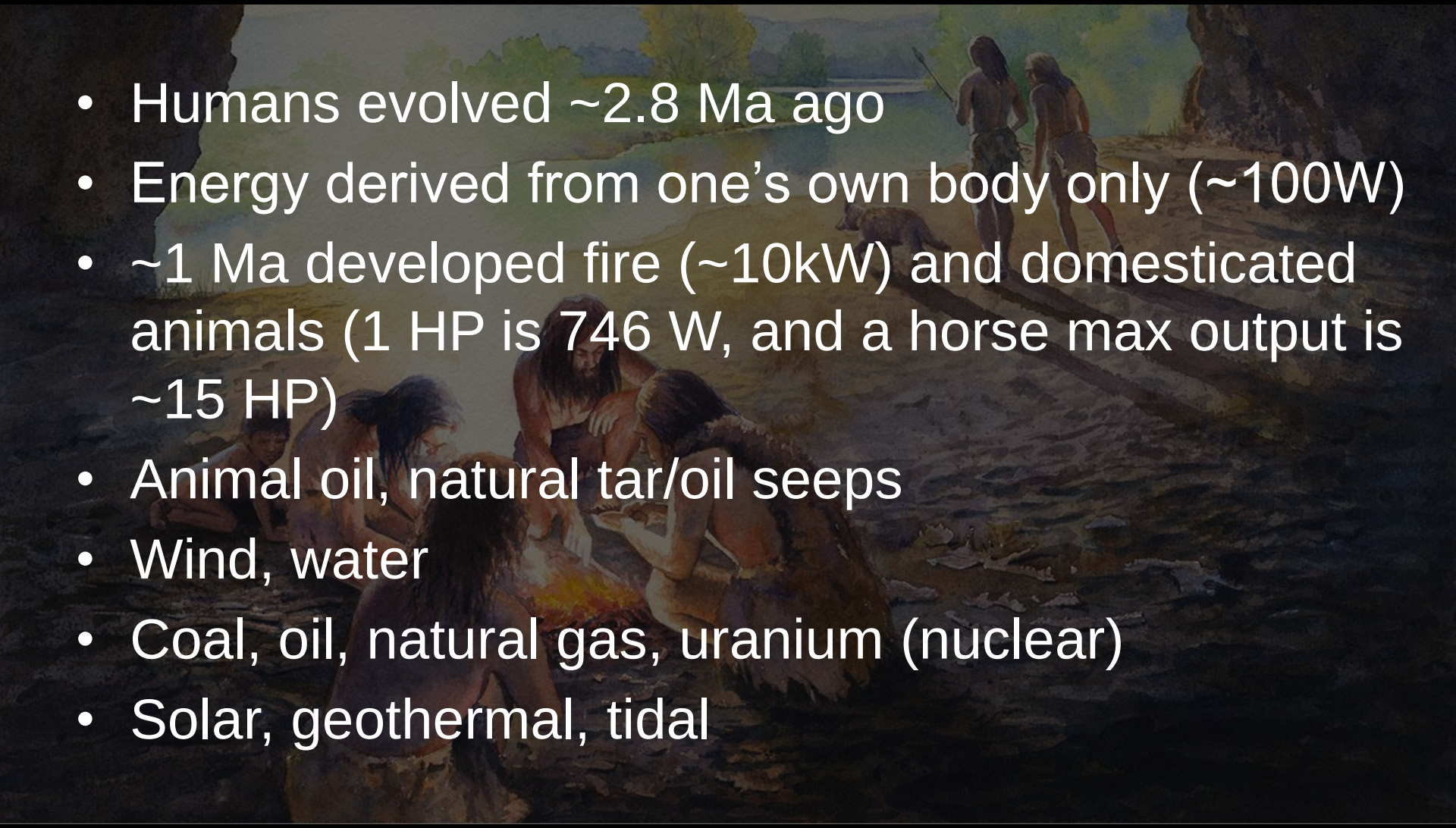
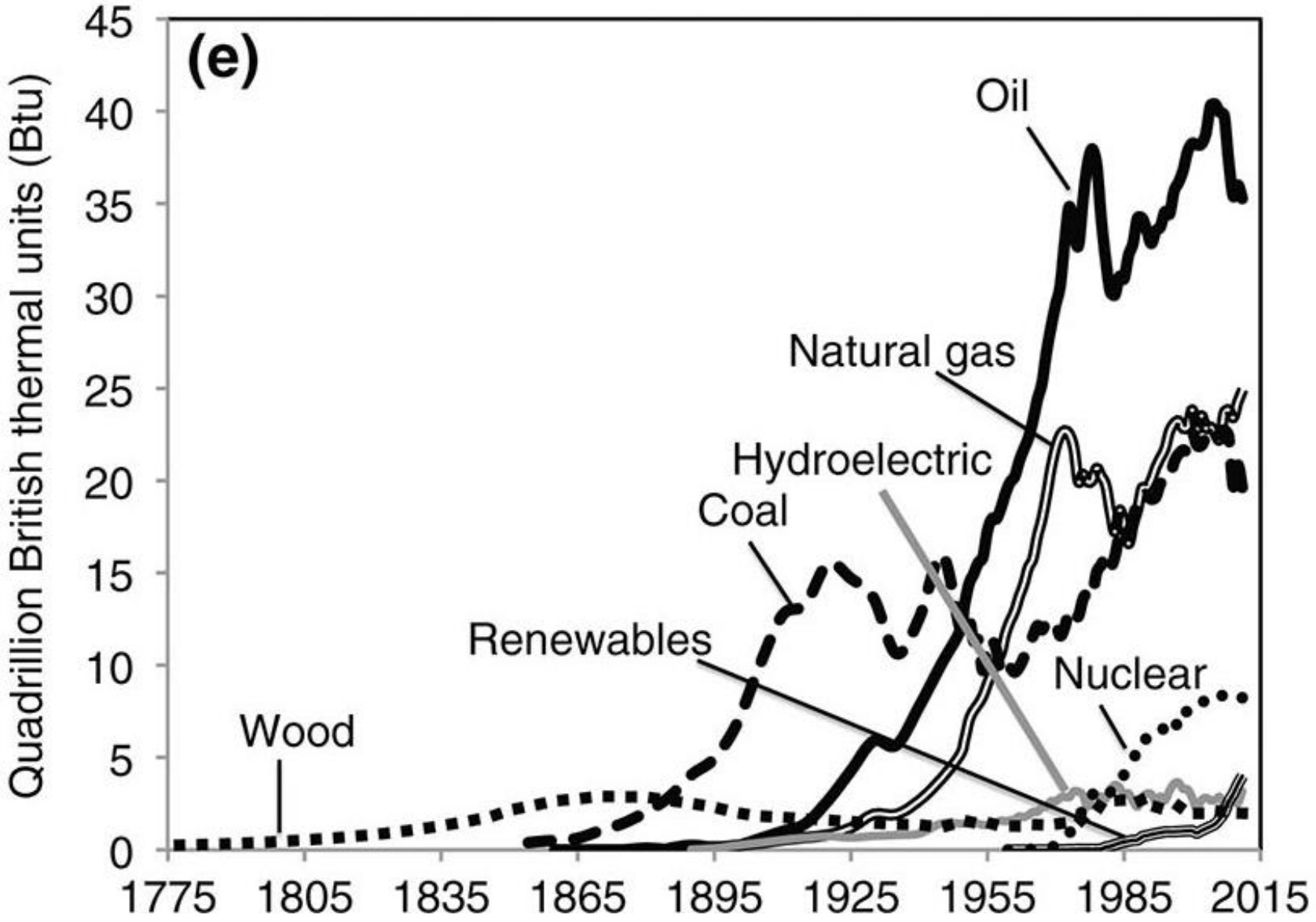
Evolution of Energy



- Humans evolved ~2.8 Ma ago
- Energy derived from one's own body only (~100W)
- ~1 Ma developed fire (~10kW) and domesticated animals (1 HP is 746 W, and a horse max output is ~15 HP)
- Animal oil, natural tar/oil seeps
- Wind, water
- Coal, oil, natural gas, uranium (nuclear)
- Solar, geothermal, tidal


(e)
Quadrillion British thermal units (Btu)
45
40
35
30
25
20
15
10
5
0
1775
1805
1835
1865
1895
1925
1955
1985
2015
Oil
Natural gas
Hydroelectric
Coal
Renewables
Nuclear
Wood

Basically, how efficiently do countries covert power to wealth? >> "energy intensity"

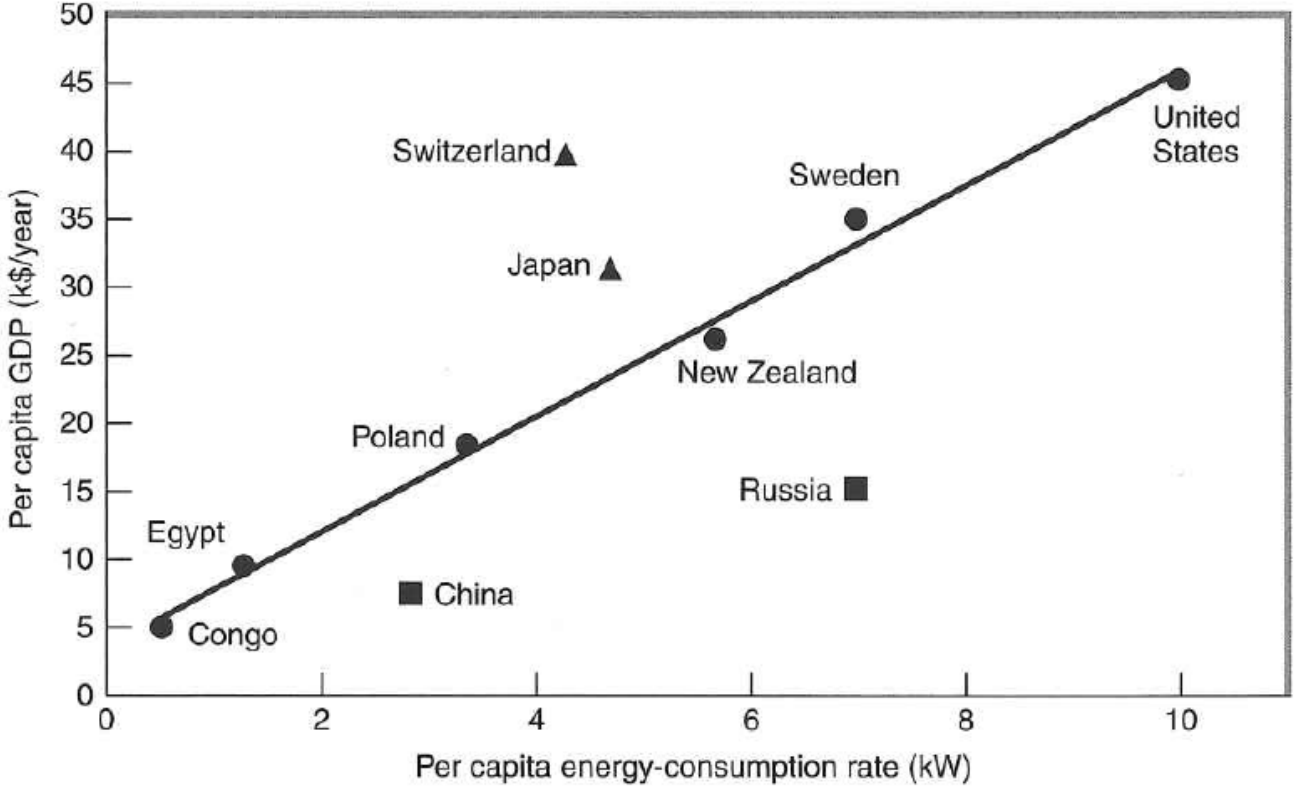


FIGURE 2.7

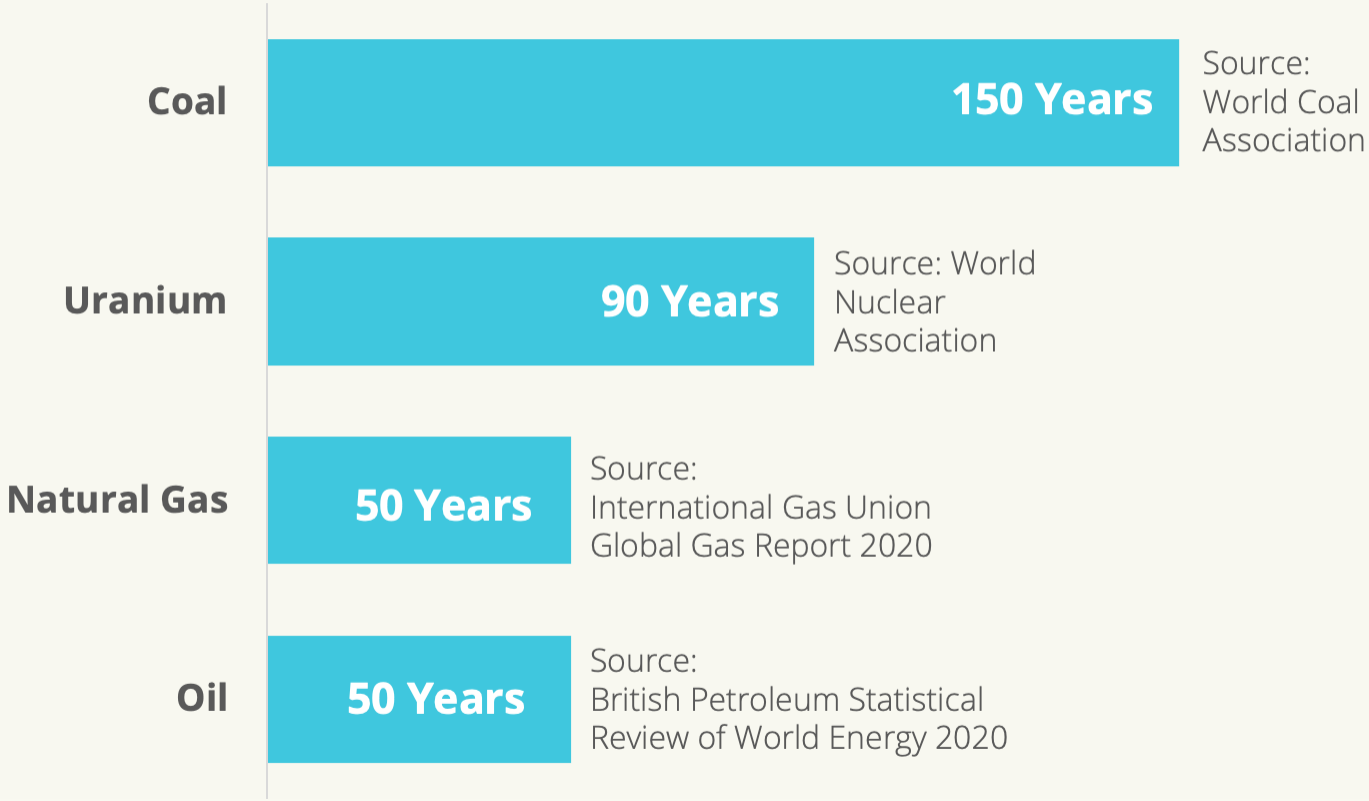
Per capita GDP (in thousands of U.S. dollars per year) versus per capita energy consumption for 10 countries. The 6 countries that fall near the straight line have approximately the same energy intensity, or energy consumed per unit of GDP (GDP figures used here are what economists call GDP *ppp*, for "purchasing power"). Japan and Switzerland are more energy efficient, and Russia and China less so. Multiplying the numbers on the horizontal axis by 10 gives the number of energy servants per capita.

Large countries = more transportation
Tropical countries = less heating
Military adventurism?

TABLE 3.3 | ENERGY CONTENT OF FUELS

	TYPICAL ENERGY CONTENT (VARIES WITH FUEL SOURCE)	
Fuel	**SI units**	**Other units**
Coal	29 MJ/kg	7,300 kWh/ton 25 MBtu/ton
Oil	43 MJ/kg	~40 kWh/gallon 138 kBtu/gallon
Gasoline	44 MJ/kg	36 kWh/gallon
Natural gas	55 MJ/kg	30 kWh/100 cubic feet 1,000 Btu/cubic foot
Biomass, dry	15–20 MJ/kg	13–17 MBtu/ton
Hydrogen gas (H_2) burned to produce H_2O	142 MJ/kg	320 Btu/cubic foot
Uranium, nuclear fission:		
Natural uranium	580 GJ/kg	161 GWh/tonne
Pure U-235	82 TJ/kg	22.8 TWh/tonne
Hydrogen, deuterium–deuterium nuclear fusion:		
Pure deuterium	330 TJ/kg	
Normal water	12 GJ/kg	13 MWh/gallon, 350 gallons gasoline equivalent per gallon water

Industry estimates of economically viable fossil fuel reserves

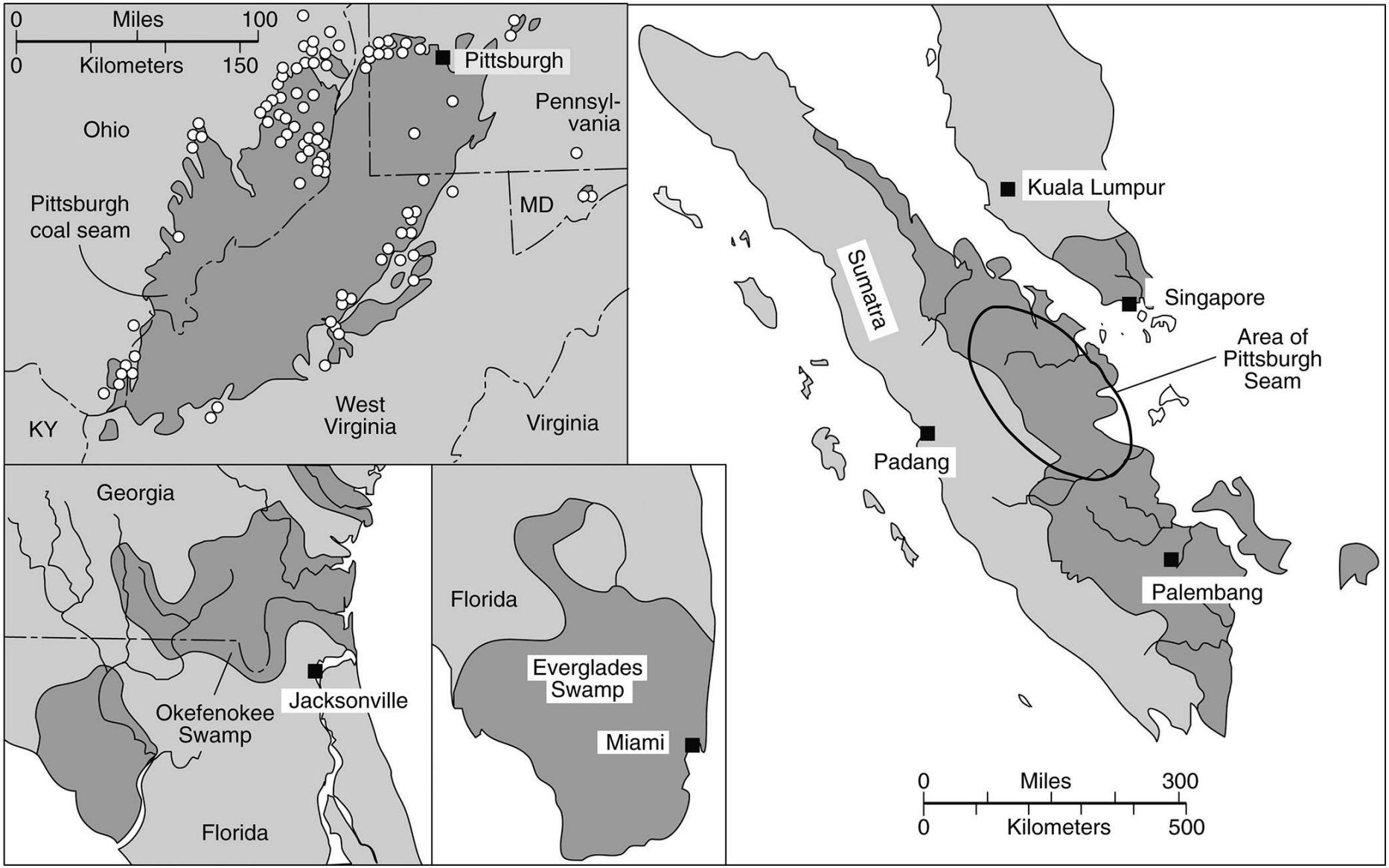


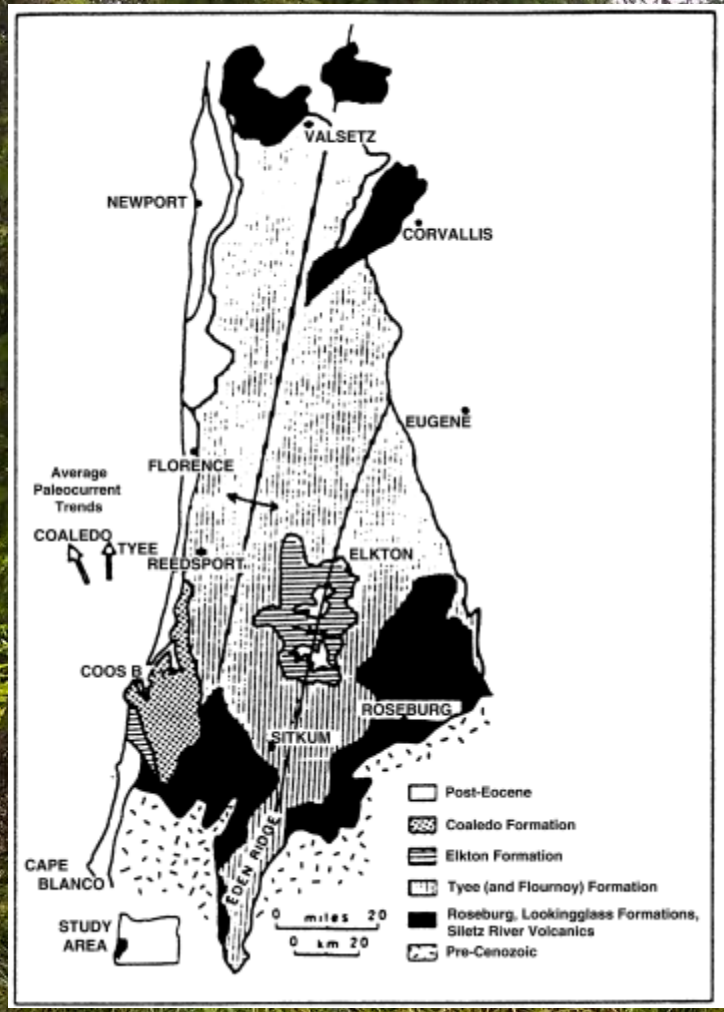
FREEING ENERGY

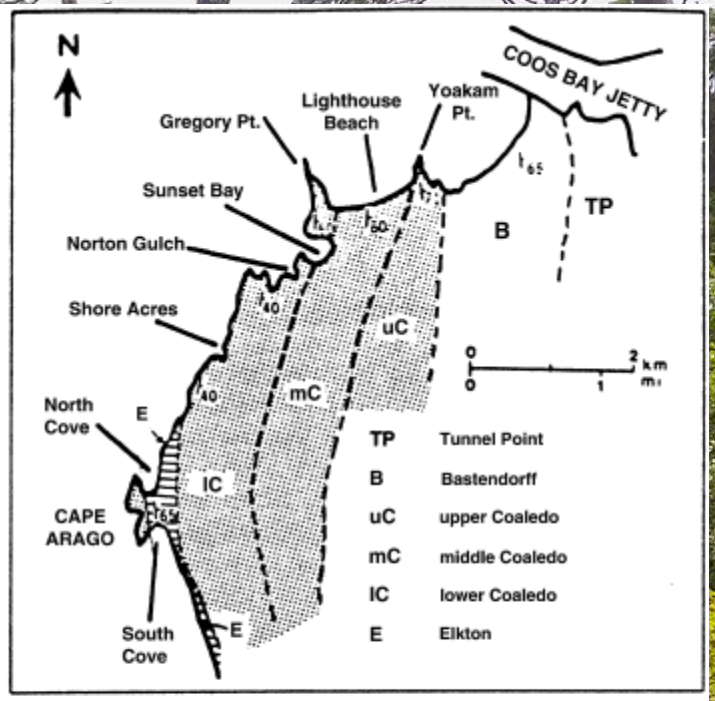
Types of Coal

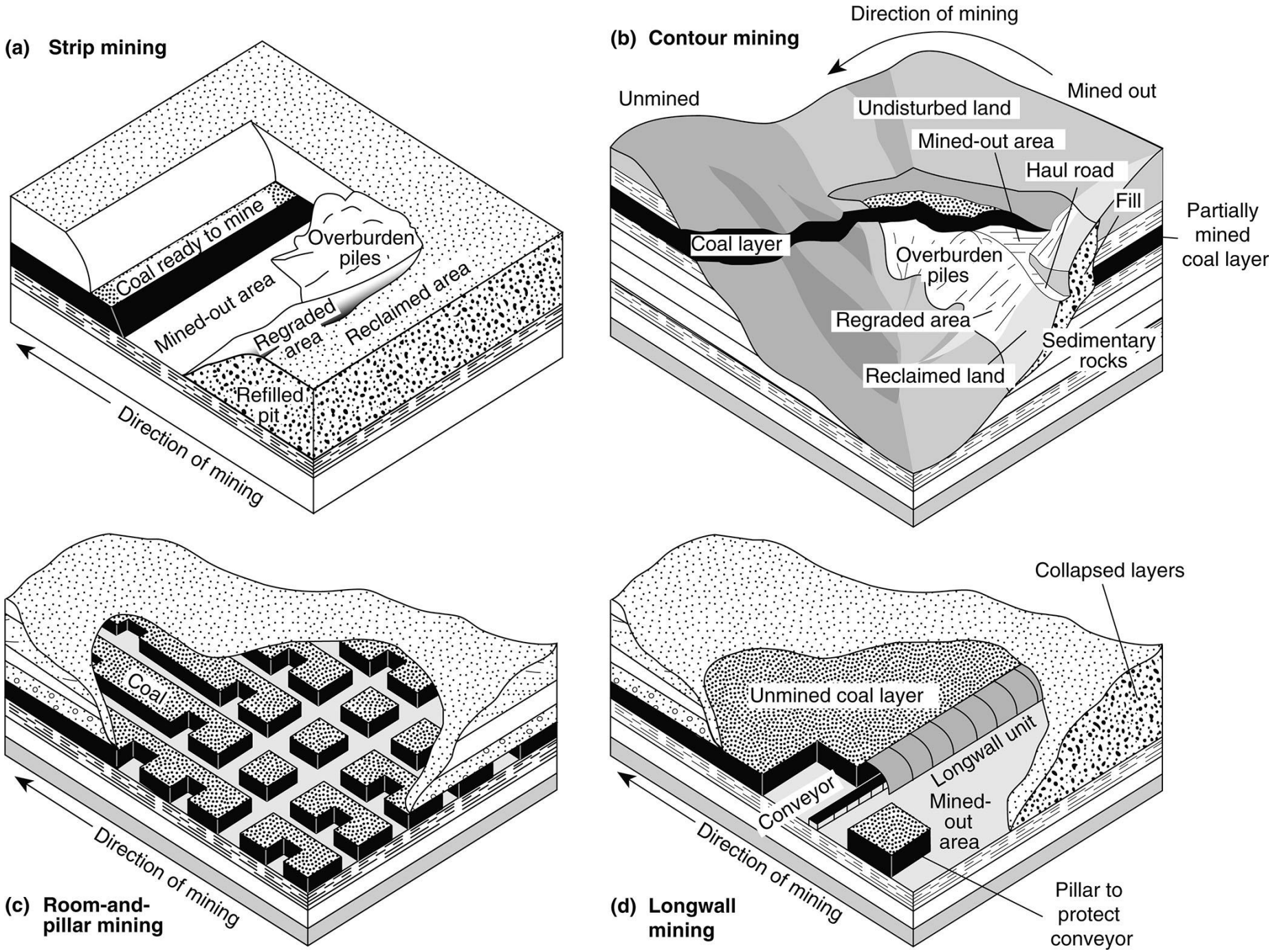
Rank of coal	C	H	Volatile	Fixed carbon	Calorific value	
		(Weight percent)			(Btu/lb)	(MJ/kg)
Lignite	73.0–78.0	5.2–5.6	45–50	50–55	<8,300	<19.31
Subbituminous	78.0–82.5	5.2–5.6	40–45	55–60	8,300–11,500	19.31–26.75
Bituminous						
High-volatile	82.5–87.0	5.0–5.6	31–40	60–70	11,500–14,000	26.75–32.56
Medium-volatile	87.0–92.0	4.6–5.2	22–31	70–80	>14,000	>32.56
Low-volatile	91.0–92.0	4.2–4.6	14–22	80–85	>14,000	>32.56
Anthracite	92.0–98.0	2.9–3.8	2–14	85–98	>14,000	>32.56

Coal basins


0 Miles 100
0 Kilometers 150
Pittsburgh
Pennsyl-
vania
Ohio
Pittsburgh
coal seam
MD
KY
West
Virginia
Virginia
Georgia
Jacksonville
Okefenokee
Swamp
Florida
Florida
Everglades
Swamp
Miami
Kuala Lumpur
Sumatra
Singapore
Area of
Pittsburgh
Seam
Padang
Palembang
0 Miles 300
0 Kilometers 500


VALSETZ
NEWPORT
CORVALLIS
EUGENE
FLORENCE
Average Paleocurrent Trends
COALEDO
TYEE
REEDSPORT
ELKTON
COOS B
ROSEBURG
SITKUM
EDEN RIDGE
CAPE BLANCO
STUDY AREA
0 miles 20
0 km 20
Post-Eocene
Coaledo Formation
Elkton Formation
Tyee (and Flournoy) Formation
Roseburg, Lookingglass Formations, Siletz River Volcanics
Pre-Cenozoic


N
COOS BAY JETTY
Gregory Pt.
Lighthouse Beach
Yoakam Pt.
Sunset Bay
Norton Gulch
Shore Acres
North Cove
CAPE ARAGO
South Cove
TP
B
uC
mC
IC
E
0 2 km
0 1 mi
TP Tunnel Point
B Bastendorff
uC upper Coaledo
mC middle Coaledo
IC lower Coaledo
E Elkton

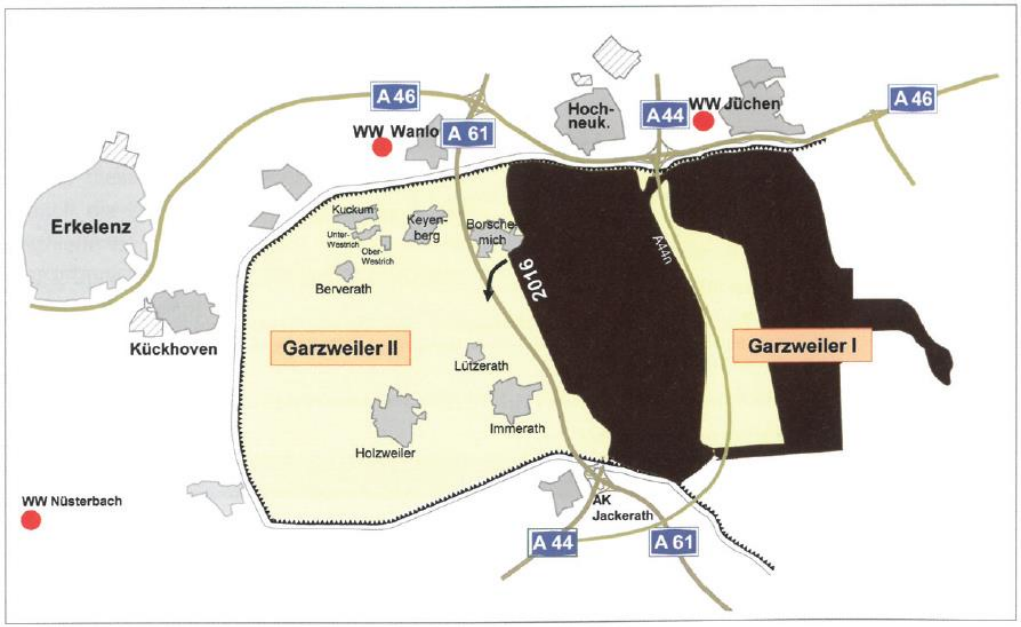

(a) Strip mining
Coal ready to mine
Overburden piles
Mined-out area
Regraded area
Reclaimed area
Refilled pit
Direction of mining
(b) Contour mining
Direction of mining
Unmined
Undisturbed land
Mined out
Mined-out area
Haul road
Fill
Partially mined coal layer
Coal layer
Overburden piles
Regraded area
Sedimentary rocks
Reclaimed land
(c) Room-and-pillar mining
Coal
Direction of mining
(d) Longwall mining
Collapsed layers
Unmined coal layer
Longwall unit
Conveyor
Mined-out area
Direction of mining
Pillar to protect conveyor


BAU
Nr. 1115

Lignite Mining in Germany (Garzweiler)

- Formed during the Miocene (5-25 Ma) when coastal swamps inundated the region
- Lignite is deposited in three beds with average thickness of 40 meters, occurring 40-210 meters below the surface
- Lower thermal grade b/c of water content (55-60%) compared to coal / anthracite
- Interbedded with sand, gravel, and clay
- Pumps must remove groundwater for mining
- IMPACTS: groundwater contamination, human resettlement (>40,000 people in the Rhineland), greenhouse gas emissions

51.070449, 6.496475



The village of Immerath is going to get totally destroyed. Once more than 1.200 people were living there.

- IMPACTS: groundwater contamination, human resettlement (>40,000 people in the Rhineland), greenhouse gas emissions

Surface coal mining at the Freedom lignite mine in North Dakota, supplies about 16 million tons of coal each year to the basin Electric Power Cooperative.

After mining, the dragline replaces the waste rock and the area is graded to near-original contours (including wetlands), covered with topsoil and revegetated (Dakota Coal Company)

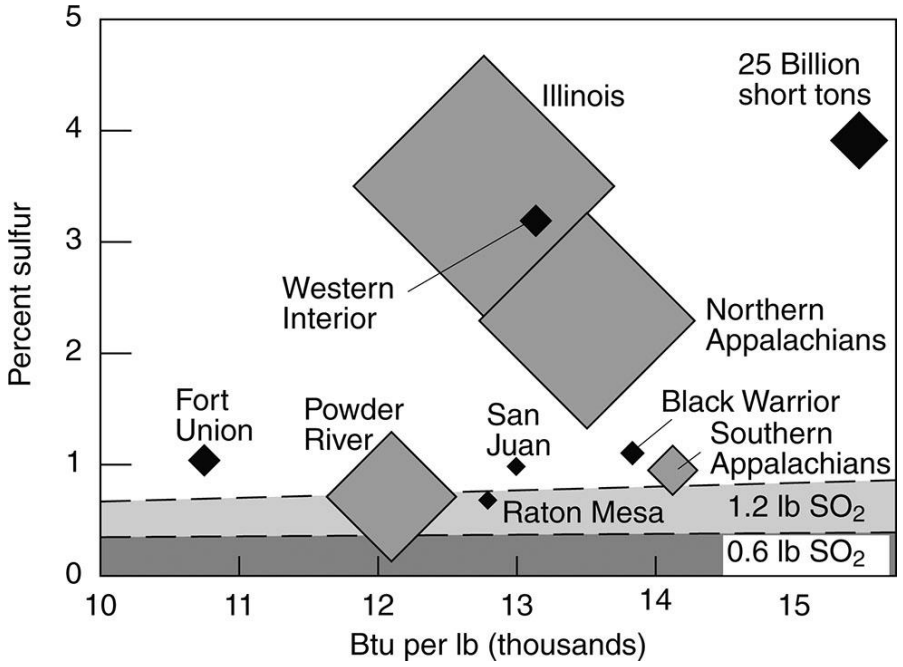
Carboniferous Period
~300-350 Ma

What happens to coal?

- USA: 93% for electricity, 7% for steel production (coke)
- China: 85% electricity, 15% for steel
- France: Only 5% is for electricity

Main by-products

- Ash (30%) - gangue minerals like clays and quartz (SiO_2)
- Sulfur (pyrite FeS_2, gypsum $CaSO_4$)
  Seawater or fresh water?
- Sulfur and nitrogen combine
  vapor to create acid rain
- Trace metals vaporize (~1,500°C)
  50% Hg, 22% Cr, 28% Ni, 62% As



“Clean Coal”

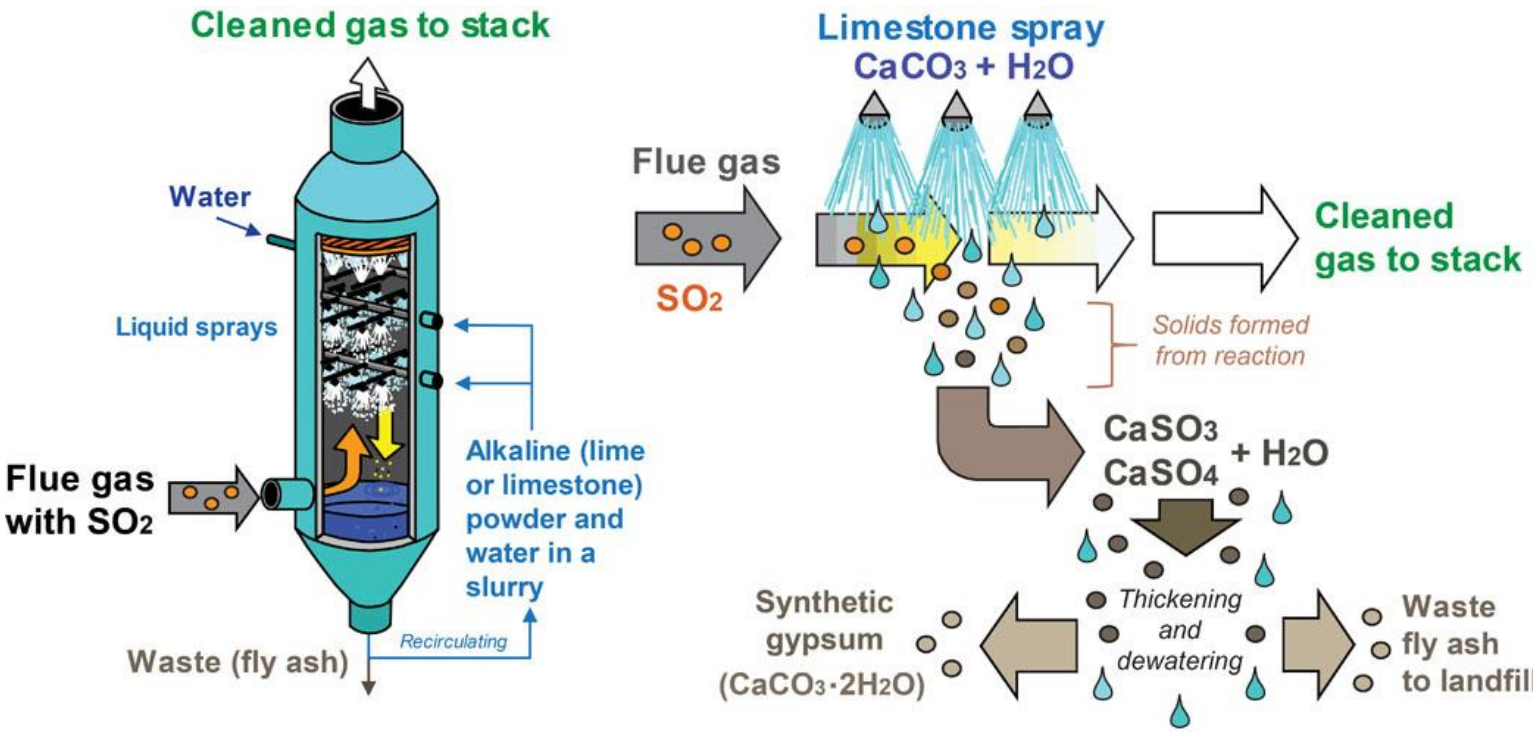
- Removes sulfur before (washing) and after combustion (scrubbers)
- Increases plant construction costs by ~50%
- Takes up 50% of land area
- Removes 80-90% of SO_2

Scrubbing with limestone follows the following idealized reaction:

$$SO_2 + CaCO_3 \rightarrow CaSO_3 + CO_2$$

The resulting calcium sulfite oxidizes in air to give gypsum:

$$O_2 + 2\ CaSO_3 \rightarrow 2\ CaSO_4$$



CO_2 Emissions from Coal

- Monitoring required as of 1995 and emissions are limited by the EPA
- Must capture / store 20-40% of CO_2 emissions
- Integrated Gasification Combined Cycle (IGCC) technology
  Captures 65% of CO_2 and most Hg
  Converts coal to gas (which is cleaner to burn)

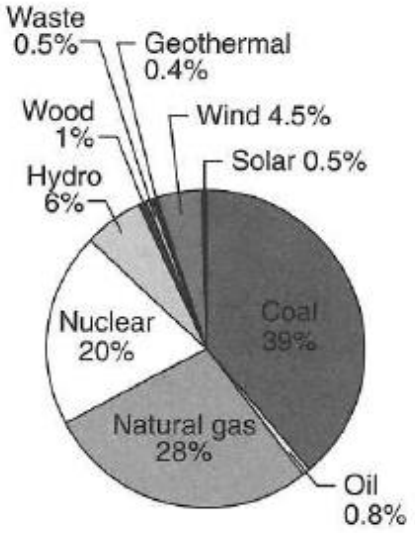
Boardman Coal Plant in Oregon

- Started in 1975, accounted for 65% of Oregon's SO_2 emissions and produced 15% of Portland General Electric's (PGE) electricity (2009)
- In October 2020, announced that the coal plant was closed and will be demolished this year (2022)
- In 2014, PGE built a new $500 million natural gas power plant nearby

Fossil Fuel Atmospheric Pollution

Fuel type	Carbon dioxide	Sulfur dioxide	Nitrogen oxides
Coal	972.73	5.91	2.72
Oil	793.18	5.45	1.82
Natural gas	554.55	0.045	0.77

Relative contributions to atmospheric pollution in 2014 by fossil fuels for electric power generation in the USA. Data from US Energy Information Administration and the US EPA

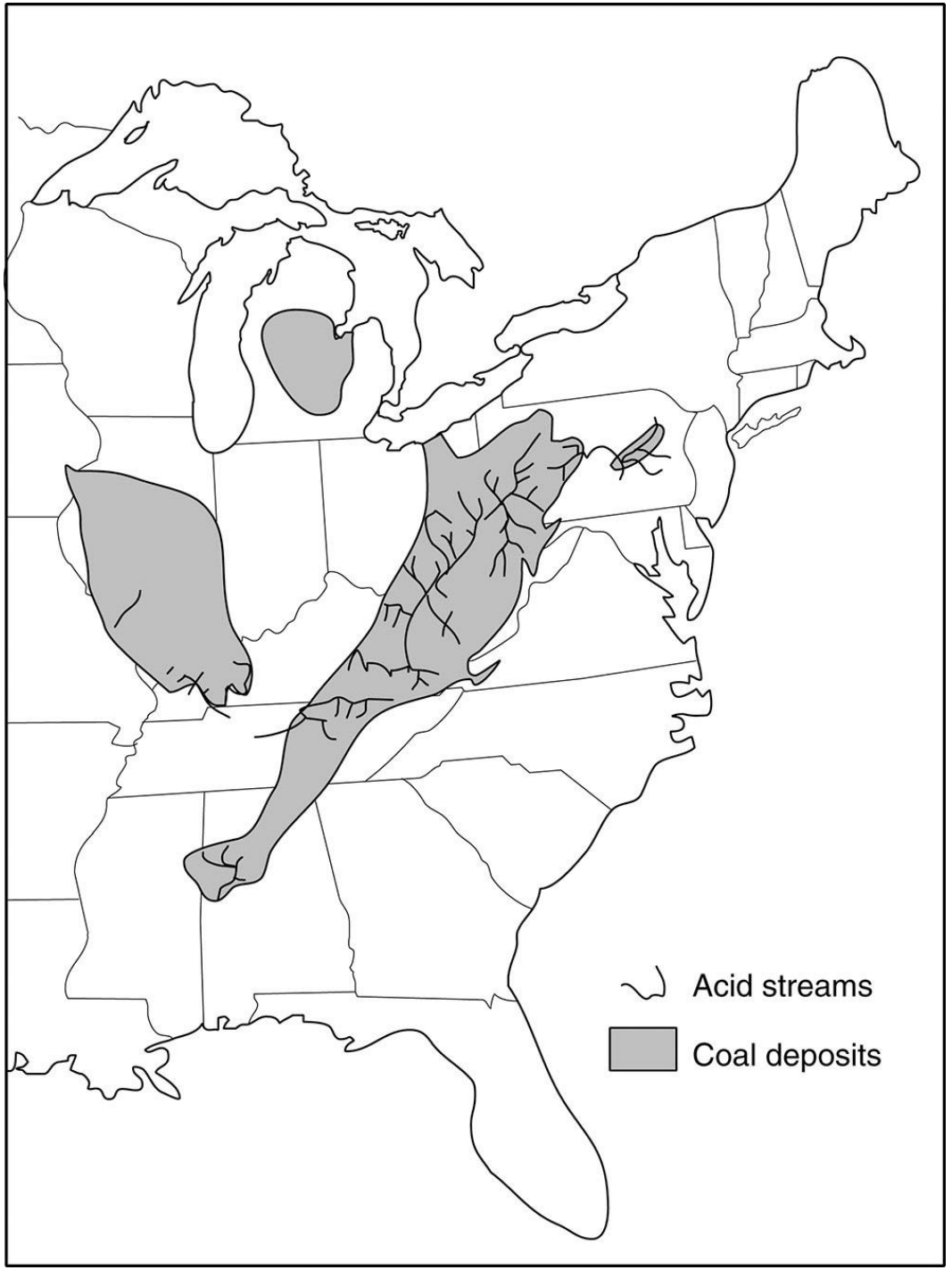


Fuel type	Carbon dioxide	Sulfur dioxide	Nitrogen oxides
Coal	972.73	5.91	2.72
Oil	793.18	5.45	1.82
Natural gas	554.55	0.045	0.77

Coal Taxes:

- 1977: Black Lung Disability Trust Fund (BLDTF)
- US Coal producers pay $1.10 / ton underground, $0.55 / ton surface mined coal
- 1977: Abandoned Mine Land Reclamation Fund (AMLRF)
- US Coal producers pay $0.35 / ton surface coal, $0.15 / ton underground coal. As of 2012, $10.1 billion was in the fund

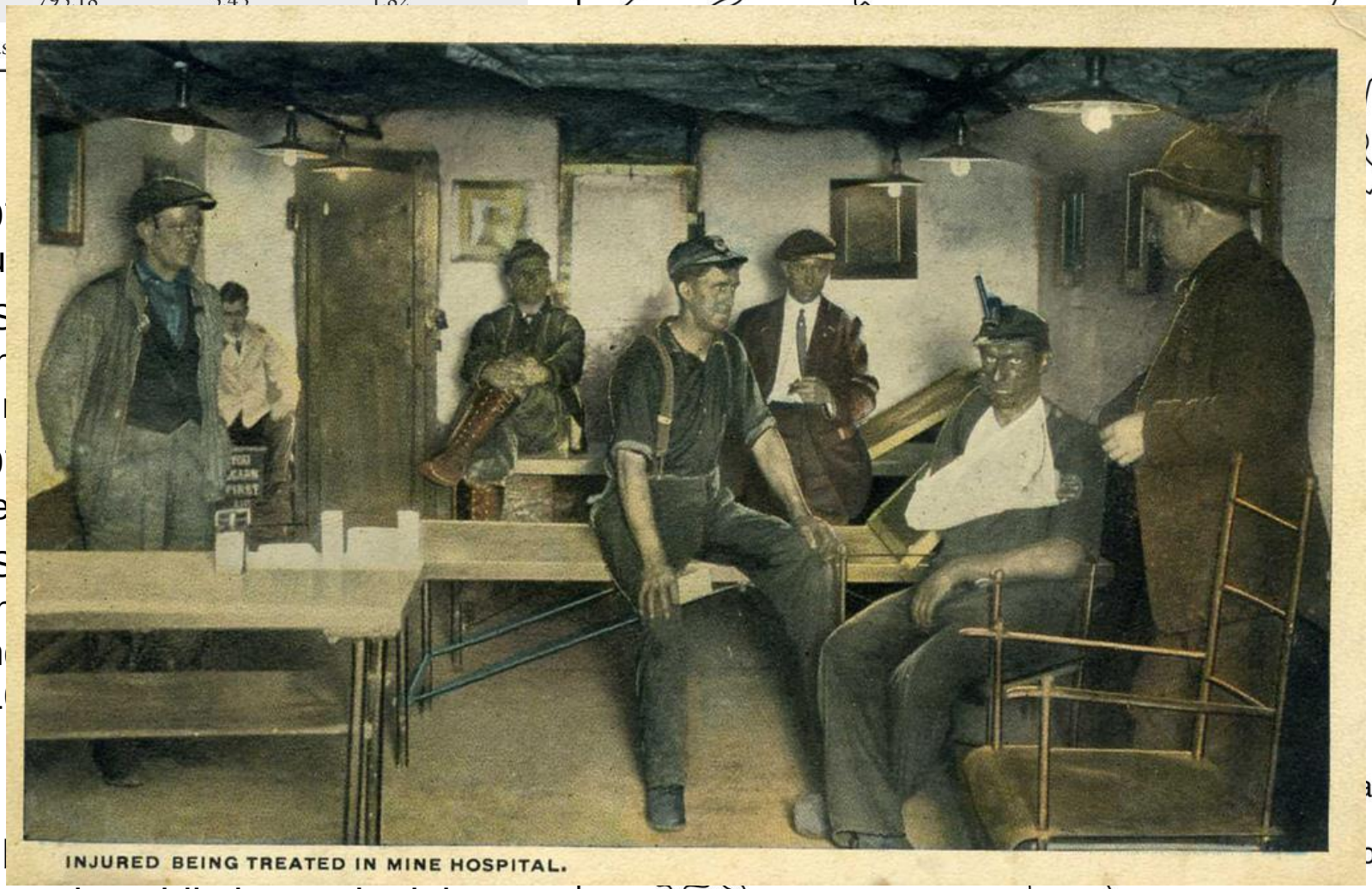
Distribution of streams in the USA made acidic by coal mining prior to present mining regulations



Fuel type	Carbon dioxide	Sulfur dioxide	Nitrogen oxides
Coal	972.73	5.91	2.72
Oil	793.18	5.45	1.82
Natural gas			

Coal

- 19
  Fu
- US
  tor
  su
- 19
  Re
- US
  tor
  un
  $1


INJURED BEING TREATED IN MINE HOSPITAL.

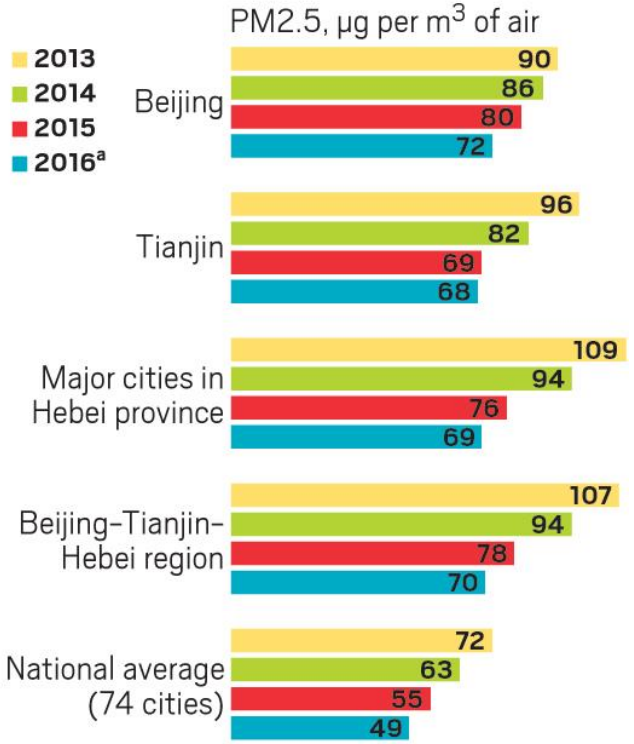
ams

Distri

osits

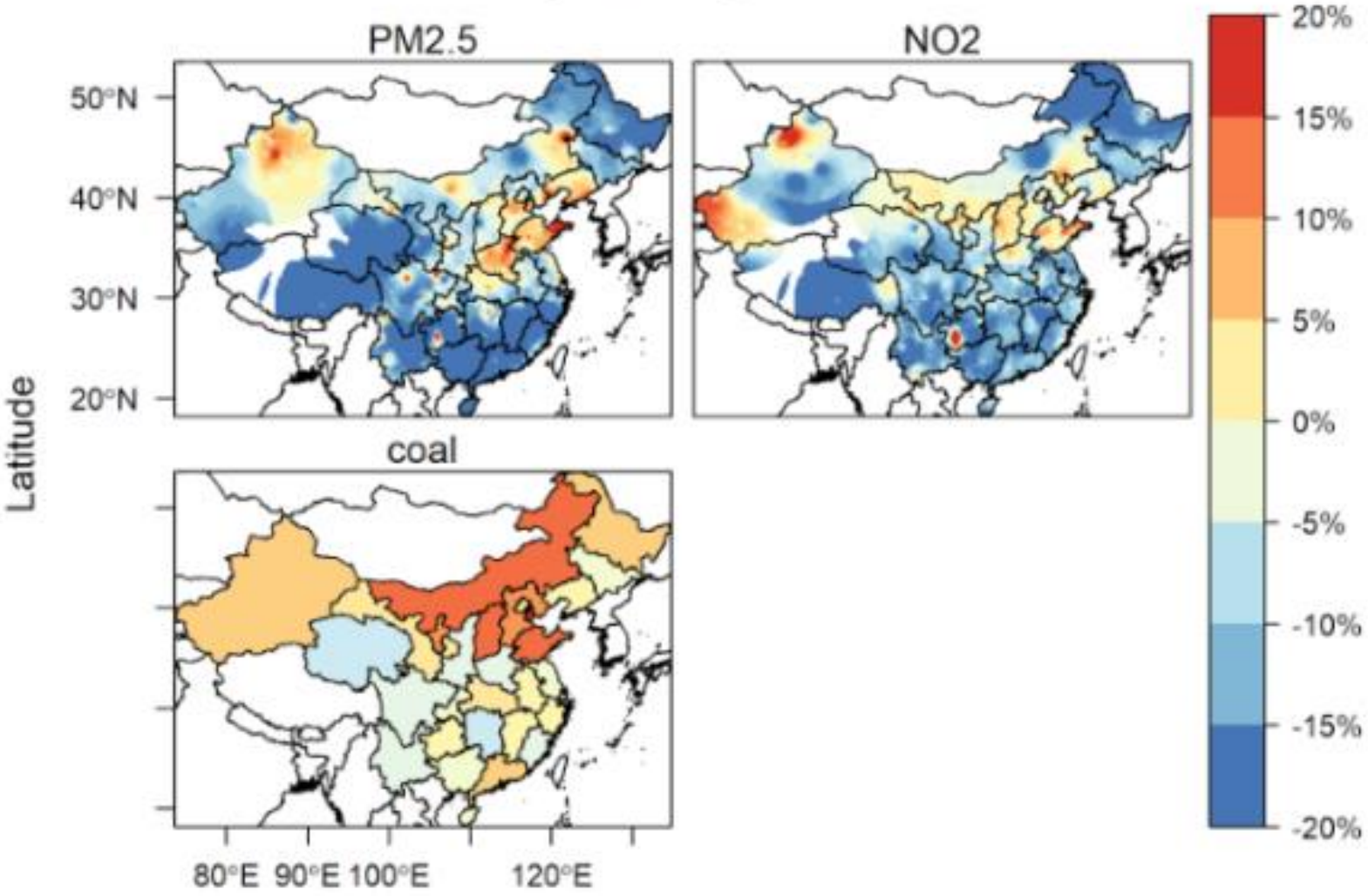
USA made acidic by coal mining prior to present mining regulations

Coal Producing Areas and Air Quality

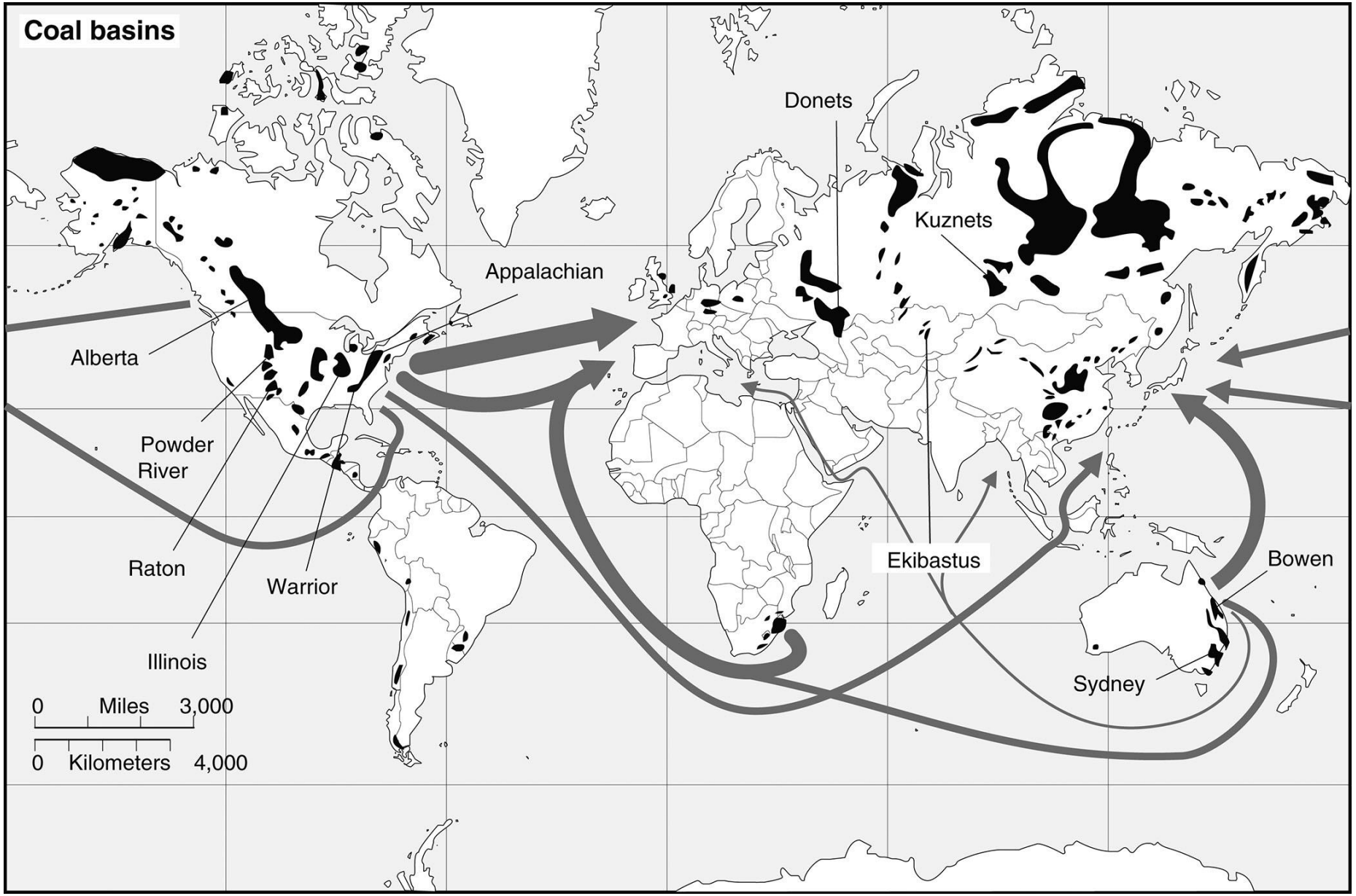


Analysis from the Ministry of Environmental Protection in China, indicated that of the PM 2.5 pollution generated from within the city of Beijing itself, 31% came from motor vehicles, 22% from coal burning, 18% from industrial production, and 14% from dust given off by construction and other sources.

Coal consumption and air quality, winter 2018-19
year-on-year



Sources: MEE; Shanxi Fenwei Energy Information Services


Coal basins
Donets
Kuznets
Appalachian
Alberta
Powder
River
Raton
Warrior
Illinois
Ekibastus
Bowen
Sydney
0 Miles 3,000
0 Kilometers 4,000

Coal Mining and Productivity

- Mechanization increased productivity significantly in the late 20th century from ~2 to 7 tons/miner/hour
- Wyoming (open pit): 30 tons/miner/hour
- West Virginia (underground): 2 tons/miner/hour
- India gets 60% of its electricity from coal and produces at only 0.4 tonnes/miner/hour

- Accounted for 56.8% of China's domestic energy generation in 2020, down from 72.4% in 2005
- China produces up to 0.15 tonnes/miner/hour
- ~6 million workers in underground mines, 1,000 die annually in mining accidents