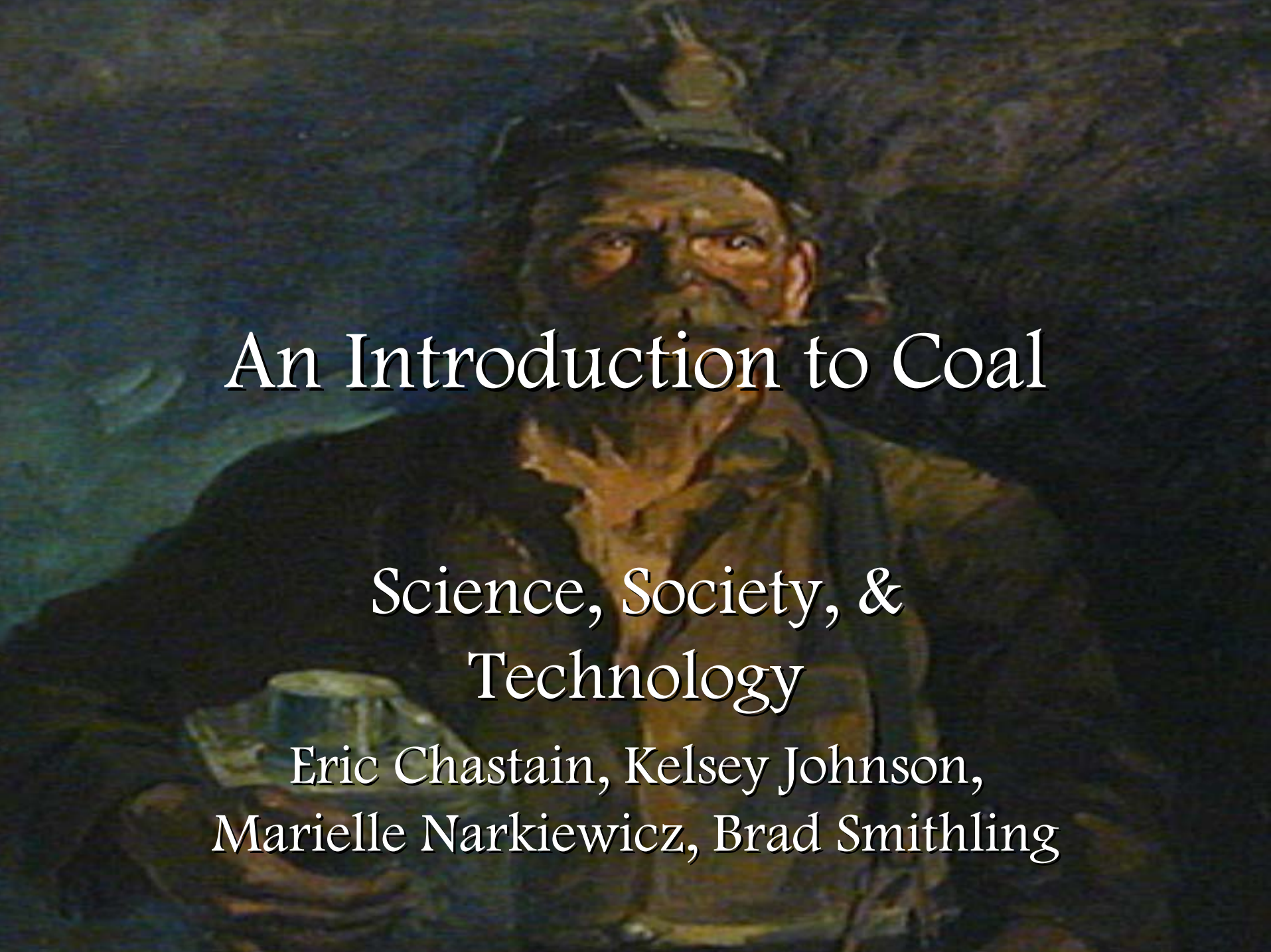

An Introduction to Coal

Science, Society, & Technology

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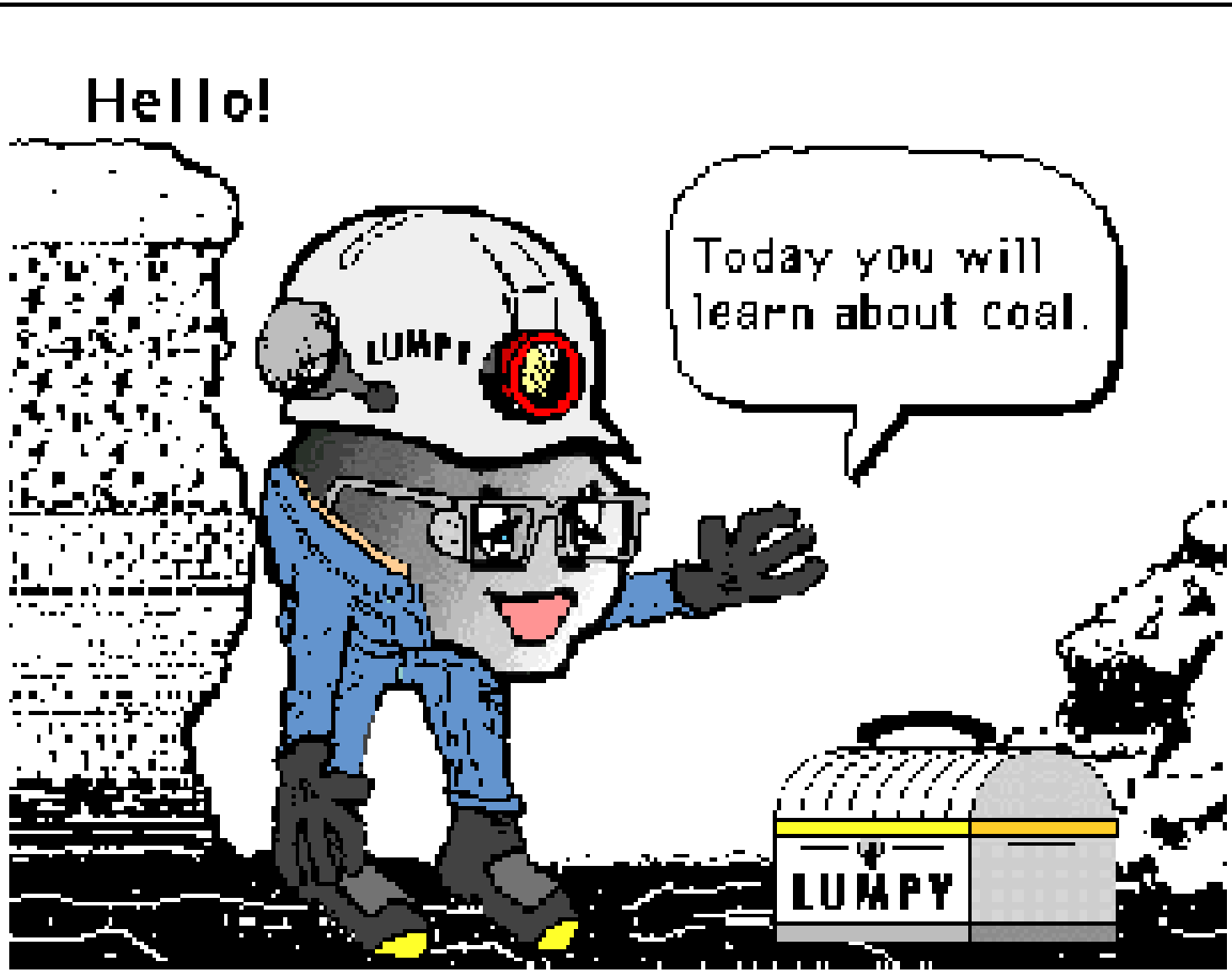
Marielle Narkiewicz, Brad Smithling

Coal Presentation Outline

- Geology
  - Chemistry
  - Formation
  - Rank & Grade
- Geography
  - United States
  - Pennsylvania
- Extraction Procedures
  - Surface
  - Underground
  - Dangers
- Social Impact
  - Miners' Lives
  - Unionization
- Using Coal
  - Heat Engines
  - Technological Advances
    - Iron & Steel Industries
    - Other uses
  - Combustion Products
  - Transportation
- Environmental Impact
  - Land
  - Air
  - Water
- References



Quit Menu Go On

"Coal in truth stands not beside but entirely above all other commodities. It is the material energy of the country~ the universal aid, the factor in everything we do with coal, almost any feat is possible; without it we are thrown back into the laborious poverty of early times" (DiCiccio, 1996).

What is Coal?

- Coal:
  - A sedimentary rock that burns
  - Mineralized vetegatative material deposited over a long period of time (although miniscule geologically)
  - altered chemical composition
  - Formed by increased T and P
  - Partial decay resulting from restricted access to oxygen

Coal Composition

- Carbon > 50%
- Impurities
  - Volatile Matter
  - Sulphur
  - Chlorine
  - Phosphorus
  - Nitrogen
- Trace amounts
  - Dirt
  - Other elements

What is Peat?

- Peat ≠ coal, but is the initial stage in coal formation
- A dark colored, brown to black, spongy substance formed from partial decay of marsh vegetation by moisture and bacteria

What is Organic Matter?

- Plant growth is a function of temperature and precipitation
- With equal precipitation, a colder environment:
  - yields more surface water to sustain life
  - Has slower decomposition rate

  than a warmer environment

OM in Sedimentary Rocks: Bitumen

- largely soluble in organic solvents
- examples:
  - petroleum = a liquid bitumen
  - asphalt = solid/semi-solid bitumen that melts when heated

OM in Sedimentary Rocks: Kerogen

- Largely *in*soluble in organic solvents
- Two types:
  - Sapropelic: from oils, waxes, fats & proteins
  - Humic: from cellulose & lignin

Sapropelic Kerogen

- Composed of lipids & proteins
- Source of OM from which most petroleum forms
  - Generally marine OM is lipid & protein rich; indicating marine source of petroleum OM

Humic Kerogen

- Composed of cellulose & lignin
- Cellulose & Lignin = polymers that give rigidity to terrestrial plants
- Source of OM from which most coal is derived
  - Indicates terrestrial OM as coal source

Destiny of Organic Matter

- 4 possibilities:

1) Exposure to atmospheric oxygen
   →decay, mineralization
2) Restricted contact with atmospheric oxygen
   → rotting, mouldering or humification
3) Immediate submersion of OM
   →peatification
4) Strongly reducing stagnant water
   → putrefaction

Environments of Coal formation

- Fresh-water peat lands
- Upper delta and alluvial plain swamps
- Marshes
- Bogs
- Limnic environments

Coal Formation

Coal formation relies on three factors:

"(1) initiation, maintenance, and repetition of environments that favor large-scale accumulation and preservation of vegetal sediment;

"(2) conditions within this depositional environment that favor biological degradation and alteration of the vegetal sediment to peat [peatification]; and

"(3) geochemical processes that induce chemical coalification of the peat to higher-rank coal."

DiCiccio, 1996

Coal Formation

- Sediment burial, subsidence of peat bogs
  - Completely cuts off contact with atmospheric oxygen
  - Overburden: compaction and subsidence
  - Increase pressure, temperature

Petroleum & Natural Gas formation vs. Coal formation

- Not-so-well-understood differences in formation:
  - Organic matter:
    - Petroleum & Natural Gas: marine OM
    - Coal: terrestrial OM
  - Pressure
  - Temperature
  - Presence of solutions

Coal Rank

- Coal is not homogeneous… it needs classification.
- Describes extent of geologic change and metamorphism since deposition as peat
- Low Rank → High Rank parallels:
  - Loss of recognizable plant remains (macerals)
  - Dull → shiny luster
  - Increasing hardness
  - Increasing Ash content

Coal Rank

Lignite→Subbituminous→Bituminous→Anthracite

Coal Rank

Ranks of Coal	Fixed Carbon	Volatile Matter	Moisture
Lignite	29	26	46
Subbituminous	42	34	23
Low-rank/volatile bituminous	47	41	12
Medium-rank/volatile bituminous	54	41	5
High-rank/volatile bituminous	65	32	3
Low-rank/volatile semibituminous	75	22	3
Semianthracite	86	12	3
Anthracite	96	1.2	3

Coal Grade

- Describes size, appearance, weight, structure, cleanliness, heat value and burning characteristics.
- A: Superior < 8% ash
- B: Good: 8~12% ash
- C: Fair: 12~16% ash
- D: Poor >16% ash

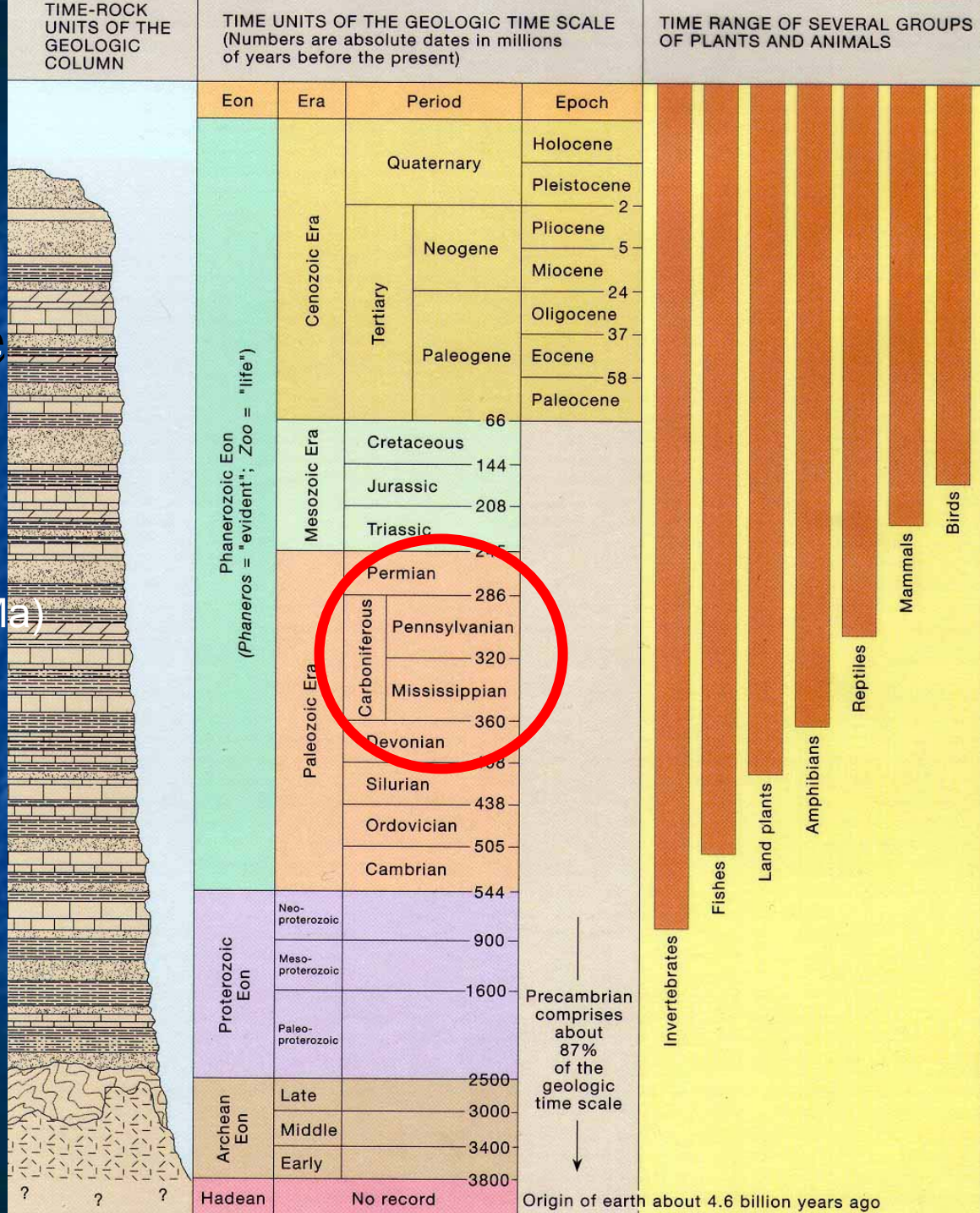
The Standard Geologic Time Scale

Carboniferous Period (354 – 290 Ma)

Mississippian (354-323 Ma)

Pennsylvanian (323-290 Ma)

→ locations of significant deposition of organic matter in what is now North America



Where and *when* did coal form?

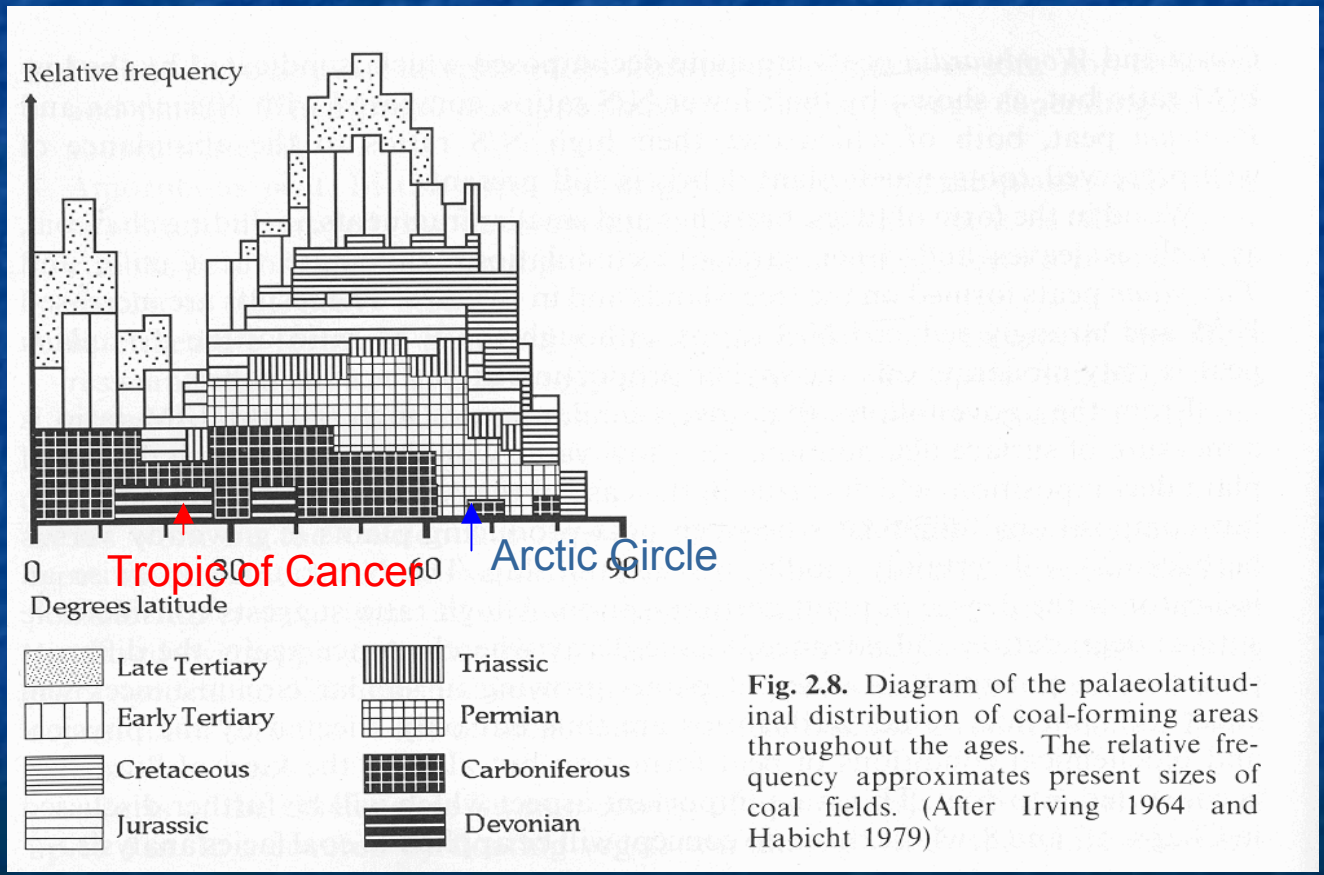


Fig. 2.8. Diagram of the palaeolatitudinal distribution of coal-forming areas throughout the ages. The relative frequency approximates present sizes of coal fields. (After Irving 1964 and Habicht 1979)

Diessel, 1992

Tropical Environment

- 23.5°N to 23.5°S
- Fastest plant growth
- Fastest plant decomposition:

  → cellulose-decomposing bacteria thrive at 35-40° C

Result: Tropics & Subtropics not best-suited to preserve organic matter necessary for coal formation

Temperate Zone

- From 23.5°N to 66°73' N (Arctic Circle) and 23.5°S to 66°73' S (Antarctic Circle)
- 15°-30°: warm, arid zones provide less surface water than colder, arid zones
  - Least OM preservation
- Cool, arid zones slow biochemical decomposition
  - Most abundant OM preservation

Polar Environment

- Higher proportion of undecomposed OM than in tropics
  - Slow growth can yield large peat deposits
- Summer: plant growth
  - extended sunlight hours
  - abundance of moisture → facilitate plant growth
- Winter: plant preservation
  - Severe cold essentially halts decomposition

Why so much polar coal?

- Reasons for abundant coal deposition in polar regions:
  - Change in paleo-tilt of Earth's rotation axis: warmer
  - Fossil greenhouse effect: warmer climate overall
  - Error in data due to plate reconstruction bias toward true north

A Geography of Coal
United States Distribution

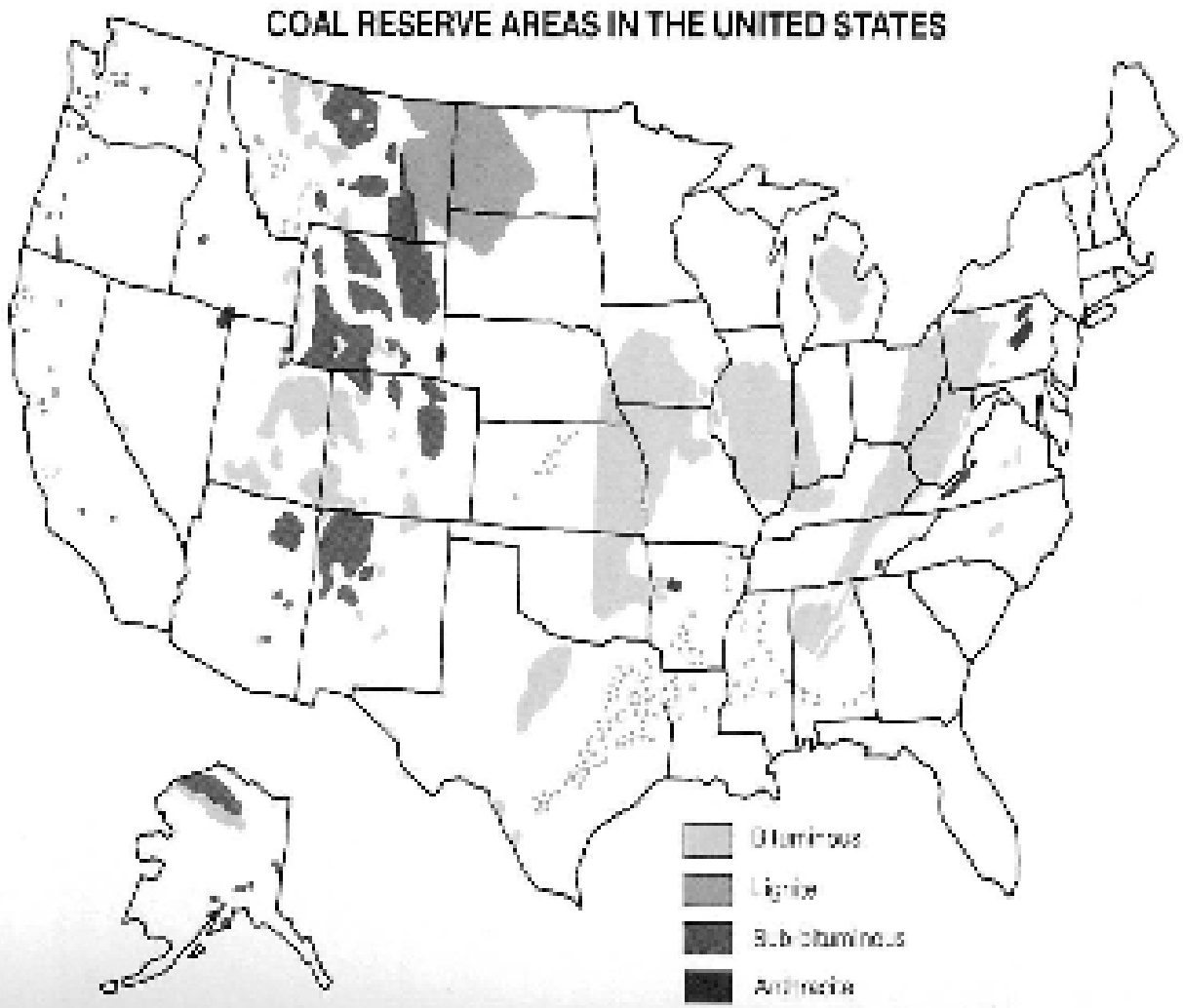
- East Coal Fields
  - Relatively thin seams
  - High heating value
  - High sulfur content
  - Deep burial of seams (mined by deep mining methods)
  - Older~300Ma
- West Coal Fields
  - Relatively thick seams
  - Low heating value
  - Low sulfur content
  - Shallow burial of seams (mined by surface mining)
  - Younger~ 100Ma

A Geography of Coal
United States Distribution

- US has largest deposits of coal in the world
- The original reserves were made up of 29% lignite, 28% subbituminous, 42% bituminous, and <1% anthracite.
- The original reserves were divided into seven regions:
  - Anthracite Region
  - Appalachian/Eastern Region
  - Middle Western Region
  - Western Region
  - Southwestern Region
  - Rocky Mountain Region
  - Pacific Coast Region

A Geography of Coal
United States Distribution

- **Lignite:** North and South Dakota, Montana, and Texas
- **Subbituminous:** Alaska, Colorado, Montana, and New Mexico
- **Bituminous:** Pennsylvania, Maryland, West Virginia, Alabama, Arkansas, and Oklahoma
- **Anthracite:** Pennsylvania, Alaska, Arkansas, Colorado, Massachusetts, Rhode Island, New Mexico, Utah, Virginia, Washington, and West Virginia



MAP 2. Coal Reserve Areas in the United States

Source: National Coal Association, Coal Facts, 1978-1979.

US Coal Production by State		
(Thousand short tons)		
State	**1997 Total**	**% of Tot.**
Wyoming	281,881	25.9
West VA	173,743	15.9
Kentucky	155,853	14.3
Pennsylvania	76,198	7.0
Texas	53,328	4.9
Illinois	41,159	3.8
Montana	41,005	3.8
Virginia	35,837	3.5
Indiana	35,497	3.2
North Dakota	29,580	2.7
Ohio	29,154	2.7
Utah	26,683	2.4

State	1997 Total	% of Tot.
Colorado	27,449	2.5
Alabama	24,468	2.2
New Mexico	27,025	2.5
Arizona	11,723	1.1
Washington	4,495	0.4
Maryland	4,160	0.4
Tennessee	3,300	0.3
Louisiana	3,545	0.3
Oklahoma	1,621	0.1
Alaska	1,450	0.1
Missouri	401	*
Kansas	360	*
Arkansas	18	*
Total U.S.	1,089,932	100.0

A Geography of Coal
United States Distribution

- Anthracite coal was first found in Rhode Island and Massachusetts in 1760; Bituminous coal was first found in Illinois in 1679.
- Earliest record of commercial mining was in 1750
- Bituminous coal production increased from 43 million tons in 1880 to 569 million tons in 1920. The number of mines increased from 100,257 in 1880 to 639,542 in 1920.

A Geography of Coal
Pennsylvania Distribution

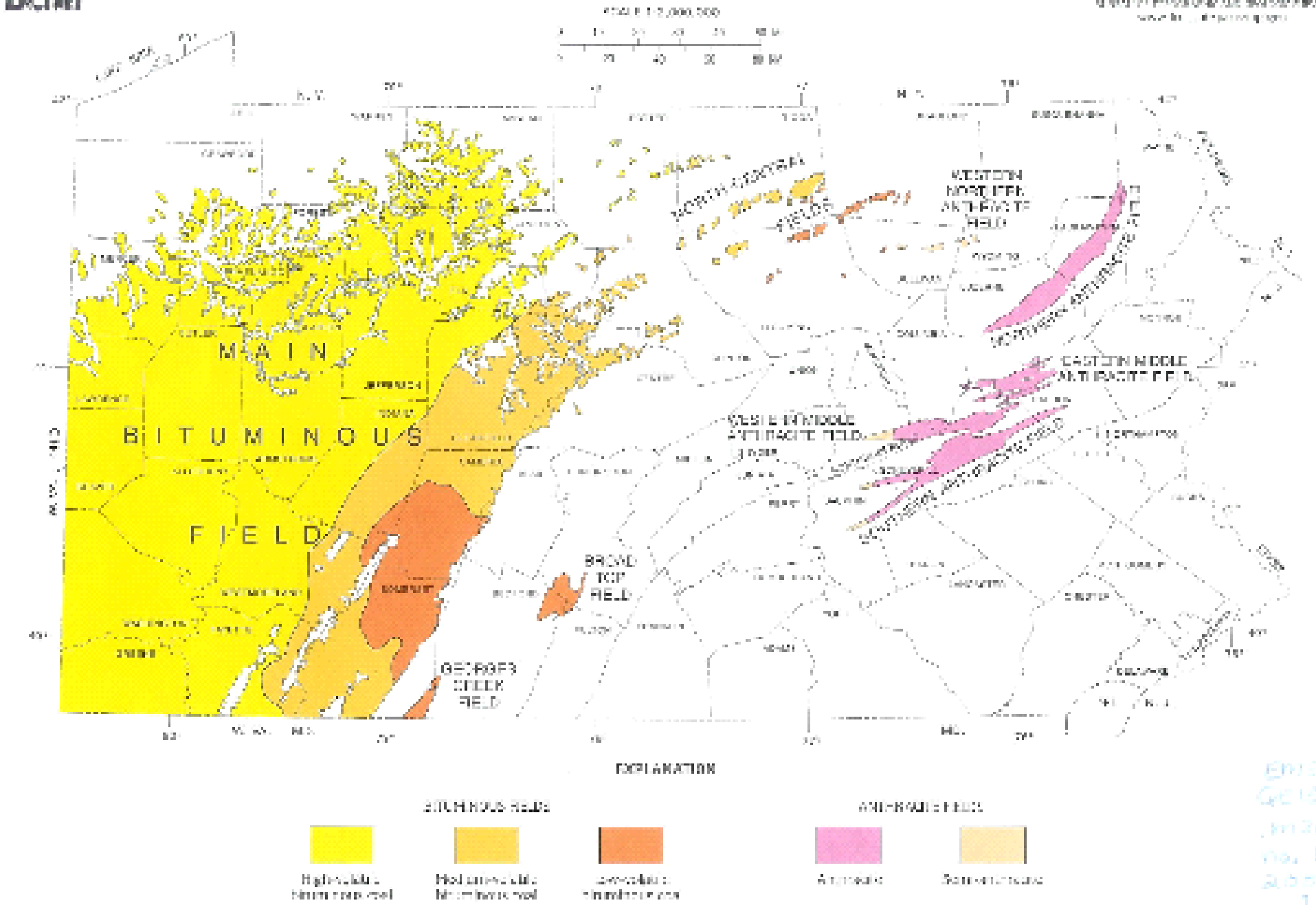
- Three kinds of bituminous coal- caking, non caking, and cannel.
- Earliest miners were farmers. They would lease their land to workers or would mine it themselves.
- Pittsburgh seam most important because it yielded more mineral value than any other seam in the world.
  - By 1830, Pittsburgh consuming four hundred tons of bituminous coal per day for domestic and light industrial uses.
  - Residential coal burning:
    - In 1810, Pittsburgh known as the "smoky city" because of transition from wood to coal as a household fuel.

A Geography of Coal
Pennsylvania Distribution

- Anthracite coal first found in Pennsylvania in 1762
- The Anthracite fields are also divided into regions:
  - Northern (Luzerne, and Lackawanna counties~ 50mi long and 6mi wide) occupies valley or basin.
  - Western Middle (Northumberland, Columbia, and Schuylkill counties~ 36mi long and 4mi wide) occupies valley or basin.
  - Eastern Middle (centered on Luzerne extending to Schuylkill, and Columbia counties~ 26mi long and 10mi wide) occupies a plateau – table land
  - Southern (Schuylkill, Carbon, Dauphin, and Lebanon counties~ 70mi long and 8mi wide) occupies a valley or basin.

MAP 11

DISTRIBUTION OF PENNSYLVANIA COALS



A Geography of Coal
Pennsylvania Distribution

- Important Counties
  - Armstrong~ cannel coal first mined; commercial mining occurred around 1899 when Cowanashannock Coal and Coke Co. opened.
  - Somerset~ mining began around the late 1770's; first RR constructed here in 1872; first coal town was built here in 1872.
  - Cambria~ mined 4 important seams.
  - Indiana~ Coal was mined around 1760's; salt making important here; Rochester & Pittsburgh Coal Co founded in 1881.
  - Jefferson~ Rochester & Pittsburgh Coal Co occupied 6000acres near Punxsutawney.

Coal Extraction

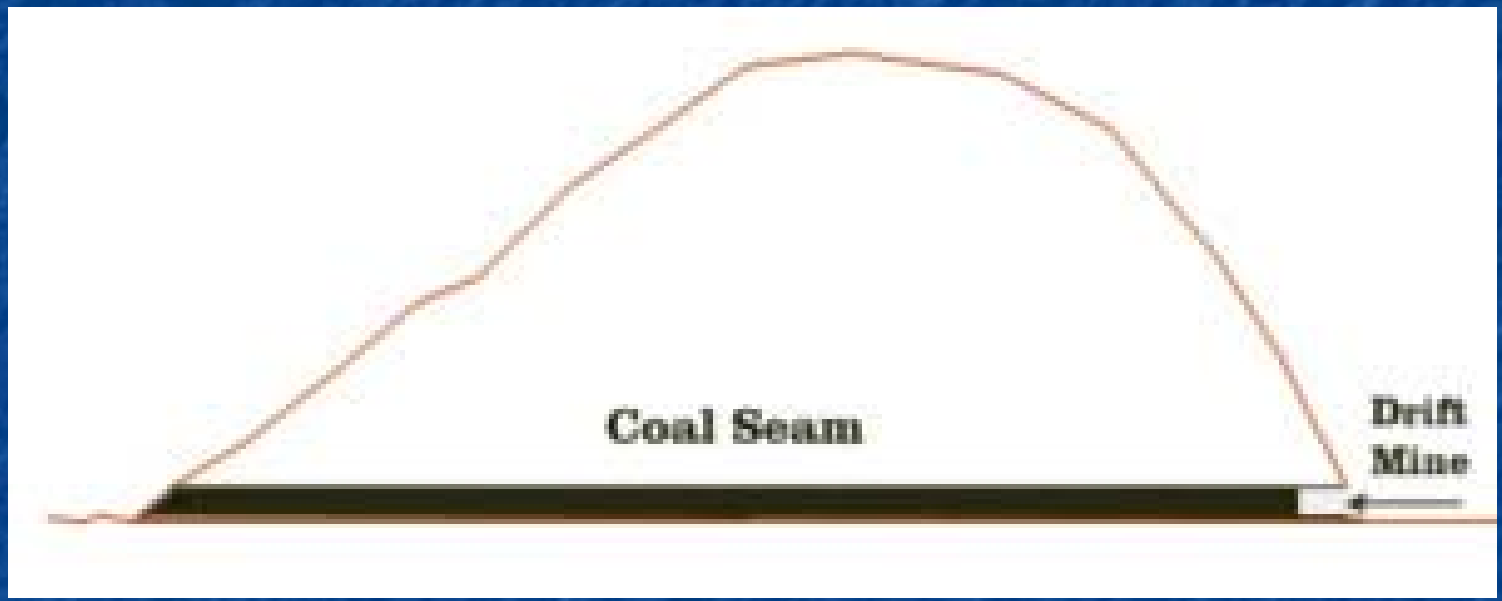
- Open Pit Mining
  - Most minerals are extracted this way
  - For near-surface ore bodies
  - Series of 'benches' are cut

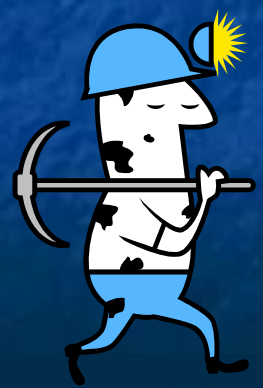
Surface Mining

Underground Mining

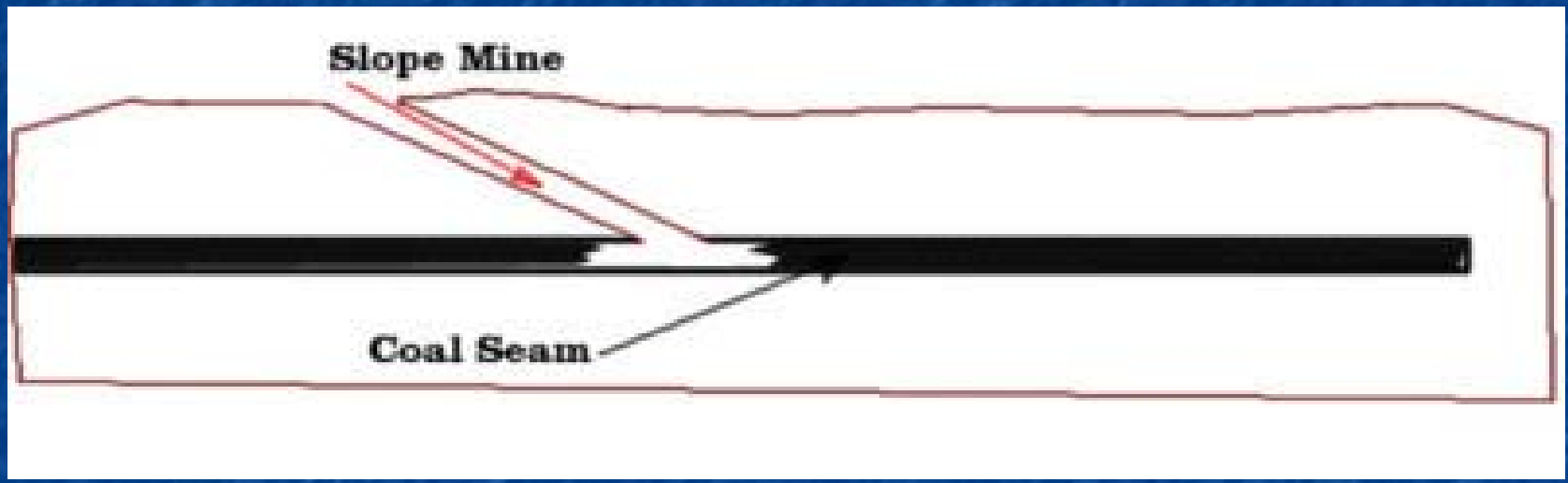
- Used when ore is far below surface
- Features:
  - Vertical shaft or inclined passageway
  - Drifts and crosscuts created to expose face
- Broken rock hauled from face and up to the surface

Underground Mining: Drift

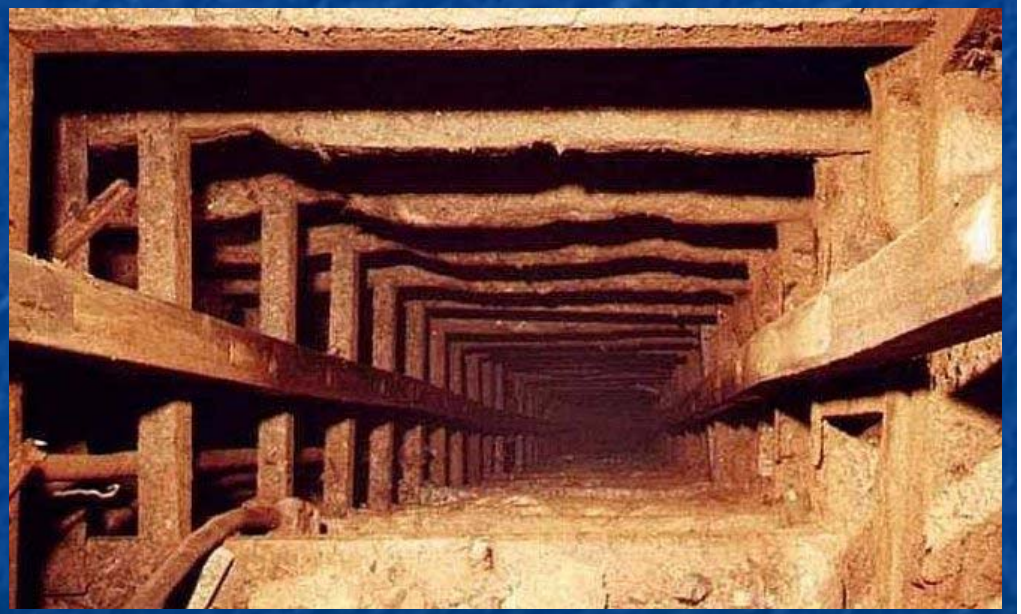


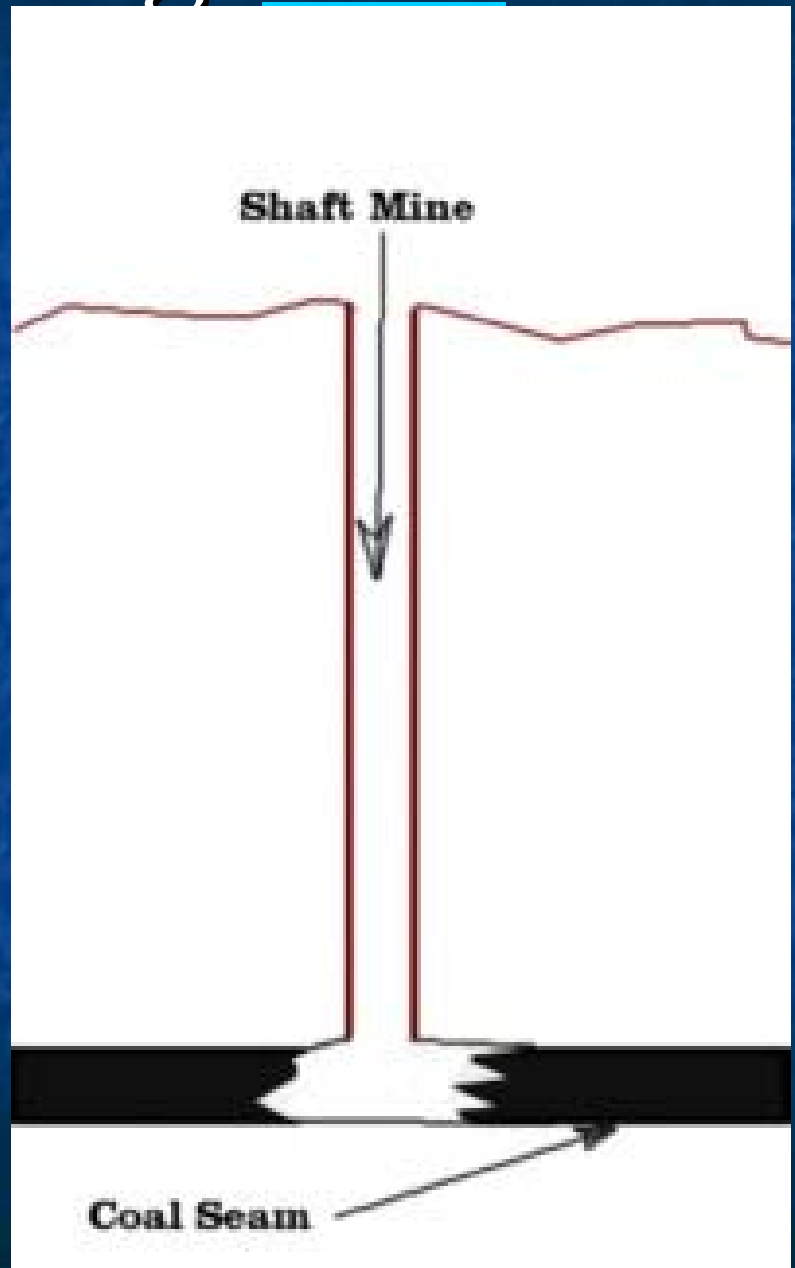


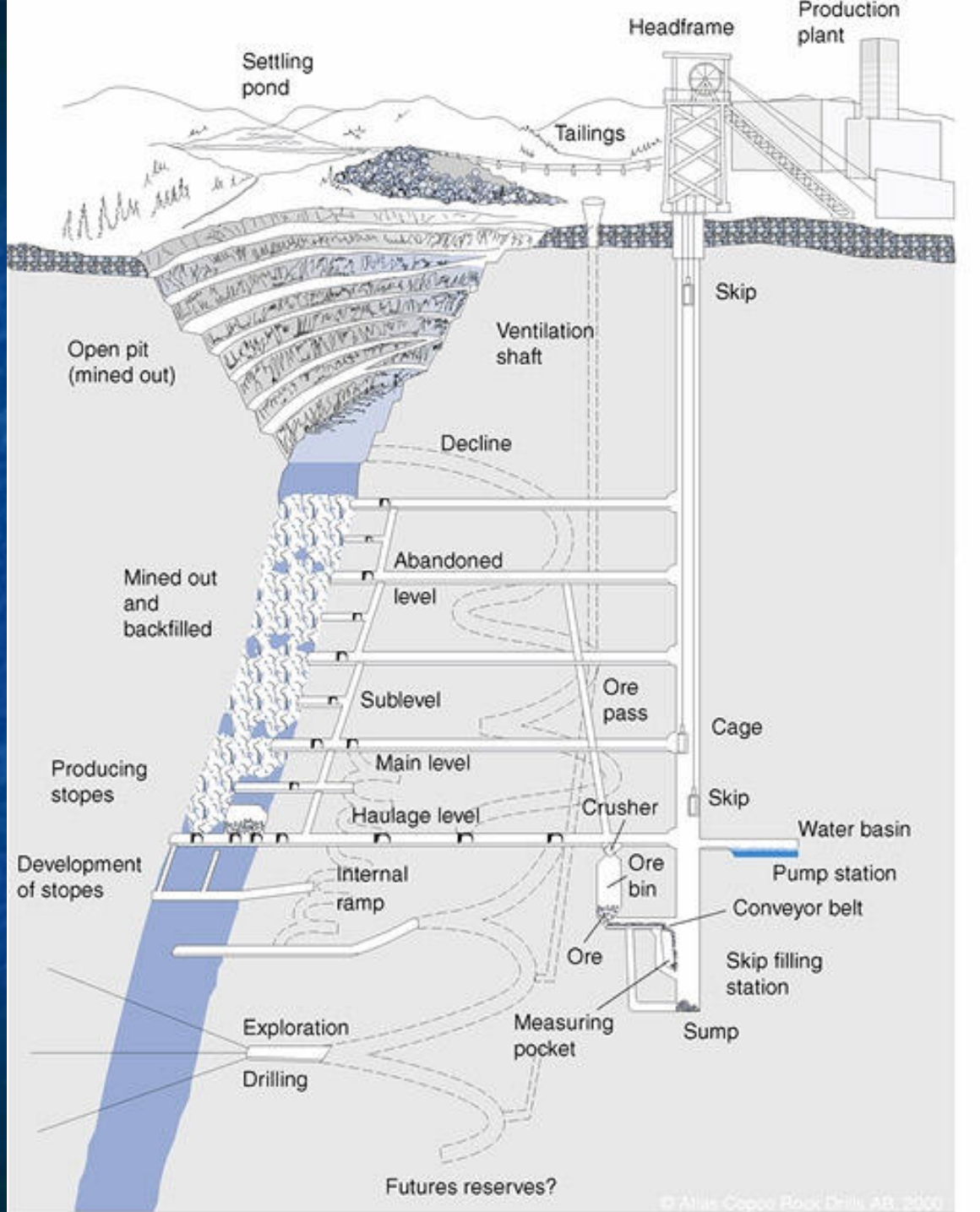
Underground Mining: Slope



Underground Mining: Shaft

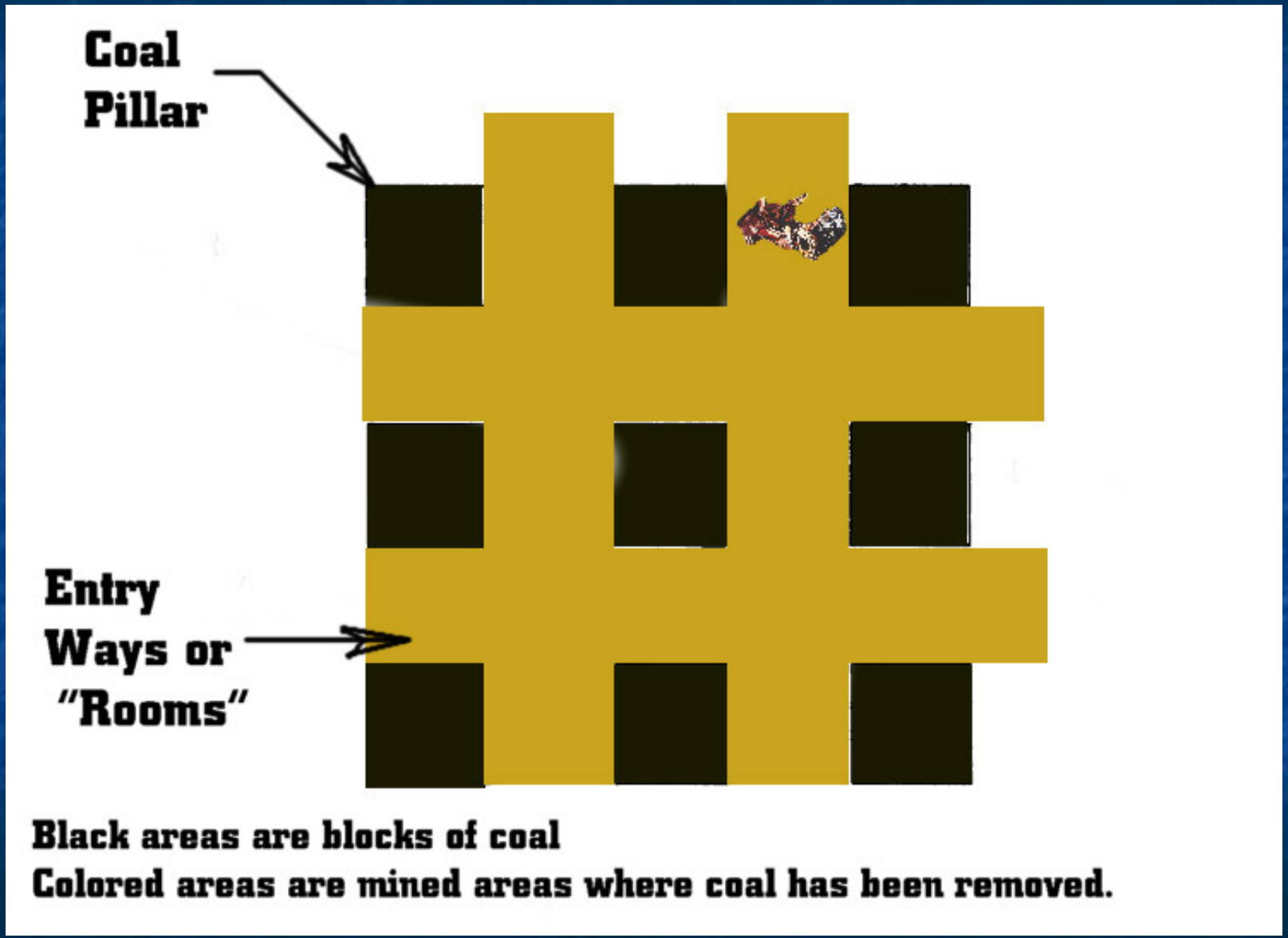




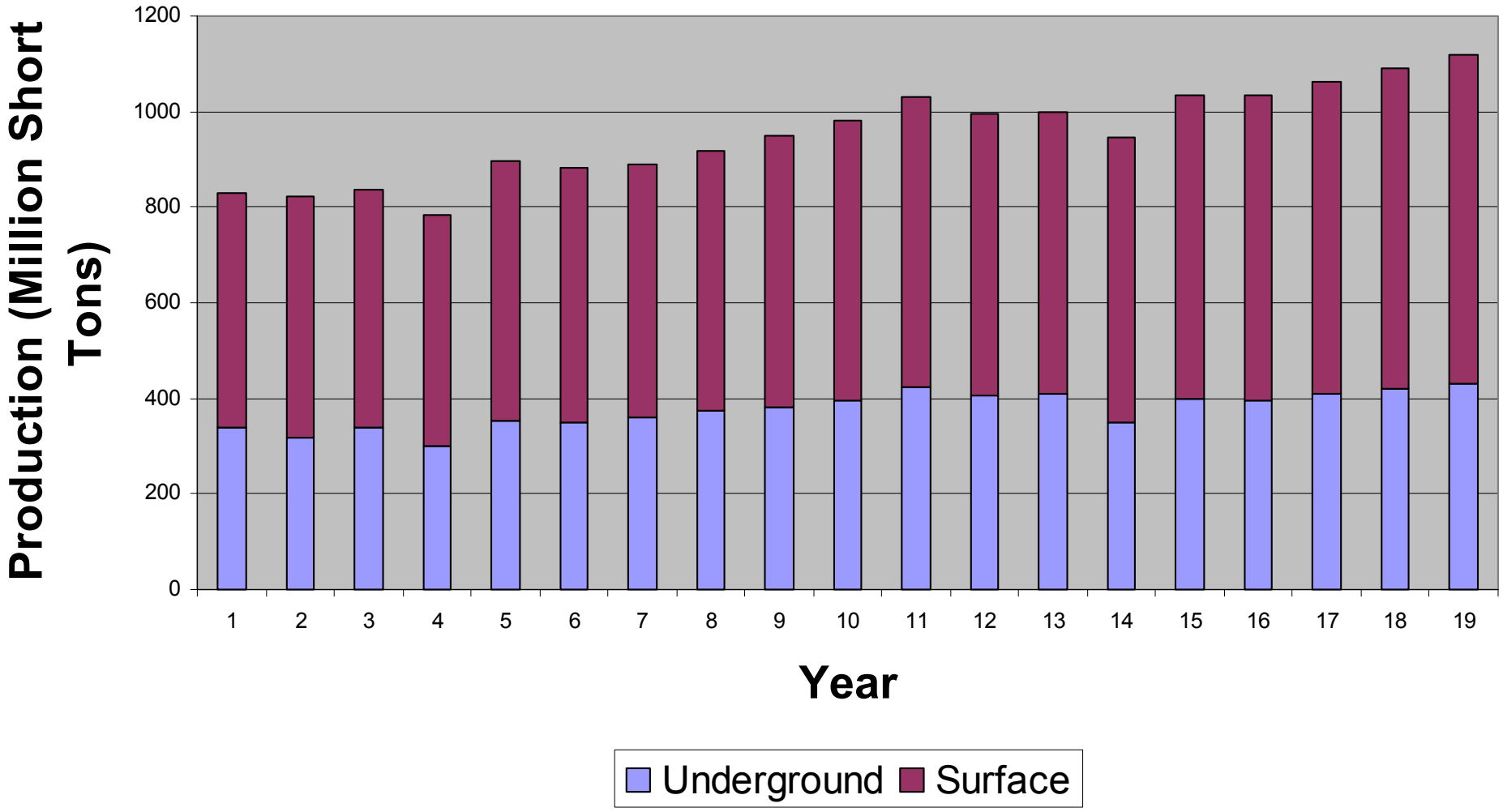

Headframe
Production plant
Settling pond
Tailings
Skip
Ventilation shaft
Open pit (mined out)
Decline
Abandoned level
Mined out and backfilled
Sublevel
Ore pass
Cage
Producing stopes
Main level
Skip
Haulage level
Crusher
Water basin
Development of stopes
Internal ramp
Ore bin
Pump station
Conveyor belt
Ore
Skip filling station
Exploration
Drilling
Measuring pocket
Sump
Futures reserves?

Longwall Mining

Room & Pillar Mining



U.S. Coal Production



Understanding Coal Resources

- Total Resources

  Total amount of coal on Earth

- Identified Resources

  Amount of coal we know about

- Demonstrated Reserve Base

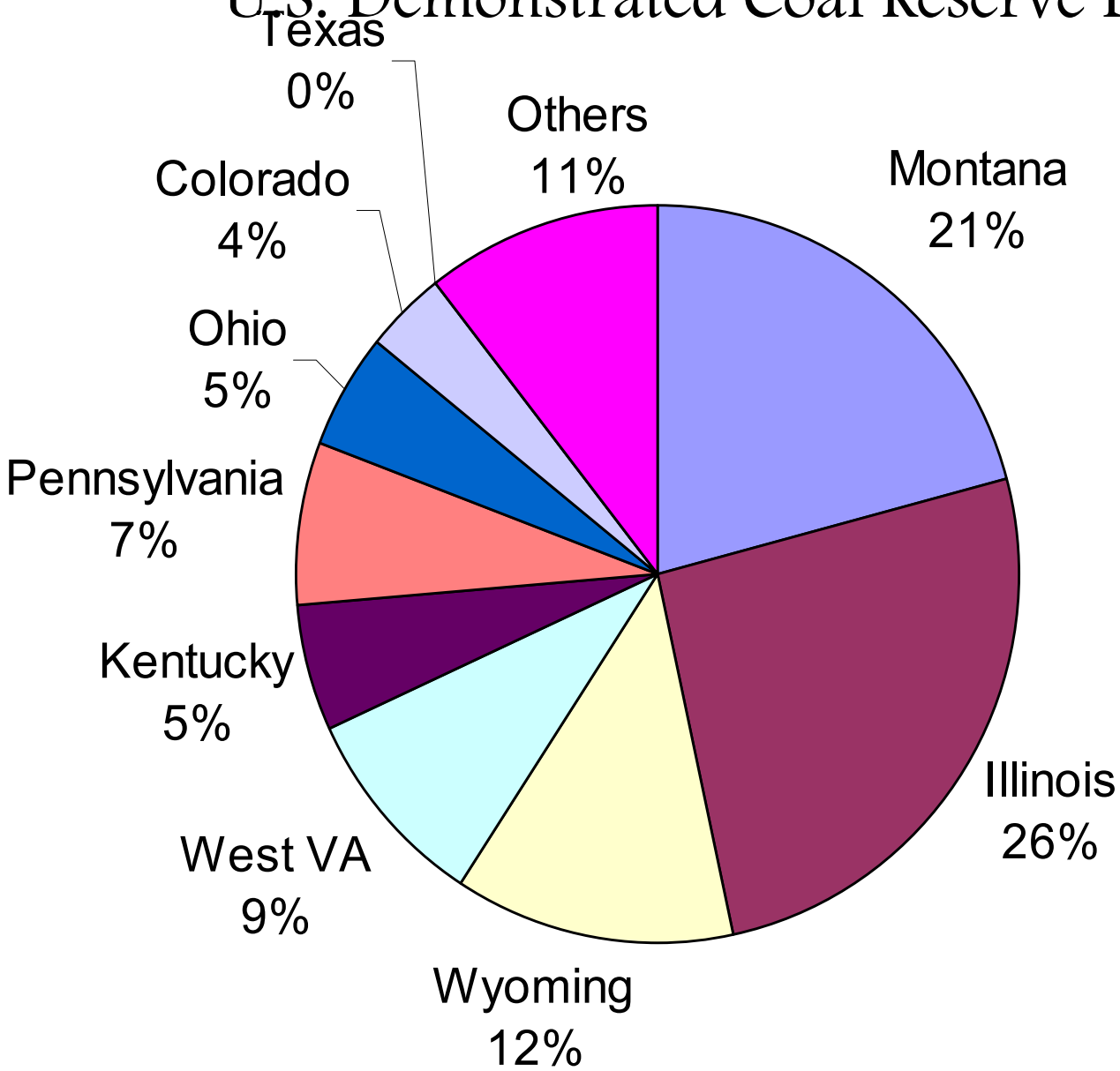
  Coal that can be reached by humans for extraction

- Recoverable Reserves

  Coal that can be extracted for a profit

Each step down is a reduction in the amount of coal contained from the previous level.

U.S. Demonstrated Coal Reserve Base



So about this coal stuff…

It's a major domestic electricity source

+

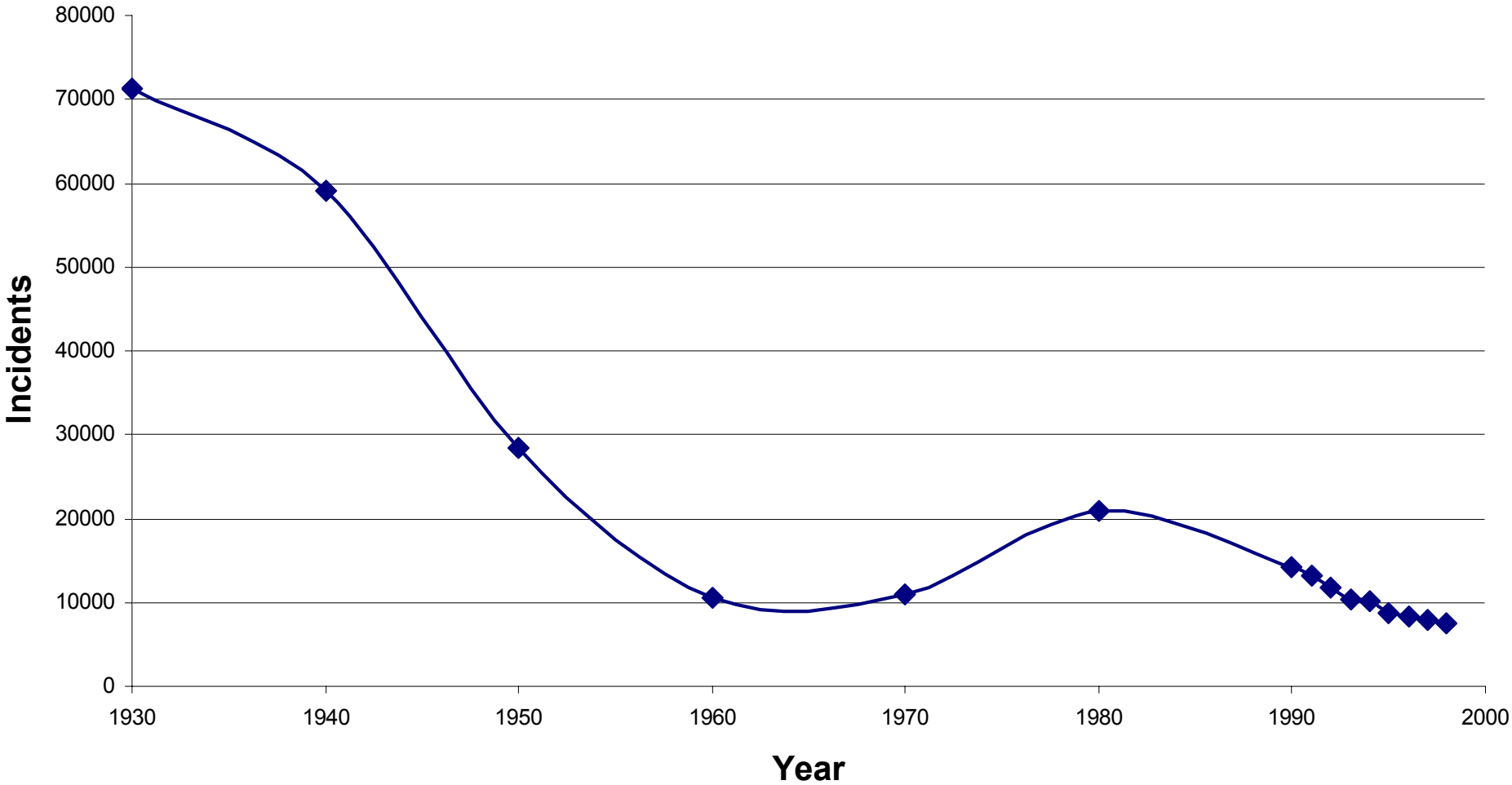
Cheapest energy available today

=

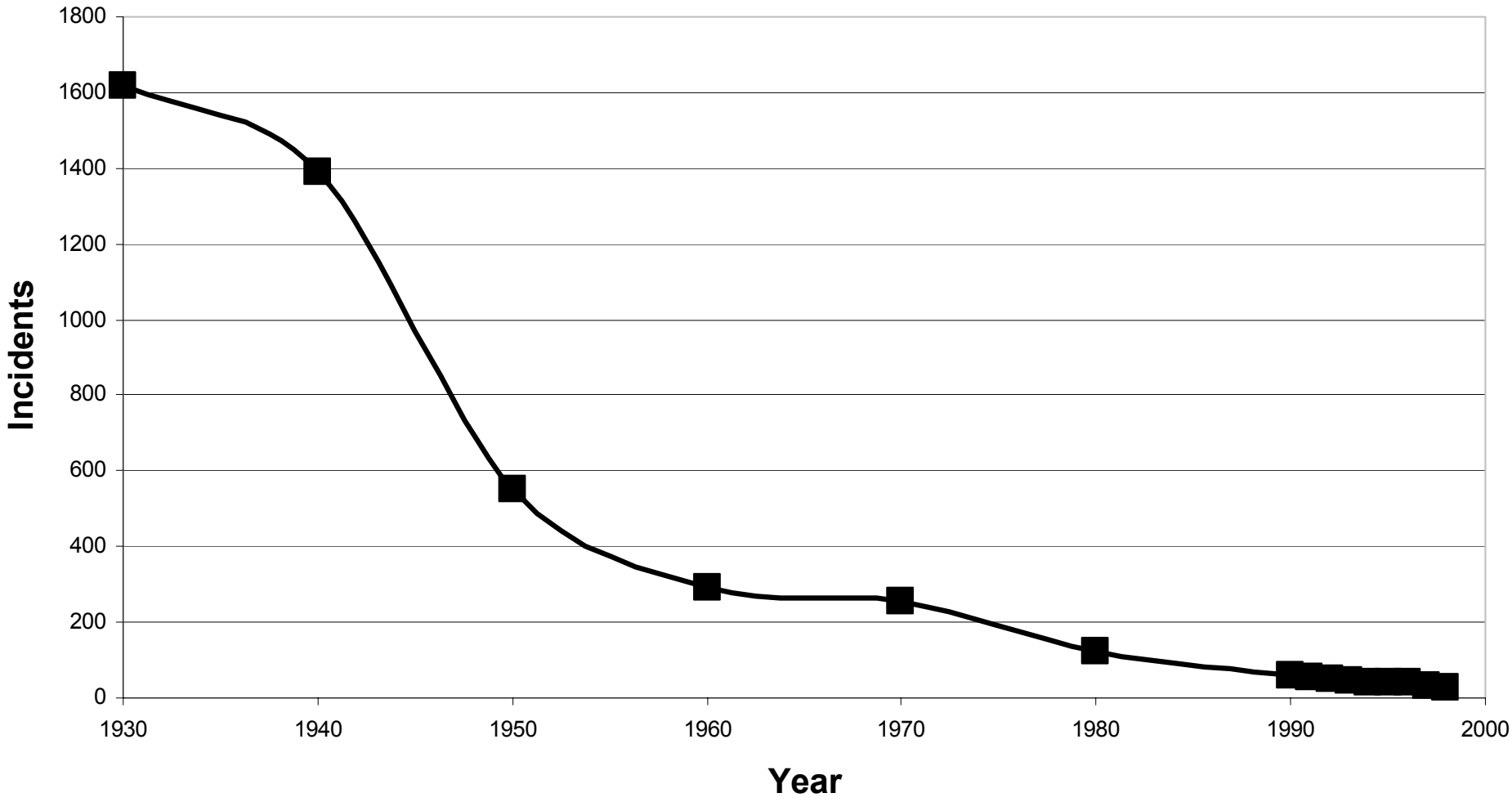
Tremendous reliance on coal

- Technological advances lead to safety and environmental improvements

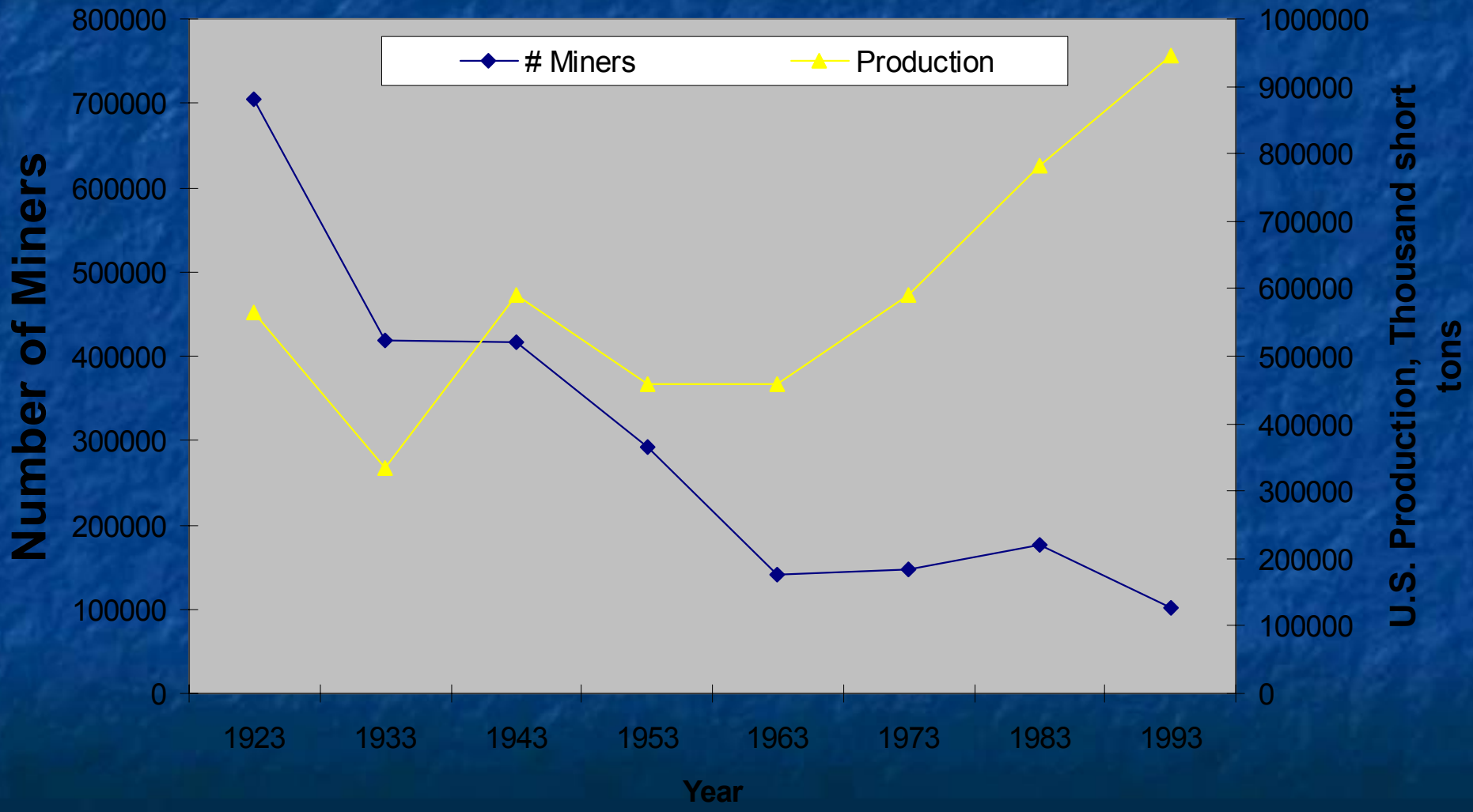
Coal Mine Injuries



Coal Mine Fatalities



Trends in U.S. Coal Mining



General Information

- Transportation~ Monongahela Navigation Co; flatboats and barges to steam boats; Railroads.
- Alternative Energy Sources~ Between 1900 and 1920 oil markets increased and coal markets decreased. Reasons why~ competition of other sources, increasing efficiency, overdevelopment of mines, and The Great Depression.
- Mechanization of the Mine~ caused a smaller workforce and more unemployment, increased level of dust and thus risk of explosions, pace quickened~man became more regimented.


DANGER

Social Effects

- Mine disasters
  - Roof falls, moving coal, explosions and other (as of 1928 they were: 60%, 20%, 10%, and 10% respectively).

- Safety Measures
  - Rock dusting, inspection of hazardous sites,
  - good lighting, screening and moving parts of
  - machinery, marked safety exits, and employ a
  - trained crew and hospital room in the mine.

Coal Fires - A Global Problem

Social Effects

- "Patch" Towns, coal mining villages
  - "A company town is any community which has been built wholly to support the operations of a single company in which all homes, and other property is owned by that company, erected for the benefit of its employees and in which the company provides most public services" (Alley, 1996).
  - A miner's diet: For lunch a scrumptious soup of coffee and bread, then for dinner our specialty, the water sandwich served with a side of bulldog gravy and miner's strawberries. Bon Apatite!

Social Effects

- Family Life
- A woman's work is never done!
  - Gathered firewood, and coal lumps left in the culm bank waste.
  - They met the beer wagon to get buckets of beer for the returning husbands.
  - Gathered hot water, and scrubbed the coal dust husbands and sons.
  - Cleaned and prepared their deceased loved ones, after the company wagon deposited the corpses at their homes.

Profile of the U.S. Coal Miner, 1997

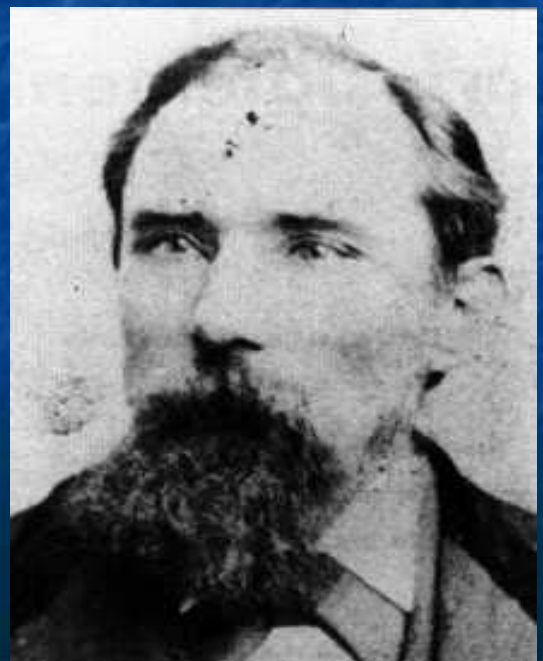
- Age (mean) 45
- Education (percent)
  - High School Diploma 54
  - Vocational School Diploma 8
  - Some College 10
  - College Degree 5
- Work Experience (median, years) 20
- Job-related training during last two years (median, hours) 35
- Earnings:
  - Average Hourly $19.01
  - Average Weekly $863.05

Social Effects

- Immigration
- Secret Societies
  - The Ancient Order of Hibernians a.k.a The Molly Maguires

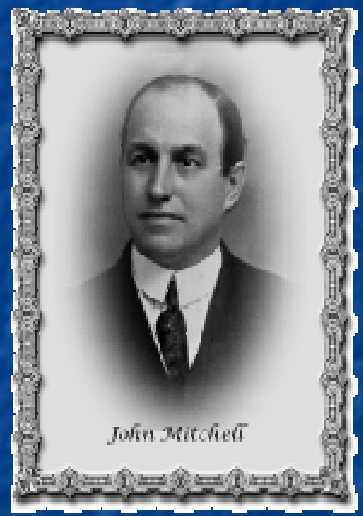
James McParlan a.k.a. Jack McKenna

John "Black Jack" Kehoe



Social Effects

- Miner's Unionization
  - Mary Harris "Mother" Jones
  - John Mitchell
  - John L. Lewis



Using Coal

- Used for heating as early as the time of cavemen and by the Romans in 100-200 A.D.

Early Commercial Coal Burning

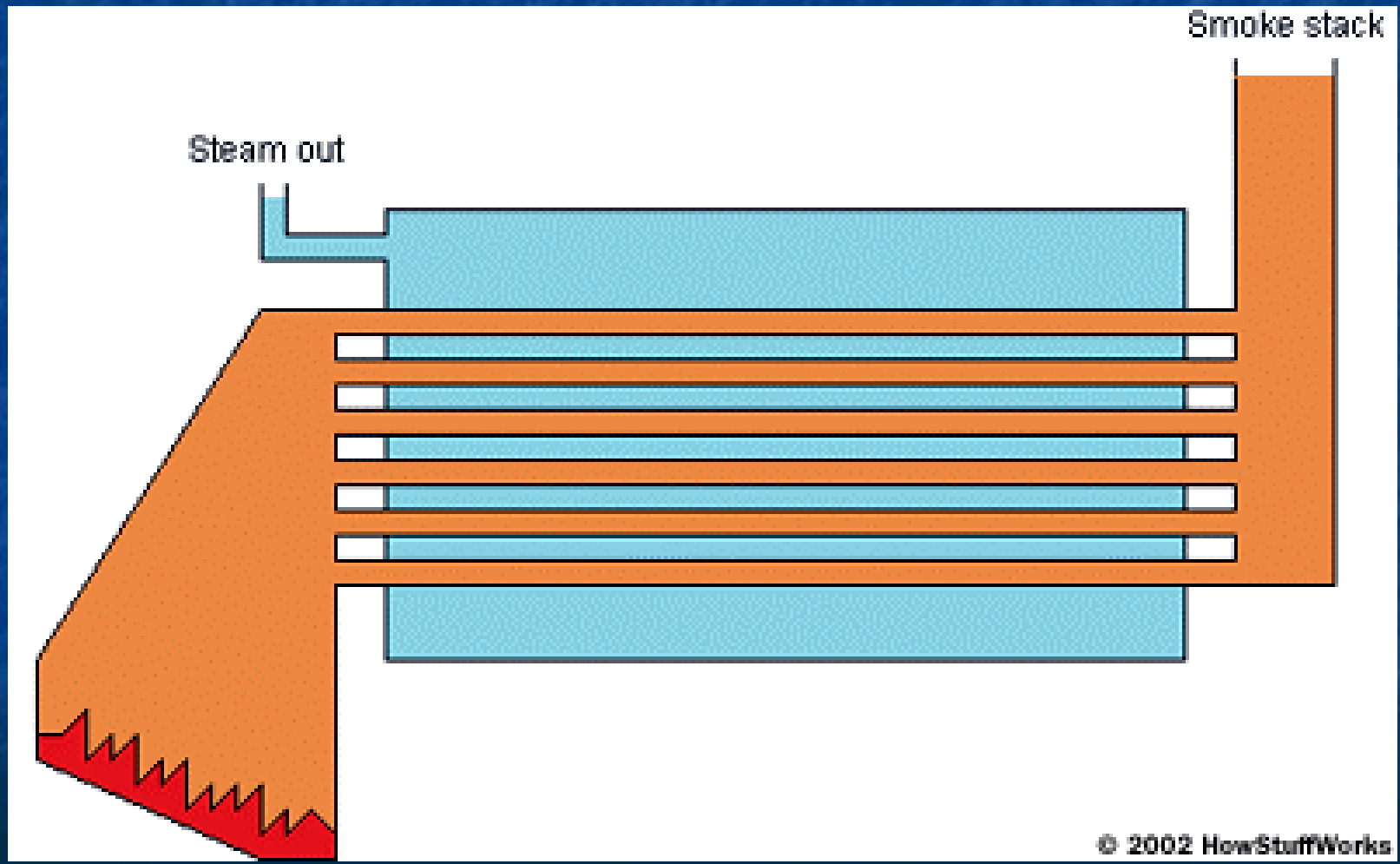
Early 1800's Commercial Coal Burning Uses

- Saltmaking~ Coal-fired steam boilers used to separate salt from brine.
- Iron Industry ~ Coal used for heating iron ore and to make Coke
- Steam engines~ used to drive machinery at flouring mills, gristmills, rolling mills, breweries, glass manufactories, and nail factories. Also used in trains and steamships.

The Salt making Industry

- In 1825:
  - Over 200,000 tons of coal per year were being used by the salt industry to produce salt for domestic consumption.
- By 1830:
  - Had become a major industry in Armstrong and Indiana Counties in western Pennsylvania.
  - 24 salt wells dug, producing 65,000 tons of salt.
- From 1815-1870:
  - ~100,000 tons of bituminous coal consumed annually by the salt making industry.

Coal-Fired Steam Boilers



The Iron Industry

- The problem =

  How to obtain pure iron from iron ore (rock with various minerals, but a high percentage of iron).

- **Hematite** - Fe_2O_3 - 70 % iron
- **Magnetite** - Fe_3O_4 – 72 % iron
- **Limonite** - $Fe_2O_3 + H2O$ - 50 to 66 % iron
- **Siderite** - $FeCO_3$ - 48 % iron

The Answer = Smelting

- When carbon is added to Iron Ore at high temperatures and in the presence of added oxygen from an external source (i.e. a blower or fan), it reacts with the added oxygen to form CO_2 (Carbon Dioxide) and CO (Carbon Monoxide). These molecules then react with the oxygen in the iron ore and leave pure iron. This process is known as smelting.
- Coal used in the heating of the ore
- Common types of smelting are bloomeries and blast furnaces.

Where Does The Carbon Come From?

- Charcoal: pure carbon obtained from heating wood at high temperatures. This heating evaporates volatile organic compounds and leaves essentially pure carbon.
- Charcoal was the originally used source of carbon in iron smelting. However, population growth and rapid industrial development caused an increase in price and resulted in a declining source of supply (trees) created need for a cheaper substitute for the charcoal.

Welcome to Coke-Land

- Coke = charcoal made from coal
- Heating value – 25million BTU's/ton
- Process of coke-making discovered in Sixteenth Century England:. Originally called ("charking").
- Obtained by heating coal at high temperatures (900-1150 °C) in the absence of oxygen; much the same way as charcoal was made from wood.

Coke-Making (Carbonization)

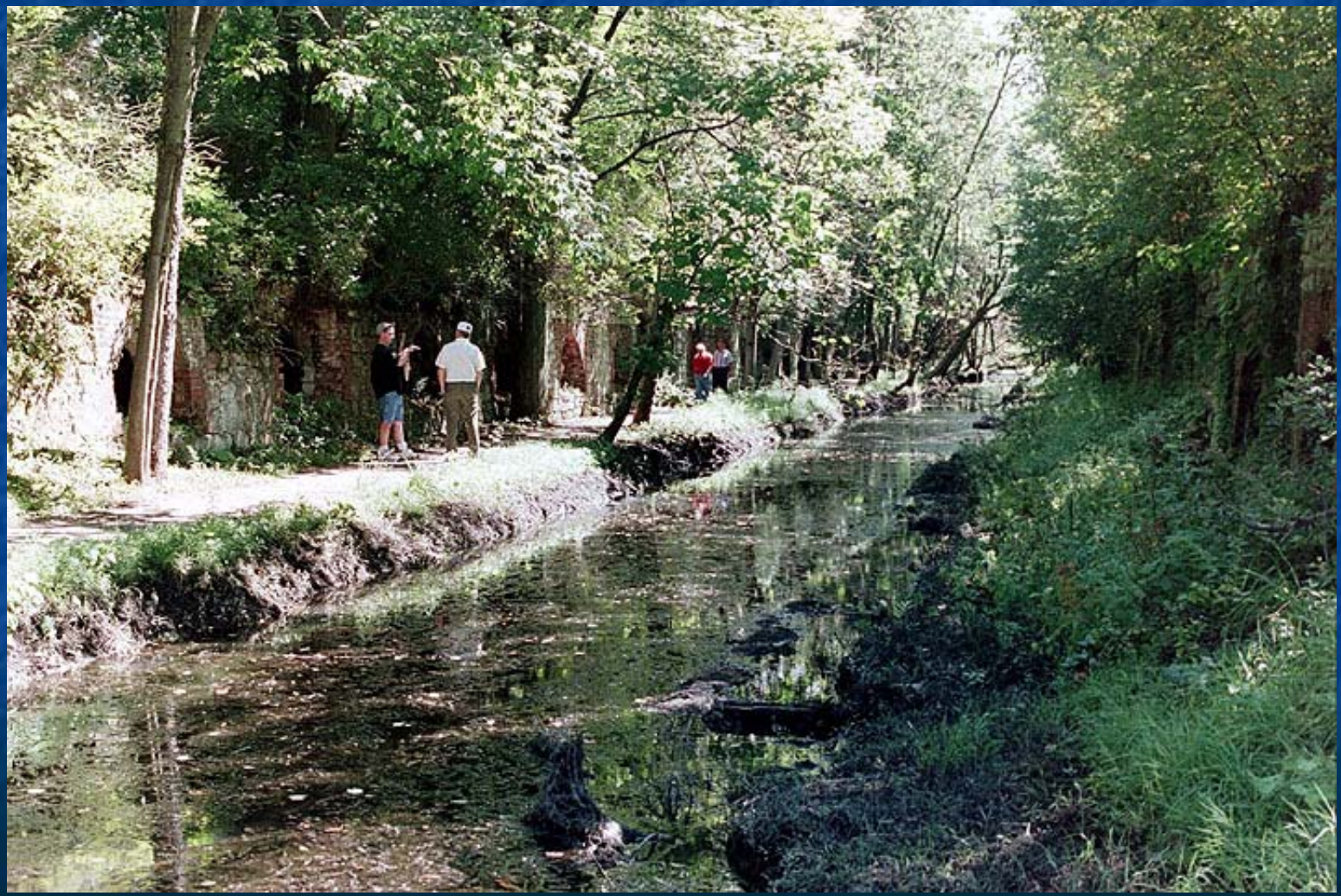
- First Pennsylvania Coke manufactured and used in Brownsville, Fayette County.
- Original method was to make coke in pits (also known as “ricks” or “racks”). This proved an inefficient, inconsistent, and slow method, yielding <55% coke from the original coal. This process sometimes took up to 8 days.

Beehive Coke Ovens

- First “Beehive” coke oven was made in Connellsville, Fayette County, PA during the 1830’s.
- Widespread use of these ovens was delayed until the 1850’s.
- These ovens proved much more efficient, producing coke with carbon contents of up to 67%.

Beehive Coke Ovens

Beehive Oven “Banks”



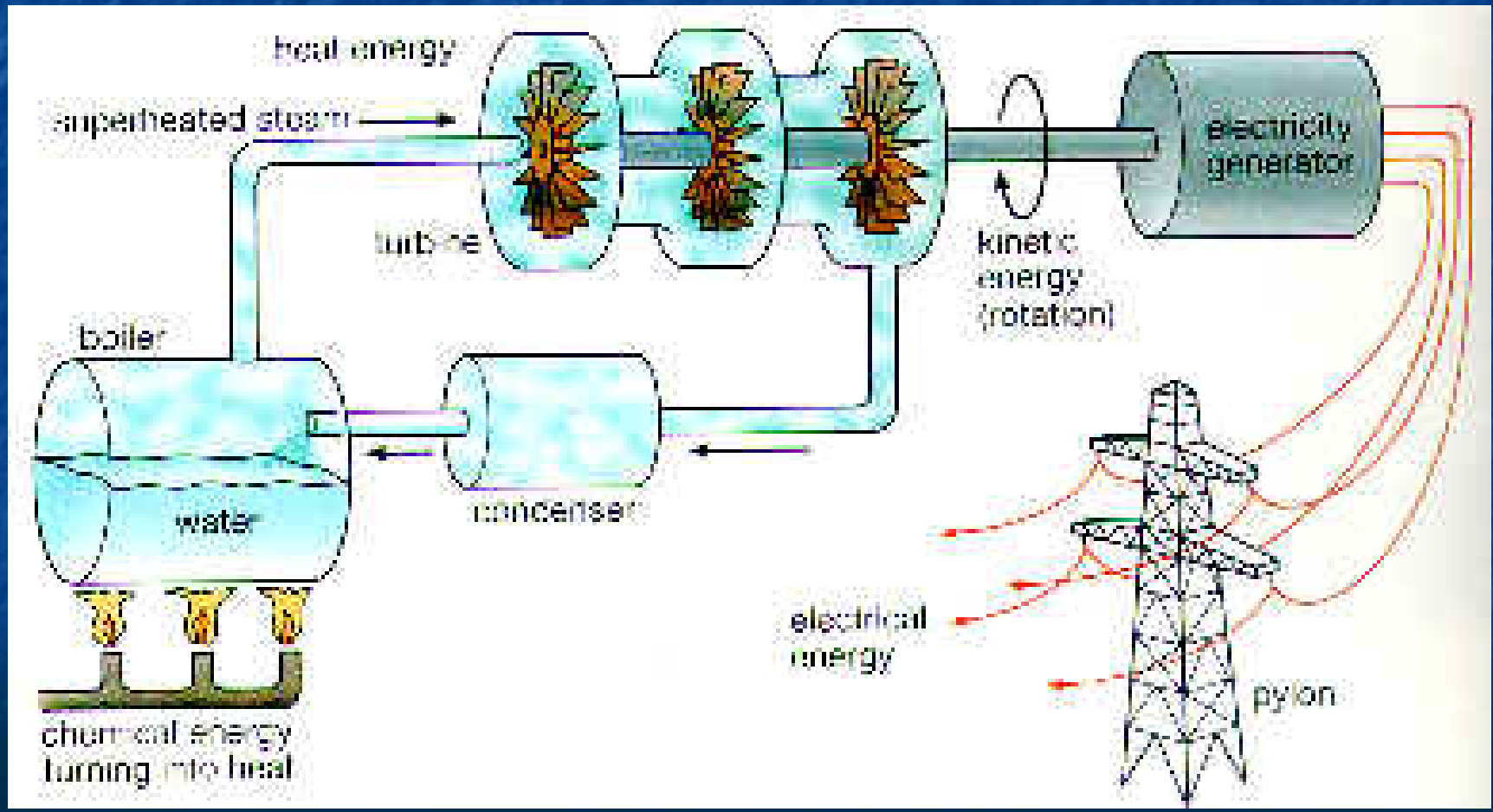
Uniting the Coke and Iron

- First coke iron furnace built in the United States was at Bear Creek Furnace, south of Parker on Bear Creek, Armstrong County, PA in 1819.
- Little success in using coke in iron blast furnaces in Pennsylvania before the 1830's

Commercial Uses of Coke Today

- Iron and Steel Industries
- Stone Burning processes
  - Uses:
    - Soda ash production
    - Sugar refining
    - Manufacturing of roofing insulation
- By~Product Utilization
  - Ammonia, light oils, tars.
  - Oils and tars used to produce plastics, motor fuel, photo developer, perfume, medicine, and sugar substitute.

Steam Engines (External Combustion)



Coal Use Today

- Coal Burned in power plants produces 56% of the total electricity used in the United States.
- In 1998, 88% of the coal in the U.S. was used for of the electricity production.

Advantages of Coal Burning Power Plants

- Safe burning
- High Efficiency (Work Output/Work Input)

Other Uses of Coal Today

- Gasification or Hydroliquefaction: blasting coal with steam to produce Carbon Monoxide and Hydrogen gas.

The Piñon Pine plant near Reno, Nevada. Converts Coal into Hydrogen gas.

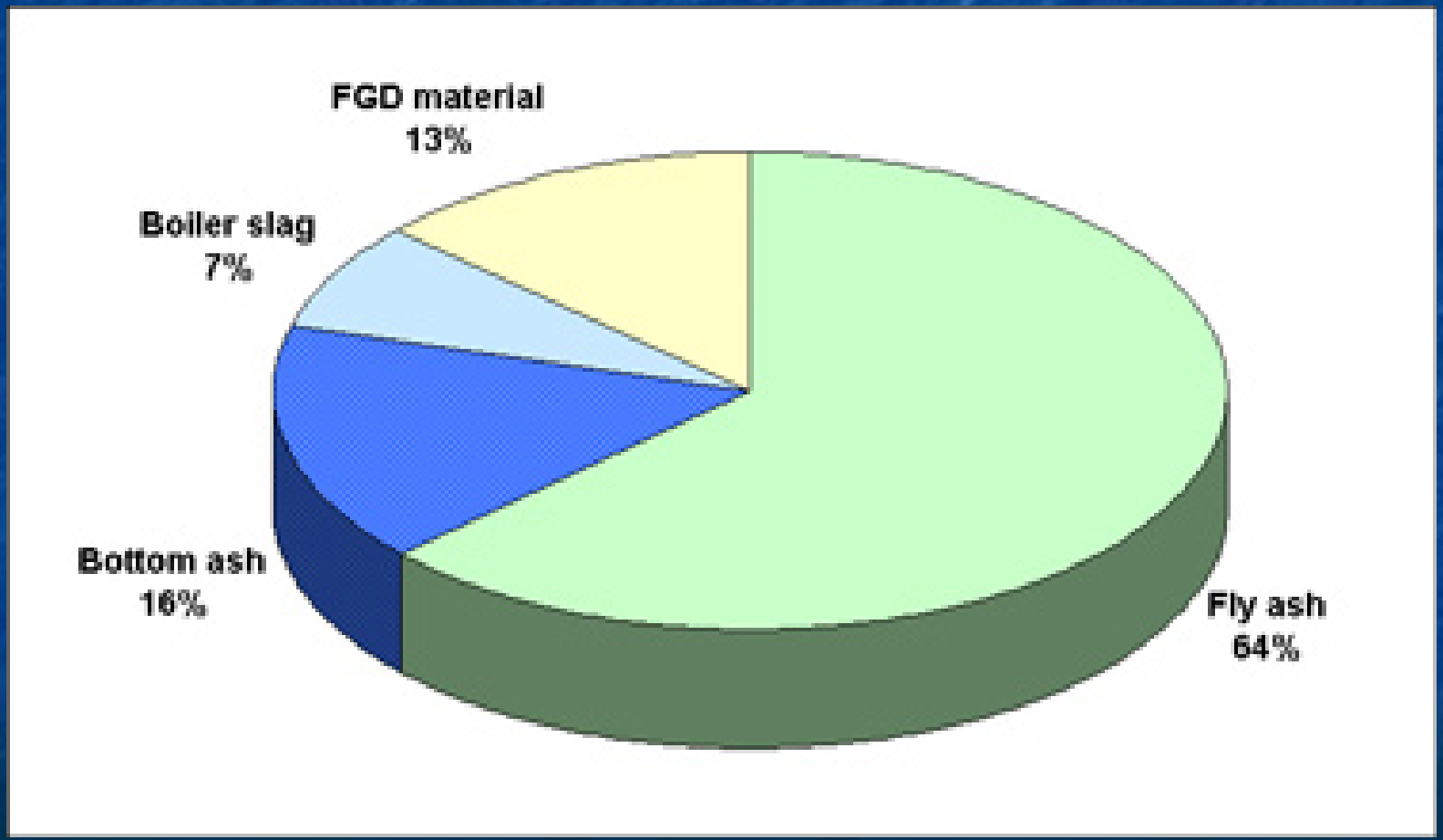
Other Uses of Coal Today

- Paper, brick, limestone, and cement industries.
- Residential Heating
  - Coal furnaces have been replaced by oil or gas furnaces or by electric heat pumps.
  - Less than one percent of the coal produced in the U.S. today is used for heating.

Miscellaneous Products Made from Coal Today

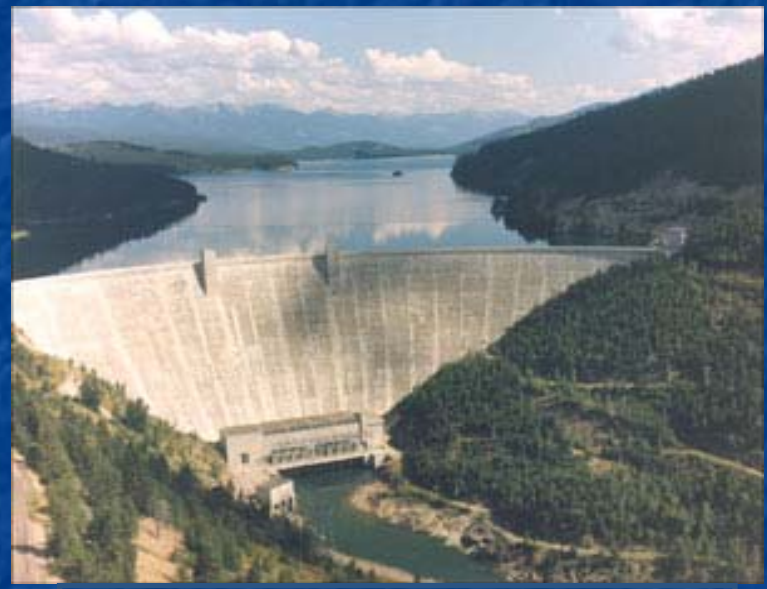
- Carbolic acid
- Fire Proofing
- Food Preservatives
- Billiard Balls
- Medicines
- Perfumes
- Baking Powder
- Rubber cement fertilizer
- Paint pigments
- Sulfur
- TNT explosive
- Linoleum

Coal Combustion Products



Coal Combustion Product Uses

- Fly Ash:
  - concrete, structural fill, and waste stabilization
- Bottom Ash:
  - structural fill, snow and ice control, road bases, and concrete.
- FGD Material:
  - wallboard manufacture
- Boiler Slag:
  - blasting grit and roofing applications



Hungry Horse Dam in Montana was built between 1948 and 1953 with concrete containing 120,000 metric tons of fly ash.

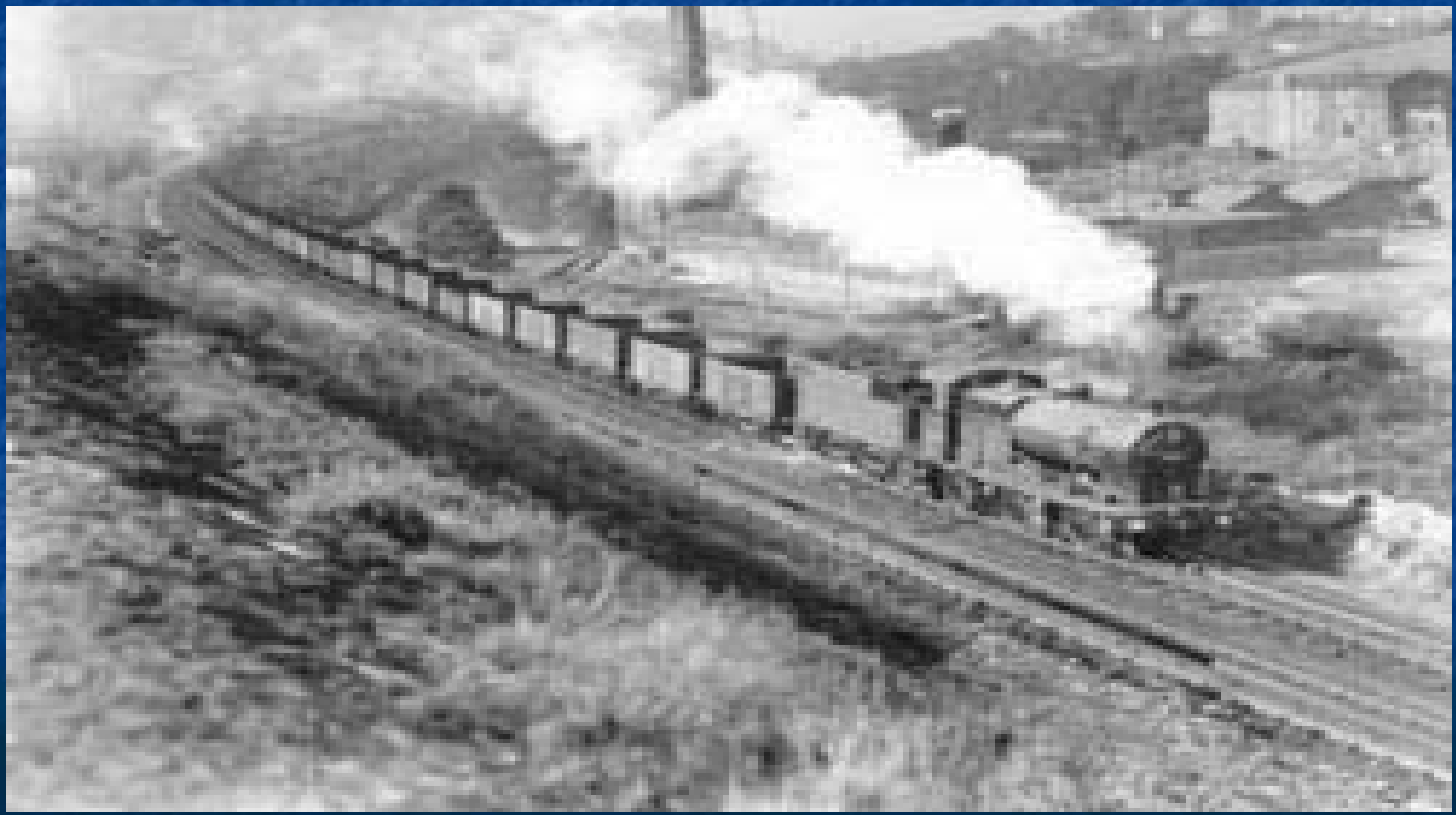
The Benefits of Using Coal Combustion Products

- Environmental and economic benefits.
- Reduced mining costs, disposal costs, landfill space usage.
- In concrete: reduction of Carbon Dioxide emissions by substituting ash for Portland cement.
- Mines: Injection of CCP's in abandoned mines controls subsidence and lessens acid mine drainage

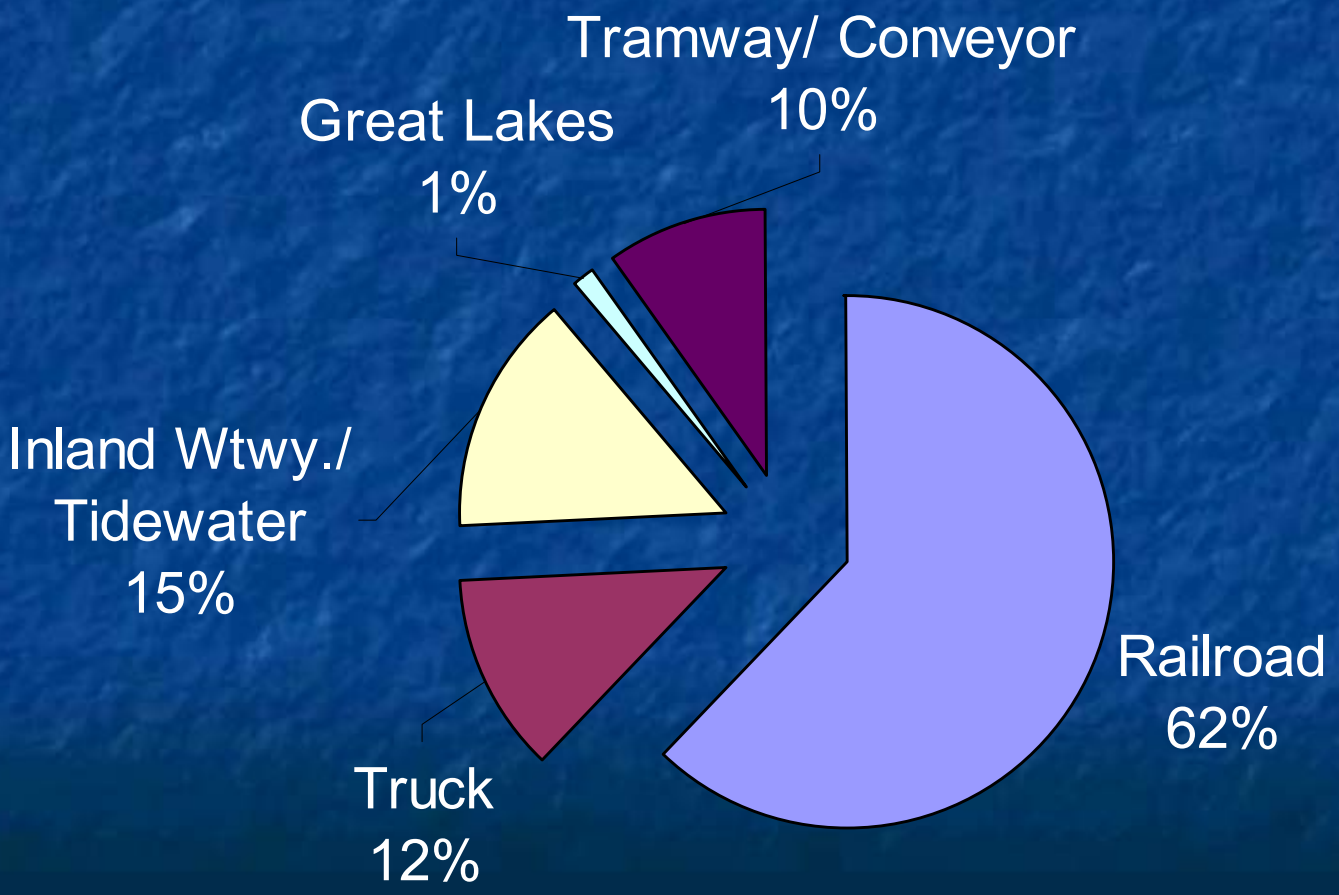
Leading Coal Producing States

- Wyoming
- Kentucky
- West Virginia
- Pennsylvania
- Texas.

Transportation



Distribution of Coal by Transportation Method, 1997



RR Traffic for Minerals and Other Commodities - 1997

	Tons	% of Tot. Tons	Total Revenue, $
Coal	705,121,000	44.48	7,697,987,000
Farm Products	125,562,000	7.92	2,645,461,000
Chemicals & allied products	139,785,000	8.82	4,764,285,000
Petroleum & coal products	39,251,000	2.48	1,028,358,000
Metallic ores:	31,851,000	2.01	398,514,000
Iron ores	23,655,000	1.49	213,800,000
Copper ores	2,411,000	0.15	52,546,000
Lead ore	411,000	0.03	6,328,000
Zinc ores	383,000	0.02	10,211,000
Bauxite	3,911,000	0.25	90,025,000
Manganese ores	144,000	0.01	3,164,000
Chromium ores	132,000	0.017	3,911,000
Other ores	936,000	0.06	22,440,000
Stone clay & glass products	40,946,000	2.58	1,063,478,000
Non-metallic minerals	109,300,000	6.89	898,714,000

United States Remaining Energy Supply

(based on 1994 consumption rates).

- Crude Oil ~ 23 years left
- Natural Gas ~ 68 years left
- Uranium ~ 364 years left
- Coal ~ 7,007 years left
- Renewable ~ not depletable

Statistics

- Today the United States produces over 1 billion tons of coal per year.
- As a nation we have more coal reserves than any other country.
- ¼ of all the known coal is in the United States.
- The United States has more coal that can be mined than the rest of the world has oil that can be pumped from the ground.
- Experts estimate that the United States has about 296 million tons of recoverable coal reserves.
- Coal accounts for 90,000 jobs in the U.S. directly, and ~1.6 million directly and indirectly

Environmental Regulations: Land

- Surface Mining Control and Reclamation Act of 1977 (SMCRA)
- SMCRA requirements:
  - Permits required before mining
  - Bond posted
  - Land will be returned to its original contour
  - Revegetation of mine site after mining
  - States must enforce the above guidelines

Air Quality

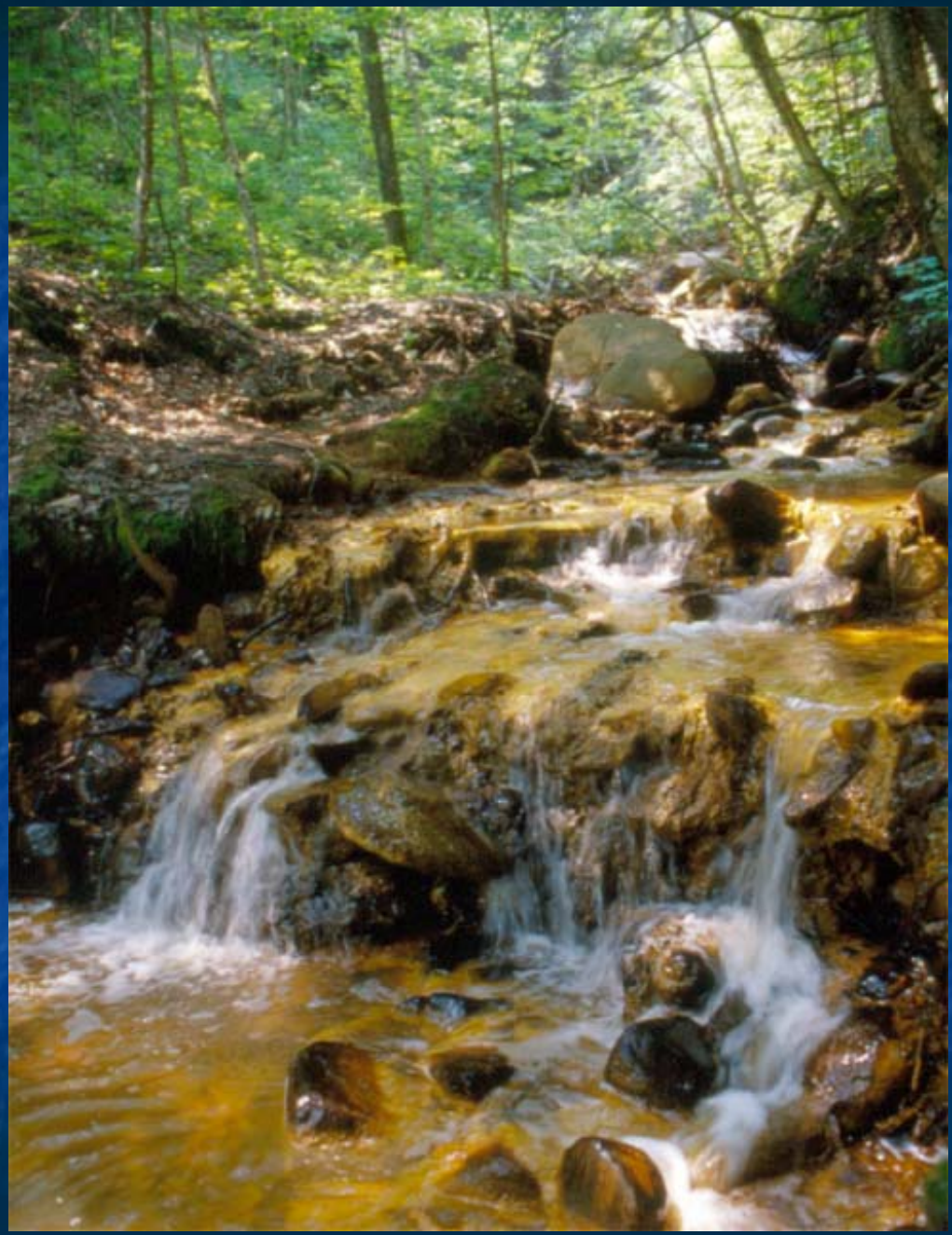
- Effects of coal combustion on air
  - Sulfur Dioxide ~ acid rain
  - Flyash ~ particulate matter pollution
- Clean Air Act of 1970
  - National Ambient Air Quality Standards (NAAQS)
  - 3 Ways to Control Pollutants
    - Pre-Combustion Removal
    - Post-Combustion Removal
    - Use of Low Sulfur Coal

Air Quality: Sulfur Content of Coals

Rank	Low: 0-1%	Med.: 1-3%	High: 3+%
Anthracite	97.1	2.8	-
Bituminous	29.8	26.8	43.4
Subbituminous	99.6	0.4	-
Lignite	90.7	9.3	-
All Ranks	65.0	15.0	20.0

Water Quality

- Acid Mine Drainage



Water Quality

- Sedimentation Control
- Clean Water Act
  - NPDES required for mining operations
- Cleanup
  - Calcium Carbonate added to some water bodies to raise pH.

Federal Environmental Laws

- National Environmental Policy Act
- Federal Land Policy and Management Act
- Clean Air Act
- Federal Water Pollution Control Act
- Safe Drinking Water Act
- Comprehensive Environmental Response, Compensation and Liability Act
- Many others

Thank you!

We welcome any questions, comments, or criticisms.

Eric

Kelsey

Marielle

Brad

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