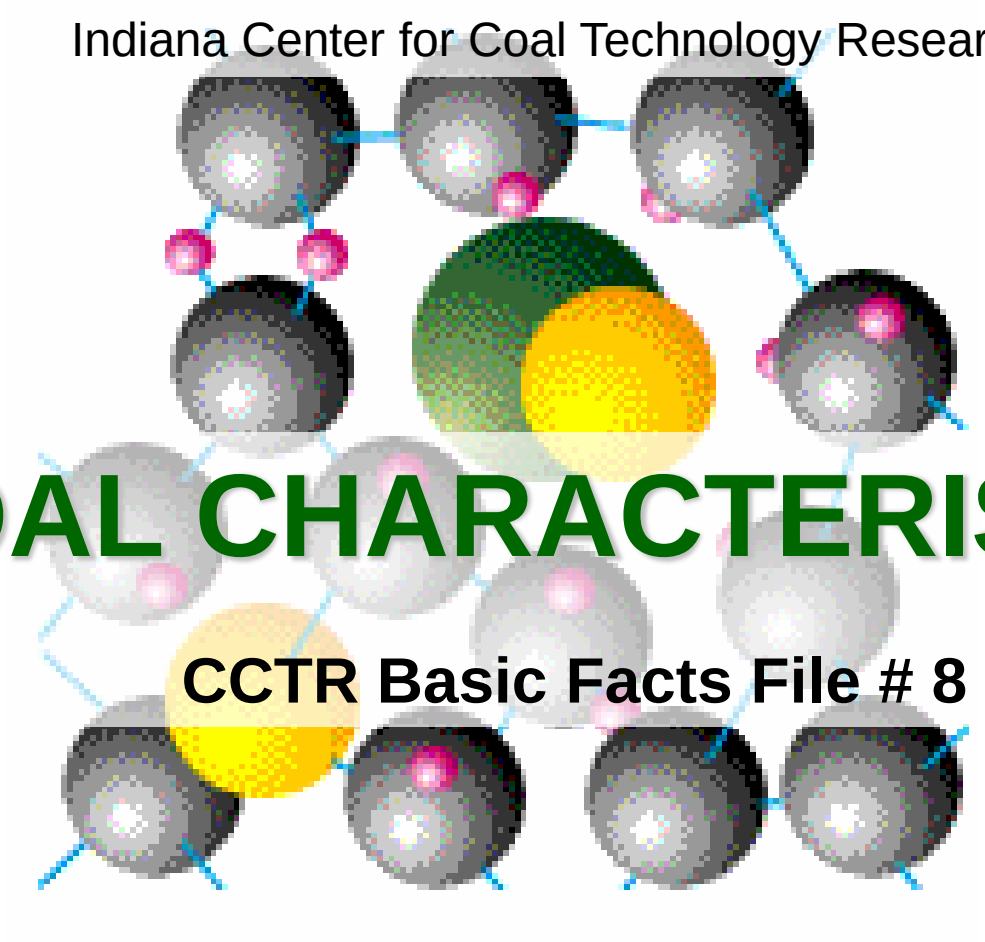
Indiana Center for Coal Technology Research



COAL CHARACTERISTICS

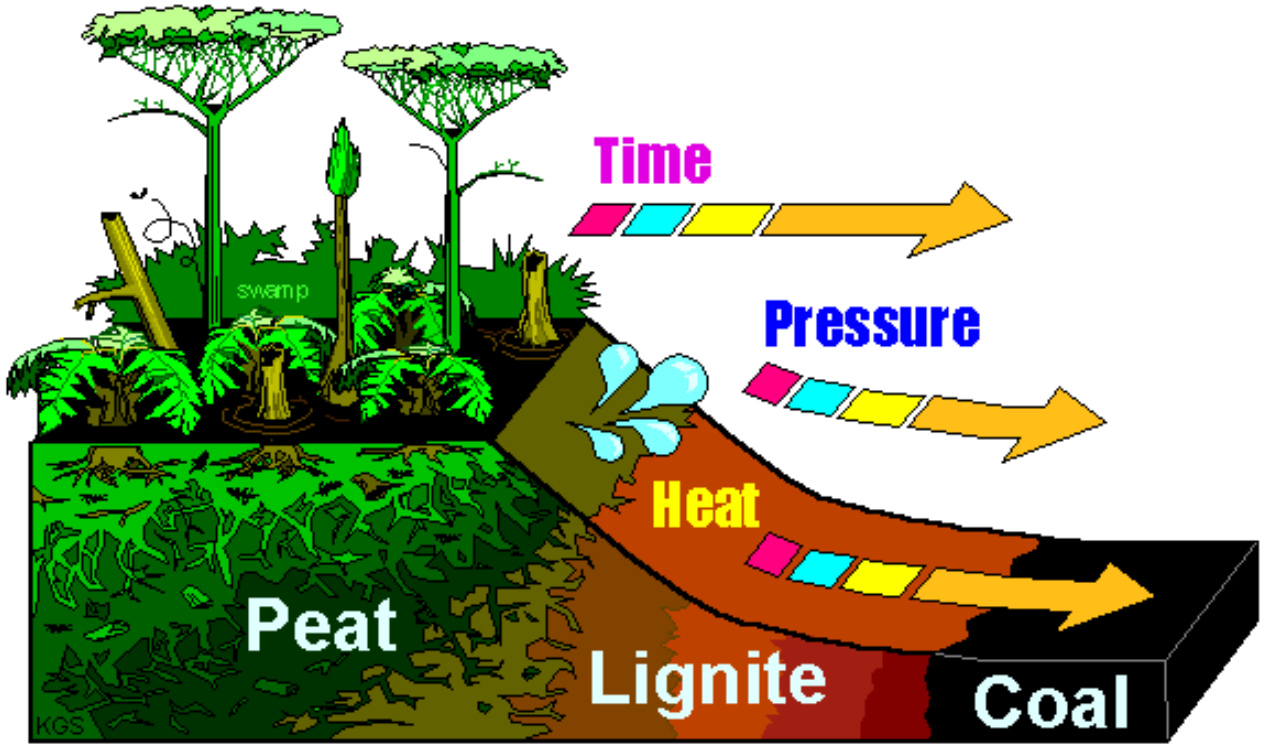
CCTR Basic Facts File # 8

Brian H. Bowen, Marty W. Irwin

The Energy Center at Discovery Park
Purdue University
CCTR, Potter Center, 500 Central Drive
West Lafayette, IN 47907-2022
http://www.purdue.edu/dp/energy/CCTR/
Email: cctr@ecn.purdue.edu

October 2008

COAL FORMATION



As geological processes apply pressure to peat over time, it is transformed successively into different types of coal

Source: Kentucky Geological Survey
http://images.google.com/imgres?imgurl=http://www.uky.edu/KGS/coal/images/peatcoal.gif&imgrefurl=http://www.uky.edu/KGS/coal/coalform.htm&h=354&w=579&sz=20&hl=en&start=5&um=1&tbnid=NavOy9_5HD07pM:&tbnh=82&tbnw=134&prev=/images%3Fq%3Dcoal%2Bphotos%26svnum%3D10%26um%3D1%26hl%3Den%26sa%3DX

COAL ANALYSIS

Elemental analysis of coal gives empirical formulas such as:

$C_{137}H_{97}O_9NS$ for Bituminous Coal

$C_{240}H_{90}O_4NS$ for high-grade Anthracite

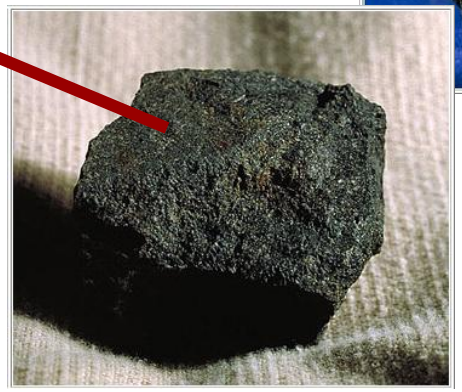
Coal is divided into 4 ranks:

(1) Anthracite

(2) Bituminous

(3) Sub-bituminous

(4) Lignite



Source: http://cc.msnscache.com/cache.aspx?q=4929705428518&lang=en-US&mkt=en-US&FORM=CVRE8

BITUMINOUS COAL

Bituminous Coal: Great pressure results in the creation of bituminous, or “soft” coal. This is the type most commonly used for electric power generation in the U.S. It has a higher heating value than either lignite or sub-bituminous, but less than that of anthracite. Bituminous coal is mined chiefly in the Midwest & Appalachia

http://images.google.com/imgres?imgurl=http://www.mii.org/Minerals/Minpics1/CoalBituminous.jpg&imgrefurl=http://www.mii.org/Minerals/photocoal.html&h=308&w=360&sz=38&hl=en&start=1&um=1&tbnid=ZKBL7apLynZMcM:&tbnh=104&tbnw=121&prev=/images%3Fq%3Dcoal%2Bphotos%26svnum%3D10%26um%3D1%26hl%3Den%26sa%3DX

ANTHRACITE COAL

Anthracite: Sometimes also called “hard coal,” anthracite forms from bituminous coal when great pressures developed in folded rock strata during the creation of mountain ranges. This occurs only in limited geographic areas – primarily the Appalachian region of Pennsylvania. Anthracite has the highest energy content of all coals & is used for making coke, a fuel used in steel foundry ovens

http://images.google.com/imgres?imgurl=http://www.mii.org/Minerals/Minpics1/CoalBituminous.jpg&imgrefurl=http://www.mii.org/Minerals/photocoal.html&h=308&w=360&sz=38&hl=en&start=1&um=1&tbnid=ZKBL7apLynZMcM:&tbnh=104&tbnw=121&prev=/images%3Fq%3Dcoal%2Bphotos%26svnum%3D10%26um%3D1%26hl%3Den%26sa%3DX

COAL RANK

Anthracite coal is a dense, hard rock with a jet-black color & metallic luster. It contains between **86% and 98% carbon** by weight, & it burns slowly, with a pale blue flame & very little smoke

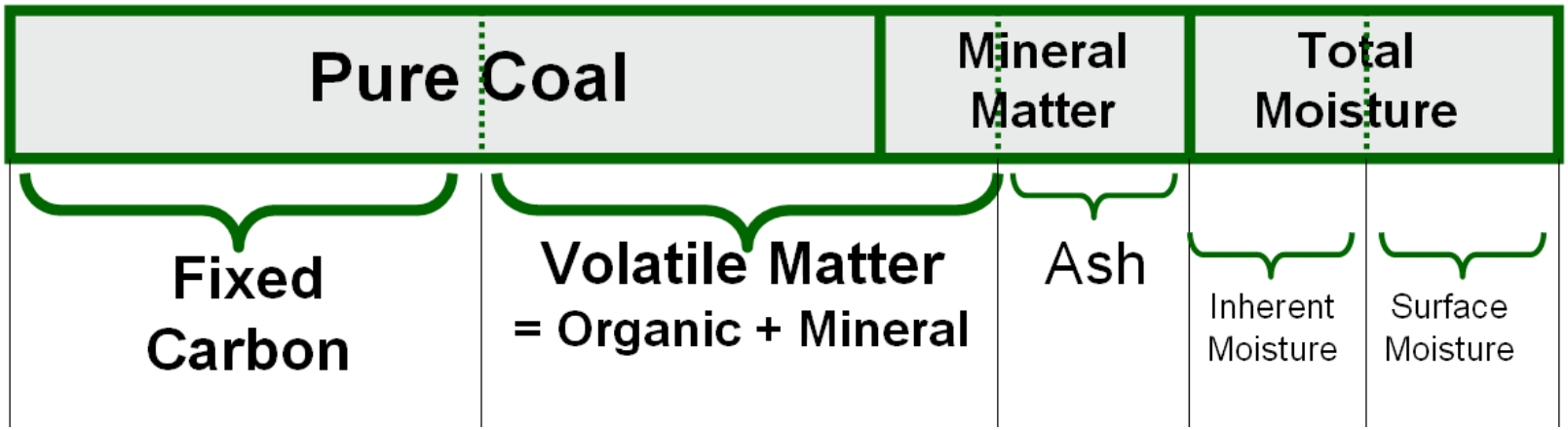
Bituminous coal (in **Indiana**), contains between **69% & 86% carbon** by weight

Sub-bituminous coal contains less carbon, more water & is a less efficient source of heat

Lignite coal, or brown coal, is a very soft coal that contains **up to 70% water** by weight. Emits more pollution than other coals

Source: http://cc.msnscache.com/cache.aspx?q=4929705428518&lang=en-US&mkt=en-US&FORM=CVRE8

COAL COMPONENTS



Volatile matter consists of aliphatic carbon atoms (linked in open chains) or aromatic hydrocarbons (one or more six-carbon rings characteristic of benzene series) and mineral matter

Ash consists of inorganic matter from the earth's crust:- limestone, iron, aluminum, clay, silica, and trace elements *(concentrations of less than 1000 ppm [<0.1% of a rock's composition] of zinc, copper, boron, lead, arsenic, cadmium, chromium, selenium)*

COAL PHYSICAL PARAMETERS

Each type of coal has a certain set of physical parameters which are mostly controlled by
(a) **moisture**
(b) **volatile content** (aliphatic or aromatic hydrocarbons) &
(c) **carbon content**

- **Aliphatic** - designating a group of organic chemical compounds (carbon compounds) in which the carbon atoms are linked in **open chains**

- **Aromatic** - containing one or more **six-carbon rings** characteristic of the benzene series

- **Hydrocarbons** - numerous organic compounds, such as benzene & methane, that **contain only carbon & hydrogen**

CARBON IN COAL

Carbon forms more than 50% by weight & more than 70% by volume of coal (this includes inherent moisture). This is dependent on coal *rank*, with **higher rank coals containing less hydrogen, oxygen & nitrogen,** until **95% purity of carbon** is achieved at **Anthracite** rank & above

Graphite formed from coal is the end-product of the thermal & diagenetic conversion (*process of chemical & physical change in deposited sediment during its conversion to rock*) of plant matter (50% by volume of water) into pure carbon

COAL VOLATILE MATTER

Volatile matter is material that is **driven off when coal is heated to 950°C (1,742°F)** in the absence of air under specified conditions - components of coal, except for moisture, which is liberated usually as a mixture of **short & long chain hydrocarbons**, aromatic hydrocarbons & some sulphur - measured practically by determining the loss of weight

Consists of a mixture of gases, **low-boiling-point organic compounds that condense into oils** upon cooling, **& tars.**

Volatile matter decreases as rank increases

http://www.britannica.com/eb/article-81704/coal-utilization

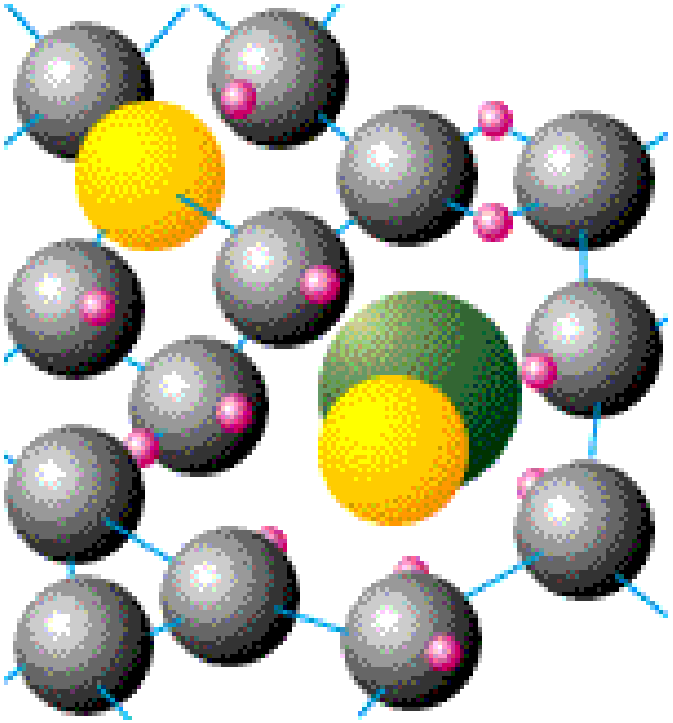
COAL VOLATILE MATTER

Class	Volatile matter[1)] (weight %)	General description	
101	< 6.1	Anthracites	
102	3.1 - 9.0		
201	9.1 - 13.5	Dry steam coals	Low volatile steam coals
202	13.6 - 15.0		
203	15.1 - 17.0	Cooking steams coals	
204	17.1 - 19.5		
206	19.1 - 19.5	Heat altered low volatile steam coals	
301	19.6 - 32.0	Prime cooking coals	Medium volatile coals
305	19.6 - 32.0	Mainly heat altered coals	
306	19.6 - 32.0		
401	32.1 - 36.0	Very strongly coking coals	High volatile coals
402	> 36.0		
501	32.1 - 36.0	Strongly coking coals	
502	> 36.0		
601	32.1 - 36.0	Medium coking coals	
602	> 36.0		
701	32.1	Weakly coking coals	
702	> 36.0		
801	32.1 - 36.0	Very weakly coking coals	
802	> 36.0		
901	32.1 - 36.0	Non-coking coals	
902	> 36.0		

http://www.engineeringtoolbox.com/classification-coal-d_164.html

SULFUR IN COAL

Although coal is primarily a mixture of **carbon (*black*)** & **hydrogen (*red*) atoms**, **sulfur atoms (*yellow*)** are also trapped in coal, **primarily in two forms**. In one form**, (1)** the sulfur is a separate particle often linked with iron (***green*, pyritic sulfur**) with no connection to the carbon atoms, as in the center of the drawing **(fools gold).** In the second form**, (2)** sulfur is chemically bound to the carbon atoms (**organic sulfur**), such as in the upper left



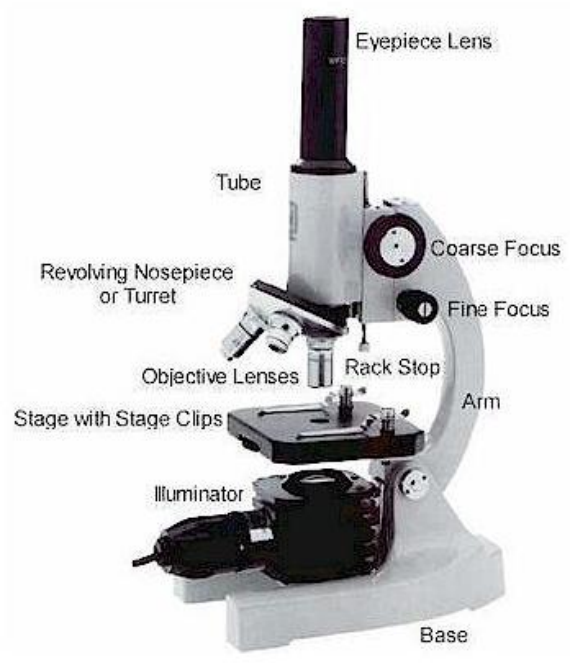
www.fossil.energy.gov/education/energylessons/coal/coal_cct2.html

COAL TYPICAL CONTENT

% weight	Anthracite	Bituminous	Sub-Bituminous	Lignite
Heat Content (Btu/lb)	13,000-15,000	11,000-15,000	8,500-13,000	4,000-8,300
Moisture	< 15%	2 - 15%	10 - 45%	30 - 60%
Fixed Carbon	85 - 98%	45 - 85%	35 - 45%	25 - 35%
Ash	10 - 20%	3 - 12%	≤ 10%	10 - 50%
Sulfur	0.6 - 0.8%	0.7 – 4.0%	< 2%	0.4 – 1.0%
Chlorine (ppm)	340 ± 40ppm	340 ± ppm	120 ± 20ppm	120 ± 20ppm

COAL TYPES

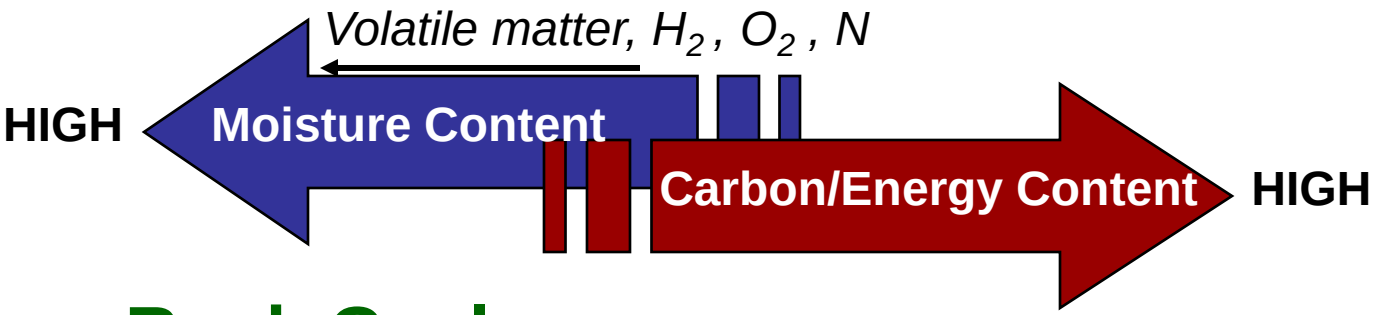
Geologists also classify coal types according to the **organic debris, called macerals**, from which the coal is formed. Macerals *(microscopic organic constituents found in coal)* are identified (*microscopically*) by reflected light - the reflective or translucent properties of the coal indicating the individual component macerals & **the way they have combined to form the coal**



The purpose of classifying coal in this way is to determine its best uses. **Mineral content is assessed** by burning coal & measuring the amount of incombustible material remaining, **referred to as the ash content of coal**

COAL RANK

The **degree of 'metamorphism' or coalification** undergone by a coal, as it **matures from peat to anthracite**, has an important bearing on its physical and chemical properties, & is referred to as **the 'rank' of the coal**



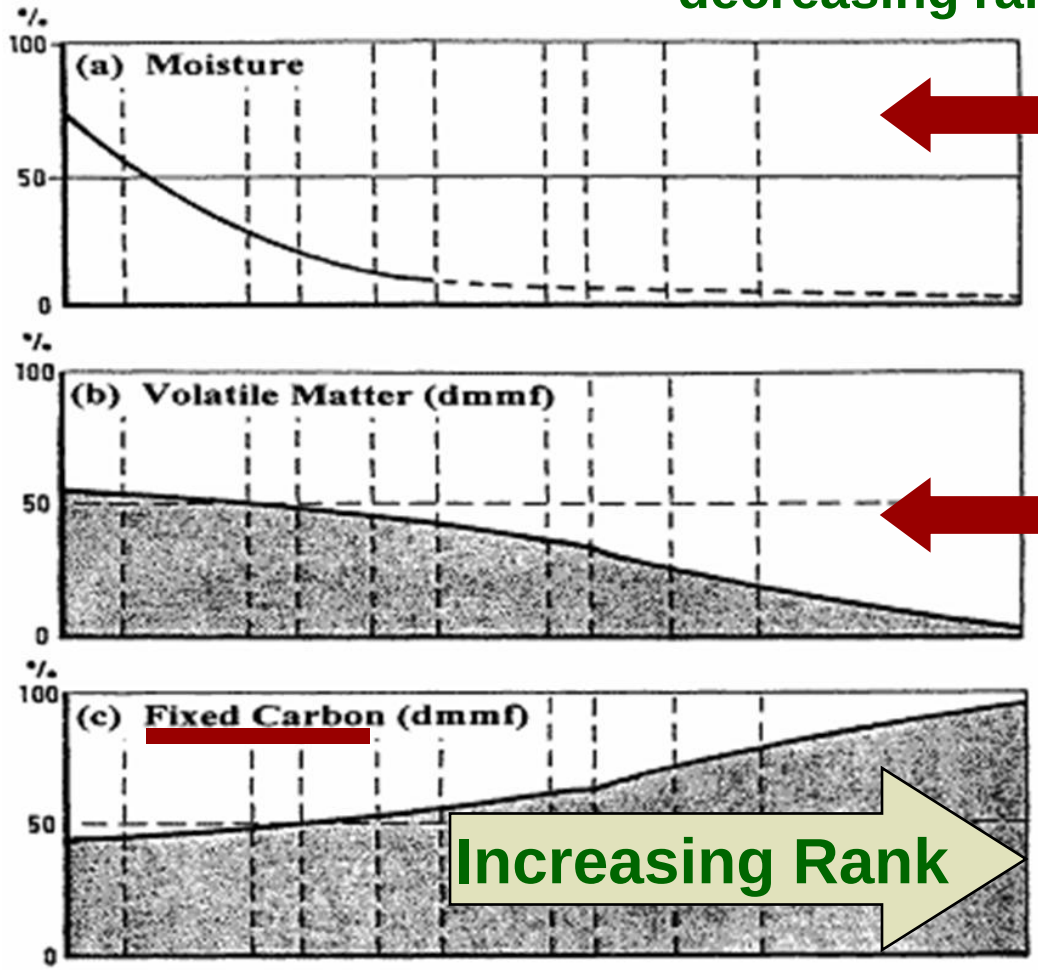
Low Rank Coal

High Rank Coal

http://www.australiancoal.com.au/classification.htm#types

COAL PARAMETER VARIATIONS WITH RANK

Generally the moisture content increases with decreasing rank & ranges from 1 to 40%



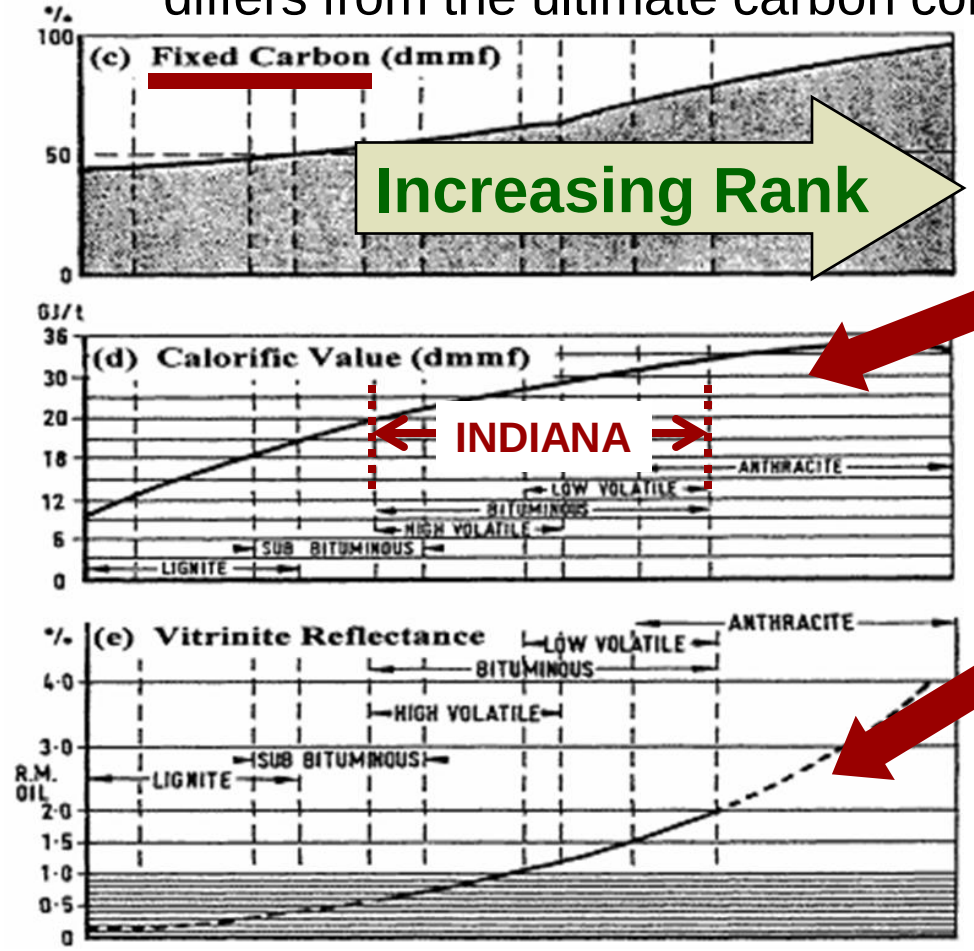
Moisture content is determined by heating an **air-dried coal sample at 105°–110° C (221°–230° F)** under specified conditions until a constant weight is obtained

Volatile matter is material that is driven off when coal is **heated to 950° C (1,742° F)** in the **absence of air** under specified conditions. It is measured practically by determining the loss of weight

Source: American Iron and Steel Institute, http://www.steel.org/learning/howmade/coal.htm

COAL PARAMETER VARIATIONS WITH RANK

The **fixed carbon** content of the coal is the carbon **found in the material which is left after volatile materials are driven off**. This differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles



Calorific value, measured in Btu is the amount of chemical energy stored in a coal that is released as thermal energy upon combustion. **It is directly related to rank**

Vitrinite is a type of maceral. Vitrinite reflectance can be used as an **indicator of maturity** in hydrocarbon source rocks

Source: American Iron and Steel Institute, http://www.steel.org/learning/howmade/coal.htm

COAL SIZES

COARSE COAL **>25.0mm** (≈1 inch)

SMALL COAL **25.0-3.0mm**

FINE COAL **< 3.00mm** (0.12 inch)

ULTRA FINE COAL **< 0.15mm** (0.006 inch)

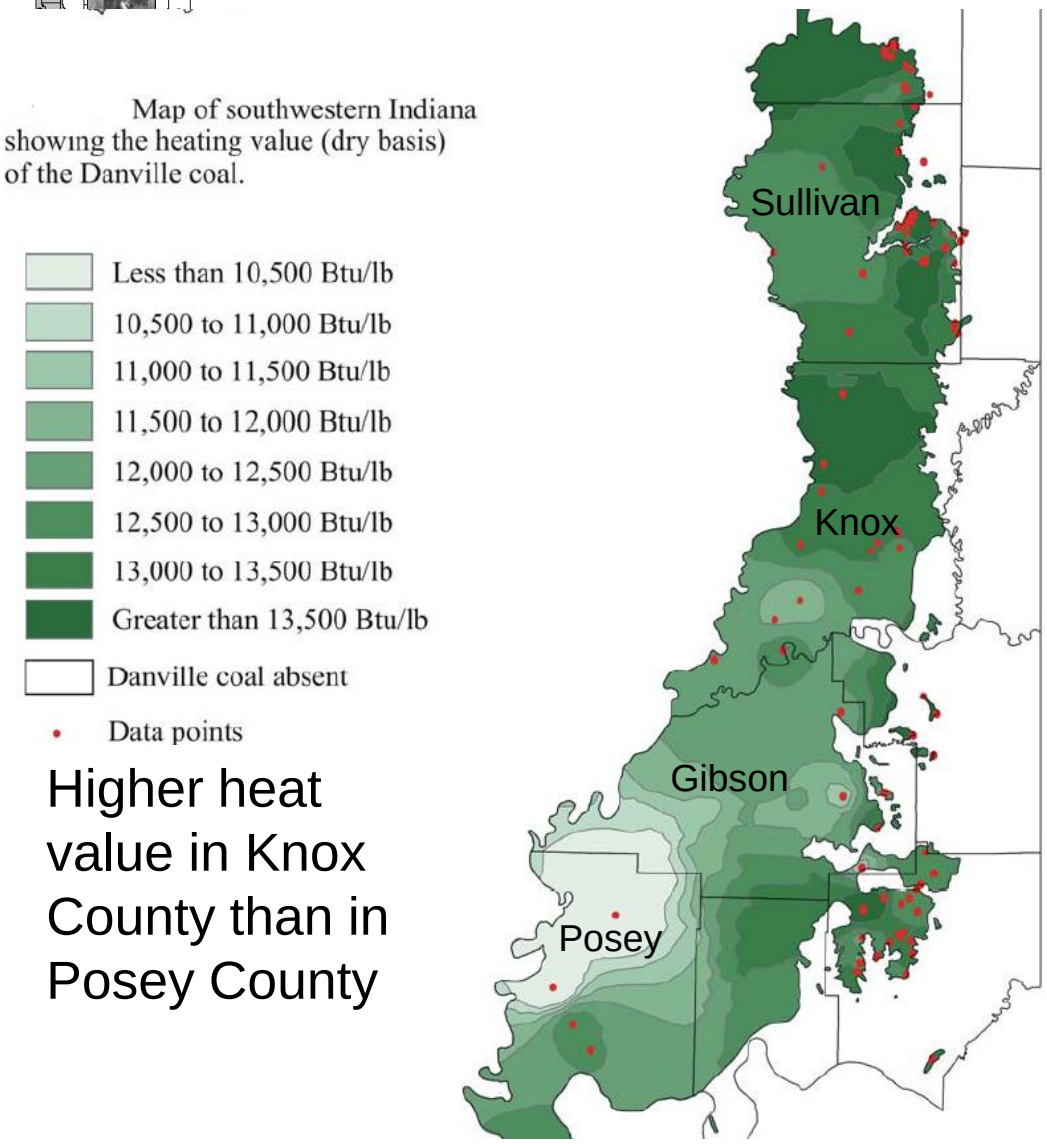
Standard Screen Sizes					
U.S. Standard Sieve			W.S. Tyler Sieve		
Mesh	Inches	Millimeters	Mesh	Inches	Millimeters
20	0.033	0.84	20	0.033	0.83
30	0.023	0.59	28	0.023	0.59
40	0.0165	0.42	35	0.016	0.42
50	0.0117	0.30	48	0.0116	0.30
60	0.0098	0.25	60	0.0097	0.25
100	**0.0058**	**0.149**	**100**	**0.0058**	**0.15**
140	0.0041	0.105	150	0.0041	0.10
200	0.0029	0.074	200	0.0029	0.074
325	0.0017	0.044	325	0.0017	0.043

ASTM-E1 lists typical screen sizes as 80, 100, 120, 140, 170, 200, 230, 270, 325, 400.

Source: *http://www.barringer1.com/dec00prb.htm*

HEATING VALUE (Btu/lb dry) OF THE INDIANA DANVILLE COAL

Map of southwestern Indiana showing the heating value (dry basis) of the Danville coal.



Higher heat value in Knox County than in Posey County

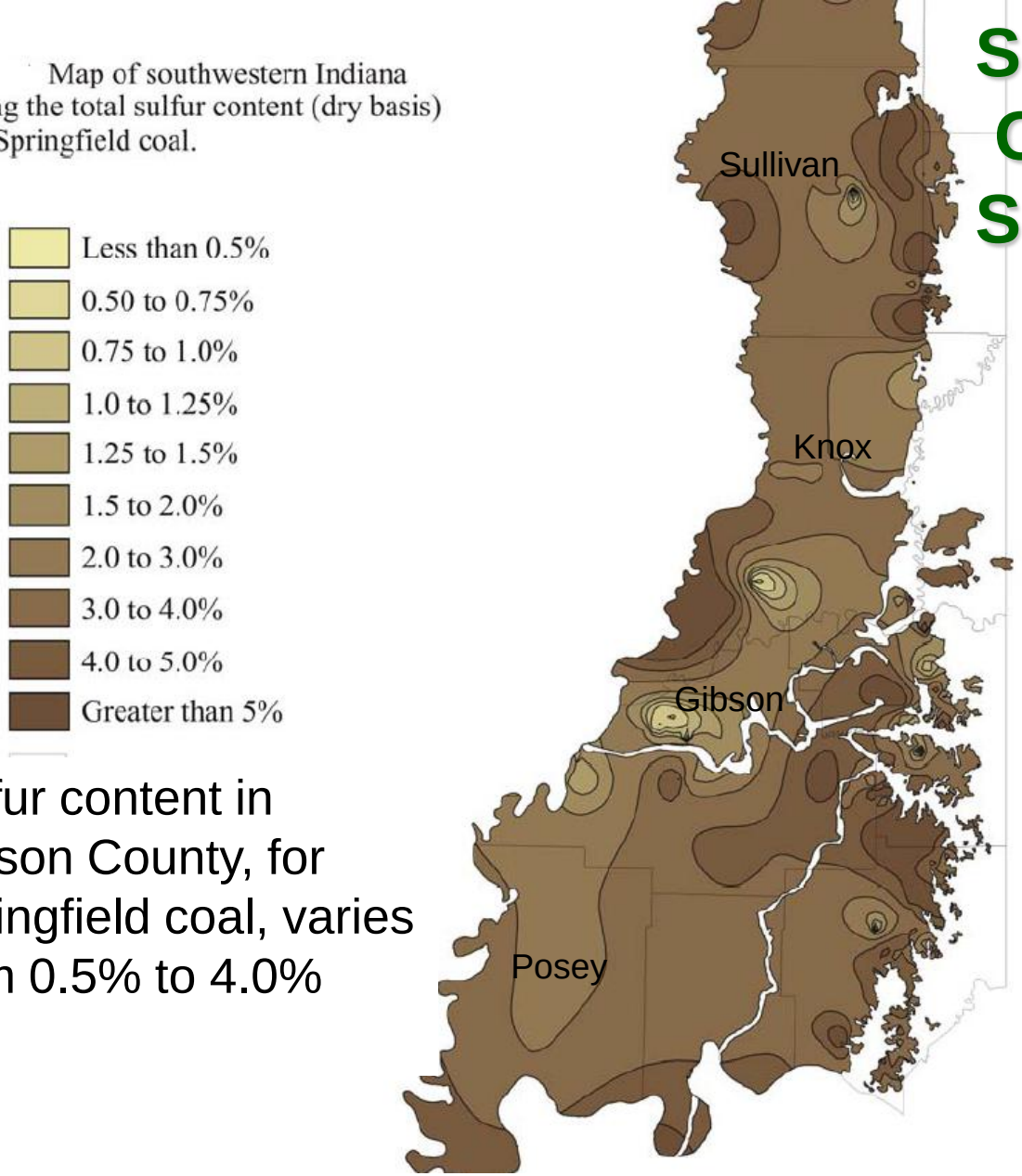
The heating value shows the amount of energy that is in the coal & is **the most important coal parameter** for economic benefits & highest engineering efficiencies

Higher heat value in Knox County than in Posey. **Indiana & Midwest coals have high energy values**

Source: M. Mastalerz, A Drobniak, J. Rupp and N. Shaffer, "Assessment of the Quality of Indiana coal for Integrated Gasification Combined Cycle Performance (IGCC)', Indiana Geological Survey, Indiana University, June 2005

SULFUR VALUE OF THE INDIANA SPRINGFIELD COAL

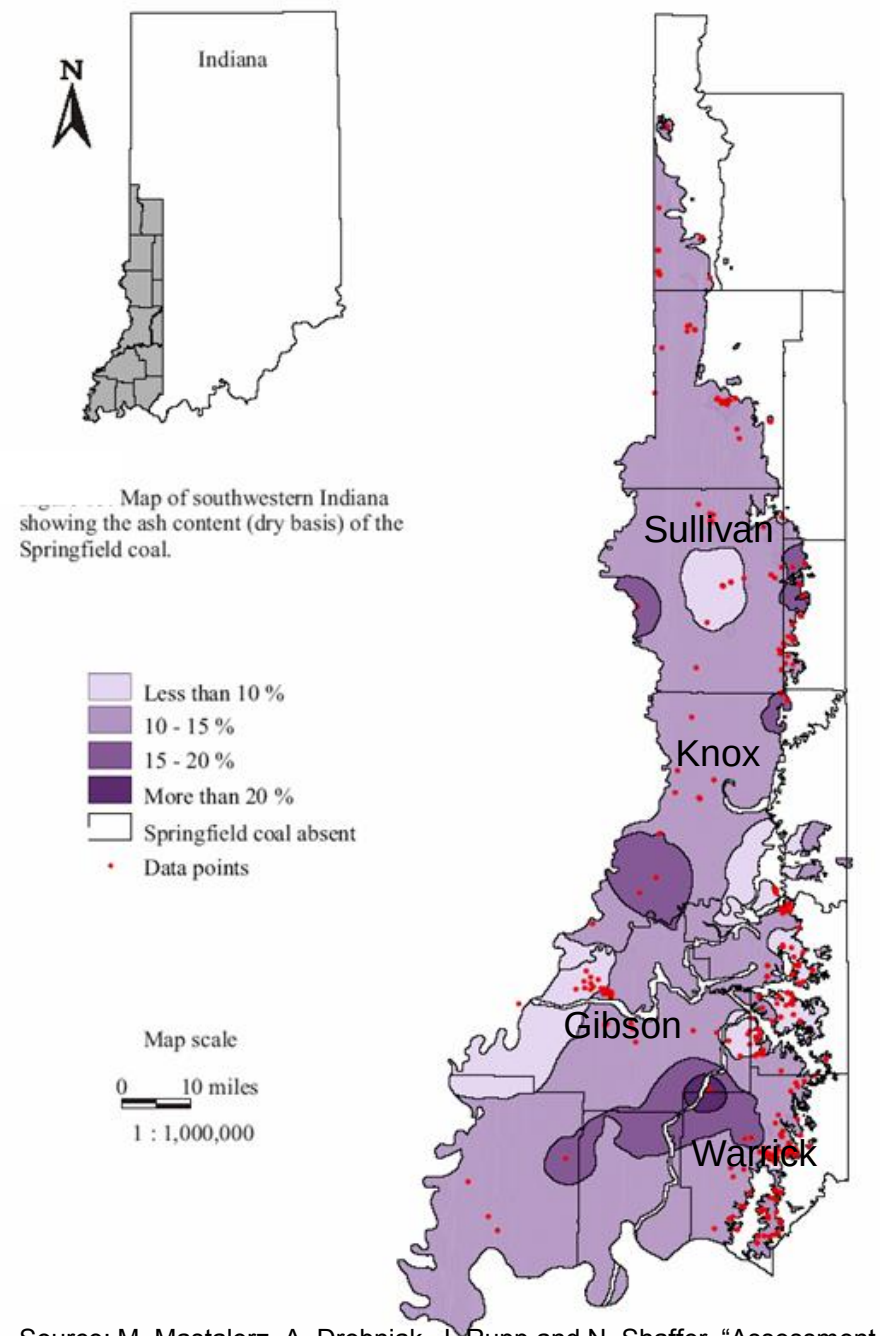
Map of southwestern Indiana showing the total sulfur content (dry basis) of the Springfield coal.



Sulfur content in Gibson County, for Springfield coal, varies from 0.5% to 4.0%

Source: M. Mastalerz, A Drobniak, J. Rupp and N. Shaffer, “Assessment of the Quality of Indiana coal for Integrated Gasification Combined Cycle Performance (IGCC)’, Indiana Geological Survey, Indiana University, June 2005

ASH YIELD (Weight %, dry) OF THE INDIANA SPRINGFIELD COAL



Midwest coals have ash yields of **3.3% to 11.7%** & average values for **Indiana are about 9.4%**

Source: M. Mastalerz, A. Drobniak, J. Rupp and N. Shaffer, "Assessment of the Quality of Indiana coal for Integrated Gasification Combined Cycle Performance (IGCC)', Indiana Geological Survey, Indiana University, June 2005

INDIANA & POWDER RIVER BASIN COAL

	Indiana coal	PRB coal
Moisture	**10 -12%**	~ 28%
Volatile matter	~ **40%**	higher
Heating value	**11,386 Btu/lb**	Btu/lb 8,088
Ash content	**9.4%**	7.6%
AFT (flow, Reduction)	Need more data	?
Slag viscosity ~1400°C	Need more data	?
Char reactivity	Very few data Less reactive (higher T needed?)	More reactive because of more volatiles?
Sulfur	**3.13%**	0.72%
Chlorine	**0.05%**	0.01%

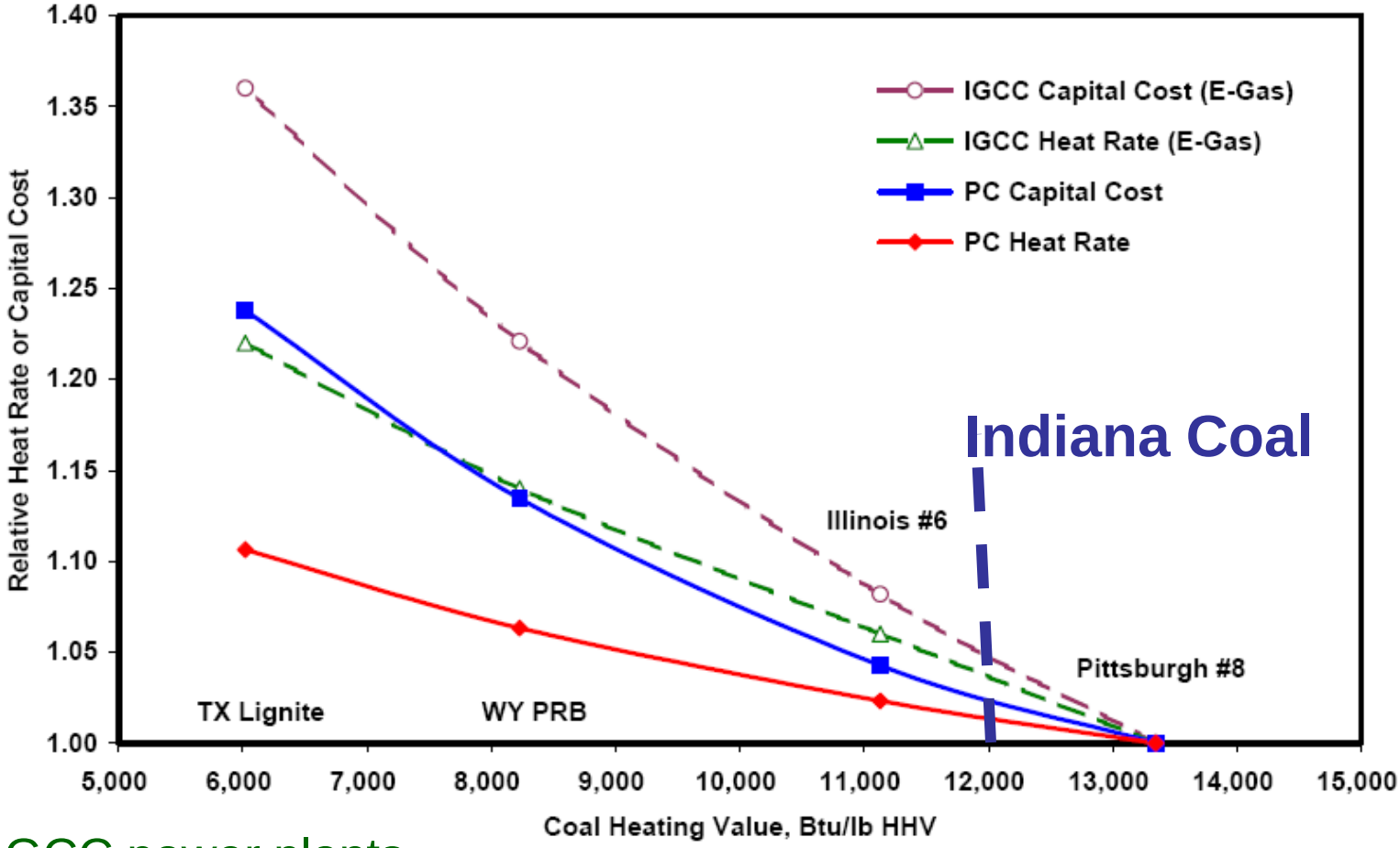
Source: M. Mastalerz, A. Drobniak, J. Rupp and N. Shaffer, "Assessment of the Quality of Indiana coal for Integrated Gasification Combined Cycle Performance (IGCC)', Indiana Geological Survey, Indiana University, June 2005

INDIANA COAL BED CHARACTERISTICS

	DANVILLE				HYMERA				SPRINGFIELD				SEELYVILLE				LOWER BLOCK			
	Min.	Max.	Ave	n	Min.	Max.	Ave	n	Min.	Max.	Ave	n	Min.	Max.	Ave	n	Min.	Max.	Ave	n
M [ar]	1.9	28.2	11.3	253	0.8	23.5	10.3	134	0.5	34.7	9.9	654	0.8	29.2	9.9	81	0.7	27.1	13.8	139
A [dry]	4.9	41.1	13.0	255	6.8	72.7	14.5	135	4.9	54.2	12.2	663	6.7	35.6	14.9	88	4.1	31.0	9.0	148
S [tot, dry]	0.33	7.62	2.65	163	1.20	5.34	3.10	36	0.30	12.19	3.27	443	2.50	9.84	5.02	28	0.55	7.0	1.36	111
Btu [dry]	7651	17314	13050	253	2520	13734	12042	134	8362	20648	13214	663	8494	13810	12149	83	9677	14702	13267	147
FC [dry]	32.0	58.2	48.4	131	11.7	54.0	46.7	110	29.0	70.7	48.0	308	19.0	61.1	44.4	73	35.5	59.5	52.6	93
VM [dry]	26.9	46.1	39.1	131	15.6	45.8	38.5	110	19.9	62.0	40.9	308	31.2	65.4	41.4	73	33.5	47.5	38.5	94
Slag viscosity temp. (°F)	2156	2900	2559	30	2150	2900	2421	15	2150	2720	2345	41	2150	2630	2273	9	2150	2900	2649	38
Cl [%]	0.01	0.10	0.03	25	0.02	0.07	0.04	23	0.01	0.24	0.15	31	0.08	0.17	0.11	3	0.01	0.06	0.02	42
SiO_2 [%]	31.0	60.0	48.3	34	17.00	55.00	39.13	20	21.0	53.0	38.6	48	19.0	45.0	31.0	14	0.4	61.7	47.2	39
Al_2O_3 [%]	14.0	26.0	20.9	34	9.10	28.40	18.00	20	9.2	28.0	18.2	48	8.5	25.0	17.2	14	16.4	34.0	25.3	39
Fe_2O_3 [%]	3.5	37.0	16.3	34	4.60	41.00	22.95	20	6.5	49.0	23.3	48	9.2	55.0	35.8	14	3.3	47.2	15.1	39
CaO [%]	0.5	10.0	2.9	34	0.43	27.00	4.80	20	0.3	16.0	4.3	48	0.5	8.2	3.1	14	0.5	7.1	1.9	39
MgO [%]	0.6	1.7	1.2	34	0.37	1.50	0.85	20	0.3	1.4	0.8	48	0.4	0.9	0.5	14	0.3	1.0	0.6	39
SiO_2/ Al_2O_3	1.75	2.73	2.31	34	1.60	2.93	2.22	20	1.46	2.59	2.16	48	1.44	2.42	1.85	14	0.02	2.52	1.89	39
Fe_2O_3+ CaO	4.01	38.50	19.26	34	5.12	42.00	27.75	20	7.60	53.80	27.42	48	10.4	58.0	38.84	14	4.80	47.66	16.51	39
Silica ratio*	0.44	0.92	0.71	34	0.28	0.90	0.58	20	0.30	0.86	0.58	48	0.25	0.80	0.45	14	0.02	0.92	0.73	39
AFTR INIT	2095	2540	2275	12	-	-	-	-	2095	2103	2099	2	-	-	2185	1	1970	2800	2430	28
AFTR SOFT	2155	2610	2375	12	-	-	-	-	2131	2151	2141	2	-	-	2275	1	2040	2800	2477	28
AFTR HEM	2210	2665	2436	12	-	-	-	-	2181	2187	2184	2	-	-	2353	1	2080	2800	2525	28
AFTR FINAL	2250	2735	2502	12	-	-	-	-	2208	2232	2220	2	-	-	2425	1	2170	2800	2558	26
AFTO INIT	2340	2705	2535	12	-	-	-	-	-	-	2528	1	-	-	2668	1	2425	2740	2578	9
AFTO SOFT	2370	2730	2570	12	-	-	-	-	-	-	2576	1	-	-	2701	1	2470	2765	2589	7
AFTO HEM	2395	2765	2594	12	-	-	-	-	-	-	2596	1	-	-	2716	1	2495	2780	2608	7
AFTO FINAL	2415	2795	2626	12	-	-	-	-	-	-	2611	1	-	-	2728	1	2540	2800	2638	7

Source: M. Mastalerz, A. Drobniak, J. Rupp and N. Shaffer, Indiana Geological Survey, Indiana University, 2008

EFFECT OF COAL QUALITY ON HEAT RATE & CAPITAL COST



PC & IGCC power plants

PC = Pulverized Coal, IGCC = Integrated Gasification Combined Cycle

Source: "Economic Analysis of New Coal Fired Generation Options", George S. Booras et al, EPRI, Palo Alto, 2004

PURDUE WADE PLANT

	%	%	Btu/lb	Btu/lb	%	lbs
	Moisture	Ash As Rec	As Rec	Dry basis	Sulfur As Rec	Sulfur per MBtu
Stoker	15.74	7.96	11,146	13,224	1.02	1.77
CFB	14.73	10.27	10,870	12,733	2.38	4.27

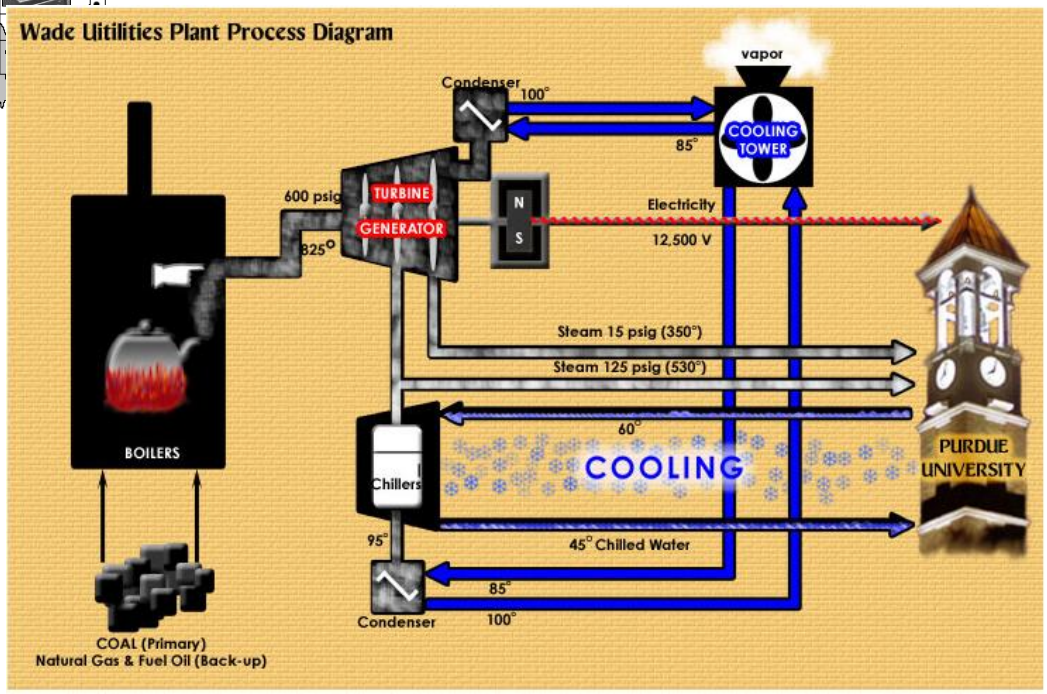
	°F		UG/G	UG/G	UG/G
	Fusion Temp	Grind Index	Mercury	D4208 Chlorine	D6721 Chlorine
Stoker	2490	57	0.05	204	128
CFB	-	59	0.09	121	-

CFB = Circulating Fluidized Bed boiler technology - environmentally acceptable technology – burns wide range of solid fuels to generate steam & electricity power ranging from 5 MW to 250 MW

Stoker = Stoker Boiler Systems - used on small boilers for over a century. They use a lump coal feed

*(**UG/G** = micro grams per gram)*

PURDUE WADE PLANT



Generation
Approx 40 MW
with **3 generators**
29 MW turbine generator
10 MW turbine generator
1.7 MW diesel generator

& **9 centrifugal chillers**

Indiana coal is the prime fuel source for the Wade Plant. During fiscal year 2005-06, Wade consumed 48,130 Ton of high-sulfur coal, 118,509 Ton of low-sulfur coal, 10,838 Ton of limestone, and 466,935 Therms of natural gas for an average fossil fuels delivered cost of approximately $2.452/MBtu

http://www.purdue.edu/utilityplant/plantoperation.htm

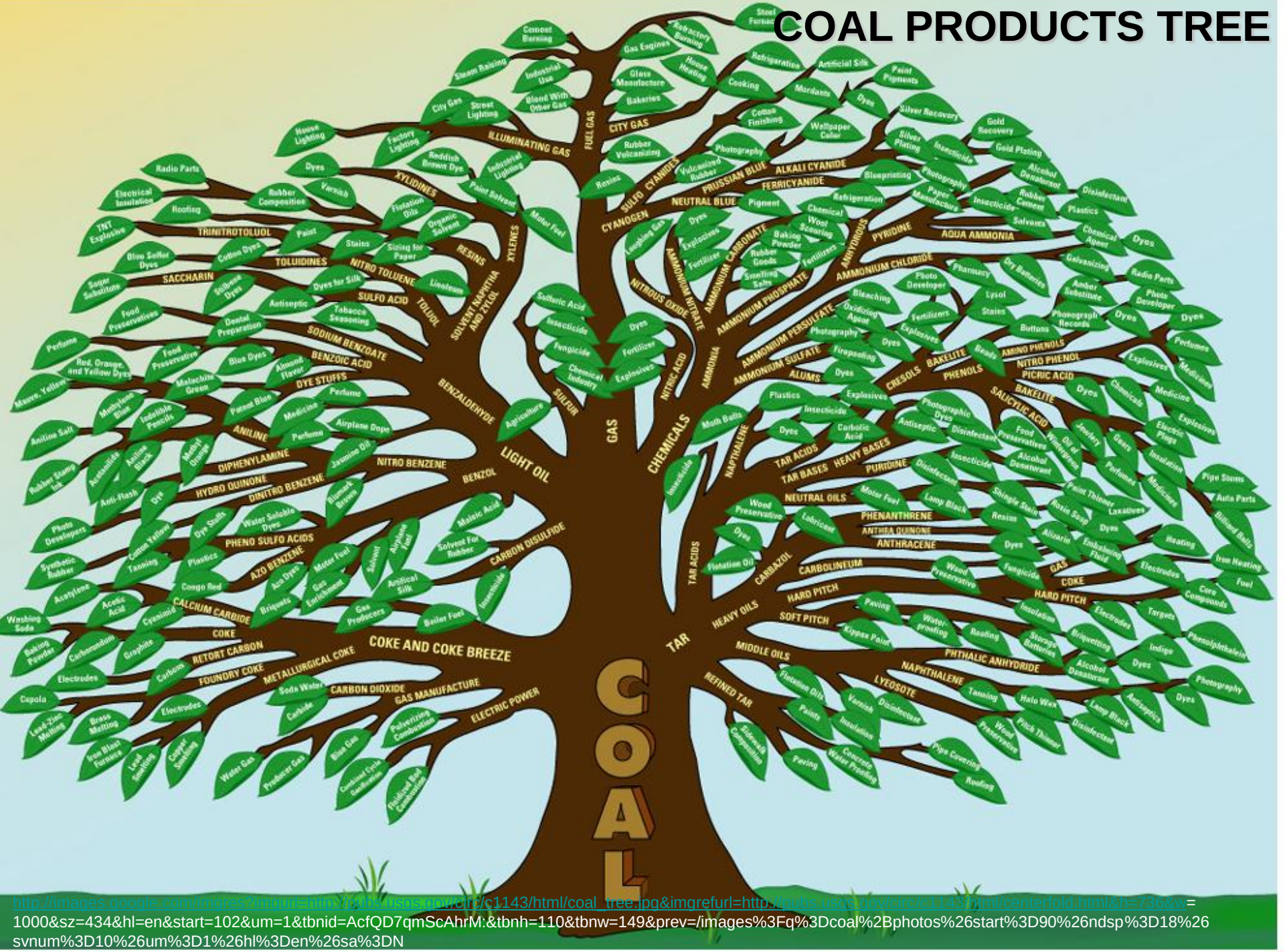
COKE & PETCOKE

Coke is a solid carbonaceous residue derived from **low-ash, low-sulfur bituminous coal** from which the volatile constituents are driven off by baking in an oven without oxygen at temperatures as high as 1,000 °C (1,832 °F) so that the fixed carbon & residual ash are fused together. Coke is used as a fuel & as a reducing agent in smelting iron ore in a blast furnace. Coke from coal is grey, hard, & porous & has a heating value of 24.8 MBtu/ton (29.6 MJ/kg). Byproducts of this conversion of coal to coke include coal tar, ammonia, light oils, and "coal-gas"

Petroleum coke is the solid residue obtained in oil refining, which resembles coke but contains too many impurities to be useful in metallurgical applications

http://en.wikipedia.org/wiki/Coal

COAL PRODUCTS TREE



http://images.google.com/imgres?imgurl=http://tbis.usgs.gov/cir/c1143/html/coal_tree.jpg&imgrefurl=http://pubs.usgs.gov/circ/c1143/html/centerfold.html&h=736&w=1000&sz=434&hl=en&start=102&um=1&tbnid=AcfQD7qmScAhrM:&tbnh=110&tbnw=149&prev=/images%3Fq%3Dcoal%2Bphotos%26start%3D90%26ndsp%3D18%26svnum%3D10%26um%3D1%26hl%3Den%26sa%3DN