Fossil Fuel Formation and Coal Preparation

Presented to the Foreign Service Officers' Coal and Power Training Course
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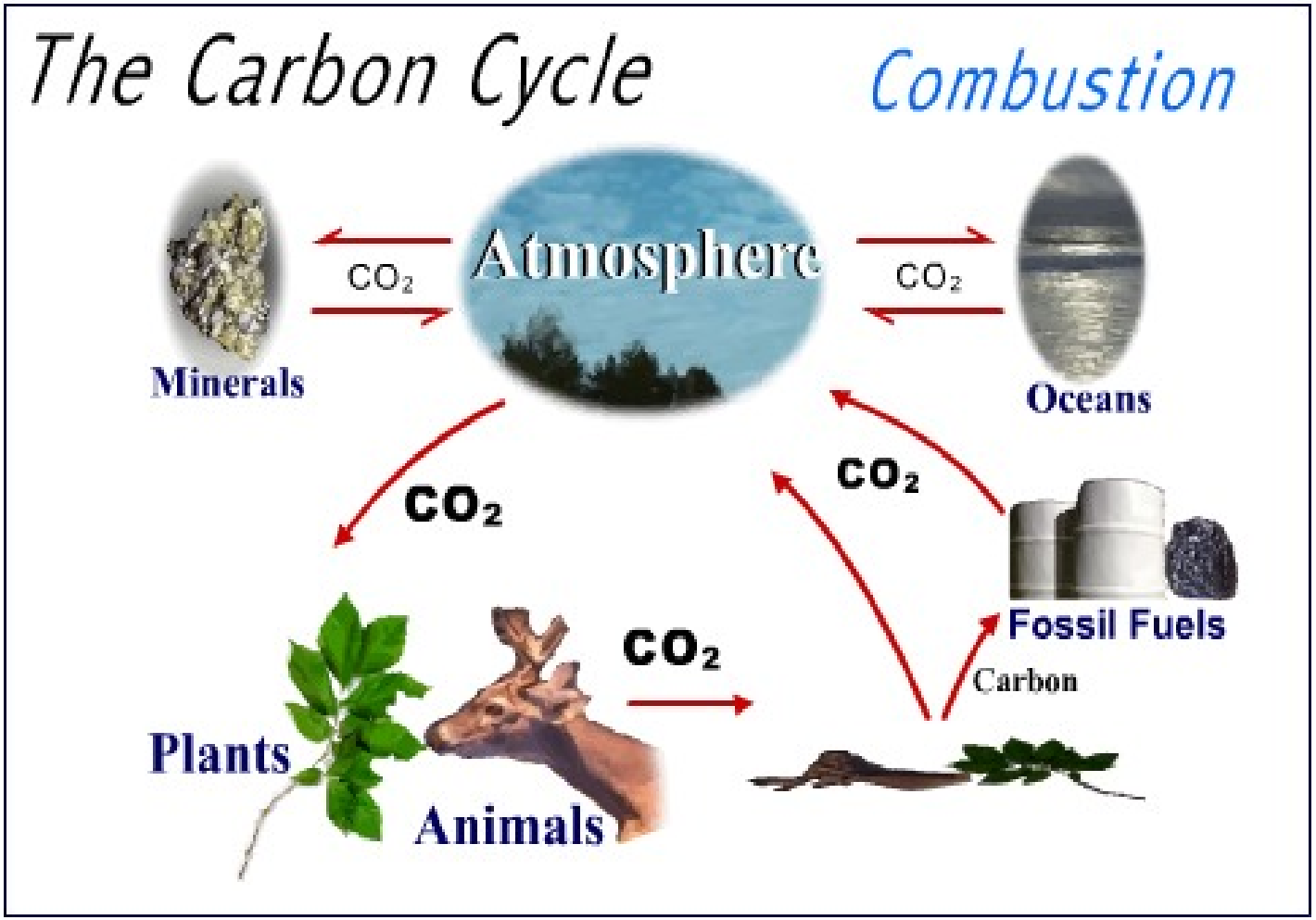
JOHN AND WILLIE LEONE FAMILY DEPARTMENT OF
ENERGY AND MINERAL ENGINEERING
COLLEGE OF EARTH AND MINERAL SCIENCES

The Global Carbon Cycle

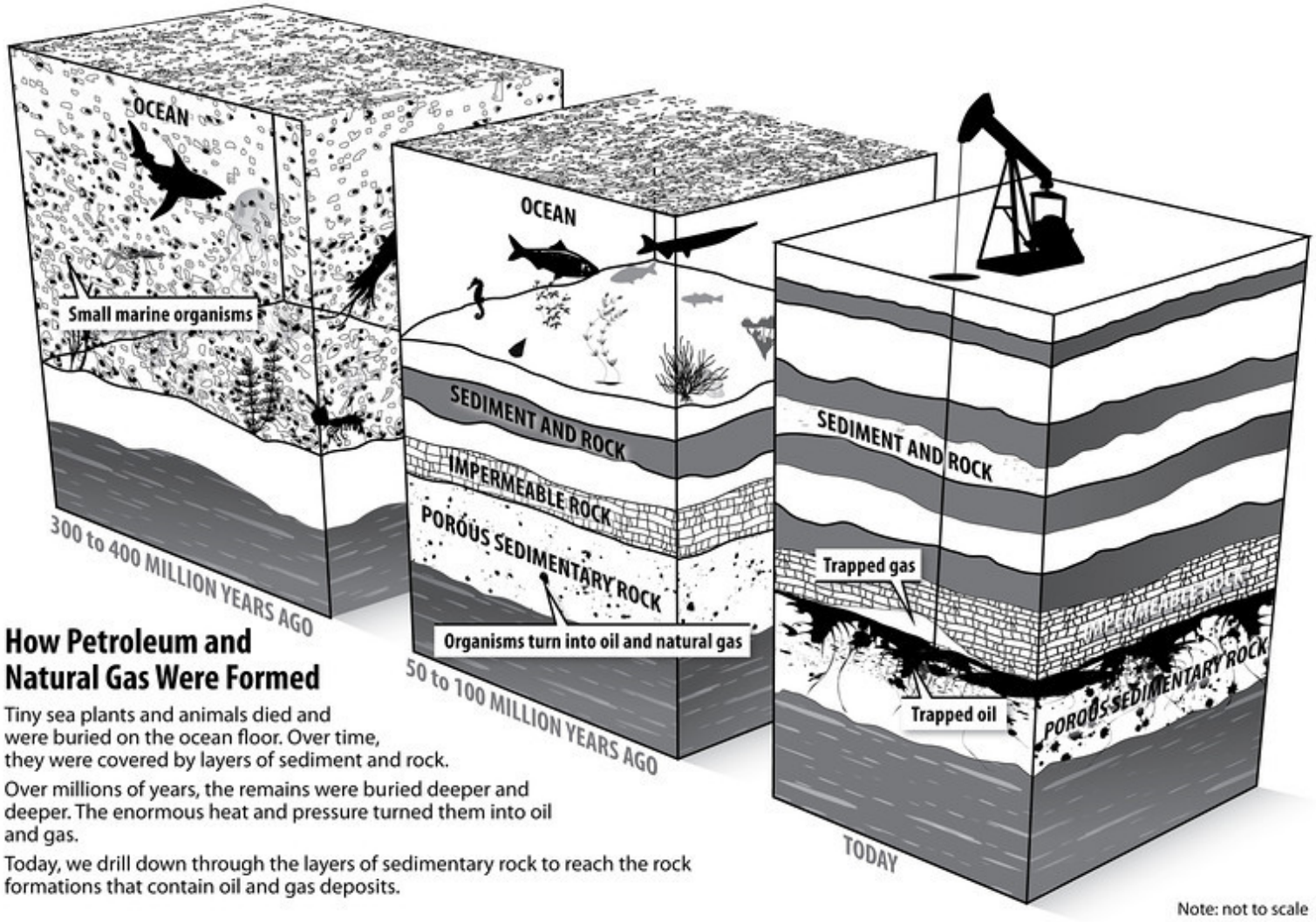
- Equilibrium
- Photosynthesis
- Death & Decay
- Combustion

Most of our energy comes from fossil fuels. When we drive our cars or use electricity, we are emitting carbon dioxide (CO_2) right back into the environment.

The carbon content in fossil fuels is very large, making this emission release significant enough to alter the concentration of CO_2 in our atmosphere.



Oil Formation

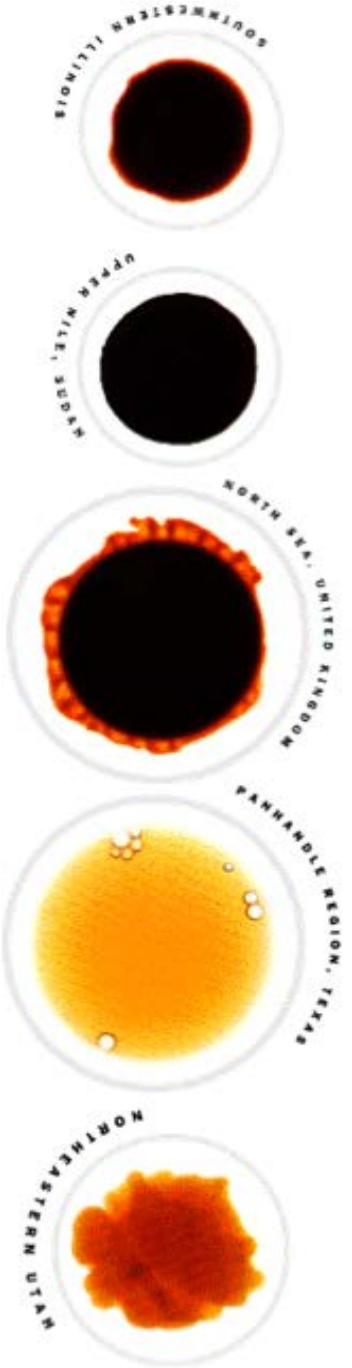


How Petroleum and Natural Gas Were Formed

Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of sediment and rock.

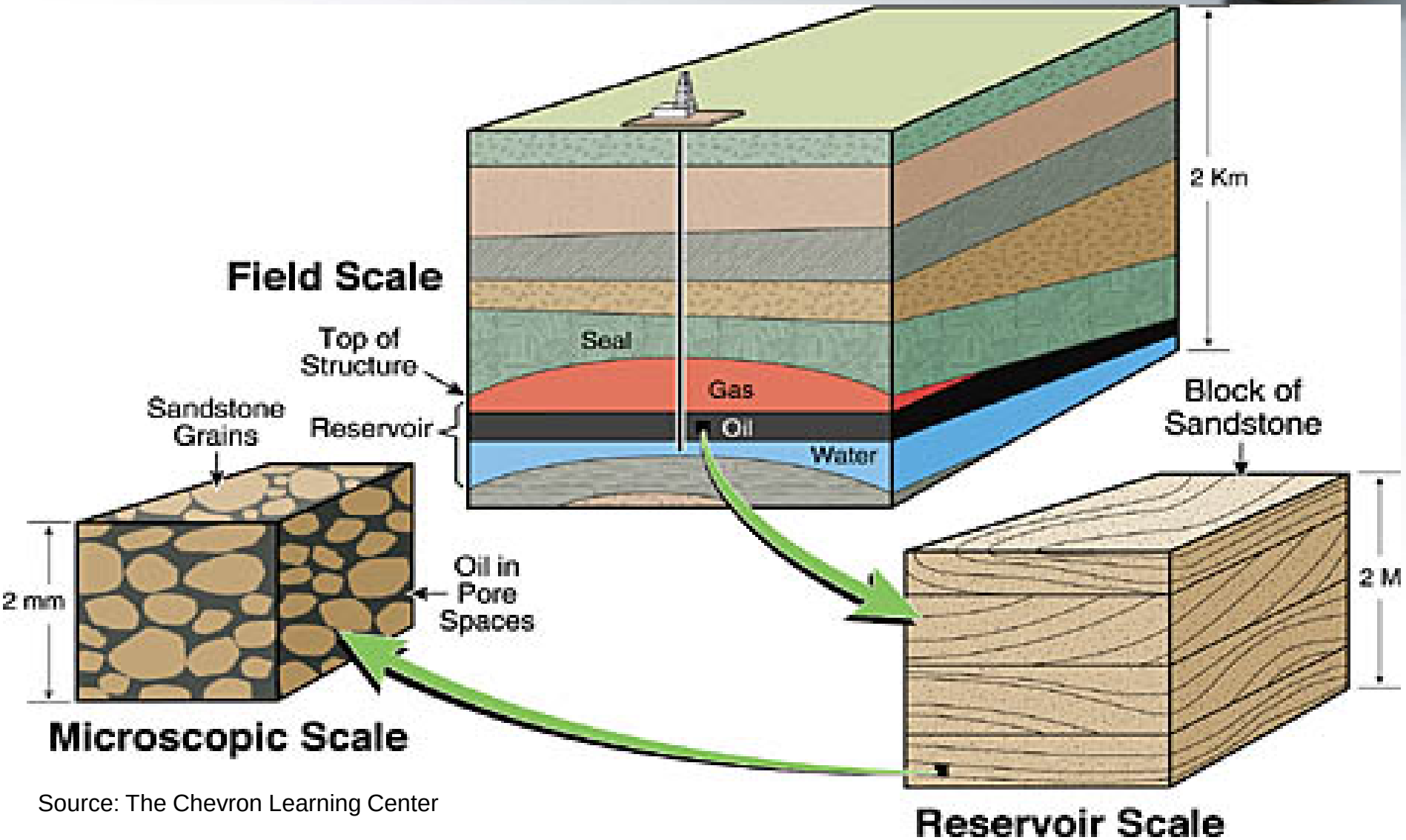
Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned them into oil and gas.

Today, we drill down through the layers of sedimentary rock to reach the rock formations that contain oil and gas deposits.



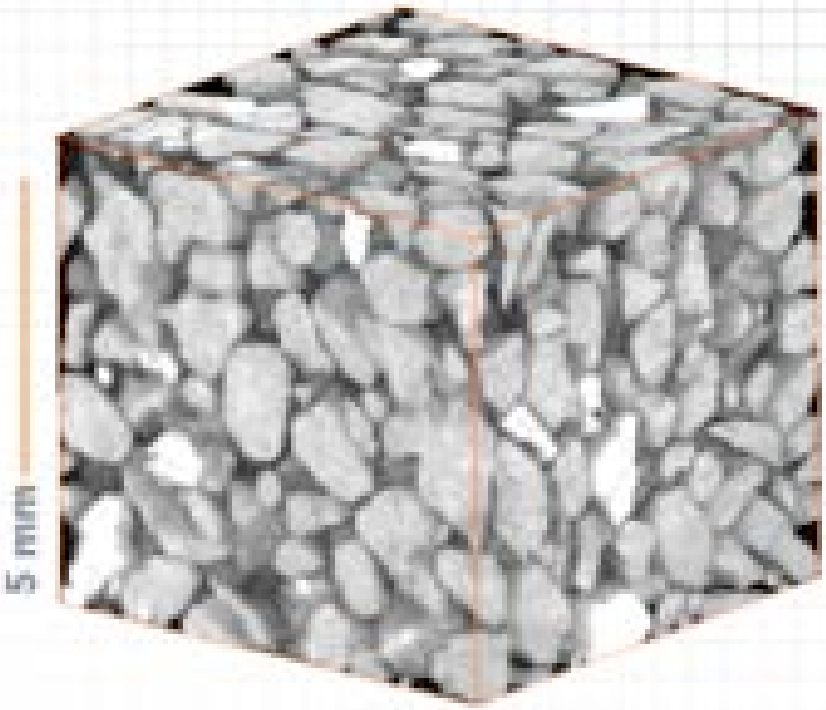
Source: NEED (National Energy Education Development Project)

Oil Reservoir

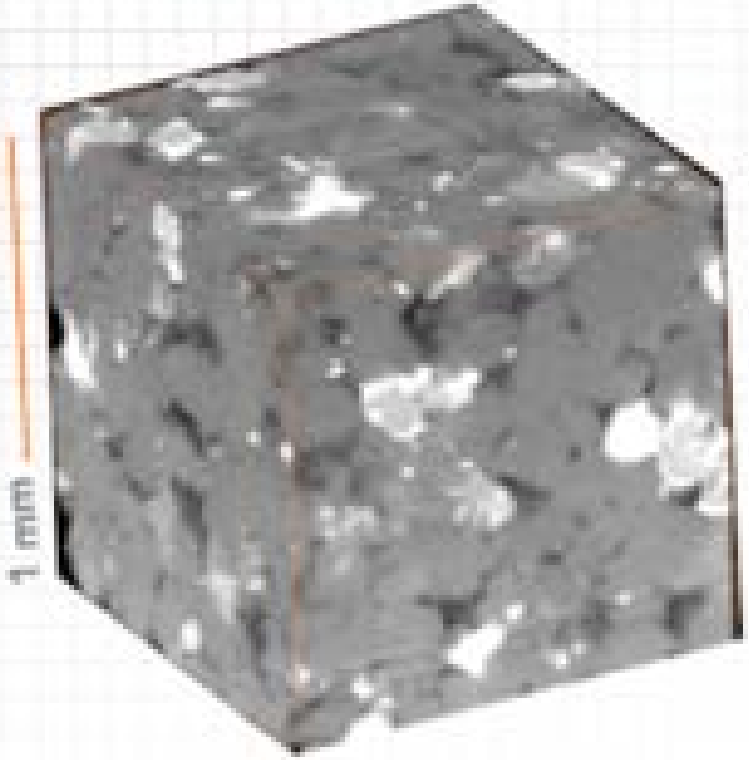


Source: The Chevron Learning Center

Reservoir Rocks



Highly Porous Sandstone
(porosity = 0.39)

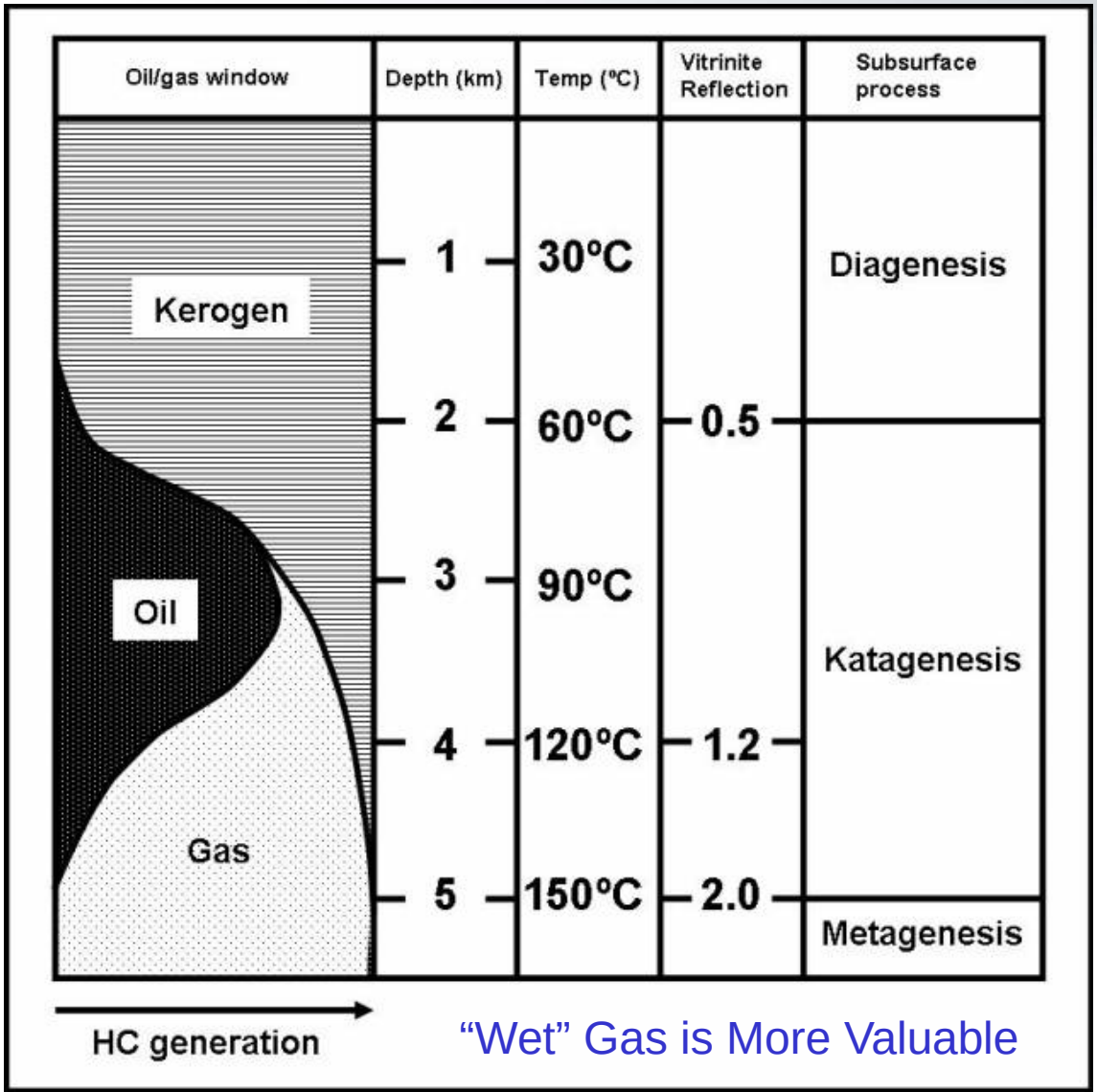


Tight Gas Sandstone
(porosity = 0.05)

X-ray CT Images

Image Source: ingrainrocks.com

Natural Gas Formation



"Wet" Gas is More Valuable

Shale, Sedimentary Rock with Organic Matter (Kerogen)

PHOTO: SCOTT THODE

Where is Natural Gas Found?

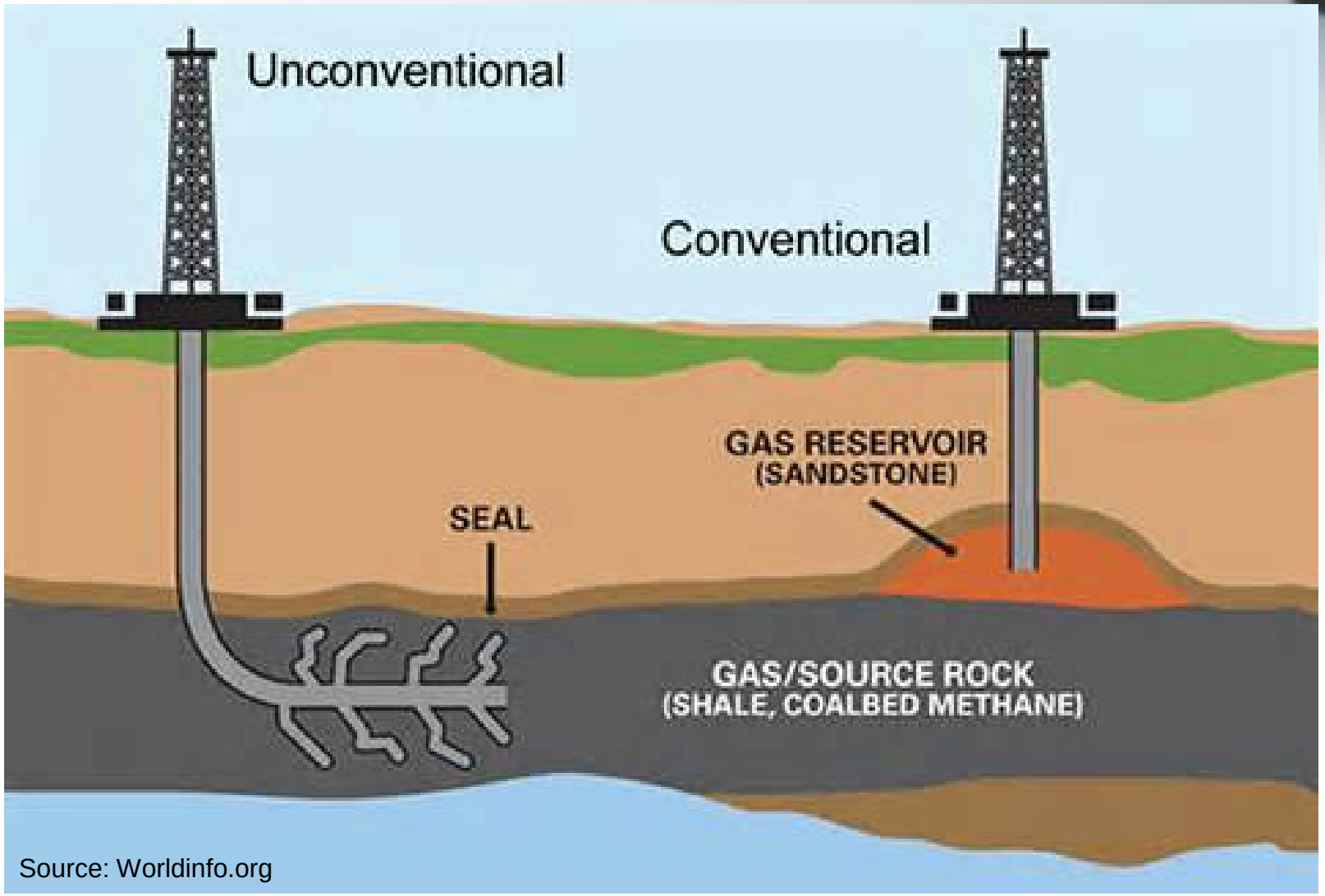
Traditional Natural Gas

- Oil wells (associated gas ~21% in the U.S.)
- Gas wells (55%)

“Unconventional” Natural Gas

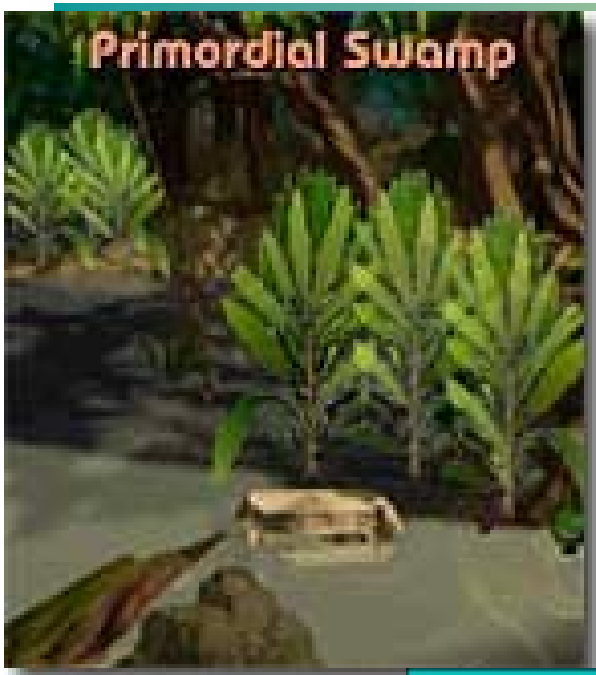
- Shale gas (16%)
- Coalbed methane (7%)
- Tight gas
- (Methane hydrates)

Natural Gas Drilling



Source: Worldinfo.org

Coal Formation



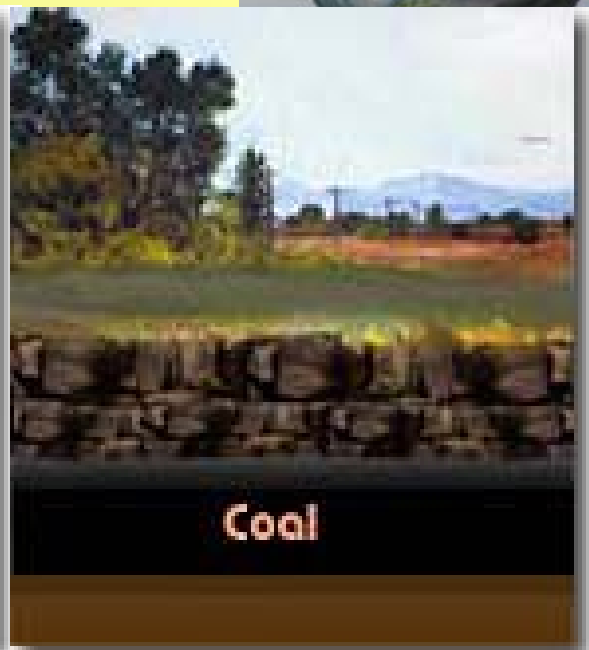
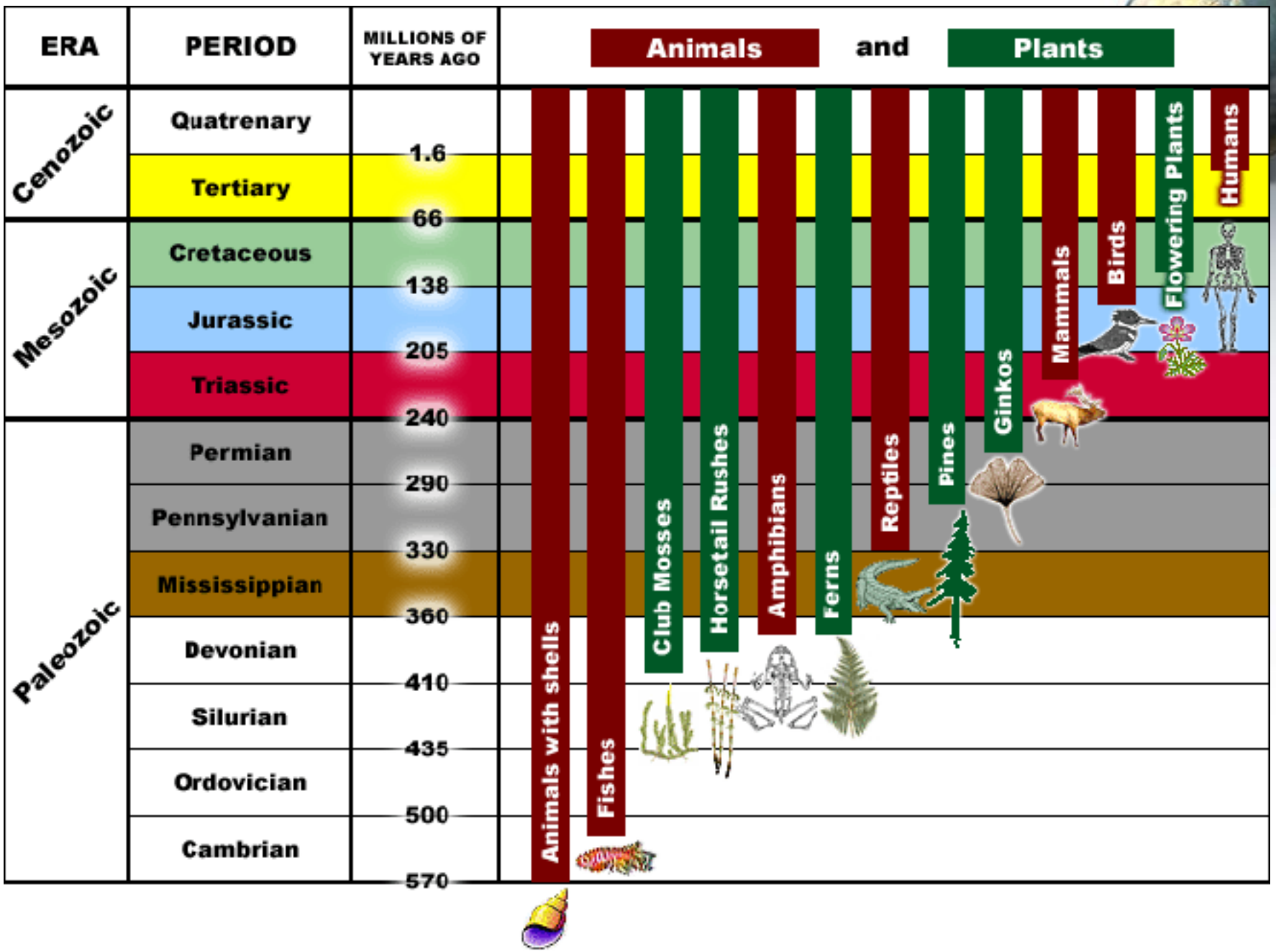
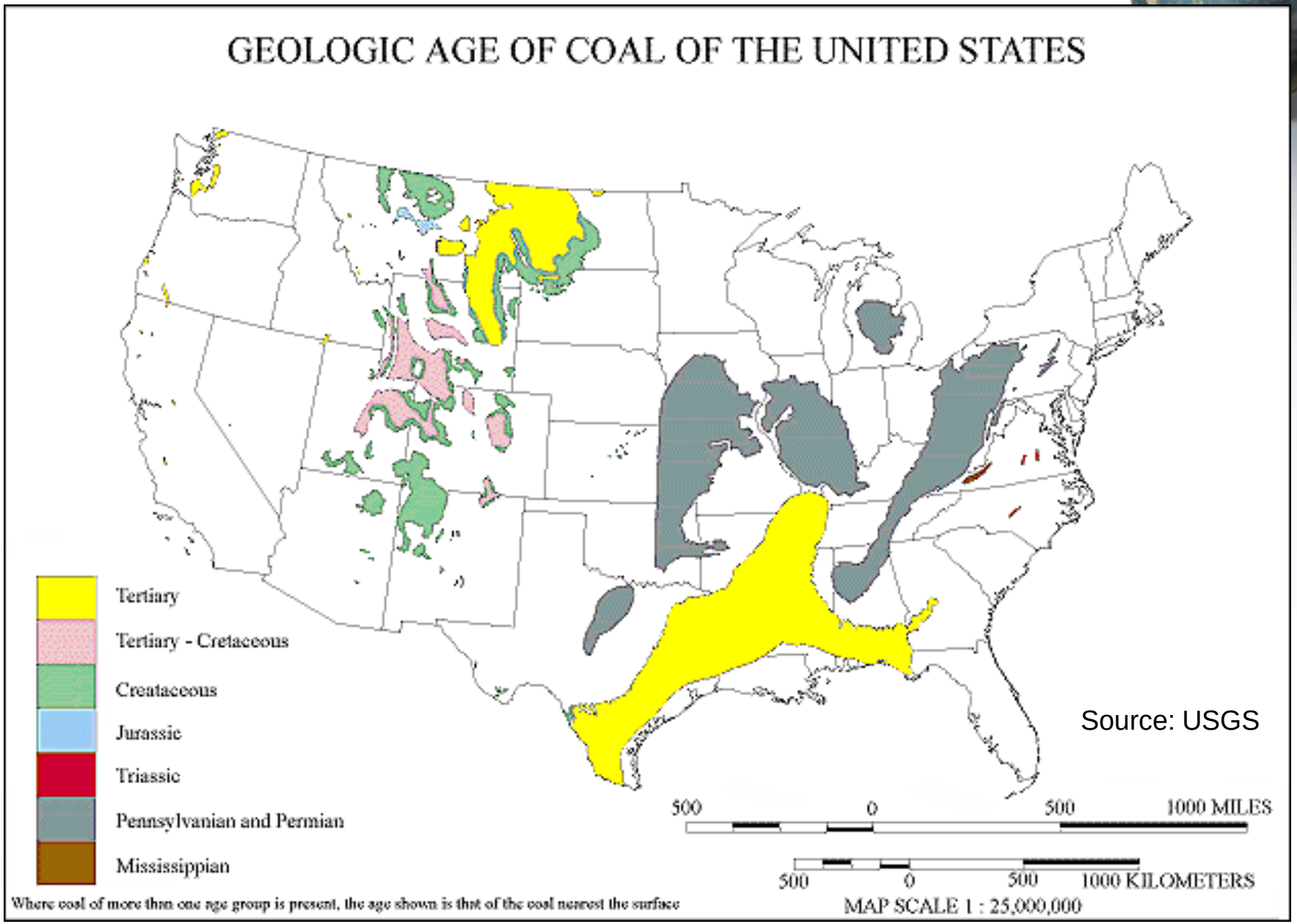


Image Source (top): U.S. Department of Energy & Kentucky Geologic Survey


ERA
PERIOD
MILLIONS OF YEARS AGO
Animals
and
Plants
Cenozoic
Mesozoic
Paleozoic
Quatrenary
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
1.6
66
138
205
240
290
330
360
410
435
500
570
Animals with shells
Fishes
Club Mosses
Horsetail Rushes
Amphibians
Ferns
Reptiles
Pines
Ginkos
Mammals
Birds
Flowering Plants
Humans

U.S. Coal Distribution by Age

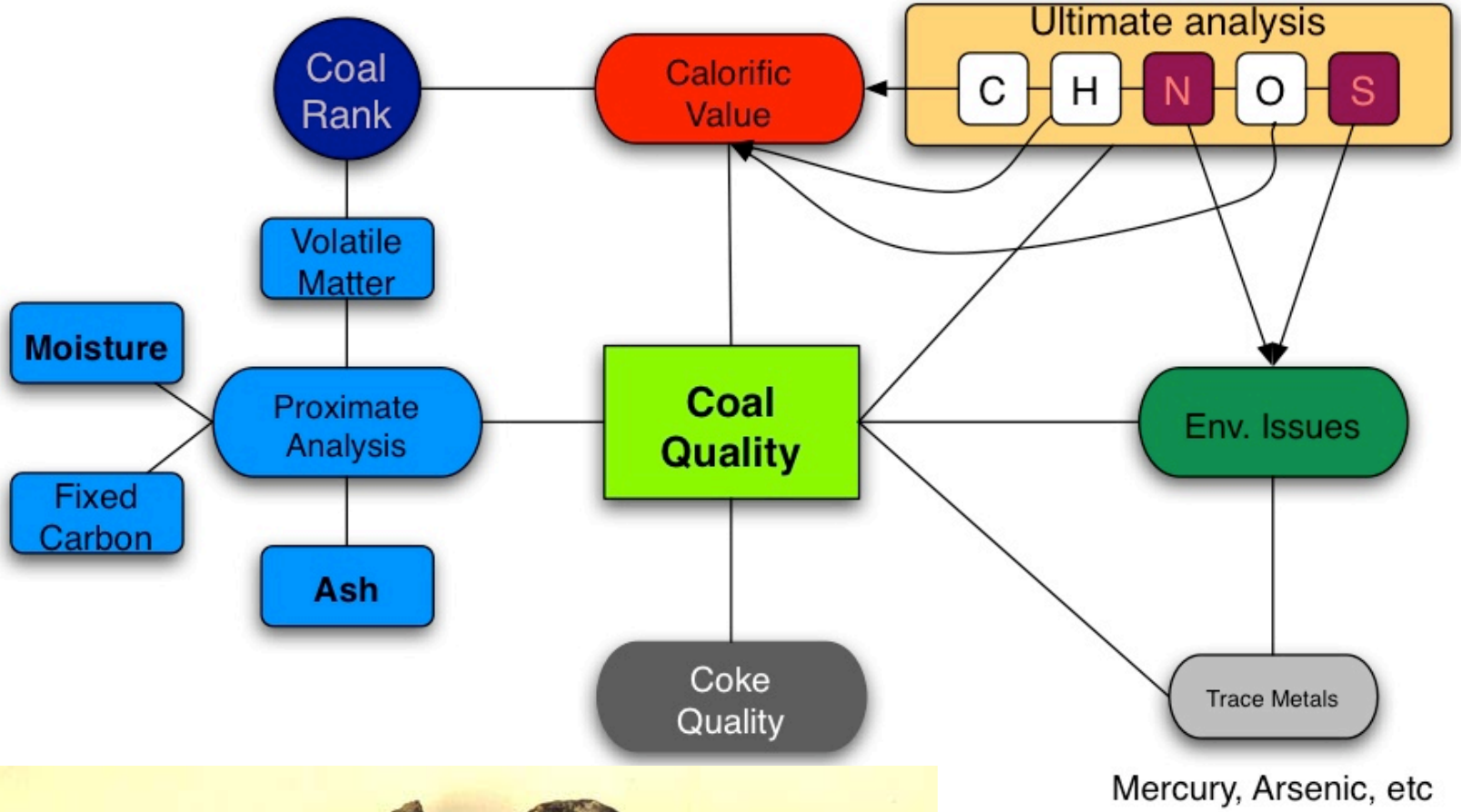


Source: USGS

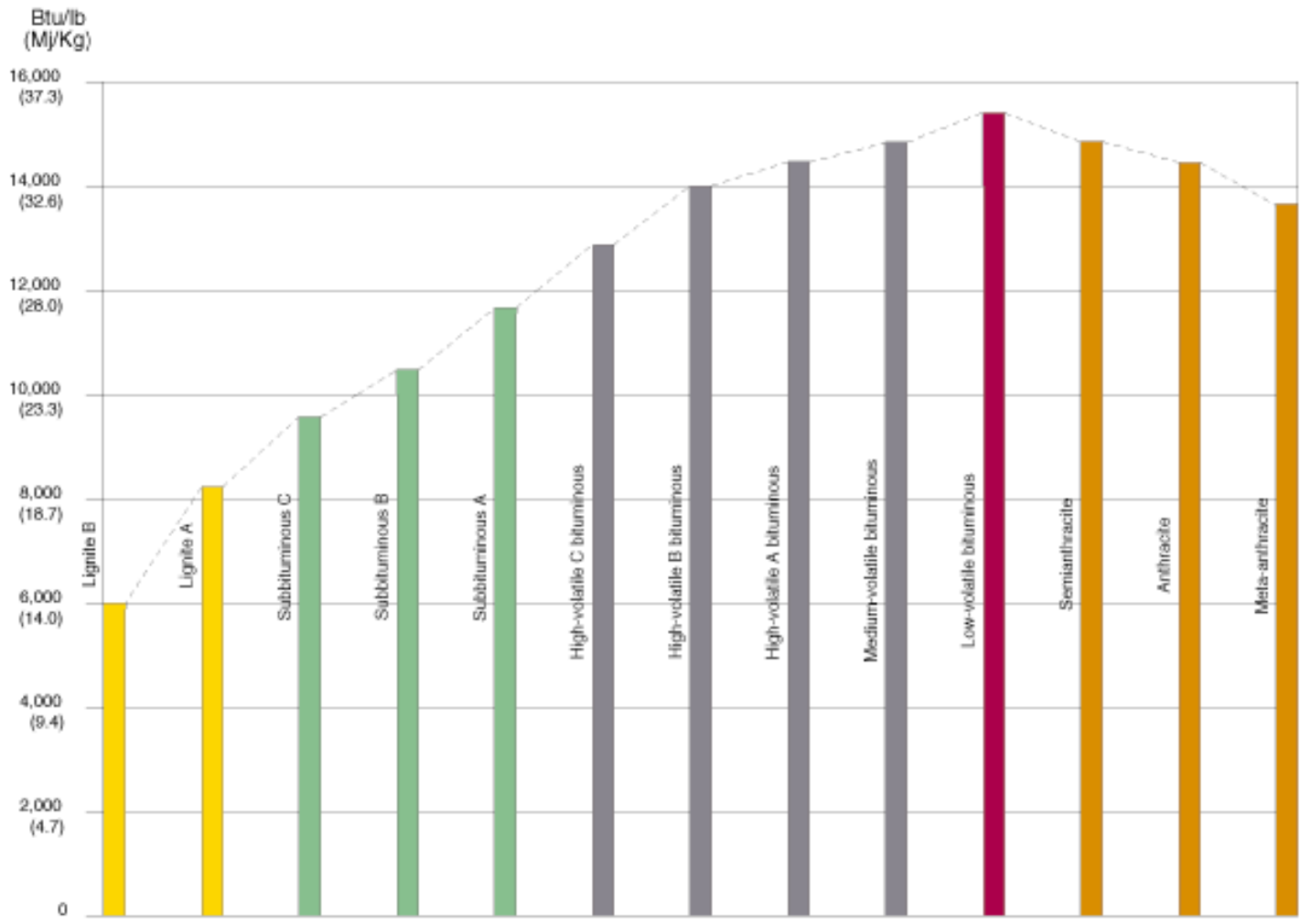
Coal Seams

- Often Multiple Seams
  - Different depths
- Thickness
  - Varies by location and often rank
- Mineral Deposition
  - From original biomass
  - During swamp stage
  - Post coal formation
- Sulfur
  - Additional deposition possible

Basic Coal Quality

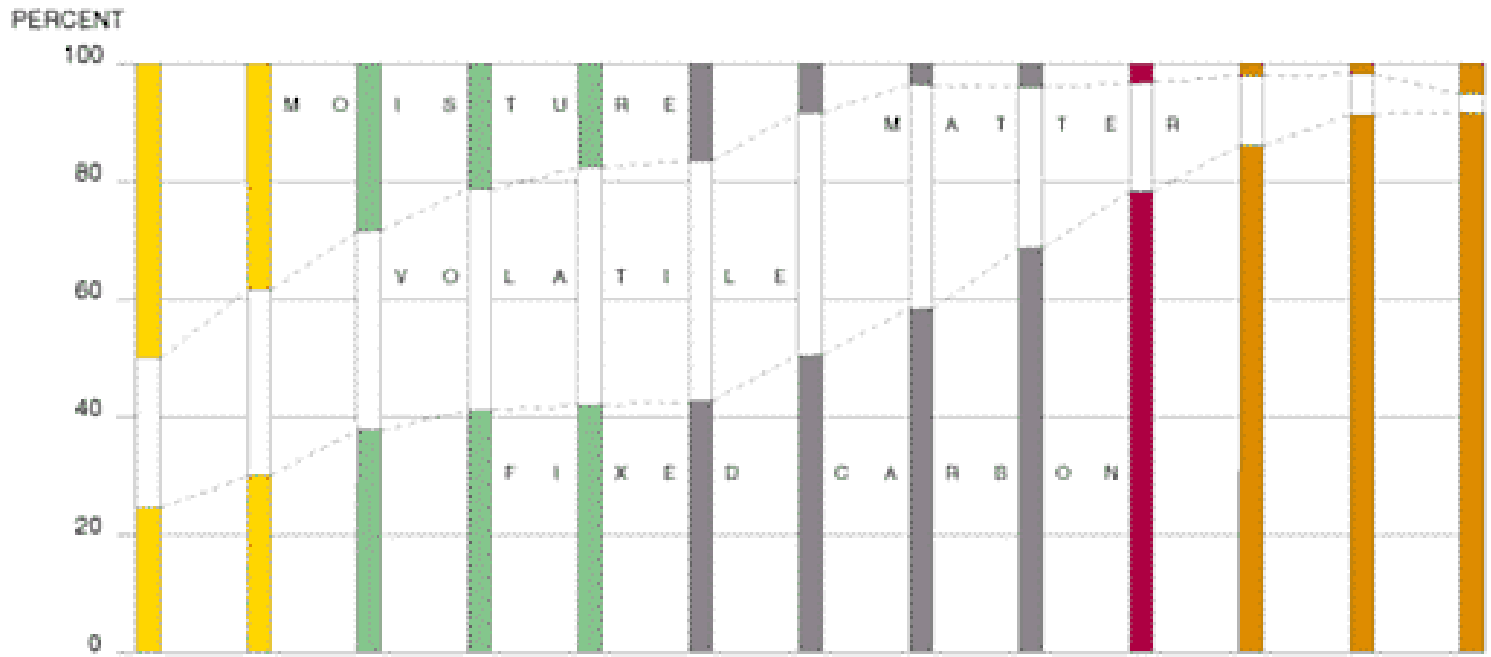


Heating Value Variation



Source: USGS

Proximate Analysis Variation



MAXIMUM CALORIFIC VALUES OF COALS OF DIFFERENT RANKS
COMPARED TO PROXIMATE ANALYSIS DATA

Source: USGS

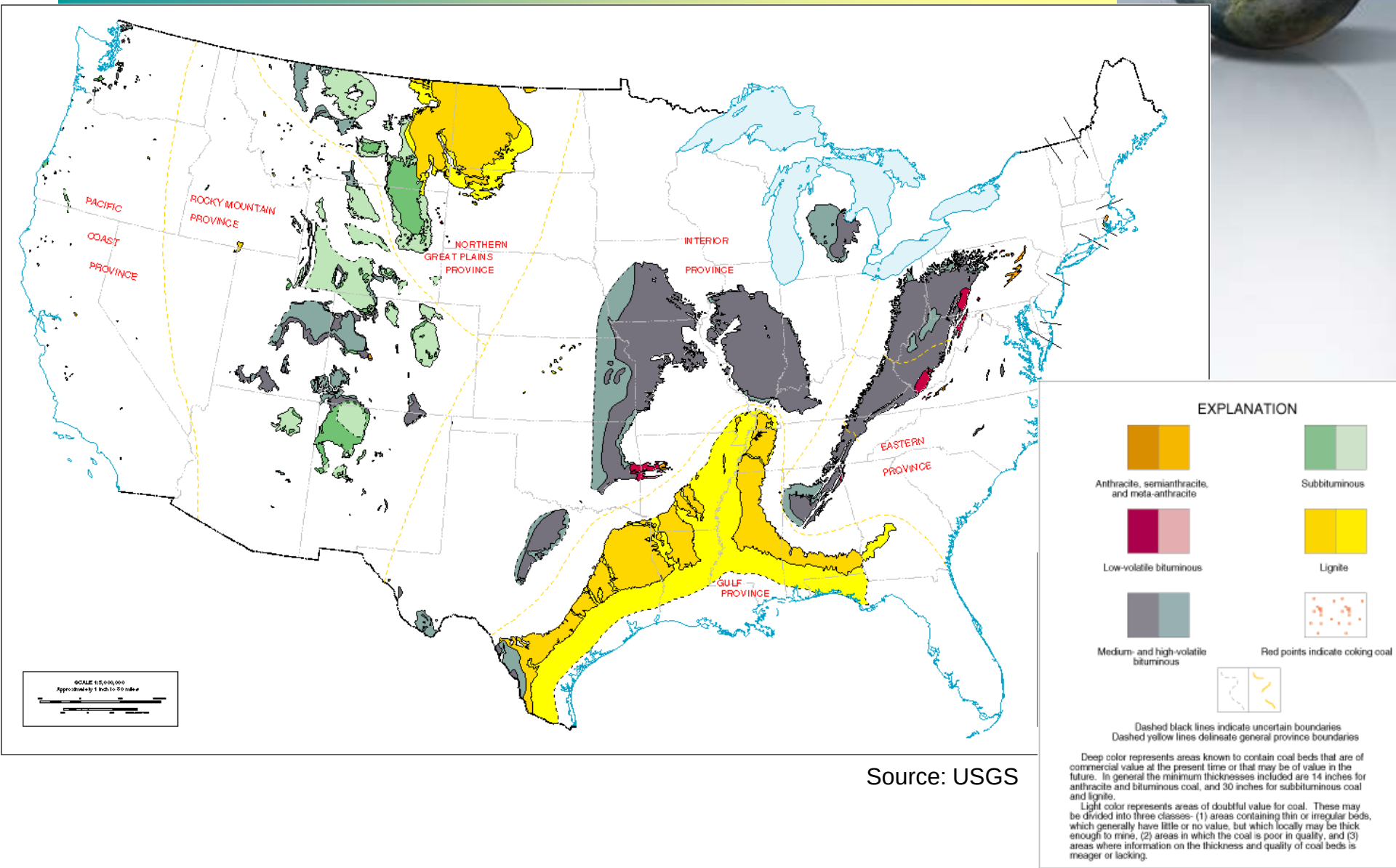
Proximate Analysis (100%) = Moisture + Volatile matter + Ash values + Fixed carbon

ASTM Method of Coal Classification

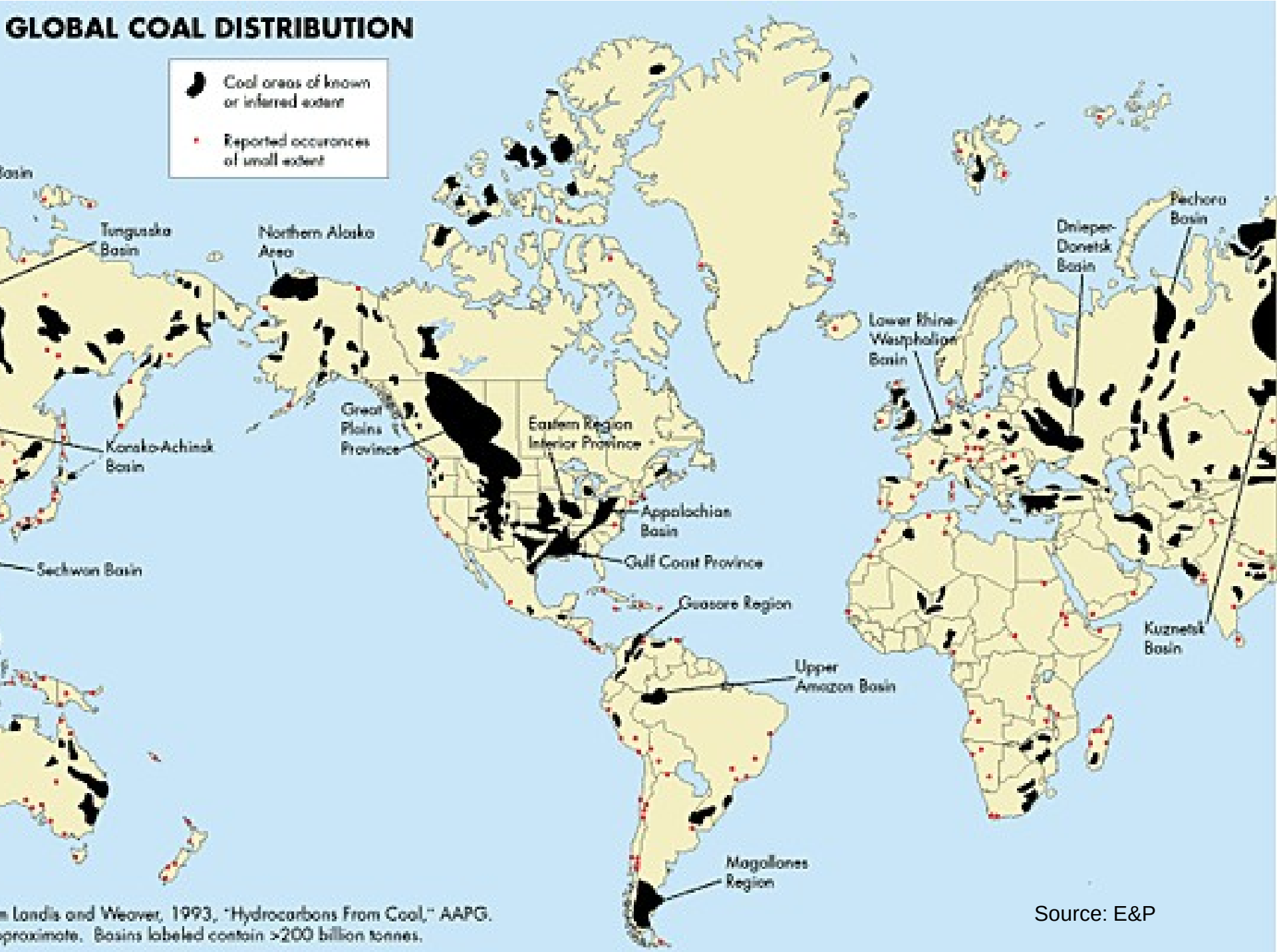
Classification of coals by rank			
Class and group	Fixed carbon (%)[a]	Volatile matter (%)[a]	Heating value (BTU / lb)[b]
I. Anthracite			
1. Metaanthracite	>98	<2	
2. Anthracite	92-98	2-8	
3. Semianthracite	86-92	8-14	
II. Bituminous			
1. Low volatile	78-86	14-22	
2. Medium volatile	69-78	22-31	
3. High volatile A	<69	>31	>14,000
4. High volatile B			13,000-14,000
5. High volatile C			10,500-13,000
III. Subbituminous			
1. Subbituminous A			10,500-11,500[c]
2. Subbituminous B			9,500-10,500
3. Subbituminous C			8,300-9,500
IV. Lignite			
1. Lignite A			6,300-8,300
2. Lignite B			<6,300

[a]dry-mineral-matter-free basis; [b]mineral-matter-free, moisture-containing basis; [c]if it does not agglomerate.

U.S. Coal Distribution by Rank



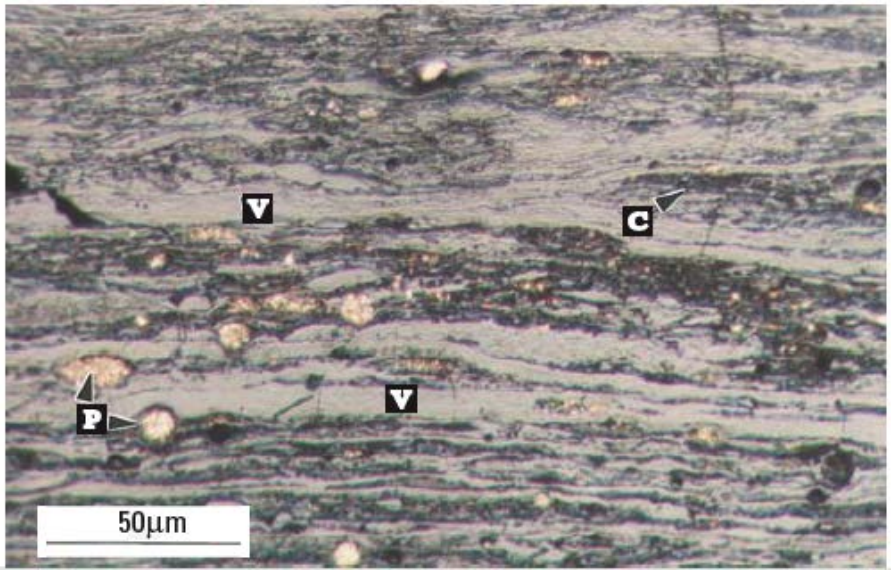
Source: USGS


GLOBAL COAL DISTRIBUTION
Coal areas of known or inferred extent
Reported occurances of small extent
Tunguska Basin
Northern Alaska Area
Kansko-Achinsk Basin
Sechwan Basin
Great Plains Province
Eastern Region Interior Province
Appalachian Basin
Gulf Coast Province
Guasare Region
Upper Amazon Basin
Magallanes Region
Lower Rhine-Westphalian Basin
Dnieper-Donetsk Basin
Pechora Basin
Kuznetsk Basin
Landis and Weaver, 1993, "Hydrocarbons From Coal," AAPG.
proximate. Basins labeled contain >200 billion tonnes.

Source: E&P

Macerals in Coal

Organic Components in Coal



Source: USGS

Vitrinite
Liptinite - Sporinite, Cutinite, Resinite
Inertinite - Fusinite, etc.
Inorganic – Clays, Pyrite, Other Minerals

- Coal is complex
- Macerals influence behavior:
  - Combustion
  - Coke properties
  - Liquefaction
  - Coalbed methane
  - Sequestration
  - International Trade Opportunities, etc.

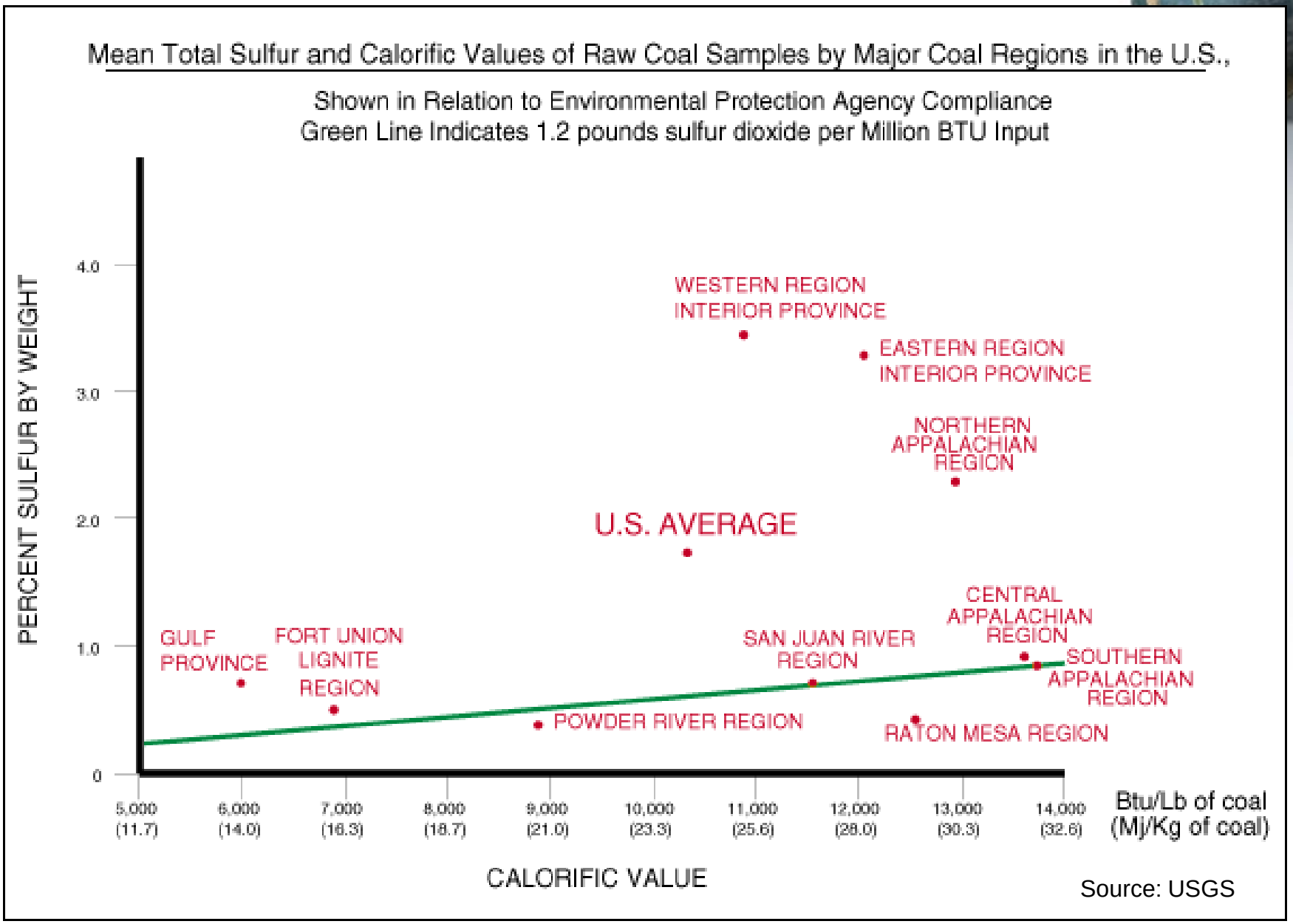
Minerals Found in Coal

Inorganic Components in Coal: Mineral bands, Discreet minerals, Trace elements, Minerals within biomass

List of mineral matter identified (after Gluskoter et al., 1981)

Mineral	Formula
Clay minerals	
Montmorillonite	$Al_2Si4O_{10}(OH)_2\ H_2O$
Illite-sericite	$KAl_2(AlSi_3O_{10})(OH)_2$
Kaolinite	$Al_4Si_4O_{10}(OH)_8$
Halloysite	$Al_4Si_4O_{10}(OH)_8$
Chlorite (prochlorite, penninite)	$Mg_5Al(AlSi_3O_{10})(OH)_8$
Mixed-layer clay minerals	
Sulfide minerals	
Pyrite	FeS_2
Marcasite	FeS_2
Sphalerite	ZnS
Galena	PbS
Chalcopyrite	$CuFeS_2$
Pyrrhotite	$Fe_{1-X}S$
Arsenopyrite	$FeAsS$
Millerite	NiS
Carbonate minerals	
Calcite	$CaCO_3$
Dolomite	$(Ca, Mg)CO_3$
Siderite	$FeCO_3$
Ankerite (Ferroan dolomite)	$(Ca, Fe, Mg)CO_3$
Witherite	$BaCO_3$
Sulfate minerals	
Barite	$BaSO_4$
Gypsum	$CaSO_4\ 2H_2O$
Anhydrite	$CaSO_4$
Bassanite	$CaSO_4\ 1/2H_2O$
Jarosite	$(Na, K)Fe_3(SO_4)2(OH)_6$
Szomolnokite	$FeSO_4\ H_2O$
Rozenite	$FeSO_4\ 4H_2O$
Melanterite	$FeSO_4\ 7H_2O$
Coquimbite	$Fe_2(SO)_3\ 9H_2O$
Roemerite	$FeSO_4\ Fe_2(SO_4)_3\ 12H_2O$
Mirabilite	$Na_2SO_4\ 10H_2O$
Kieserite	$MgSO_4\ H_2O$
Sideronatrite	$2Na_2O\ Fe_2O_3\ 4SO_3\ 7H_2O$
Chloride minerals	
Halite	$NaCl$
Sylvite	KCl
Bschofite	$MgCl_2\ 6H_2O$
Silicate minerals	
Quartz	SiO_2
Biotite	$K(Mg, Fe)_3(AlSi_3O_{10})(OH)_2$
Zircon	$ZrSiO_4$
Tourmaline	$Na(Mg, Fe)_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$
Garnet	$(Fe, Ca, Mg)_3(Al, Fe)_2(SiO_4)_3$
Kyanite	Al_2SiO_5
Staurolite	$Al_4FeSi_2O_{10}(OH)_2$
Epidote	$Ca_2(Al, Fe)_3Si_3O_{12}(OH)$
Albite	$NaAlSi_3O_8$
Sanidine	$KAlSi_3O_8$
Orthoclase	$KAlSi_3O_8$
Augite	$Ca(Mg, Fe, Al)(Al, Si)_2O_6$

Sulfur and Calorific Value are Important



Source: USGS

What is Coal Preparation?

- The conversion of run-of-mine coal into a marketable product
- Requires knowledge of the raw coal properties as related to particle behavior during processing
- Involves the development of an appropriate circuit to produce the marketable coal
- Achieves key objectives of coal processing:
  - Liberation of impurities from the coal
  - Separation of the coal from the impurities
  - Production of a uniform quality product
- Incorporates environmentally sound waste disposal including water recycle

Impact of Clean Coal

- Reduced Transportation Bulk
- Lower Coal Burn Rate
- Decreased Ash Loading
- Altered Ash Slagging/Fouling
- Reduced Desulfurization Requirements
- Improved Fuel Uniformity

Coal Components

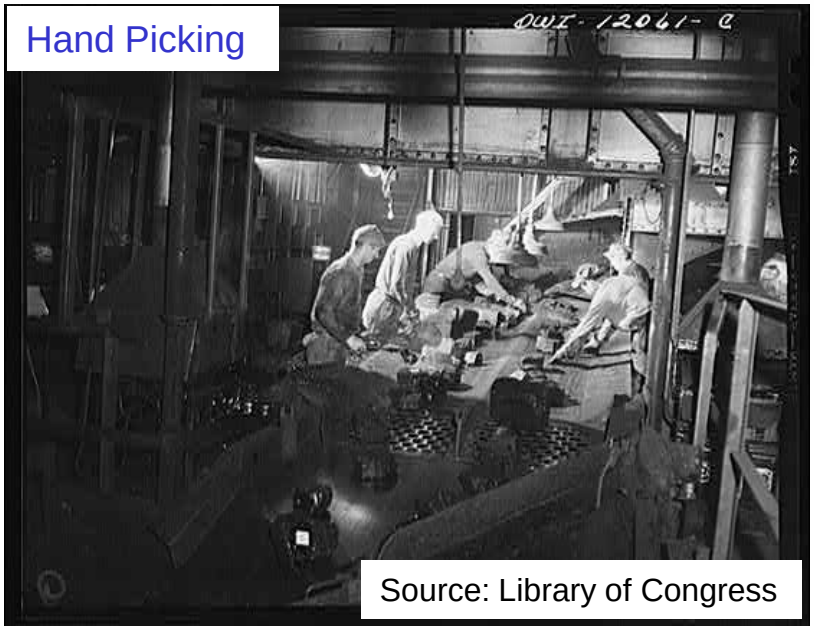
Component	Specific Gravity
• Bituminous Coal	1.25 - 1.35
• Bone Coal (high ash)	1.4 - 1.7
• Carbonaceous Shale	1.6 - 2.2
• Shale and Clays	2.0 - 2.6
• Pyrite	4.8 - 5.2

Generic Steps of Coal Processing

- Characterization
  - Size and density fractionation, coal analyses
- Liberation
  - Size reduction
- Separation
  - Gravity concentration, flotation
- Disposition
  - Dewatering, material handling

Coal Preparation Operations

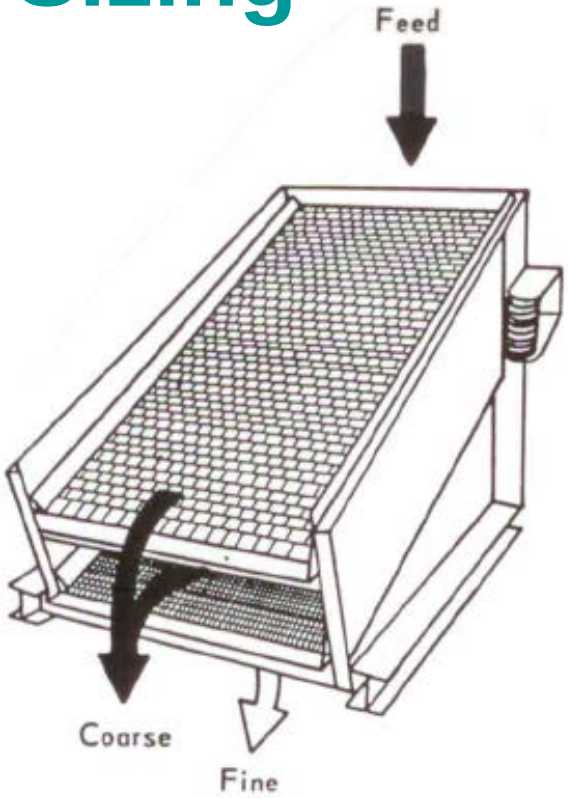
- Reducing particle size by crushing
- Preparation of coal into appropriate size ranges depending on devices and products
- Removing “ash” (mineral matter) and sulfur (inorganic)
- Dewatering (washed coal) and drying (low-rank coal)



Levels of Cleaning

- No Washing
  - Size reduction only
- Coarse Coal
  - +1/2 in material
- Coarse + Intermediate Coal
  - +1/2 in, -1/2 in +1 mm material
- Coarse + Intermediate + Fine Coal
  - +1/2 in, -1/2 in +1 mm, -1+0.15 mm material
- Coarse + Intermediate + Fine + Ultrafine Coal
  - +1/2 in, -1/2 in +1 mm, -1+0.15 mm, -0.15 mm material

Size Reduction and Sizing



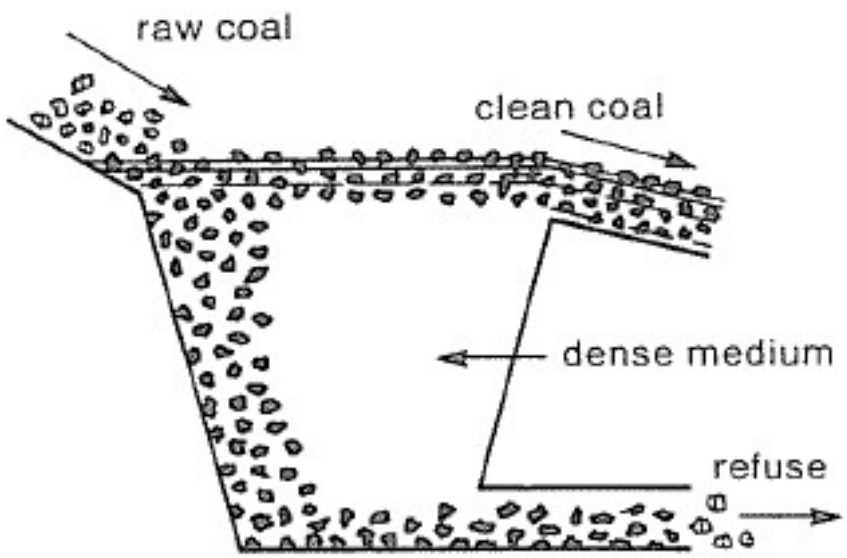
Source: Library of Congress

- Crushing/sizing of feed coal (-4 in)
- Crushing after coal cleaning (-1.5 in)
- Pulverizing for PC combustion (-0.075 mm)
- Grinding for fluidized-bed combustion
- Grinding to various sizes for coal gasification

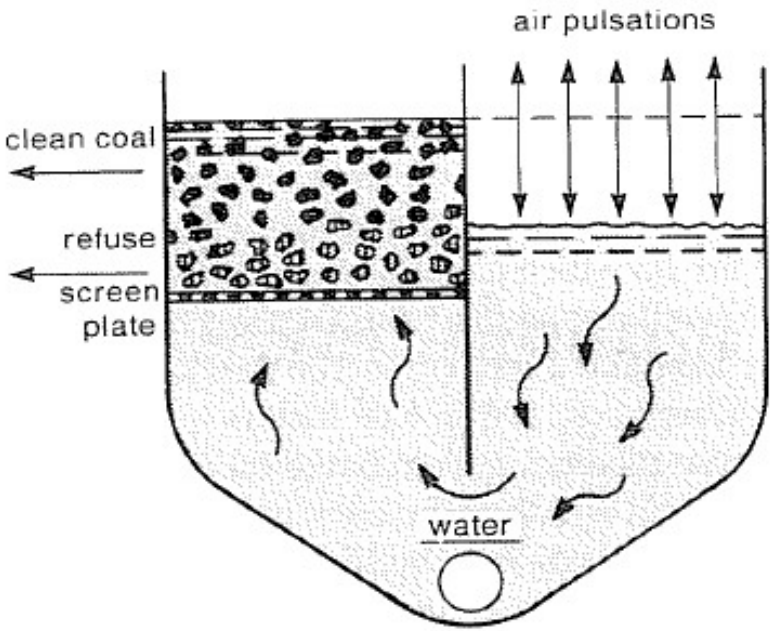
Coal Cleaning - Wet Processing

- Coarse Coal
  - Dense-medium vessel
  - Jig (also dry-cleaning version)
- Intermediate Coal
  - Dense-medium cyclone
  - Dry cleaning table
- Fine Coal
  - Spiral concentrator
  - Concentrating table
  - Other (autogenous cyclone, teeter-bed column, etc.)
- Ultrafine Coal
  - Flotation

Coarse Coal



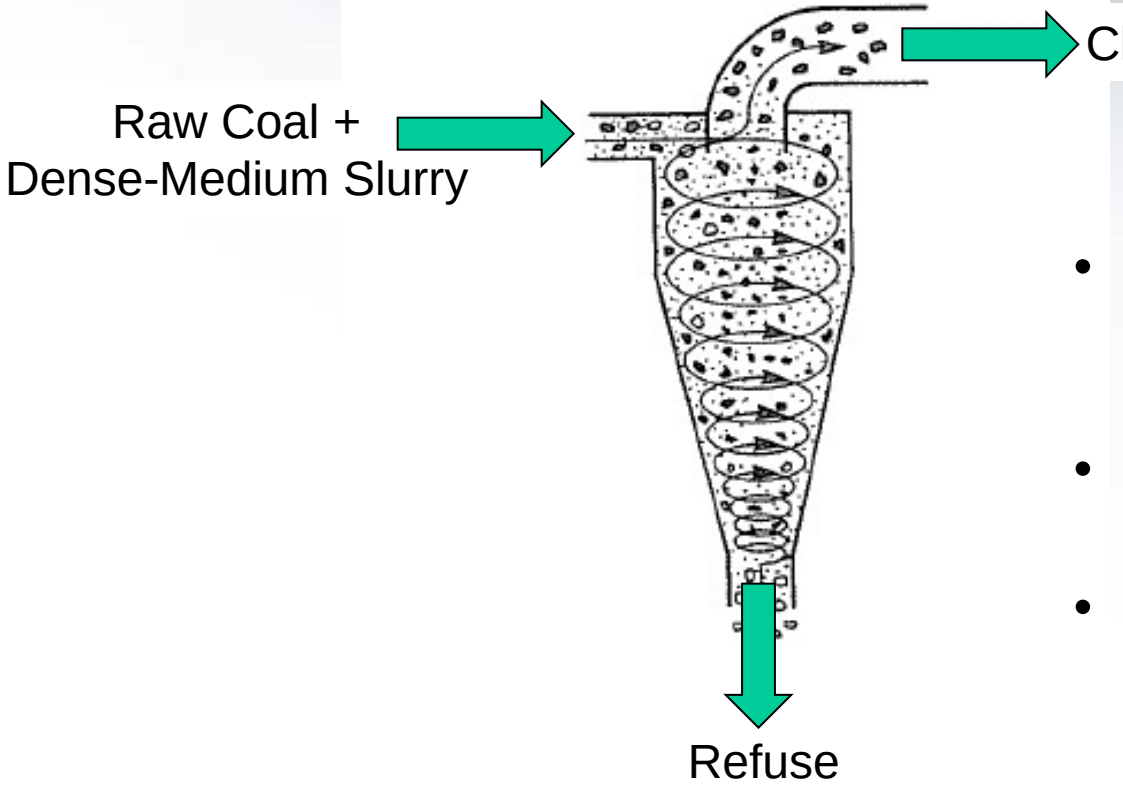
Dense-Medium Vessel



Baum-Type Jig

Source: U.S. Dept. of Energy

Intermediate Coal



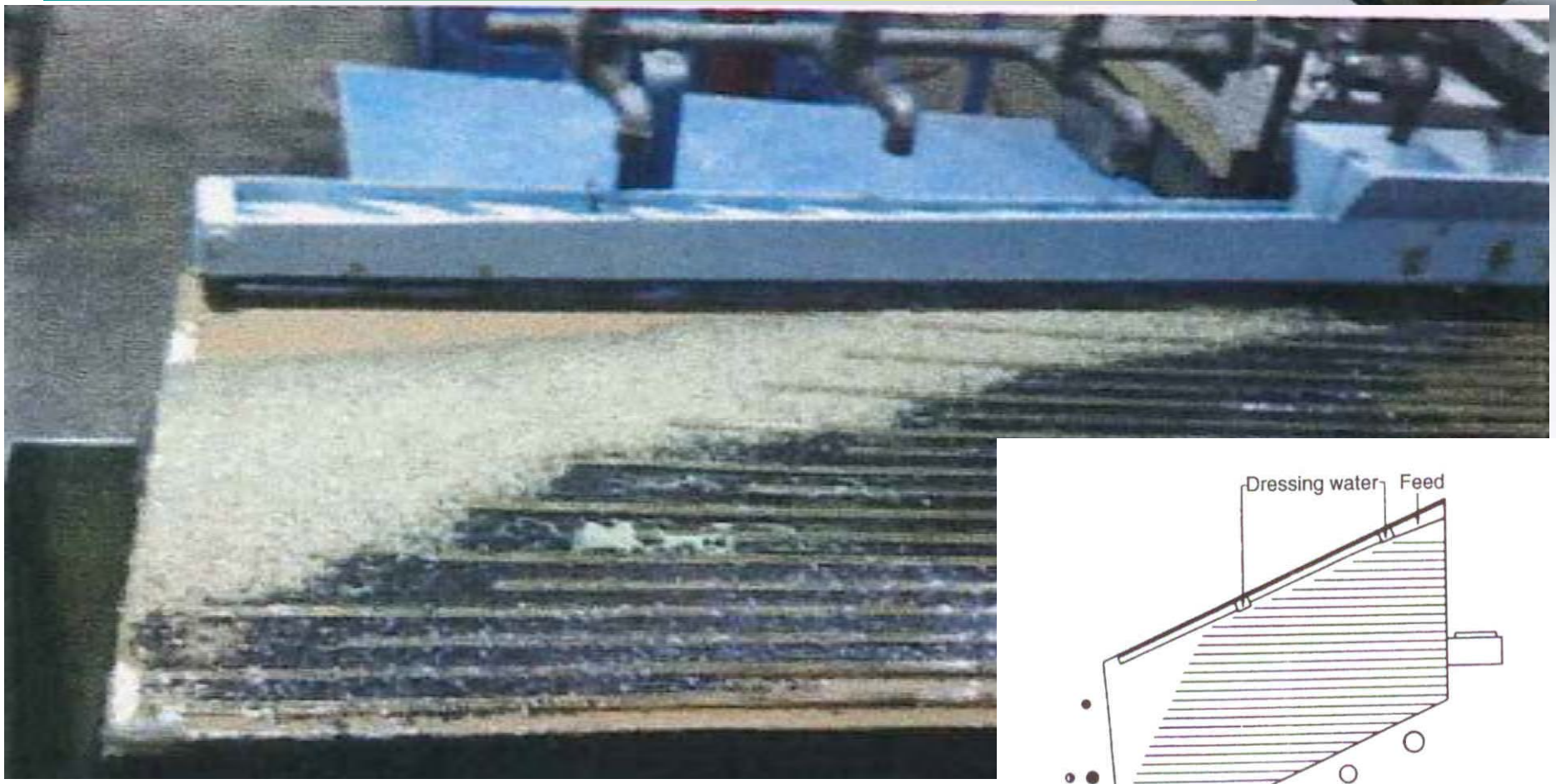
- Slurry enters under pressure
- Increases number of g's
- Improves separation of finer particles

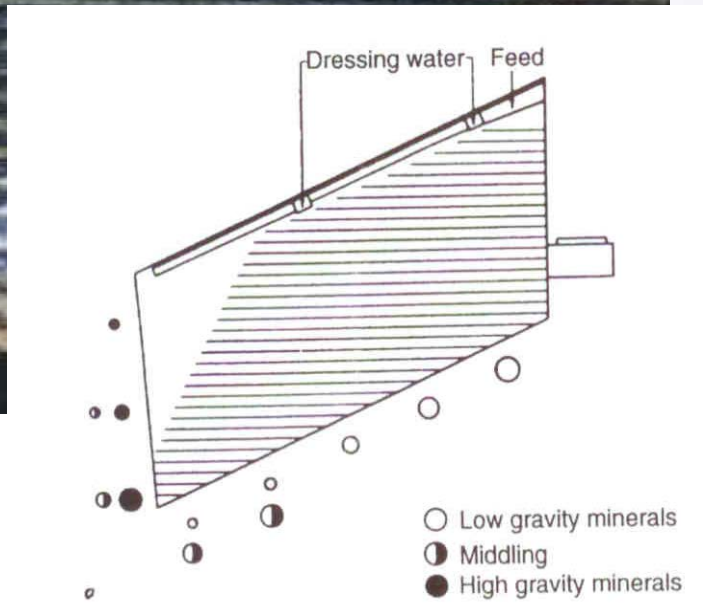
Dense-Medium Cyclone

Fine Coal - Spiral Concentrator

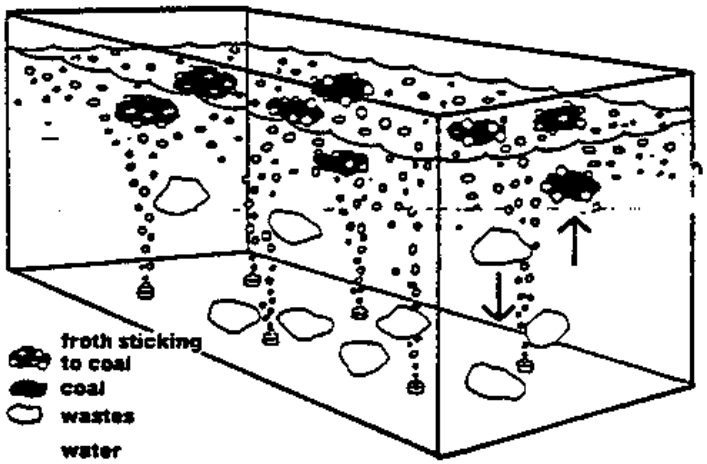
- Flowing-film separation
- Several cuts of coal qualities

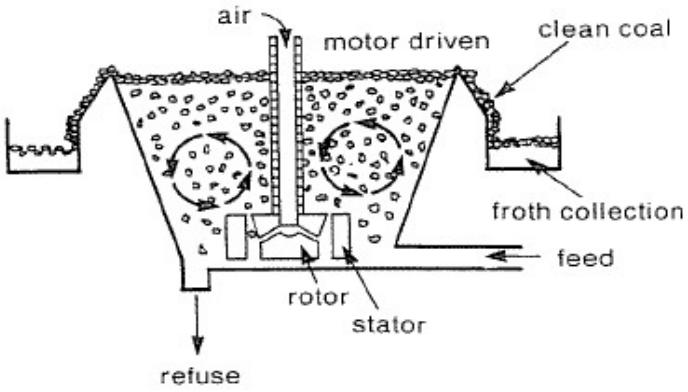
Fine Coal - Concentrating Table





Fine/Ultrafine Coal - Flotation





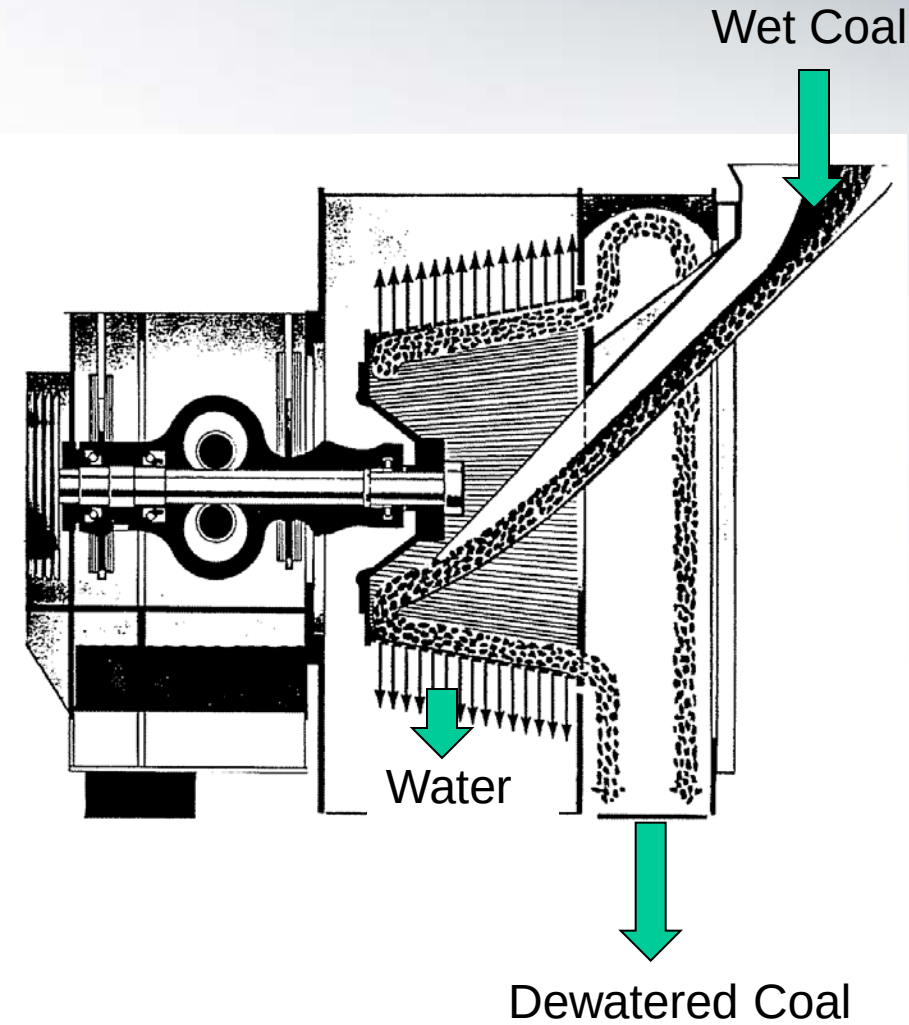
Source: Advanced Coal Cleaning Technology, IEA

Coal/Refuse Dewatering and Water Reuse

- Screening
  - Coarse/intermediate/fine coal/refuse
- Centrifugation
  - Intermediate/fine/ultrafine coal
- Filtration
  - Vacuum filter (fine/ultrafine coal)
  - Pressure filter (ultrafine coal/refuse)
- Sedimentation
  - Thickener (ultrafine refuse)

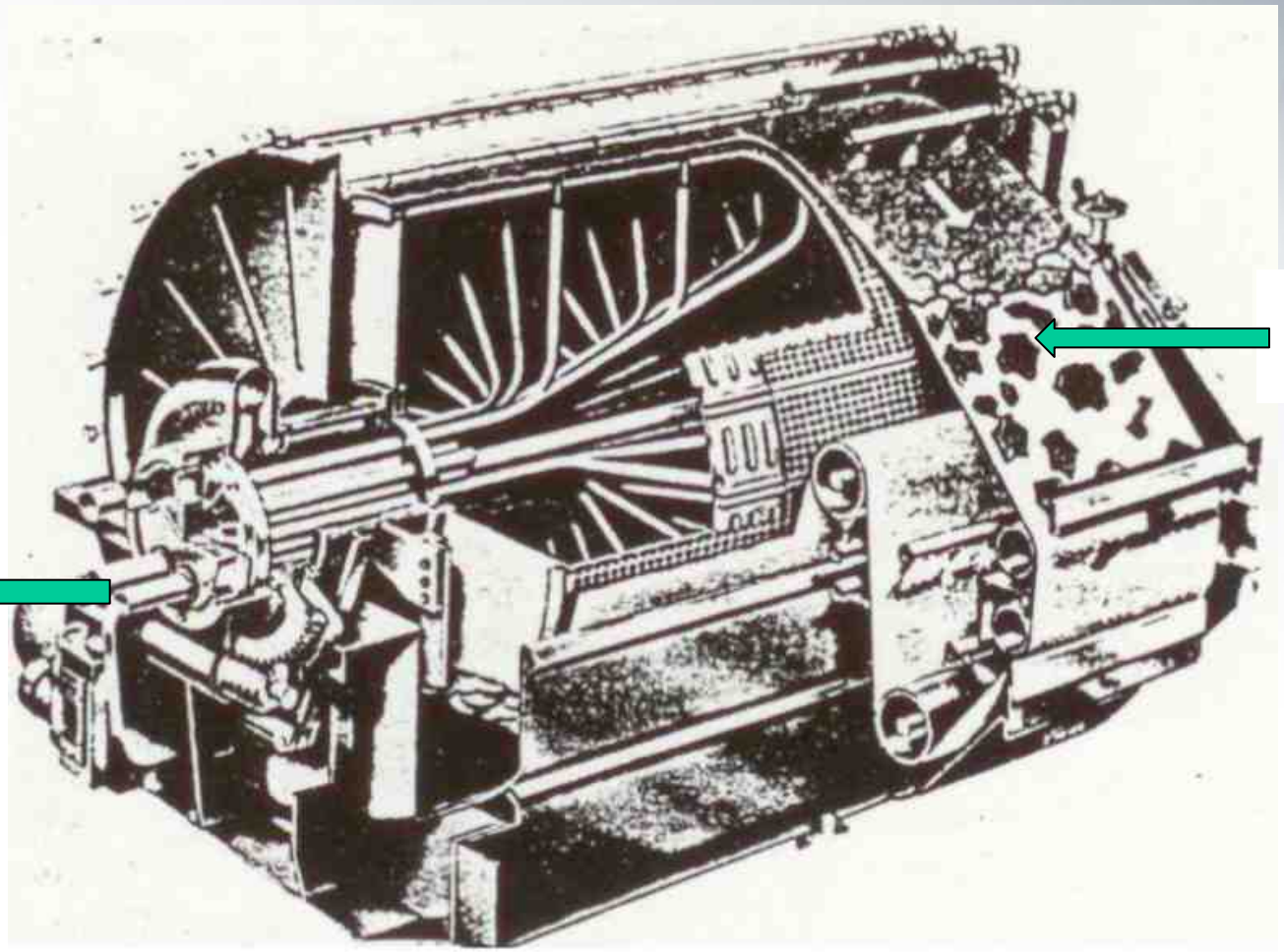
Screening

Centrifuge



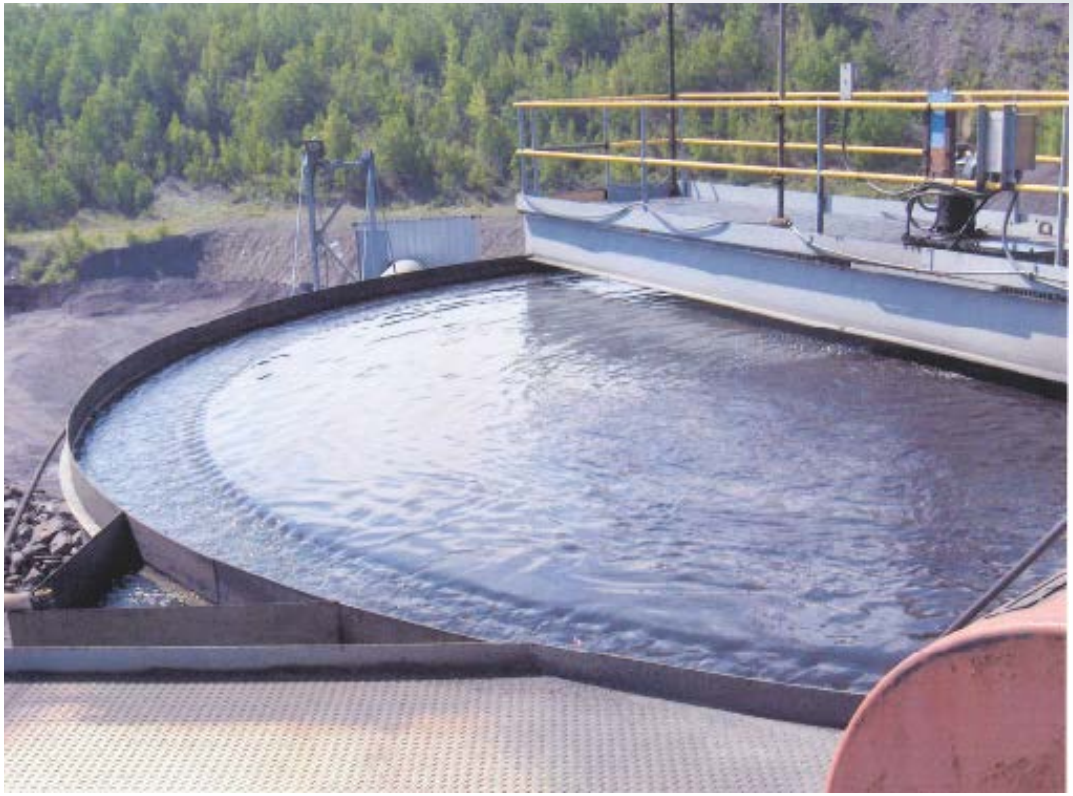
Basket Centrifuge

Vacuum Filtration

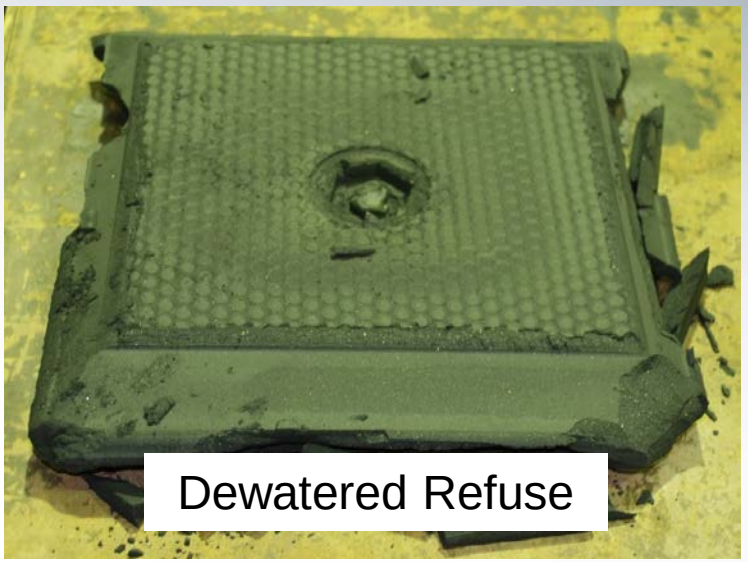


Drum Filter

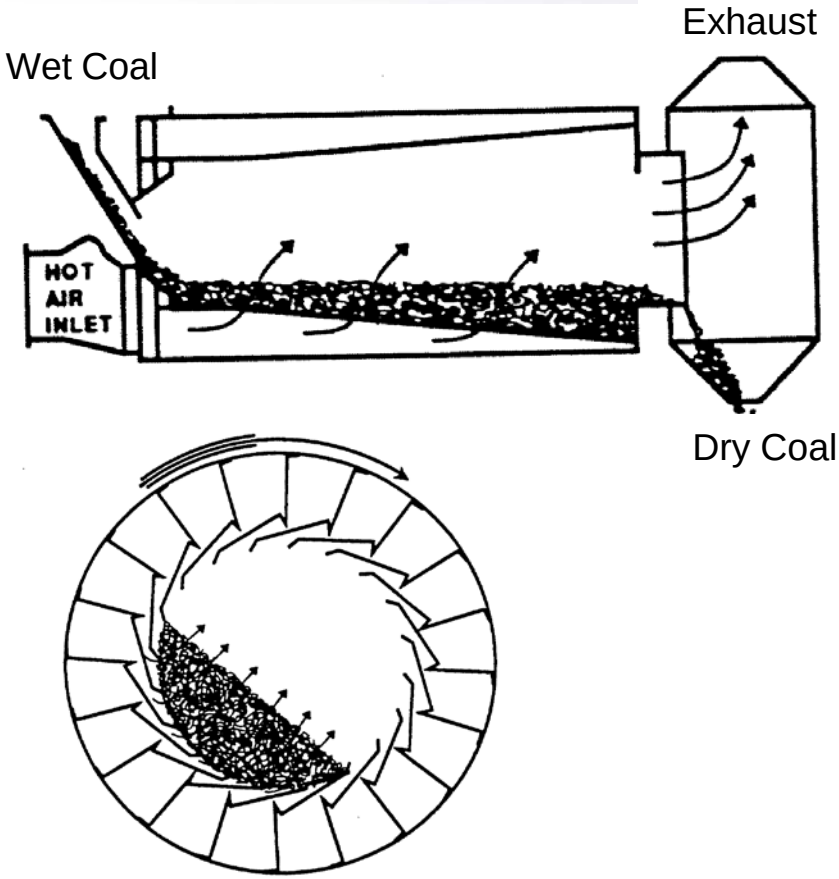
Sedimentation - Thickener



Pressure Filtration



Thermal Drying



Great River Energy's Coal Creek Station in Underwood, North Dakota.

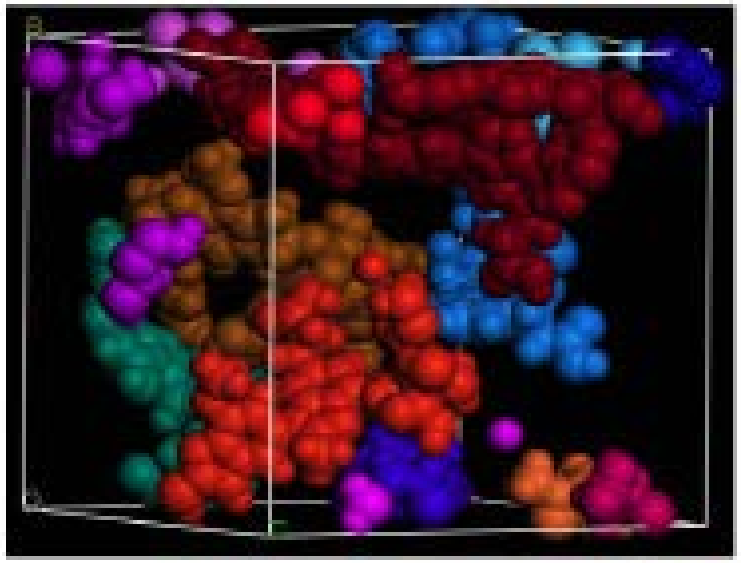
Rotary-Type Dryer

Mechanical Thermal Expression

Lignite-Water Interactions

Water removed to illustrate pore volume

Porosity = 45.4%



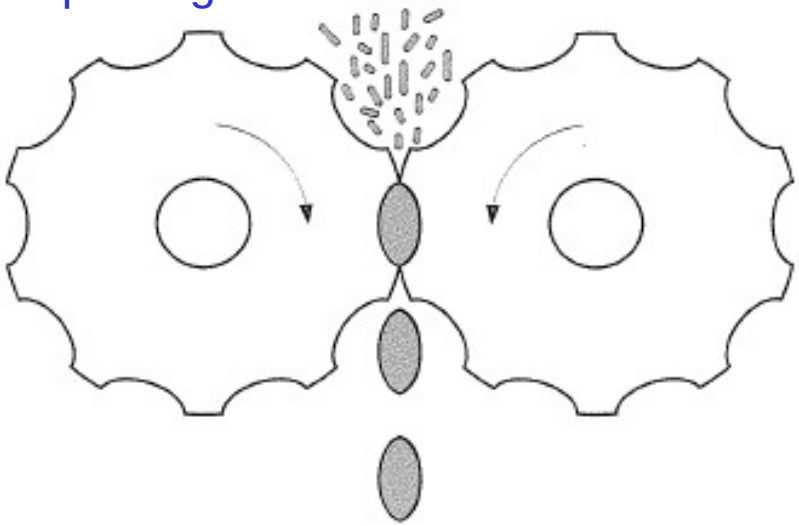
- Lignite (Australian) can be 60% water by mass
- Evaporate the water (large energy input required)
- Compress the coal removes liquid water

MONASH University

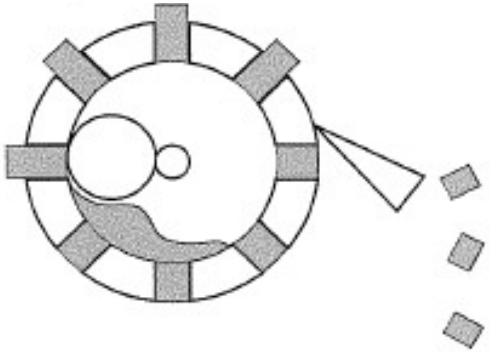
Image source: Dr. Alan Chaffee Monash University

Briquetting, Pelletizing, etc.

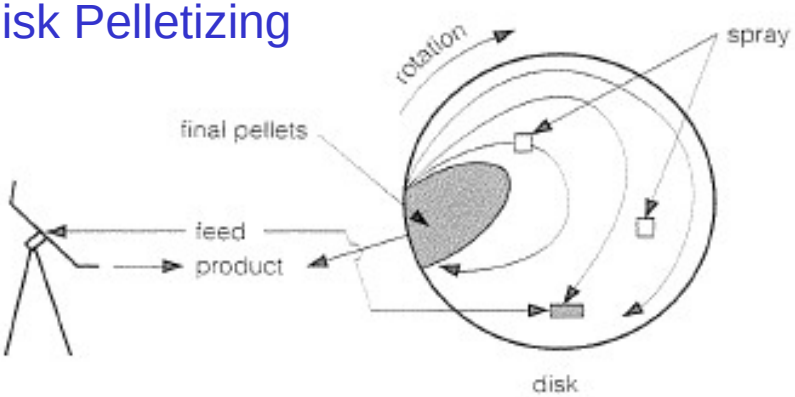
Briquetting



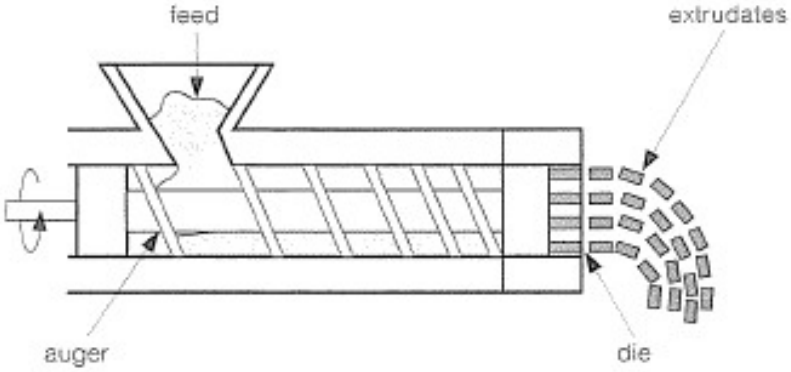
Roll and Die Pelletizing



Disk Pelletizing



Extrusion



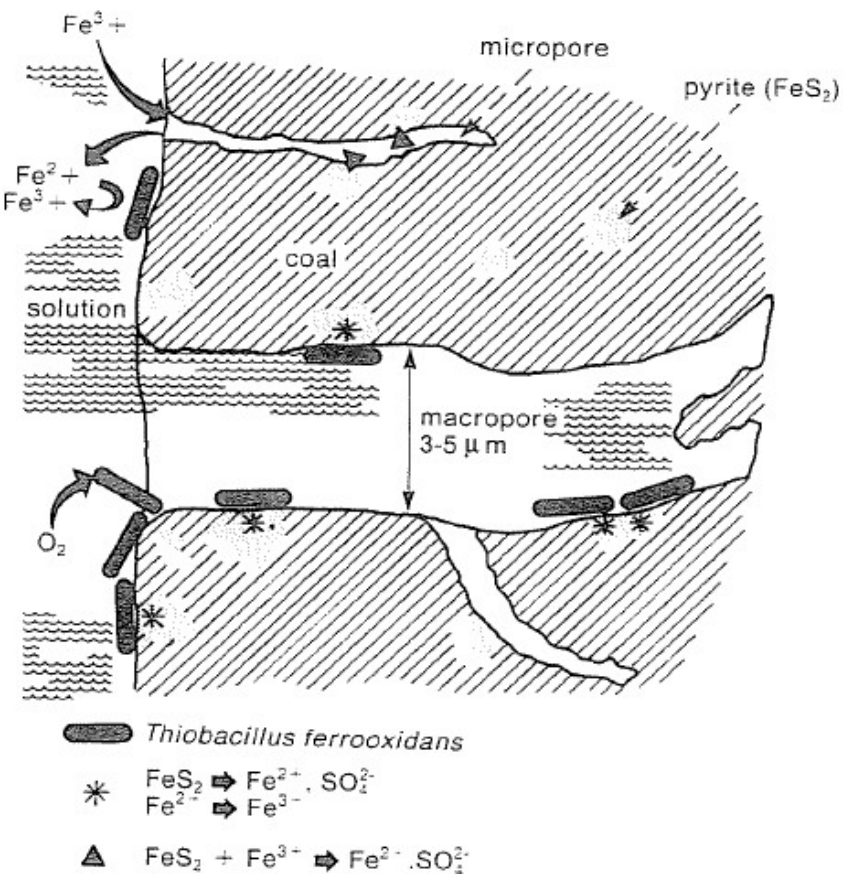
Source: G.R. Couch, *IEA Coal Research*

Coal Blending

Source: Utah Geologic Survey

- Producing a uniform feed coal
- Meeting environmental mandates
- Achieving an appropriate quality of coke
  - 20 or so coals may be blended

Advanced Coal Cleaning



Source: G.R. Couch, Advanced coal cleaning technology, 1991, IEA Coal Research

- Advanced physical coal cleaning
- Bio-desulfurization
- Chemical coal cleaning
- Not economic currently