is that anytime the sulfur goes above 1.7%, the boilers begin to slag and the sootblowers can't keep up.

Such-a-Deal

What happened?

Can it be fixed?

Who bought lunch?

Remember:

"There Ain't No Such Thing As A Free Lunch"

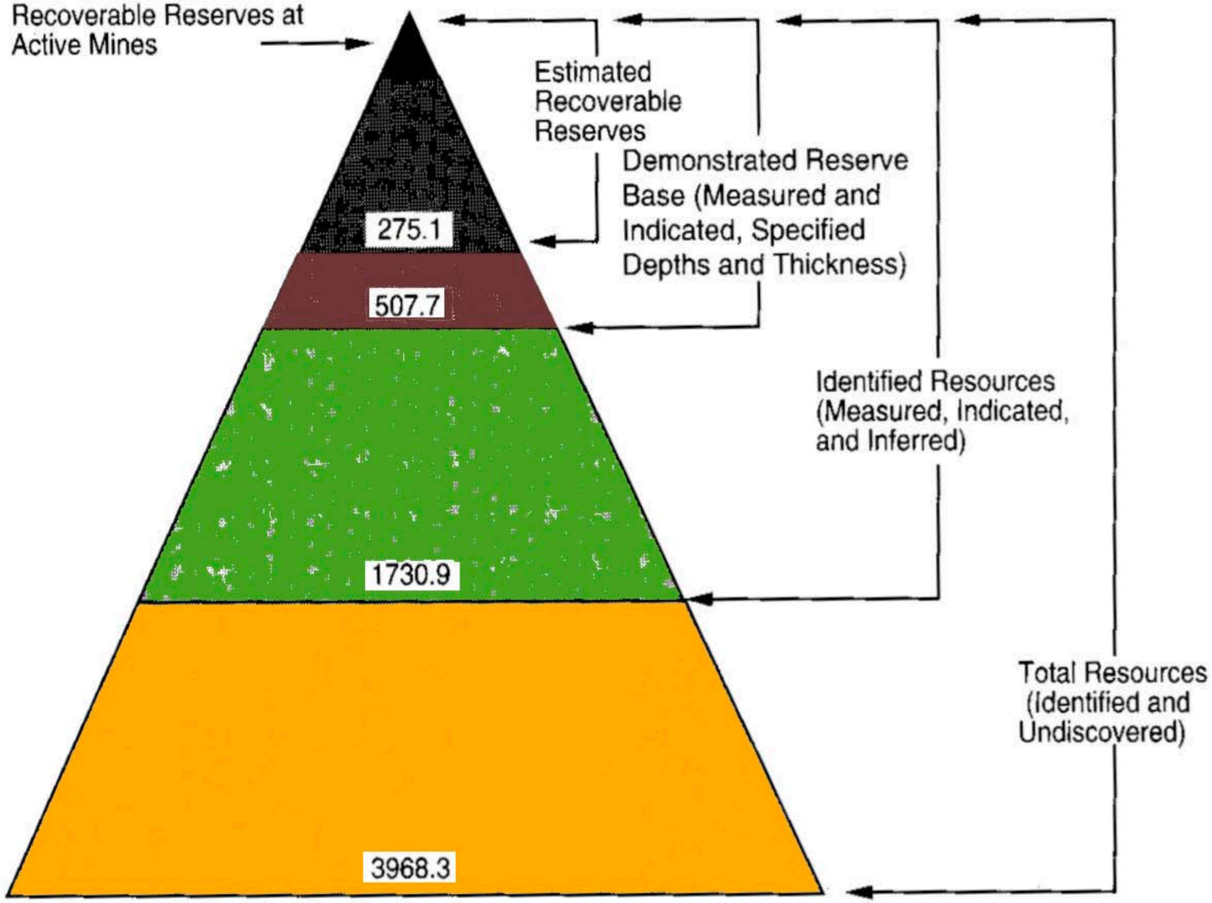
Unfortunately, no coal can be fully evaluated unless basic coal science is understood. Without understanding:

- *Operators* make decisions without adequate training
- *Engineers* over/under engineer the design
- *Management* may be lead in the wrong or less than optimum direction
- *Regulators* interpret laws based on a the lack of knowledge of what can/cannot be done
- *Lawmakers* make laws not based on science, but on pseudo-science and inaccurate information from biased lobbyists and staff members
- *Overseers* make reactive statements and misinform the public
- *Public* is given either incorrect or only partially correct information and react accordingly

Definitions of Coal

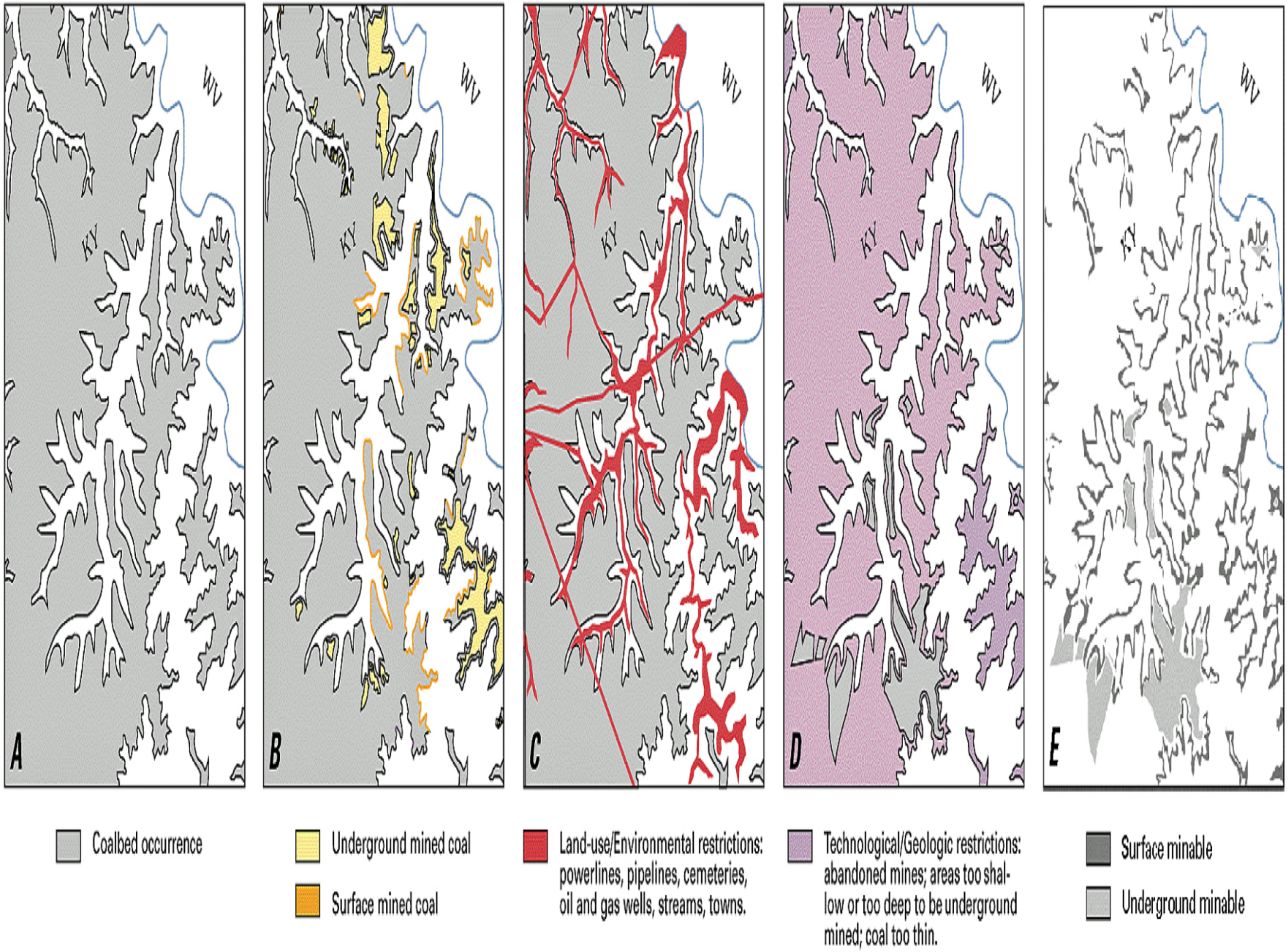
- **A brown or black combustible sedimentary rock (in the geological sense) composed principally of consolidated and chemically altered plant remains.** (ASTM D121)
- Coal is a rock, a sediment, a conglomerate, a biological fossil, a complex colloidal system, an enigma in solid-state physics and an intriguing 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)

US Coal Resources & Reserves

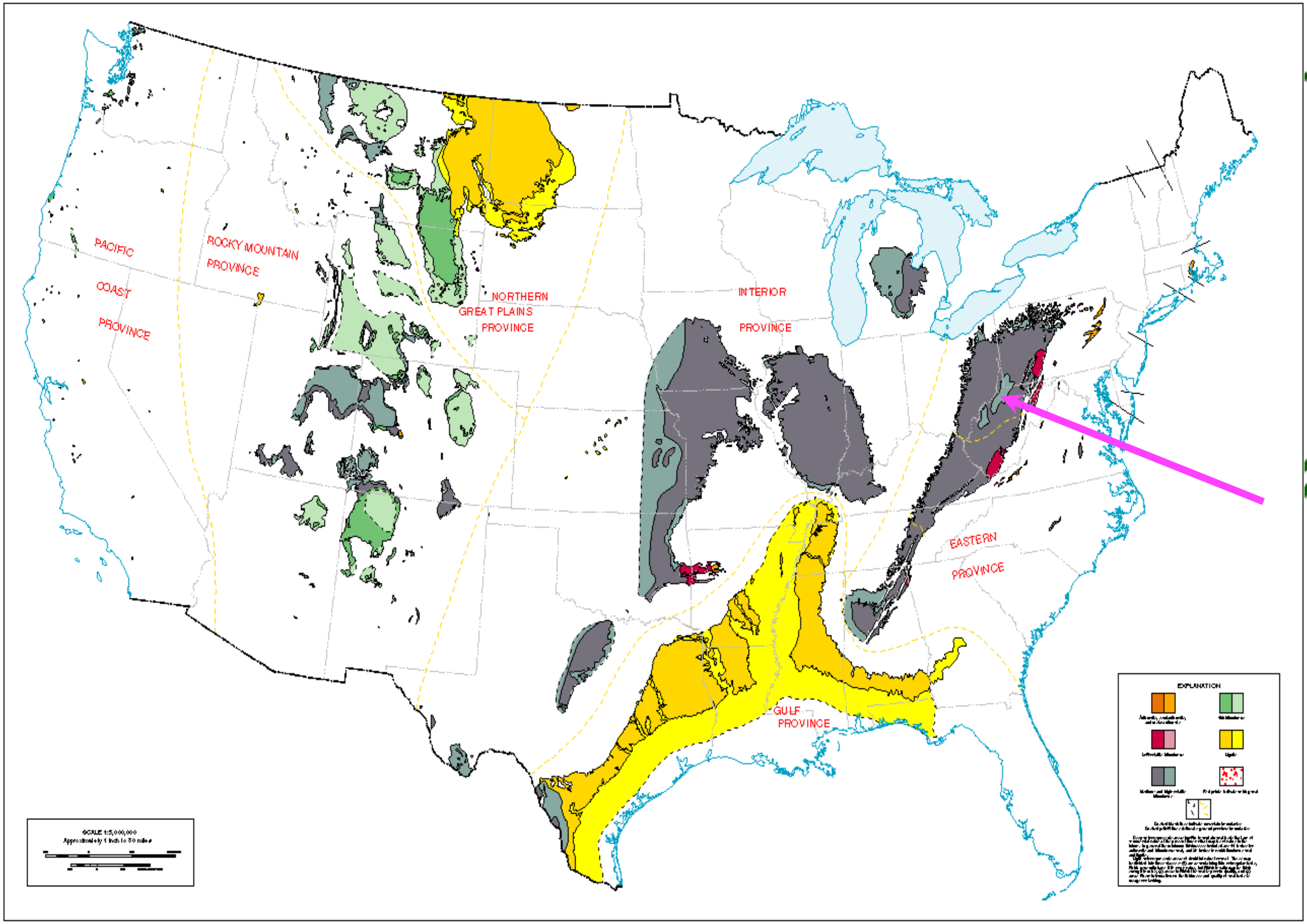


United States coal resources and reserves in billion short tons. (From EIA, *U.S. Coal Reserves: 1997 Update*, U.S. Department of Energy, Energy Information Administration, Washington, D.C., February 1999, p. 5, Appendix A.)

Reserves vs. Resources



Coal Deposits in the USA



Fuel Characteristics

Its Properties & Effects

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 (diff) (%) (+)	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
Equilbrium Moisture (%)	1.73
Surface Moisture (%)	2.84
Moisture Load (lbs/MBu)	3.38
Ash Load (lbs/MBu)	5.07
SO2 (lbs/MBu)	3.07
V/FC (fuel)	0.63
FC/V (combustion)	1.59

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 (diff) (%)	4.97	5.21	5.61

Hardgrove Grindability Index

HGI	50.8	@ 2.54% Moisture

Coal Analysis

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Sample Description:	S> 1.7%	Sample Receipt:	2/26/1999

ASH FUSION - 8 point

	Reducing	Oxidizing
Initial (°F)	2,209	2,535
Spherical (°F)	2,280	2,575
Hemispherical (°F)	2,372	2,595
Fluid (°F)	2,460	2,665
Plastic Range (°F)	251	130
T250 (°F)	2,530	

ASH MINERAL (Dry Ash Basis)

SiO2 (%)	50.52	% Acid	77.58%
Al2O3 (%)	23.10	% Base	22.42%
TiO2 (%)	0.93	B/A	0.29
Fe2O3 (%)	15.63	Ash Ratio	0.22
CaO (%)	2.64	Ash Type	Bituminous
MgO (%)	0.78	Slagging Index	0.56
K2O (%)	1.94	Slagging Type	Medium
Na2O (%)	0.56	Fouling Index	0.16
		Fouling Type	Low
SO3 (%)	1.25		
P2O5 (%)	0.35	Silica Ratio	0.73
BaO (%)	0.26	Si/Al	2.19
SrO (%)	0.81	Fe/Ca	5.92
MnO2 (%)	0.01	Dolomite %	15.87
Undetermined (%)	1.22	ESP Index	74

Coal

Mechanical combination of coal + mineral matter

Coal Maceral (bark, sap, leaves)

- Sorry, no dinosaurs
- Complex aromatic hydrocarbon
  - C, H, N, O, S, (Cl, Na, …)
- 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, + …
  - 60^{+} of the first 92 elements
- Hydrophilic (accepts water)

Moisture

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

Hypothesized Coal Structures

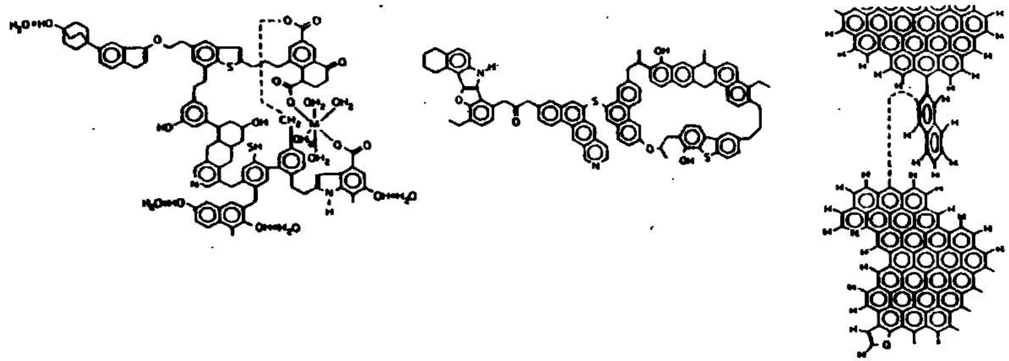


Figure 13. Spiro and Kosky (1982) models for a low-, intermediate-, and high-rank coal.

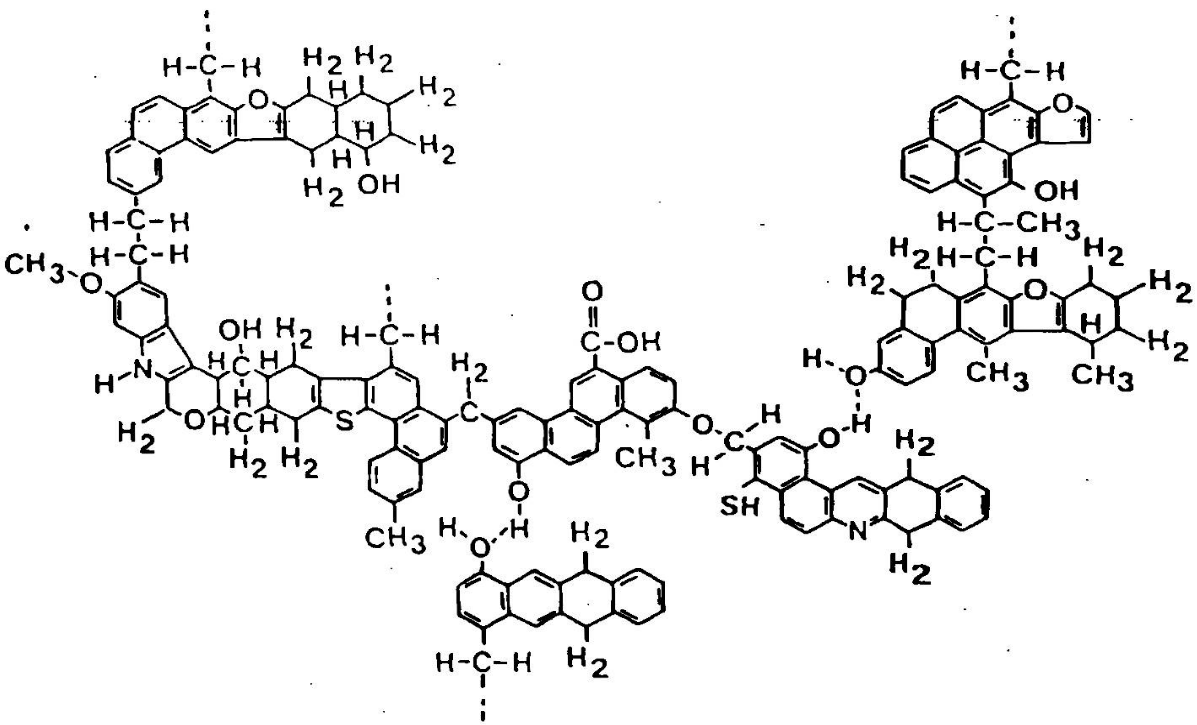
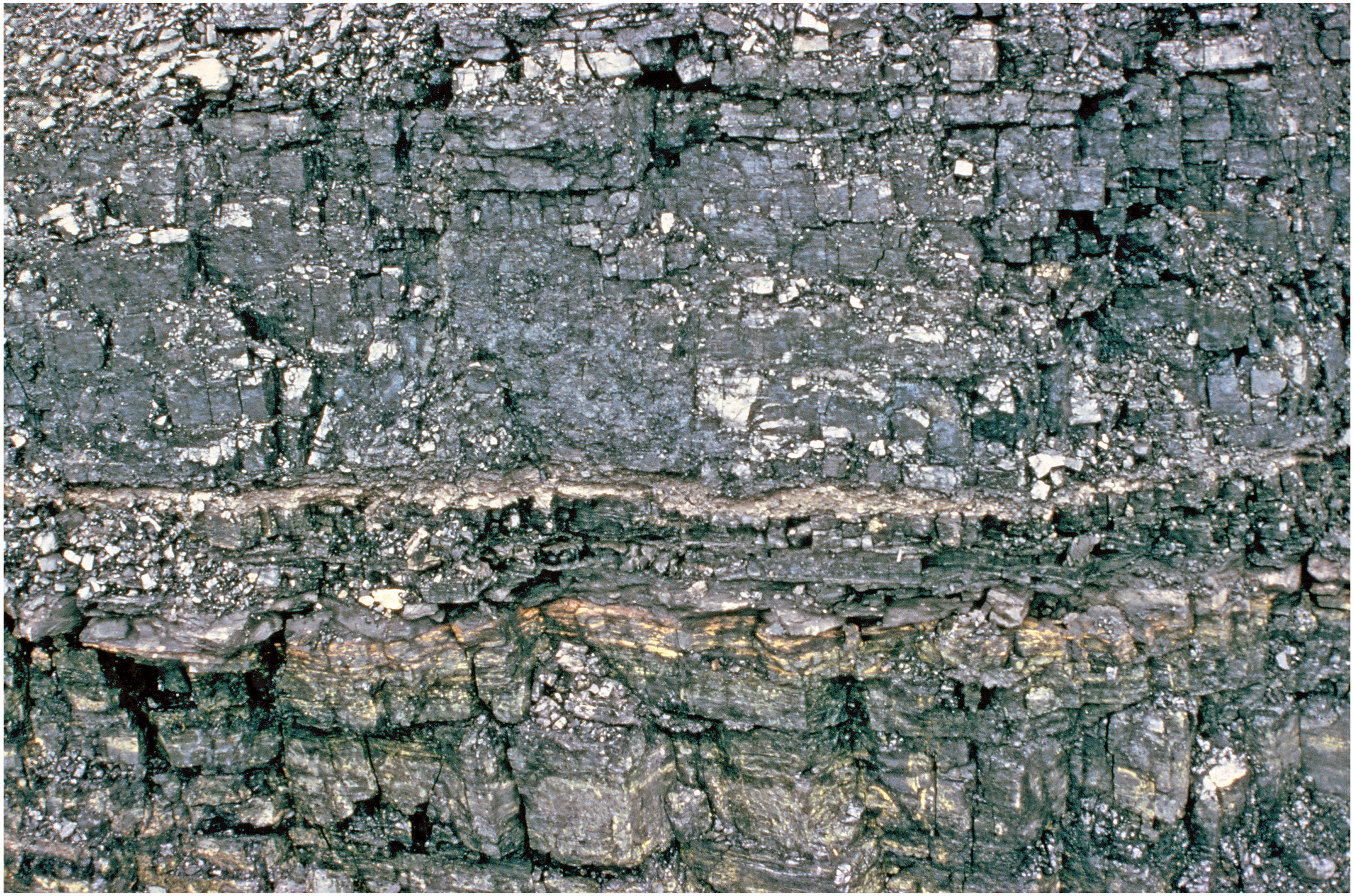
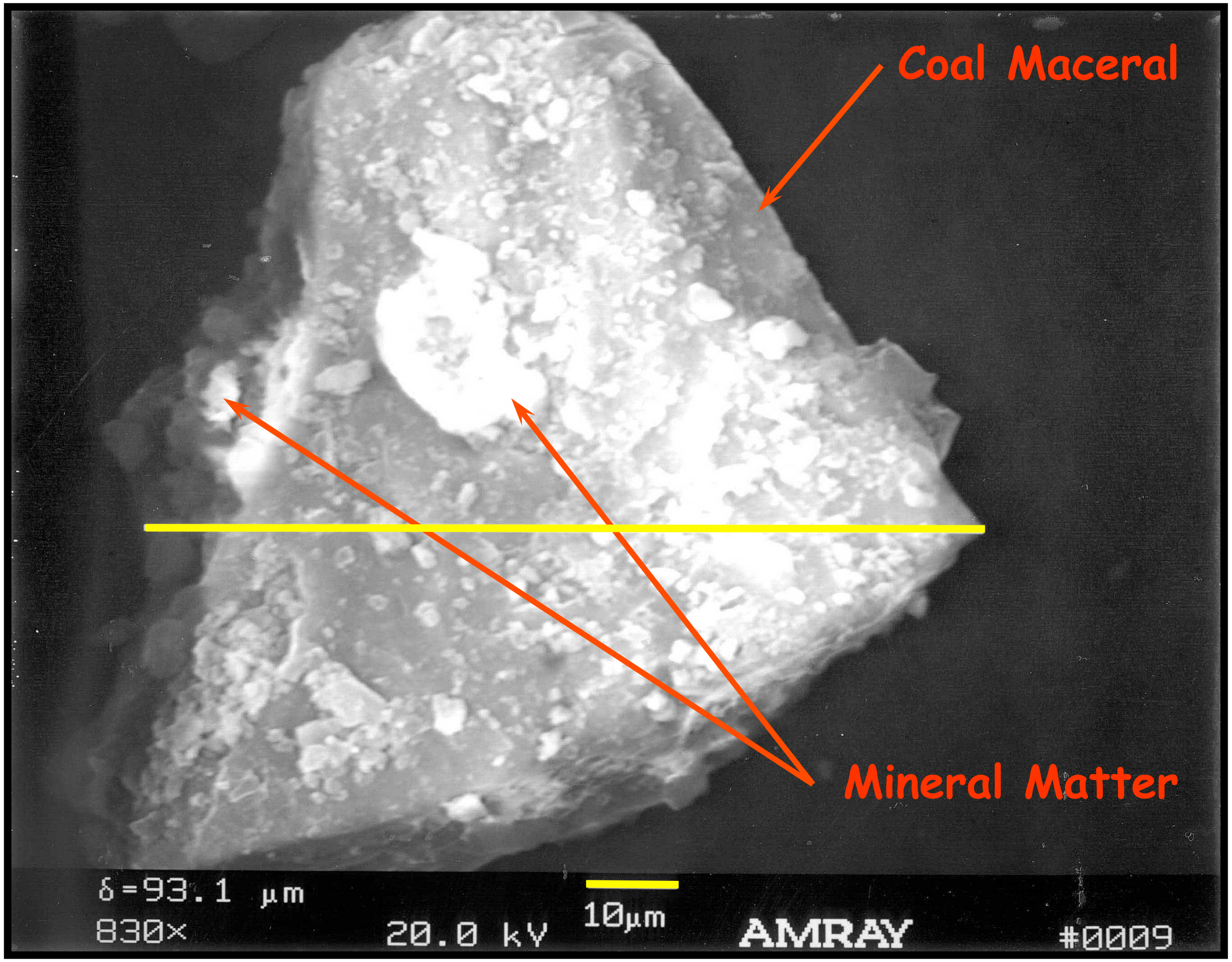


Figure 12. The Solomon (1981) model of a Pittsburgh high-volatile bituminous coal.

Coal 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

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

That is unless you are looking for a free lunch

PROXIMATE & SHORT PROX

- Moisture
- Ash
- Volatile
- Fixed Carbon
- Sulfur
- Heating Value

- MAF Heating Value
- Moisture Load
- Ash Load
- SO_2
- Volatile/Fixed Carbon

Included by convention

PROXIMATE

- [-] Moisture
- [-] Ash (really Mineral Matter)
- [+] Volatile
- [+] Fixed Carbon
- Btu (HHV), **MAF**
- Sulfur
- SO_2 (lbs SO_2/MBtu)
- Ash loading (lbs ash/MBtu)

ULTIMATE

- C + H + N + O ⇨ Volatile & Fixed Carbon

ASH MINERAL

- (Si, Al, Ti), (<u>Fe</u>, <u>Ca, Mg, K, Na</u>)
- % Acid, % Base
- Base-Acid Ratio
- Na2O (%)
- Na loading (lbs Na_2O/MBtu)

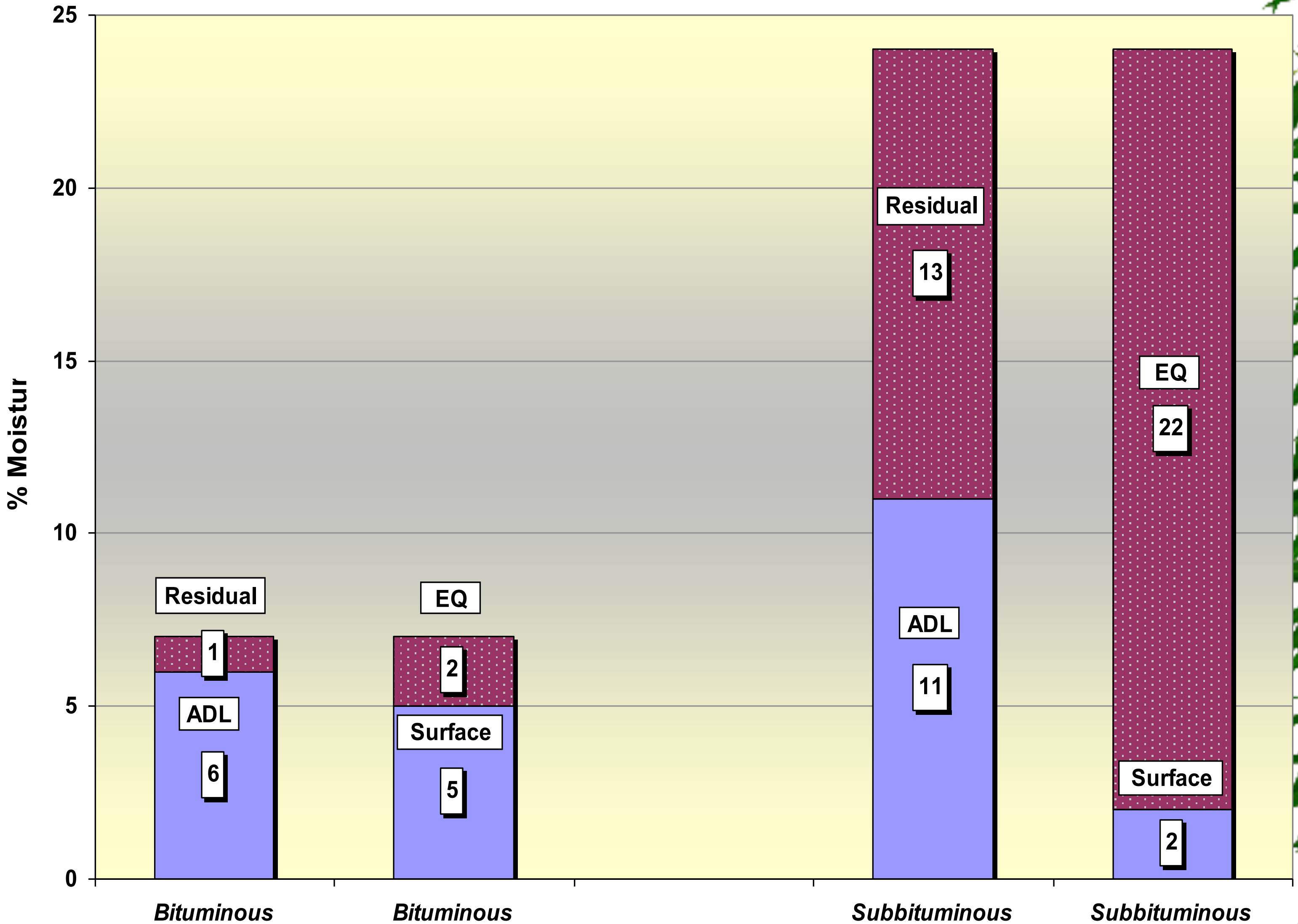
Total Moisture

- Must determine ADL & Residual Moisture (M_R)
  - $M_T = (M_R * (100 - ADL) / 100) + ADL$
    Where:

    ADL = Air Dry Loss
    M_R = Residual Moisture

- DO NOT confuse
  - ADL with Surface Moisture
  - Residual Moisture with Inherent or Equilibrium Moisture
  - They are NOT the same

Moisture Components



Ash & Ash Load

Potential back-end grain loading is based on ash load, not % Ash.

- *f*(particle size, ash deposition rate & ash viscosity)

Lbs Ash/MBtu ≡ Ash% * 10,000 / Calorific Value (Btu/lb)

6.4% Ash @ 8,000 Btu/lb =

8.0% Ash @10,000 Btu/lb = 8.0 lbs Ash/MBtu

9.6% Ash @12,000 Btu/lb =

Ash With Your Coal? — No Thank You!

Sulfur & SO_2

Air emission regulations are based on SO_2, not % Sulfur, although the regulations seldom state it this way.

Lbs SO_2/MBtu ≡ S% * 20,000 / Calorific Value (Btu/lb)

1.0% S @12,000 Btu/lb =

1.1% S @13,200 Btu/lb = 1.67 lbs SO_2/MBtu

0.9% S @10,800 Btu/lb =

Btu (Heating Value, Calorific Value)

- **As-Received**
  - Contractual, regulatory
  - HHV (higher heating value)
  - Performance
- ***As-Determined***
  - ***All calculations are based on these values***
  - *Laboratory basis*
  - *Seldom reported*
  - *Air-dried only*
- **Dry**
  - Lab comparison
  - Quality comparison
  - Corrects for moisture bias
- **MAF**
  - Fingerprint
  - Theoretical total energy
    - volatile + fixed carbon
    - **C + H + N + O + …**

Coal Comparisons

Proximate	Pitt (S<1.7)	Pitt (S>1.7)
Moisture (%) (-)	6.24	4.52
Ash (%) (-)	6.70	6.78
Volatile (%) (+)	31.89	34.31
Fixed Carbon (%) (+)	54.75	54.39
Sulfur (%)	1.42	2.05
HHV (Btu/lb)	13,061	13,376
MAF (Btu/lb)	15,002	15,080
Moisture Load (lbs/MBtu)	4.78	3.38
Ash Load (lbs/MBtu)	5.13	5.04
SO2 (lbs/MBtu)	2.17	3.07
V/FC (%/%)	0.58	0.63

ULTIMATE

- Moisture
- Ash
- Sulfur
- Carbon
- Hydrogen
- Nitrogen
- *Chlorine*
- Oxygen (by Δ)

Atomic Ratios

- H:C
- O:C
- N:C

ULTIMATE

Ultimate	Pitt (S<1.7)	Pitt (S>1.7)
Carbon	79.36	78.82
Hydrogen	5.14	5.24
Nitrogen	1.57	1.52
Chlorine	0.095	0.103
Oxygen	5.27	5.17
Atomic Ratios		
H:C	0.772	0.792
O:C	0.050	0.049

ASH (MINERAL MATTER), %

- 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

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

ASH (MINERAL MATTER), %

- **Slagging / Fouling Parameters**
  - **Fe, Na, Ca, Mg, K** (plastic-phase deposition)
  - **Na** (vapor deposition, especially MT-PRB)
    - Organic vs. inorganic
  - **Fe & Ca** act as fluxes to depress the ash melting temperature
    - **S** generally trends with **Fe**
- **Base-Acid Ratio**
  - $(Fe_2O_3 + CaO + MgO + Na_2O + K_2O) / (SiO_2 + Al_2O_3 + TiO_2)$
  - Minimum fusion temperature, **B:A** ~ 0.6-0.8
  - High slagging probability, **B:A** ~ 0.4-1.2
- **Silica vs. Silicates**
  - "Glass" vs. clay
  - Material handling & combustion considerations

Coal Comparisons

Ash Mineral	Pitt (S<1.7)	Pitt (S>1.7)
SiO_2	53.31	51.57
Al_2O_3	24.98	23.58
TiO_2	1.04	0.95
Fe_2O_3	11.84	15.95
CaO	3.07	2.69
MgO	0.86	0.80
K_2O	2.01	1.98
Na_2O	0.61	0.57
% Acid	81.18	77.58
% Base	18.82	22.42
Base / Acid	0.23	0.29
Slagging Type	Low	Severe
Fouling Type	Low	Low

Coal Comparisons

Ash Mineral	Pitt (S<1.7)	Pitt (S>1.7)
Si Ratio	73	77
Si/Al	2.19	2.13
Fe/Ca	5.92	3.85
Dolomite %	15.87	21.37
Fe + Ca	18.65	14.91
Fe Load	0.81	0.61
Ca Load	0.14	0.16
ESP Index	75	78

Coal Mineral Types

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

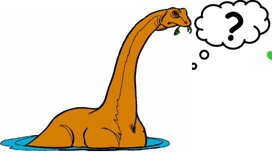
Mineral type	Chemical formula[a]
Quartz	SiO_2
Al-silicate (kaolinite)	$Al_4Si_4O_{10}(OH)_8$
Fe-aluminosilicate	$Fe_xAl_ySi_z$
K-aluminosilicate (illite)	$K(Al, Fe)_4(Si, Al)_8O_{20}(OH)_4$
Ca-aluminosilicate	Ca_xAl_y, Si_x
Iron oxide	Fe_2O_3
Pyrite	FeS_2
Gypsum	$CaSO_4 \cdot 2H_2O$
Calcite	$CaCO_3$
Rutile	TiO_2
Barite	$BaSO_4$
Ankerite	$Ca(Mg, Fe, Mn)(CO_3)_2$
Siderite	$FeCO_3$
Crandallite	$CaAl_3(PO_4)_2(OH)_5 \cdot H_2O$
Dolomite	$CaMg(CO_3)_2$
Calcium aluminate	$Ca_3Al_2O_6$
Apatite	$Ca_5F(PO_4)_3$
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: Zygarlicke *et al.* (1990a).

Fusion Characteristics of Ash Components

Element	Chemical Property	Oxide	Melting Temperature (°F)	Compound	Melting Temperature (°F)
Si	Acidic	SiO_2	3120	Na_2SiO_3	1610
Al	Acidic	Al_2O_3	3710	K_2SiO_3	1790
Ti	Acidic	TiO_2	3340	$Al_2O_3 \cdot N_2O \cdot 6SiO_2$	2010
Fe	Basic	Fe_2O_3	2850	$Al_2O_3 \cdot K_2O \cdot 6SiO_2$	2010
Ca	Basic	CaO	4570	$FeSiO_3$	2090
Mg	Basic	MgO	5070	$CaO \cdot Fe_2O_3$	2280

Source: *Routine Coal & Coke Analysis,* Dr John Riley, *pg 74, ASTM, 2007*



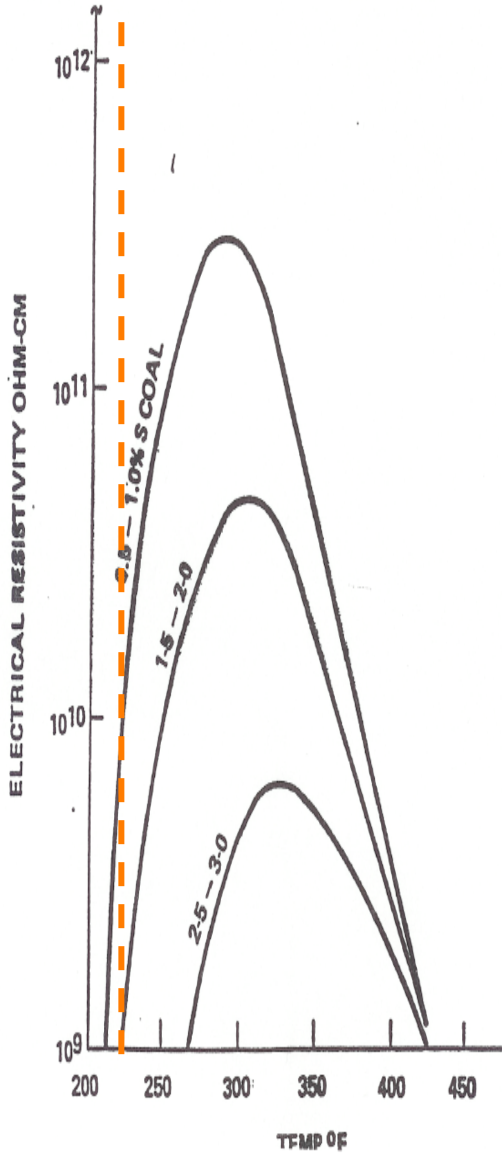
Ash ESP Parameters

- Ash Load (Grain Loading)
  - Lbs Ash/MBtu ≡
    Ash% * 10,000 / Heating Value (Btu/lb)
  - Not all ash travels to ESP
    - *f*(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 hold more ash in furnace and pendants in the form of slag
  - Low rank coals (PRB) have finer fly ash than high rank
- Fly Ash Sales effected by S, Ca, Na+Mg, C, SO_3
  - Class C & Class F Fly Ash
  - C: concrete air entrainment & appearance
  - S, SO_3: concrete strength
  - Ca: concrete pozzalonic properties
  - Na+Mg: concrete strength

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
- Base %*: <15, good; 15-40, medium; >40, poor
- Base/Na_2O*: <20, good; 20-30, medium; >30, poor
- K_2O*: <1, good
- CaO+MgO*: >20 poor



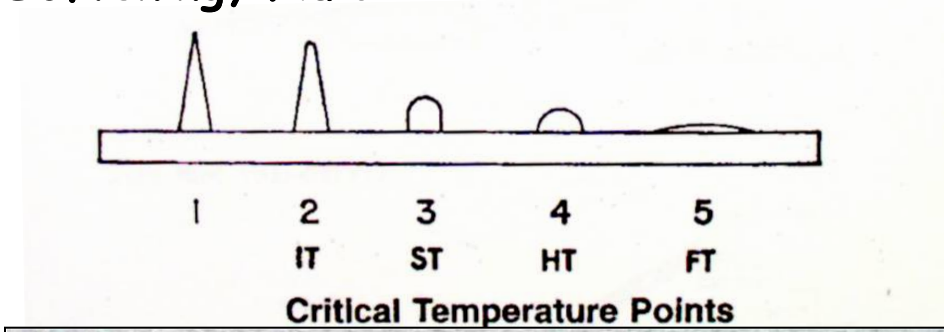
* Source: *Routine Coal & Coke Analysis*, Dr John Riley, *pg 74, ASTM, 2007*

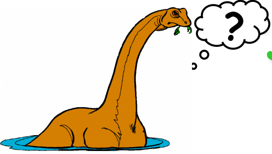
Ash Fusion Temperatures

- Reducing & oxidizing atmospheres (CO/CO_2 vs. air)
  - **Initial, Spherical, Hemispherical, Fluid**
- Plastic range (**fusion box**)
  - Fluid – Initial
- Ash melting temperatures follows a hysteresis curve (lab furnace vs. operating boiler)
- **Eutectics & Eutectoids** in blends
- Need to correlate with unit operation
  - Compare relative changes
  - Suggest to not use absolute values

Ash Fusion

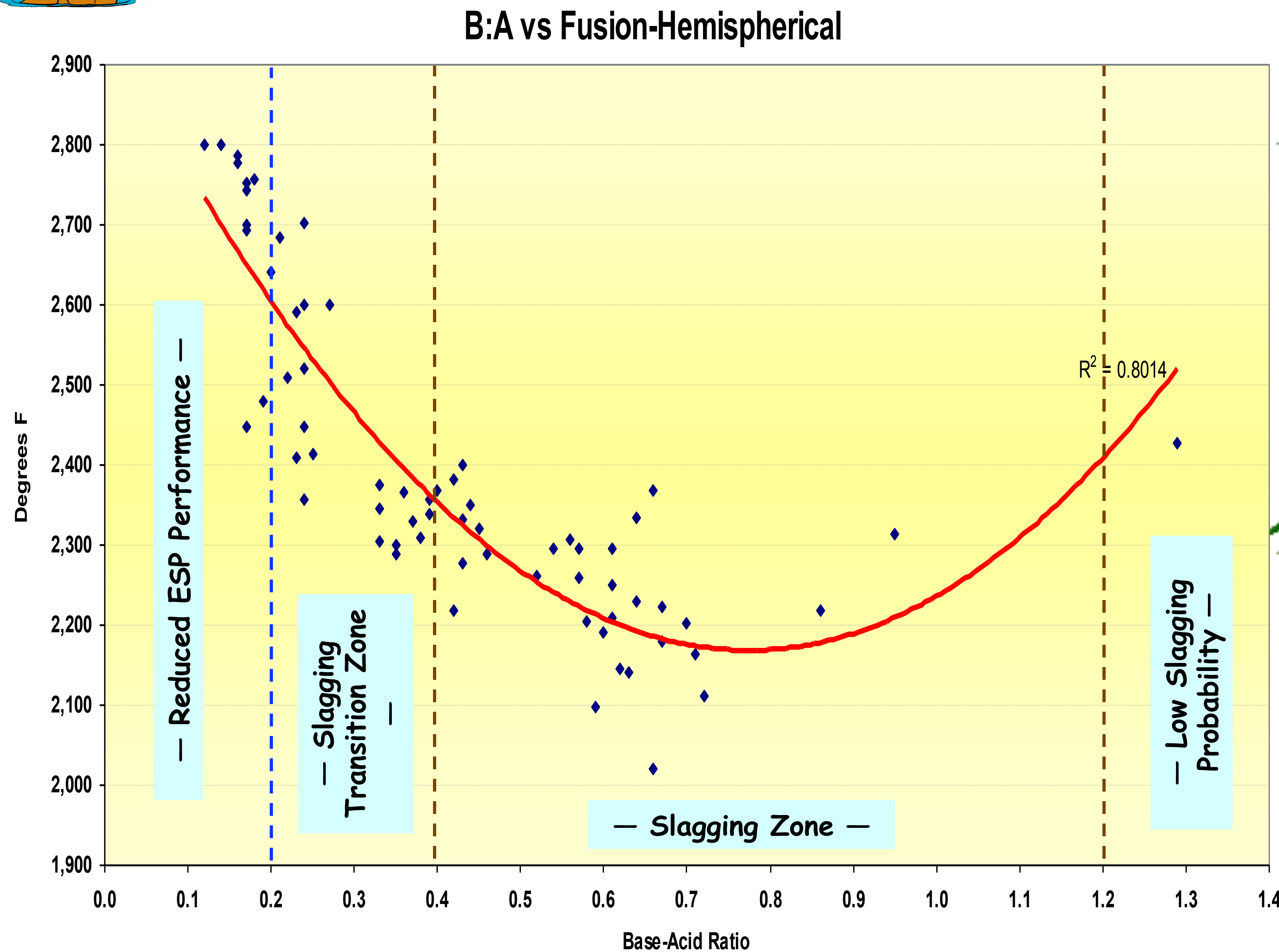
- Slagging & Fouling Predictors
- Eutectic Predictor
- Oxidizing & Reducing Atmospheres
- Initial Deformation, Spherical Softening, Hemispherical Softening, Fluid
- Plastic Range



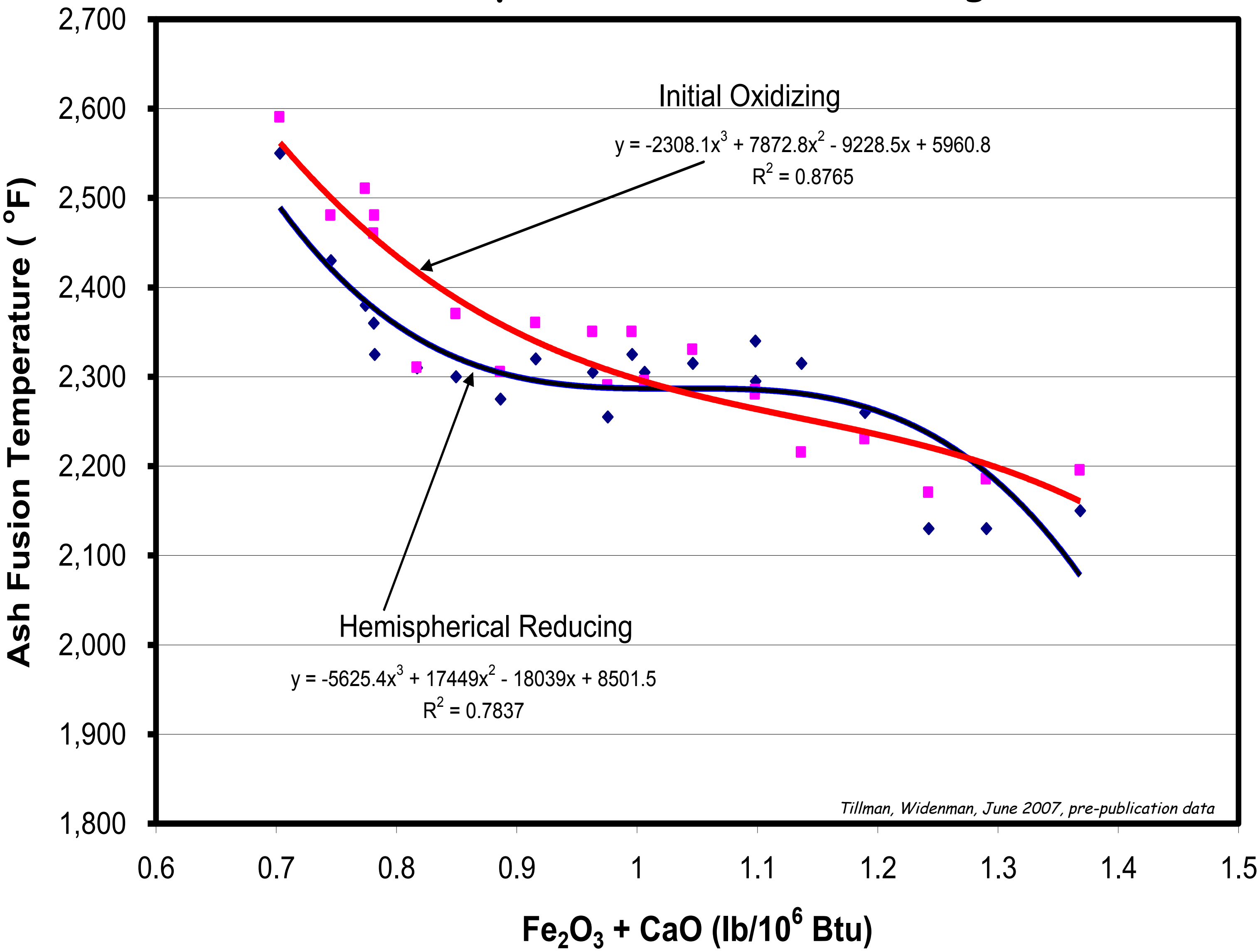


Ash Fusion

Ash Fusion	Pitt (S<1.7)	Pitt (S>1.7)
Reducing Atmosphere (°F)		
Initial Deformation	2,472	2,209
Spherical Softening	2,499	2,280
Hemispherical Softening	2,530	2,372
Fluid	2,585	2,460
Plastic	113	251
Oxidizing Atmosphere (°F)		
Initial Deformation	2,550	2,535
Spherical Softening	2,590	2,575
Hemispherical Softening	2,625	2,595
Fluid	2,670	2,665
Plastic	120	130


B:A vs Fusion-Hemispherical
Degrees F
2,900
2,800
2,700
2,600
2,500
2,400
2,300
2,200
2,100
2,000
1,900
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Base-Acid Ratio
R2 = 0.8014
— Reduced ESP Performance —
— Slagging Transition Zone —
— Slagging Zone —
— Low Slagging Probability —

Ash Fusion Temperature Prediction Using Coal Fe+Ca



Coal Analysis Special Tests

Equilibrium Moisture

- Must determine ADL & Residual Moisture (M_R)
  - M_T = (M_R * (100 - ADL) / 100) + ADL
  - M_T = (EQ * (100 - M_S) / 100) + M_S

Where:

ADL = Air Dry Loss

M_R = Residual Moisture

EQ = Equilibrium Moisture

M_S = Surface Moisture

M_S cannot be determined directly. Use the 2 M_T equations and solve for M_S.

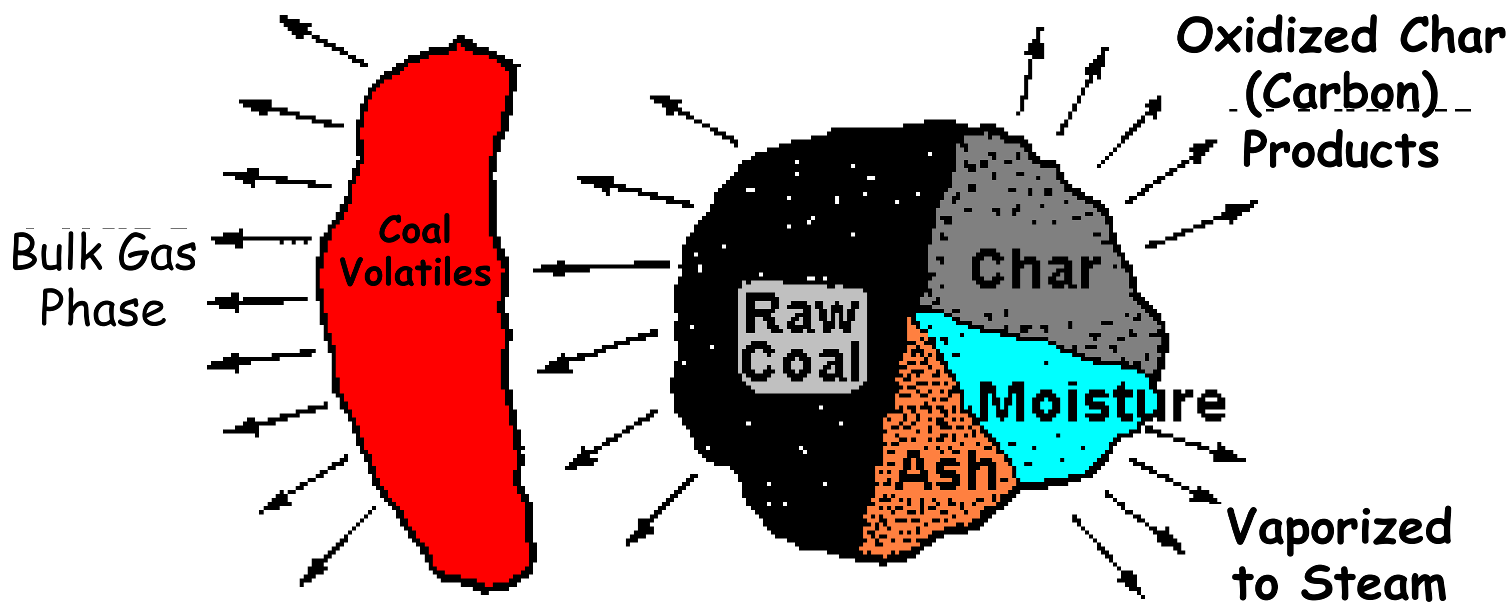
- DO NOT confuse:
  - ADL with Surface Moisture
  - Residual Moisture with Inherent or Equilibrium Moisture
  - They are NOT the same

S-Forms, EQ Moisture, HGI

	Pitt (S<1.7)	Pitt (S>1.7)
Sulfur Forms		
Organic S	0.80	1.10
Pyritic S	0.70	1.02
Sulfate	0.01	0.03
Equilibrium Moisture		
EQ Moisture	4.0	3.7
Hardgrove Grindability Index		
HGI	51	53
@ Moisture	1.52	1.64

Particle Combustion

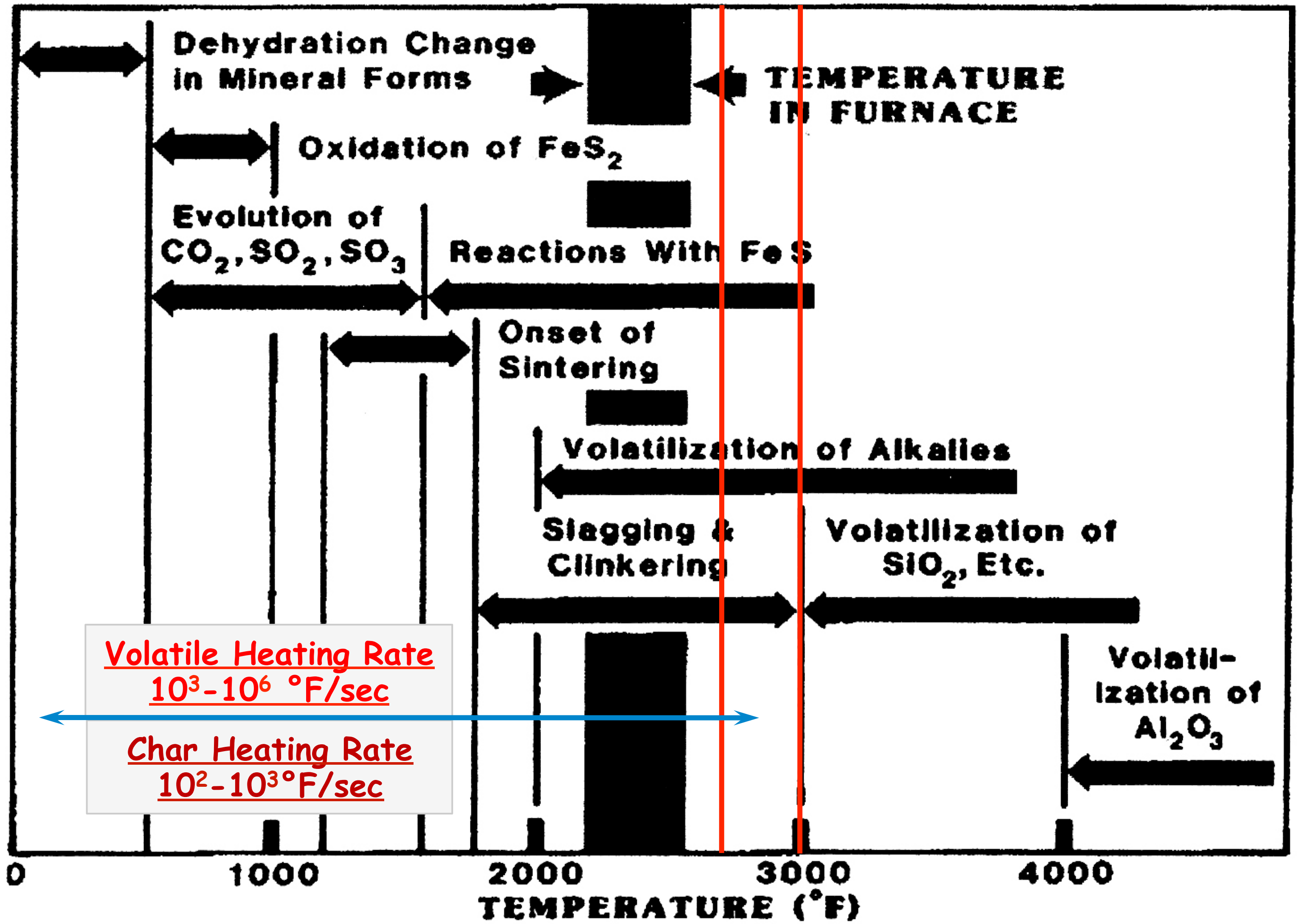
Generalized Combustion Depiction



Lump of Coal

David Tillman, Fundamentals of Combustion Tutorial

Chemical Changes in Coal Ash as a Function of Temperature



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

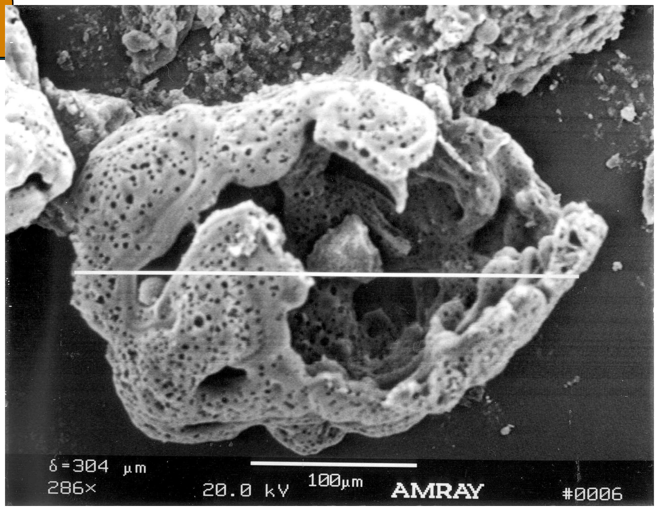
Combustion Characteristics for Pulverized Coal Furnaces

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

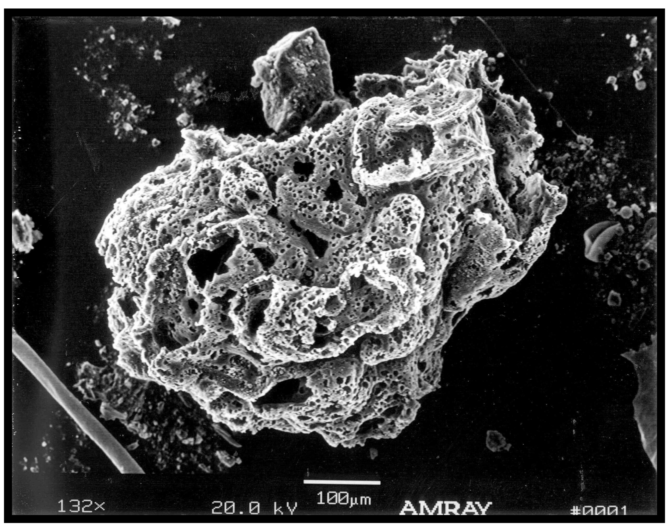


286X, SEM-photomicrograph
Char Particle

Char.

Note the "popcorn" appearance.

Particle is about 304-µm across. Note the small seed-like ash particle in the center. Holes on the surface are made by escaping gases during combustion.



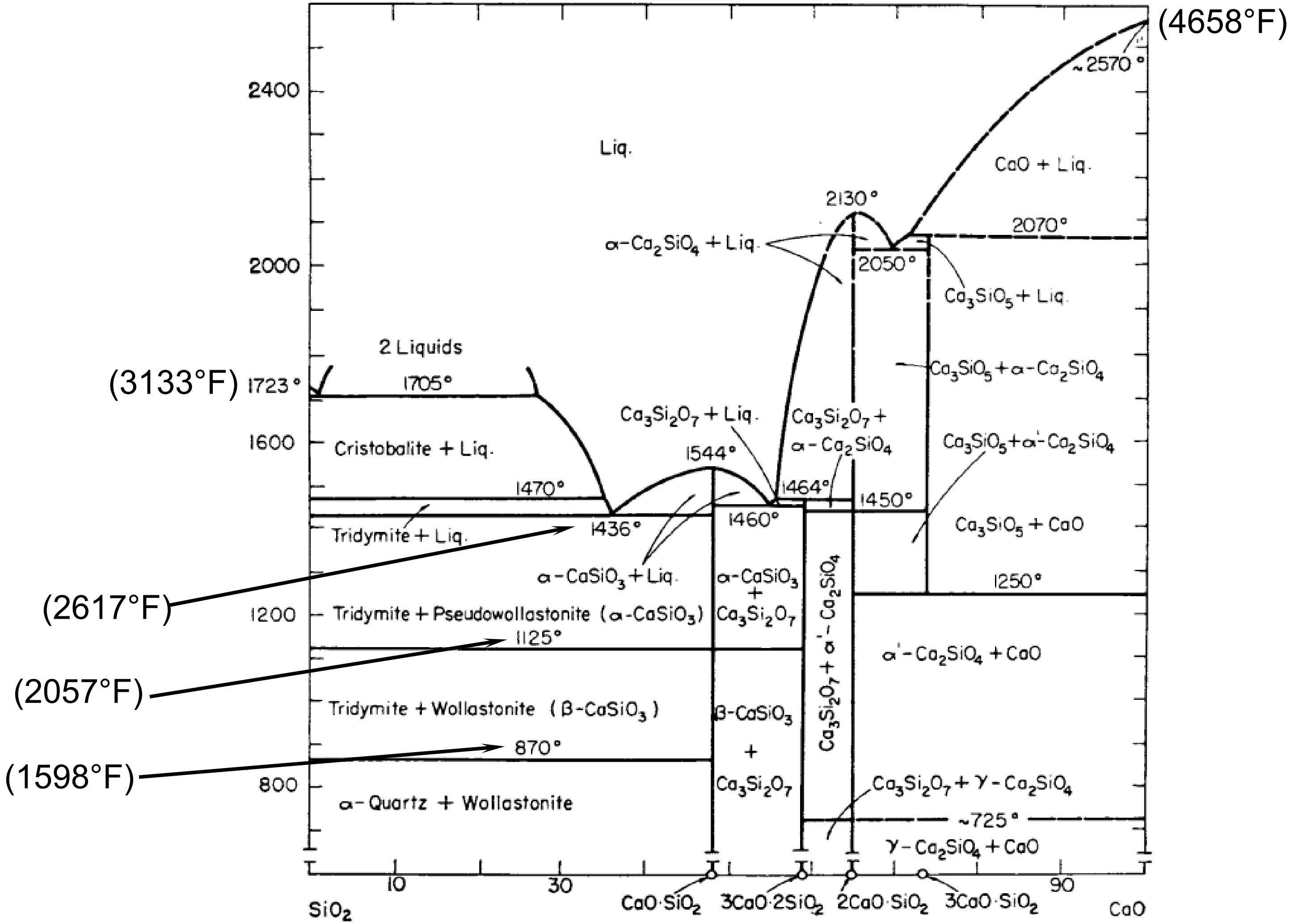
132X, SEM-photomicrograph
Char Particle

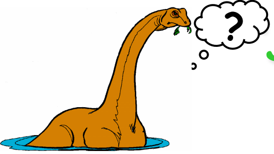
Char.

Particle is about 580-µm across, very porous and hollow. Initial combustion likely occurred at the right end where there is a large hole. Smaller holes on the surface were made by escaping gases during combustion.

Slagging & Fouling

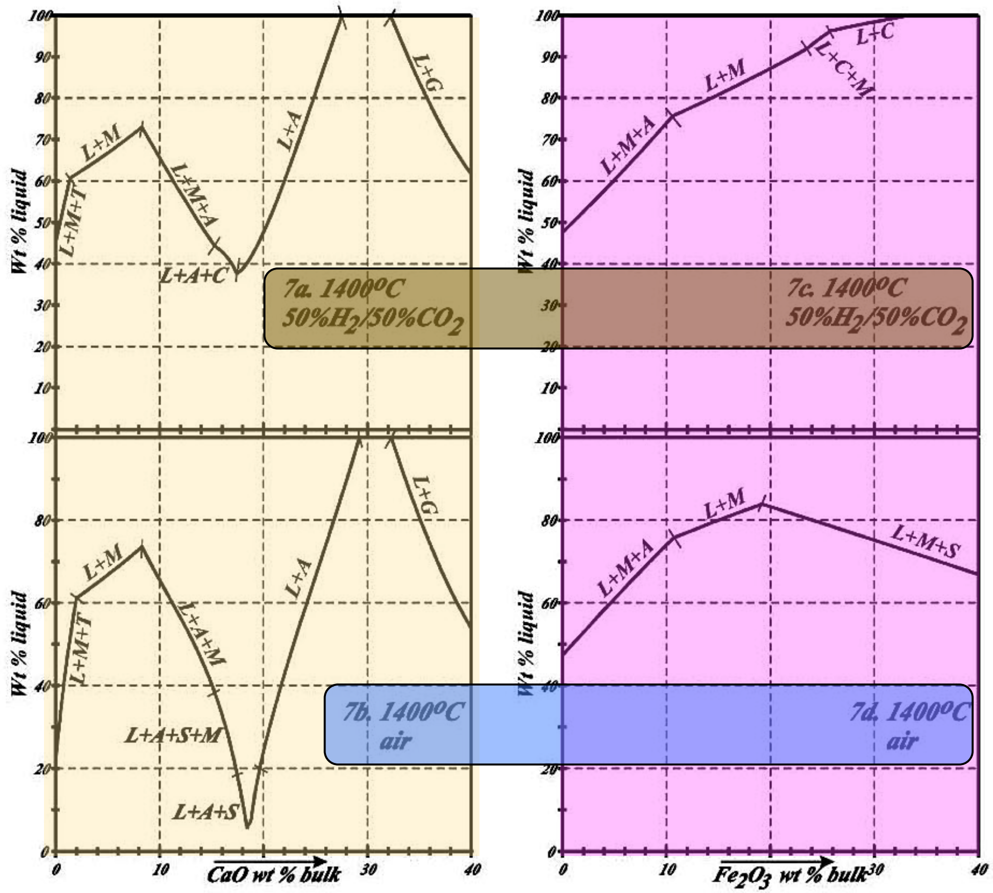
2 Parameter Model: CaO and SiO_2





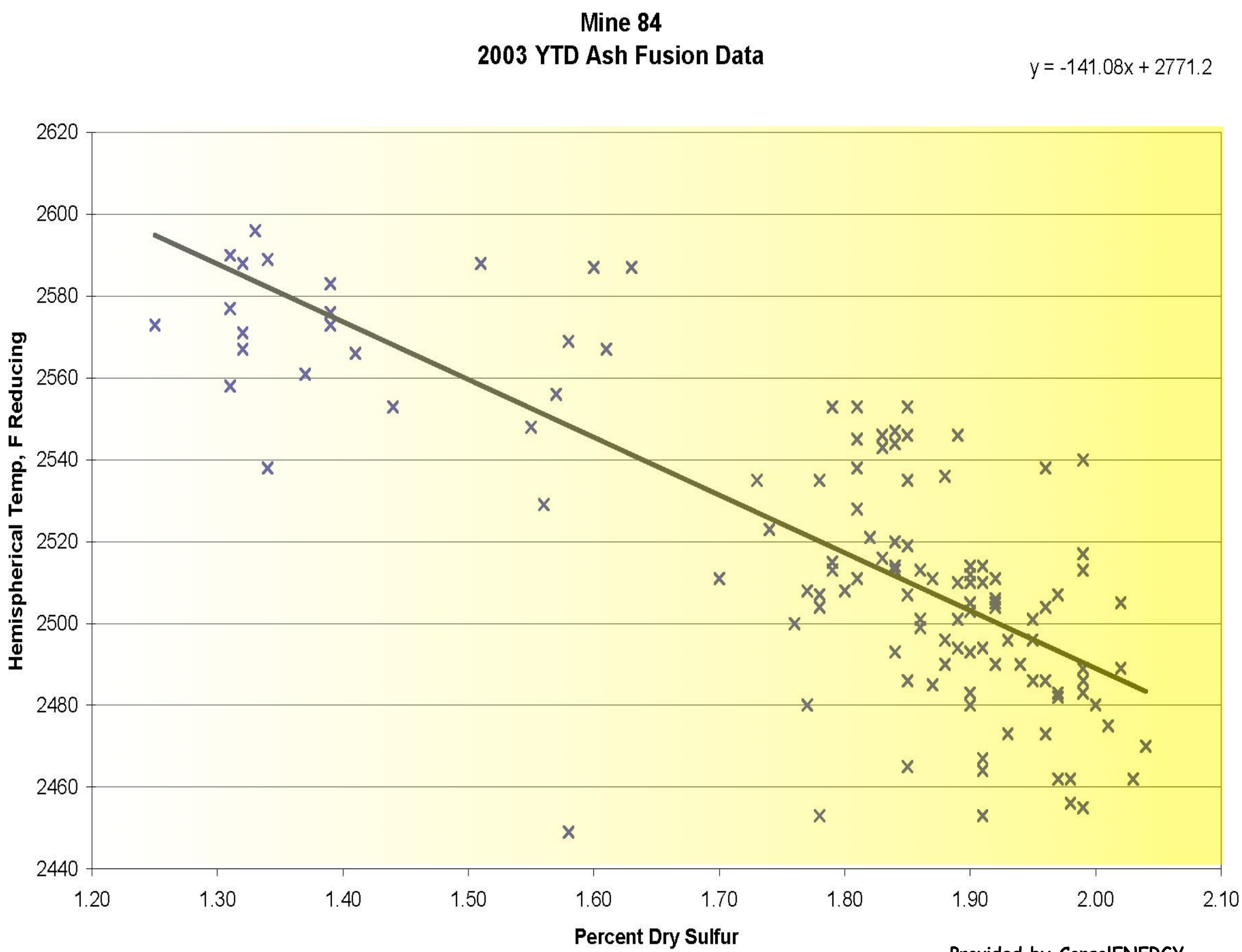
Proportions of Liquid @2552°F in Slag

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

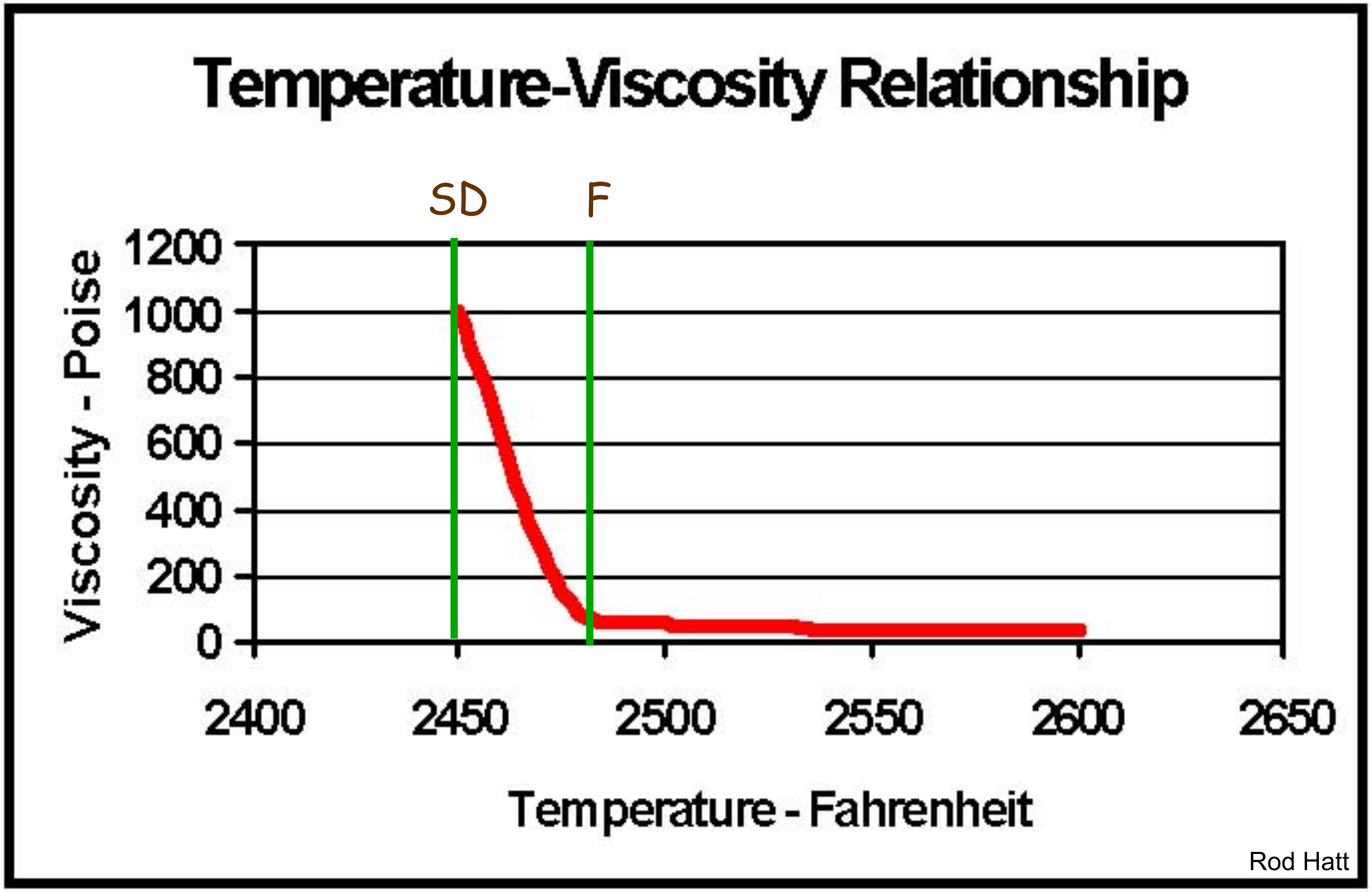


Proportions of liquid at 1400 °C for slags with weight ratios of $SiO_2/Al_2O_3 = 1.20$ and $(SiO_2 + Al_2O_3)/Fe_2O_3 = 9.0$ in 50% H_2/50% CO_2 gas (a) and in air (b) and $(SiO_2 + Al_2O_3)/CaO = 9.5$ in 50% H_2/50% CO_2 gas (c) and in air (d); phase names are: L: liquid, M: mullite, A: anorthite, G: gehlenite, S: spinel, C: corundum.

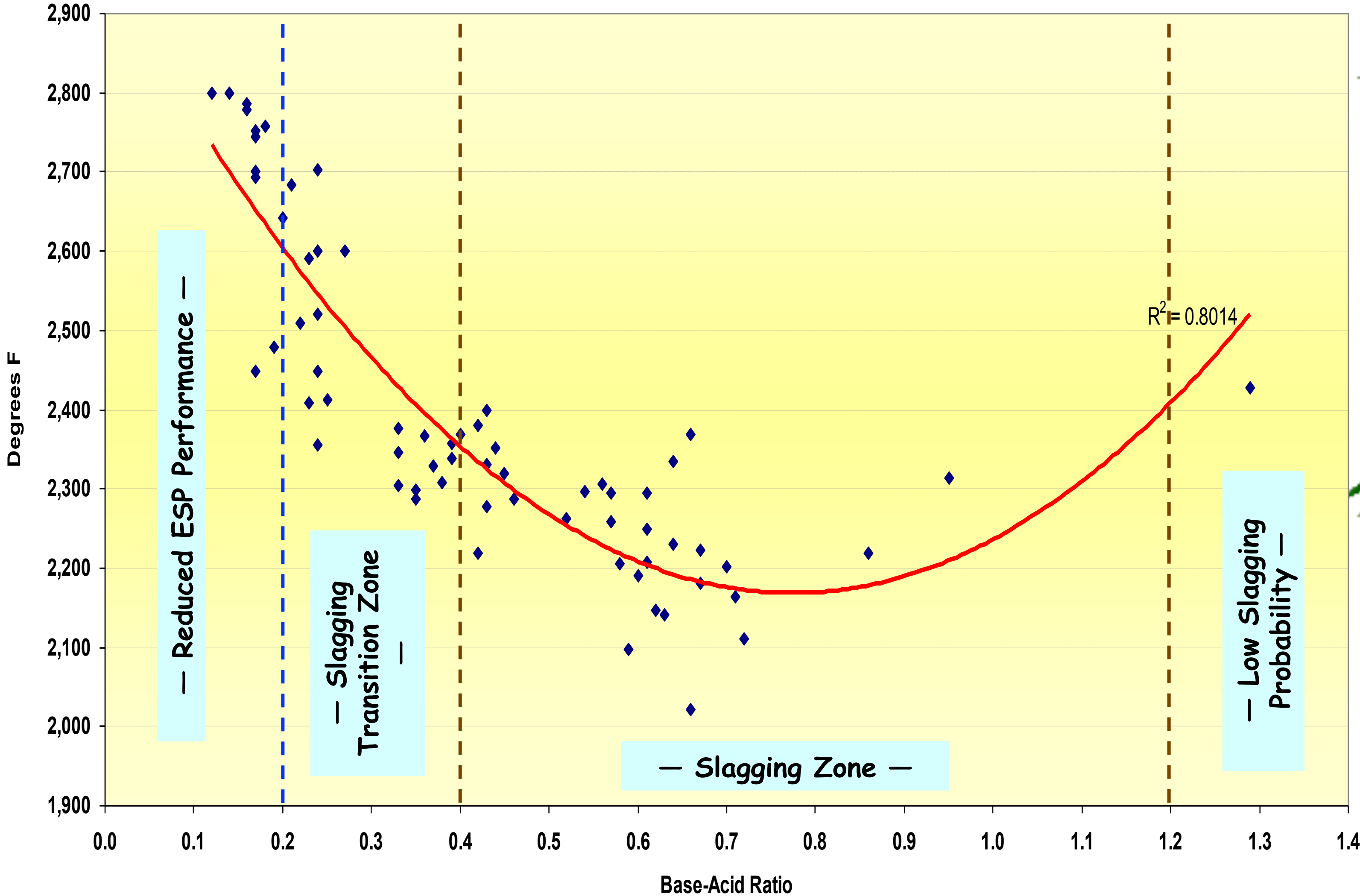
Sulfur vs. Ash Fusion Temperature



Provided by ConsolENERGY


Temperature-Viscosity Relationship
SD
F
1200
1000
800
600
400
200
0
Viscosity - Poise
2400
2450
2500
2550
2600
2650
Temperature - Fahrenheit
Rod Hatt

B:A vs. Fusion-Hemispherical



Such-a-Deal

- *What happened?*
  - High Fe reduced ash fusion temperature
- *Can it be fixed?*
  - Only by changing to a coal with lower Fe
- *Who bought lunch?*
  - Coal Buyer & Plant

Remember:

"There Ain't No Such Thing As A Free Lunch"

Coal Analysis Summary

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 (diff) (%) (+)	54.39	56.99	61.32
Sulfur (%)	2.05	2.14	
Heating Value (%)	13,376	14,010	**15,080**

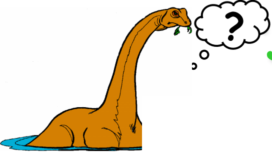
ADL (%)	2.30
Residual Moisure (%)	2.27
Equilbrium Moisture (%)	1.73
Surface Moisture (%)	2.84
Moisture Load (lbs/MBu)	3.38
Ash Load (lbs/MBu)	5.07
SO2 (lbs/MBu)	3.07
V/FC (fuel)	0.63
FC/V (combustion)	1.59

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 (diff) (%)	4.97	5.21	5.61

Hardgrove Grindability Index

HGI	50.8	@ 2.54% 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

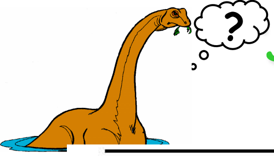
ASH FUSION - 8 point

	Reducing	Oxidizing
Initial (°F)	2,209	2,535
Spherical (°F)	2,280	2,575
Hemispherical (°F)	2,372	2,595
Fluid (°F)	2,460	2,665
Plastic Range (°F)	251	130
T250 (°F)	2,530	

ASH MINERAL (Dry Ash Basis)

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

% Acid	77.58%
% Base	22.42%
B/A	0.29
Ash Ratio	0.22
Ash Type	Bituminous
Slagging Index	0.56
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
ESP Index	74



Such-a-Deal I Have for You" Fuel Tutorial— 8 July 2013

- What is this
- Can we burn it?
- **You** probably burn too much of it?

03F005000

Sample Date:	01/30/2003		
Material Type Fuel:		**Sampling Method:**	Manual
Sample Type:	As-Requested	**Sampled By:**	Lupi
Unit:			

Moisture	*Procedure*	*Units*	*Value*		
Total Sample Size	ASTM D2013	grams	50.0		
Air-Dry Loss	ASTM D2013	%	0.00		
Residual	ASTM D3173	%	0.15		
Short Proximate			***As Received***	***Dry***	***MAF***
Total Moisture	ASTM D3302	%	0.15		
Ash	ASTM D3180	%	1.48	1.48	
Volatile	ASTM D3175	%	72.96	73.07	74.17
Fixed Carbon-A/R	ASTM D3175	%	25.41	25.45	25.83
Sulfur	ASTM D4239	%	0.17	0.17	
Calorific Value	ASTM D5865	Btu/lb	8,389	8,402	8,528
SO2 (fuel maximum)		lbs/MBtu	0.41		
Ash Load (fuel max)		lbs/MBtu	1.76		
V/FC Ratio			2.87		
Ultimate					
Carbon	ASTM D3176	%	47.61	47.69	
Hydrogen	ASTM D3176	%	6.63	6.64	
Nitrogen	ASTM D3176	%	2.86	2.86	
Oxygen	ASTM D3176	%	41.09	41.15	

Ash Mineral	*Units*	*Value*		*Units*	*Value*
Silcon Dioxide, SiO2	%	6.47	Acid	%	16.67
Alum Oxide, Al2O3	%	2.22	Base	%	83.33
Titanm Dioxide, TiO2	%	0.54	Base_Acid Ratio		5.00
			Ash Ratio		9.26
Iron Oxide, Fe2O3	%	1.85	Ash Type		Lignitic
Calcium Oxide, CaO	%	7.92	Silica Ratio		0.25
Magnesium Oxide, MgO	%	9.21	Silica Alumina Ratio		2.91
Potassium Oxide, K2O	%	0.54	Iron Calcium Ratio		0.23
Sodium Oxide, Na2O	%	26.62	Dolomite Percentage	%	20.56
			ESP Index		8.69
Mang Oxide, Mn3O4	%	0.18			
Sulfur Trioxide, SO3	%	2.08			
Phos Pentoxide, P2O5	%	43.40	Undetermined	%	-1.09
Barium Oxide, BaO	%	0.02			
Strontium Oxide, SrO	%	0.04			

Trace Elements	*Units*	*Value*		*Units*	*Value*		*Units*	*Value*
Sb, Antimony	ppm	0	Pb, Lead	ppm	0.1	Ag, Silver	ppm	0
As, Arsenic	ppm	0.1	Mn, Manganese	ppm	8.3	Tl, Thalium	ppm	0
Ba, Barium	ppm	1	Hg, Mercury	ppm	<0.02	V, Vanadium	ppm	1.3
Be, Beryllium	ppm	0.1	Mo, Molybdenum	ppm	0.37	Zn, Zinc	ppm	10
Cd, Cadmium	ppm	0.015	Ni, Nickel	ppm	0.6			
Cl, Chlorine	ppm	9893	Se, Selenium	ppm	1.1			
Cr, Chromium	ppm	2.4						
Co, Cobalt	ppm	0						
Cu, Copper	ppm	2.4						
F, Fluorine	ppm	<10						

Thank You!

Be Safe
&
Work Safely