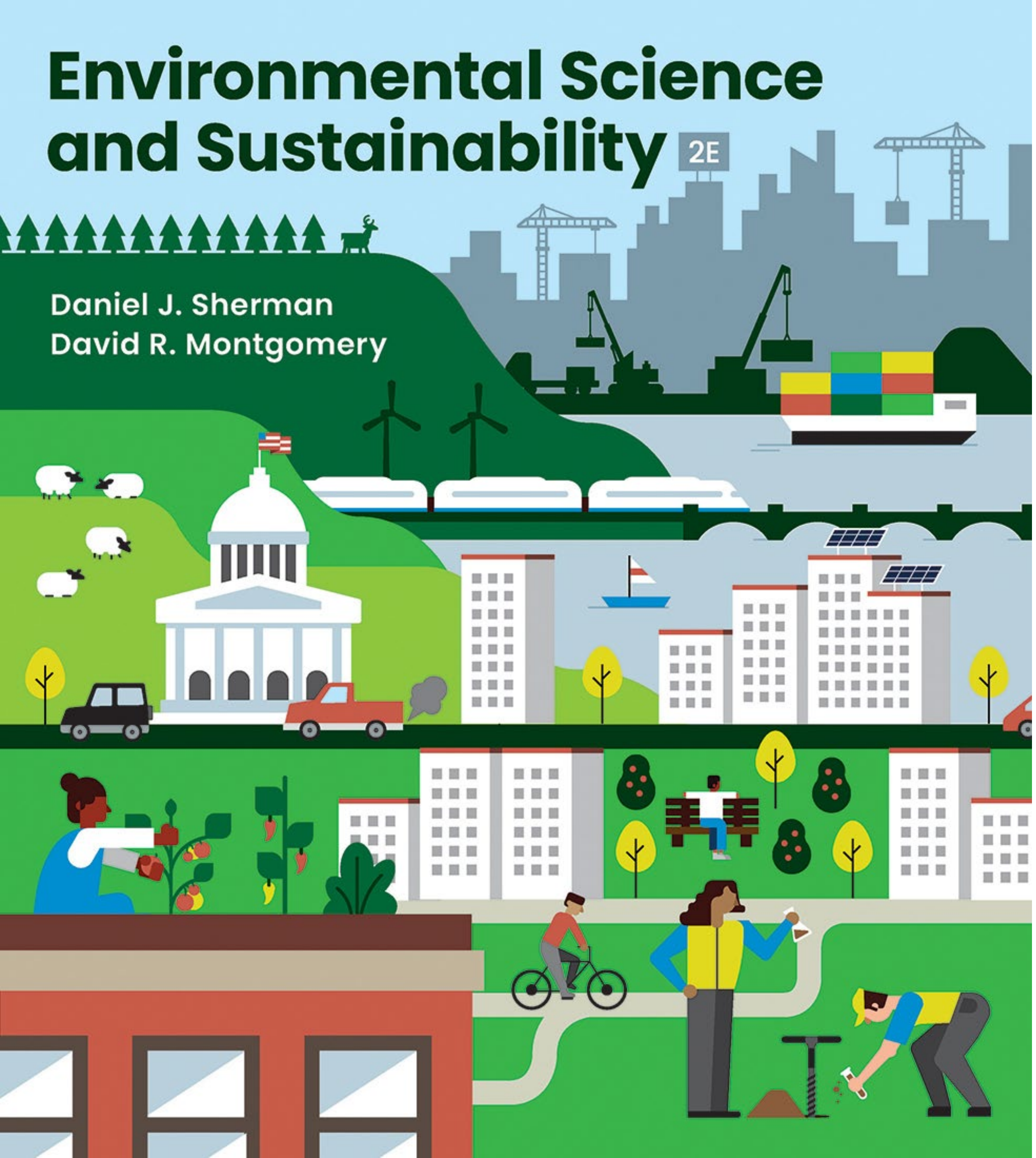


CHAPTER 13: Fossil Fuels

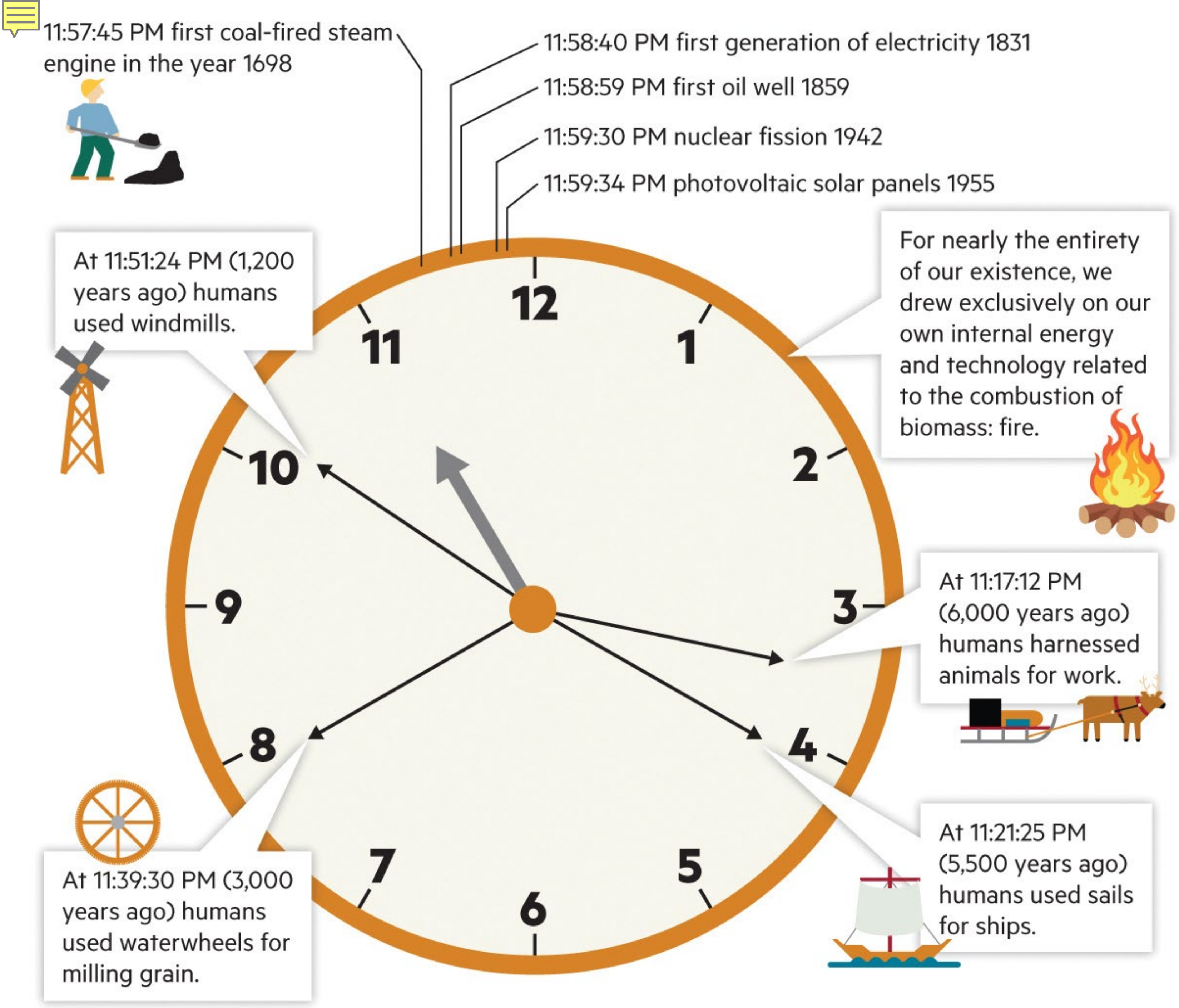
Energy of the Industrial Age

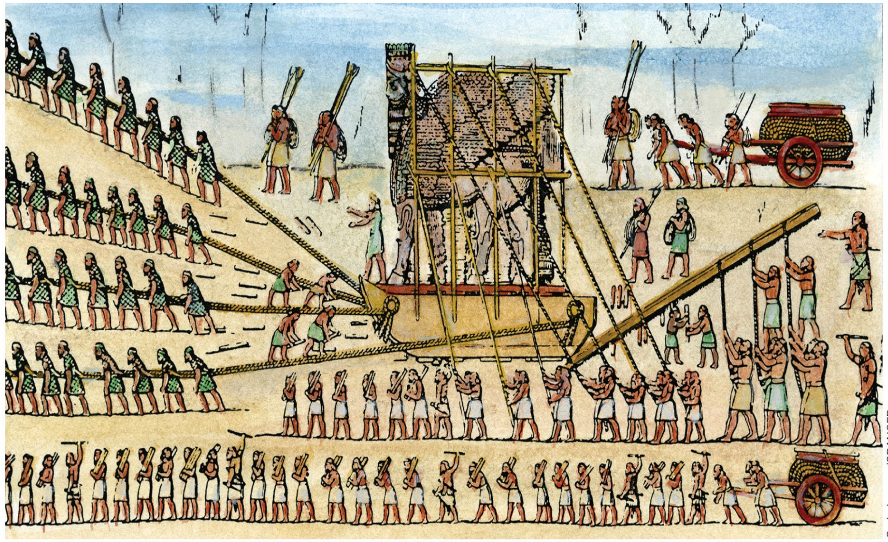
Our civilization runs by burning the remains of humble creatures who inhabited the Earth hundreds of millions of years before the first humans came on the scene. – Carl Sagan

SUSTAINABLE DEVELOPMENT GOALS

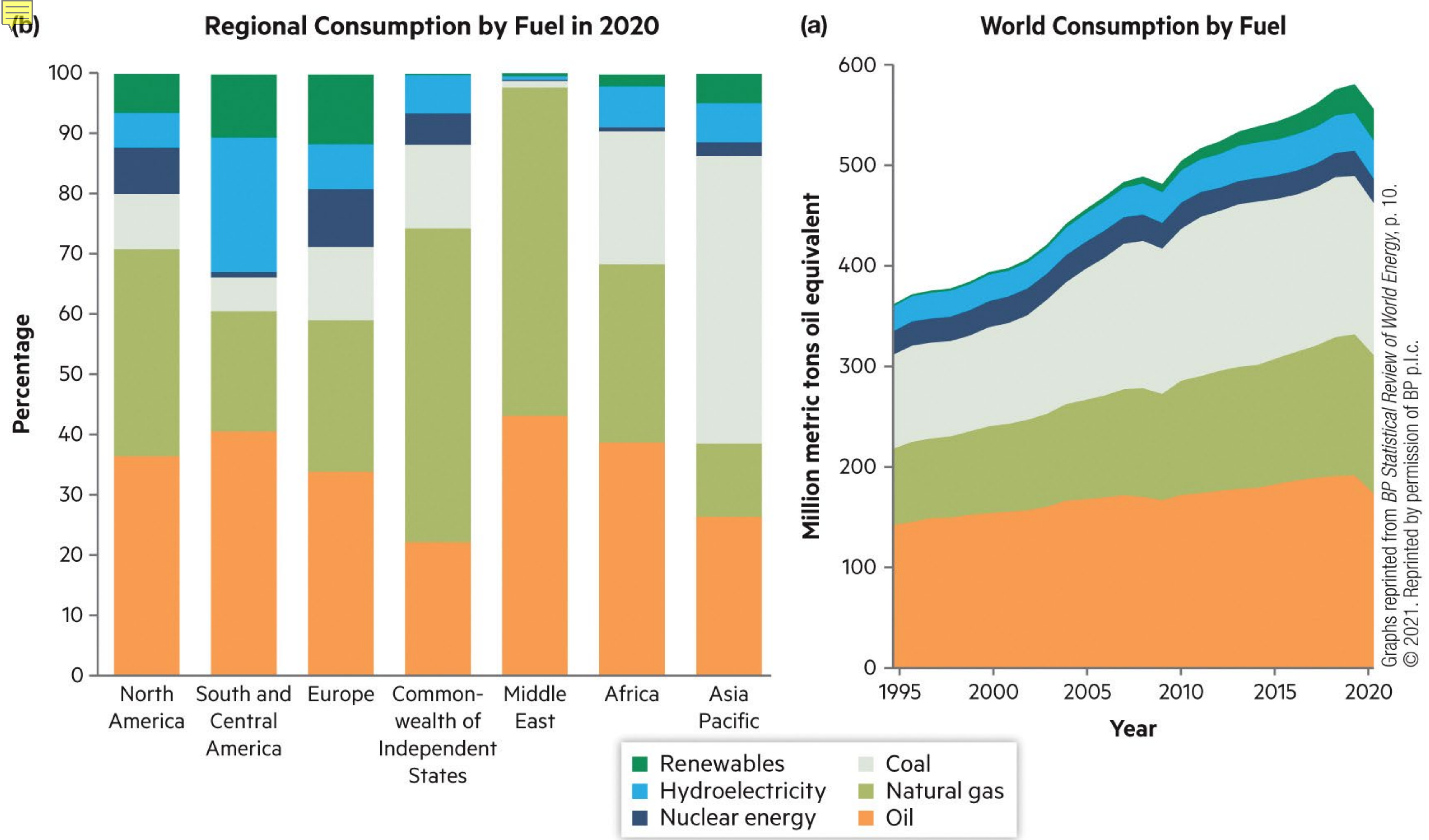
Learning objectives…

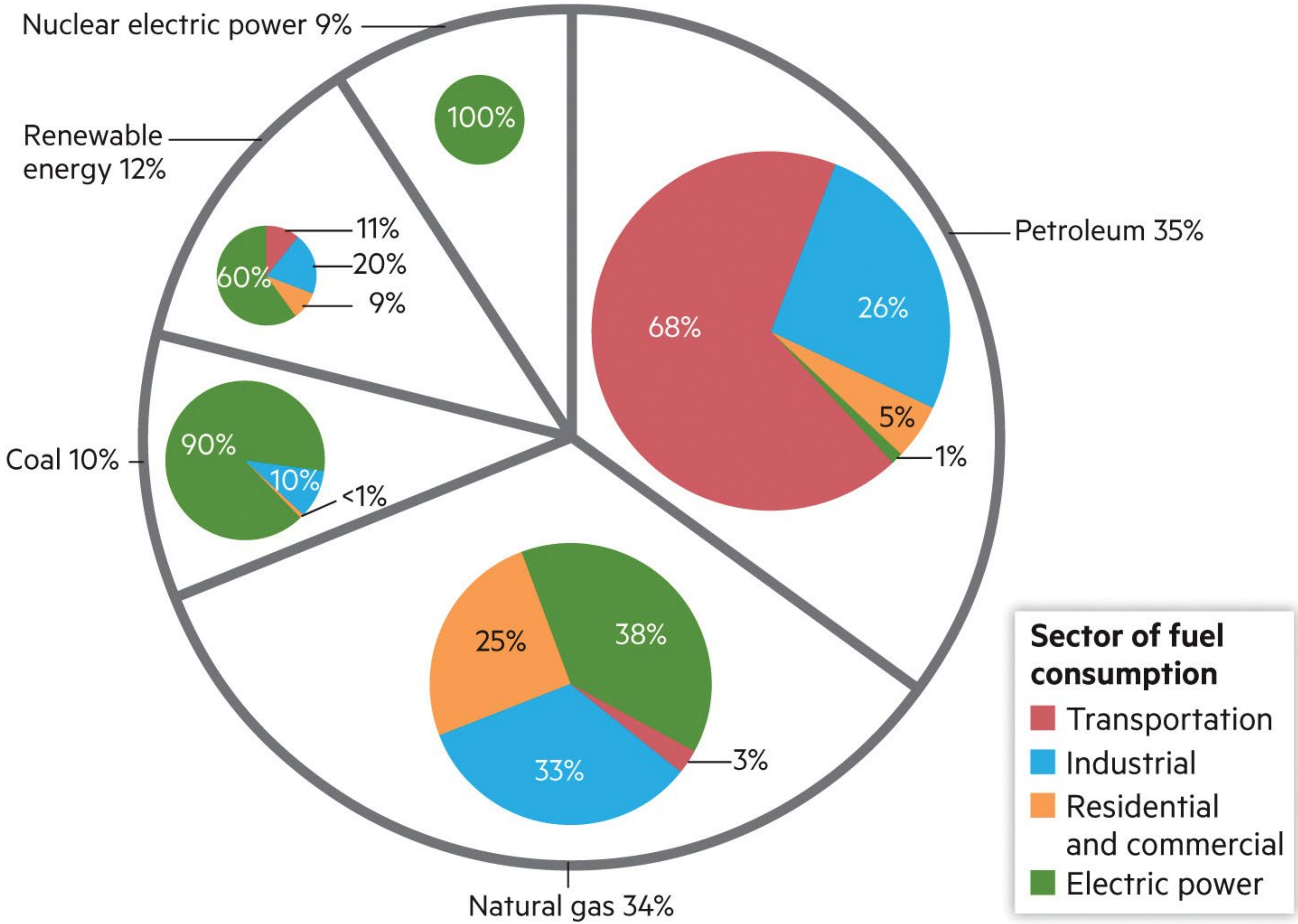
- Fossil fuels are linked to the Sun’s energy, depositional environments, biology and geologic time.
- Heat, pressure and time convert organic material to fossil fuel.
    - Coal, oil and gas
- Why we use fossil fuels and how they are recovered.
- Pros and cons of non renewable and renewable energy.

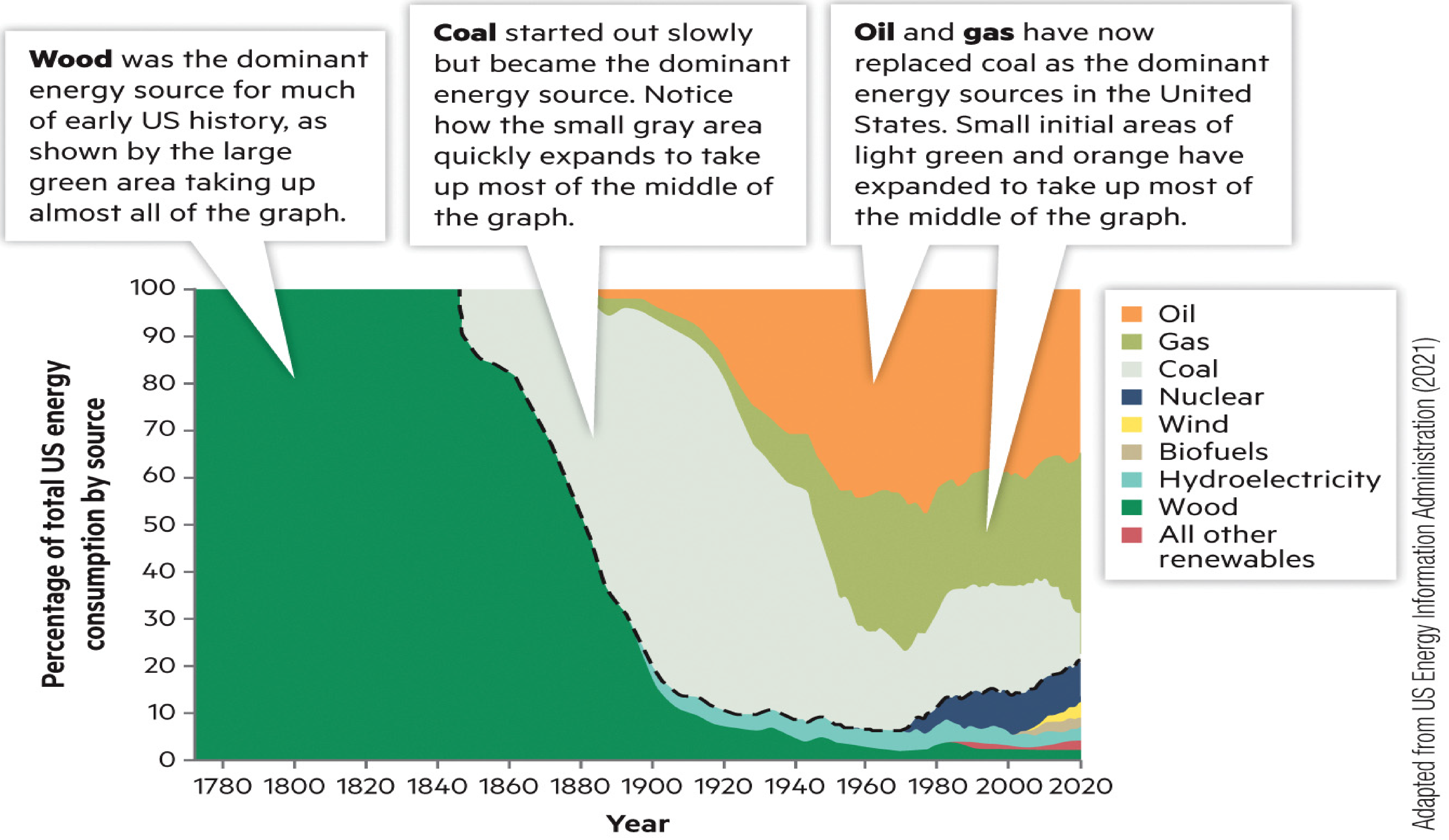



Sarin Images/GRANGER

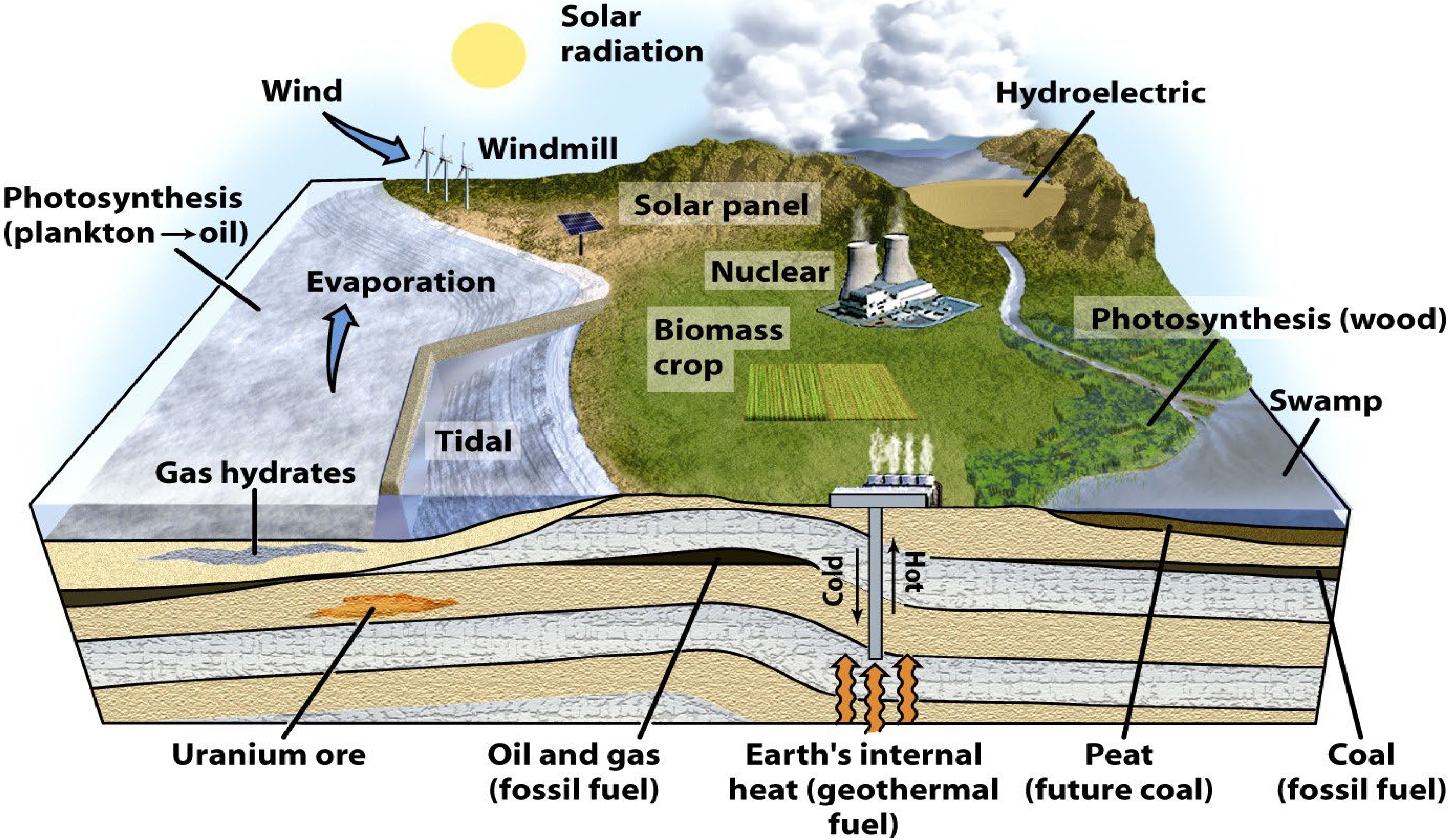

CathyRL/Shutterstock

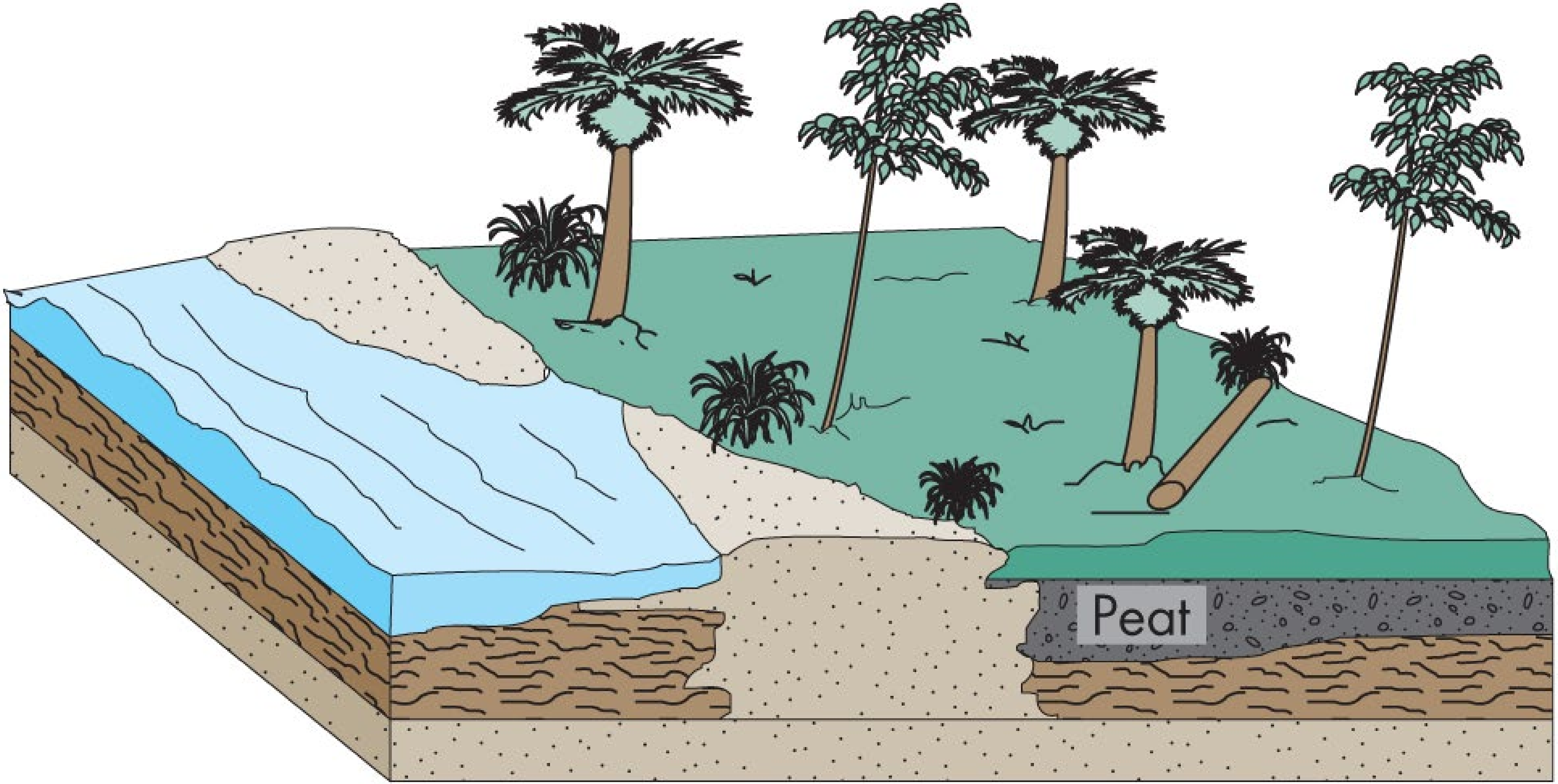

(b)
Regional Consumption by Fuel in 2020
Percentage
100
90
80
70
60
50
40
30
20
10
0
North America
South and Central America
Europe
Common-wealth of Independent States
Middle East
Africa
Asia Pacific
(a)
World Consumption by Fuel
Million metric tons oil equivalent
600
500
400
300
200
100
0
1995
2000
2005
2010
2015
2020
Year
Renewables
Hydroelectricity
Nuclear energy
Coal
Natural gas
Oil
Graphs reprinted from BP Statistical Review of World Energy, p. 10.
© 2021. Reprinted by permission of BP p.l.c.


Nuclear electric power 9%
100%
Renewable energy 12%
11%
20%
9%
60%
Coal 10%
90%
10%
<1%
Petroleum 35%
68%
26%
5%
1%
Natural gas 34%
25%
38%
33%
3%
Sector of fuel consumption
Transportation
Industrial
Residential and commercial
Electric power

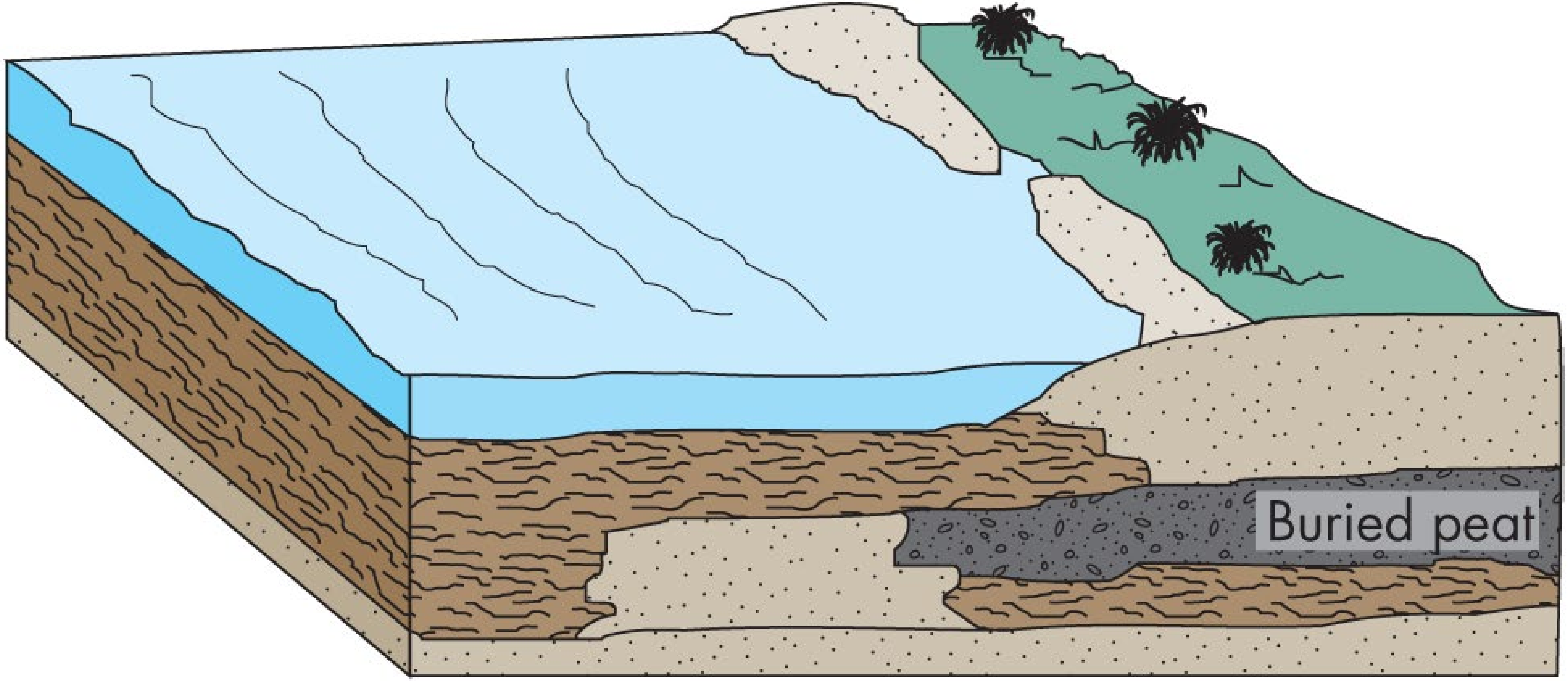

Wood was the dominant energy source for much of early US history, as shown by the large green area taking up almost all of the graph.
Coal started out slowly but became the dominant energy source. Notice how the small gray area quickly expands to take up most of the middle of the graph.
Oil and **gas** have now replaced coal as the dominant energy sources in the United States. Small initial areas of light green and orange have expanded to take up most of the middle of the graph.
Percentage of total US energy consumption by source
100
90
80
70
60
50
40
30
20
10
0
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
Year
Oil
Gas
Coal
Nuclear
Wind
Biofuels
Hydroelectricity
Wood
All other renewables
Adapted from US Energy Information Administration (2021)

Energy Resources

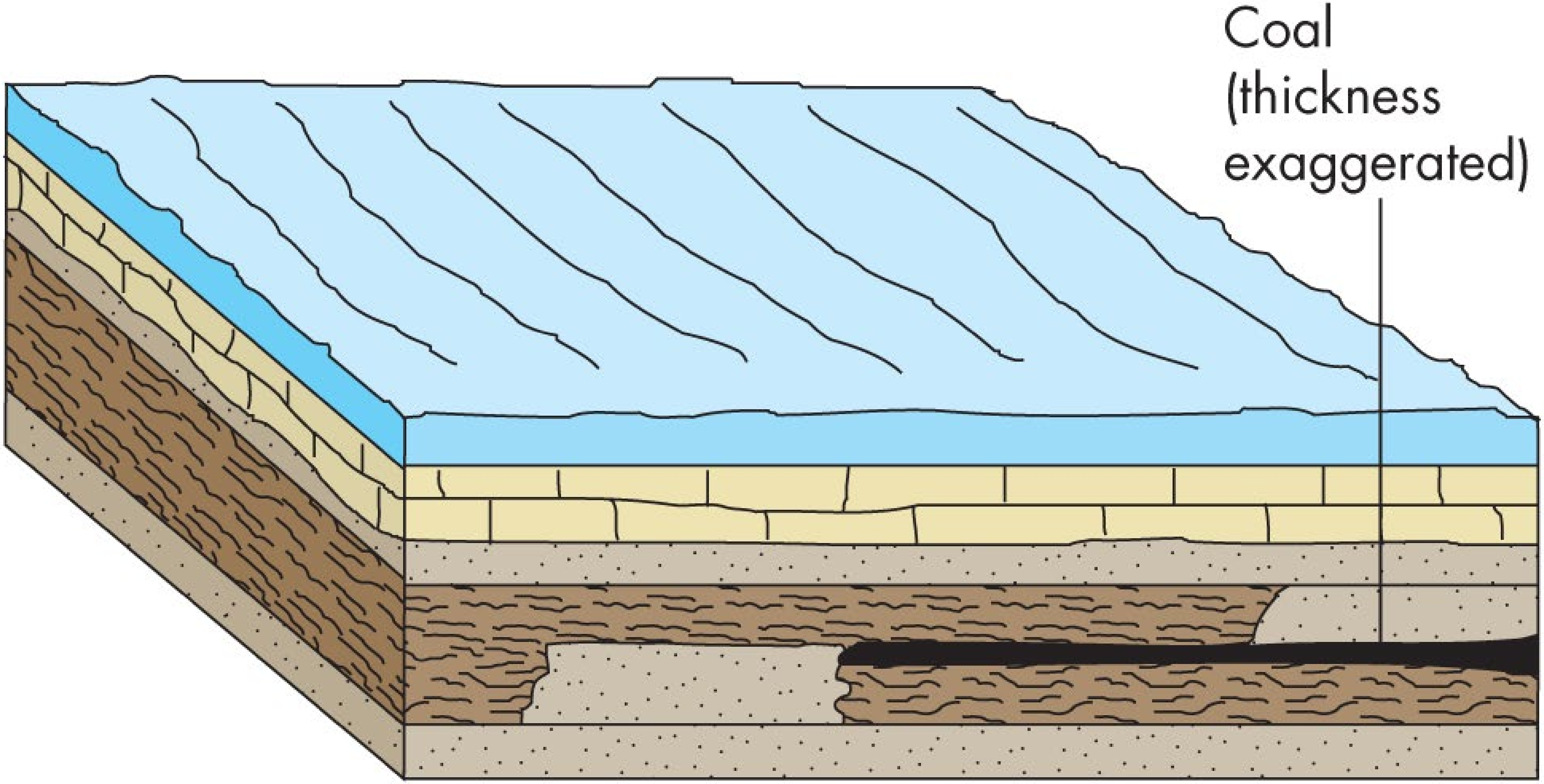




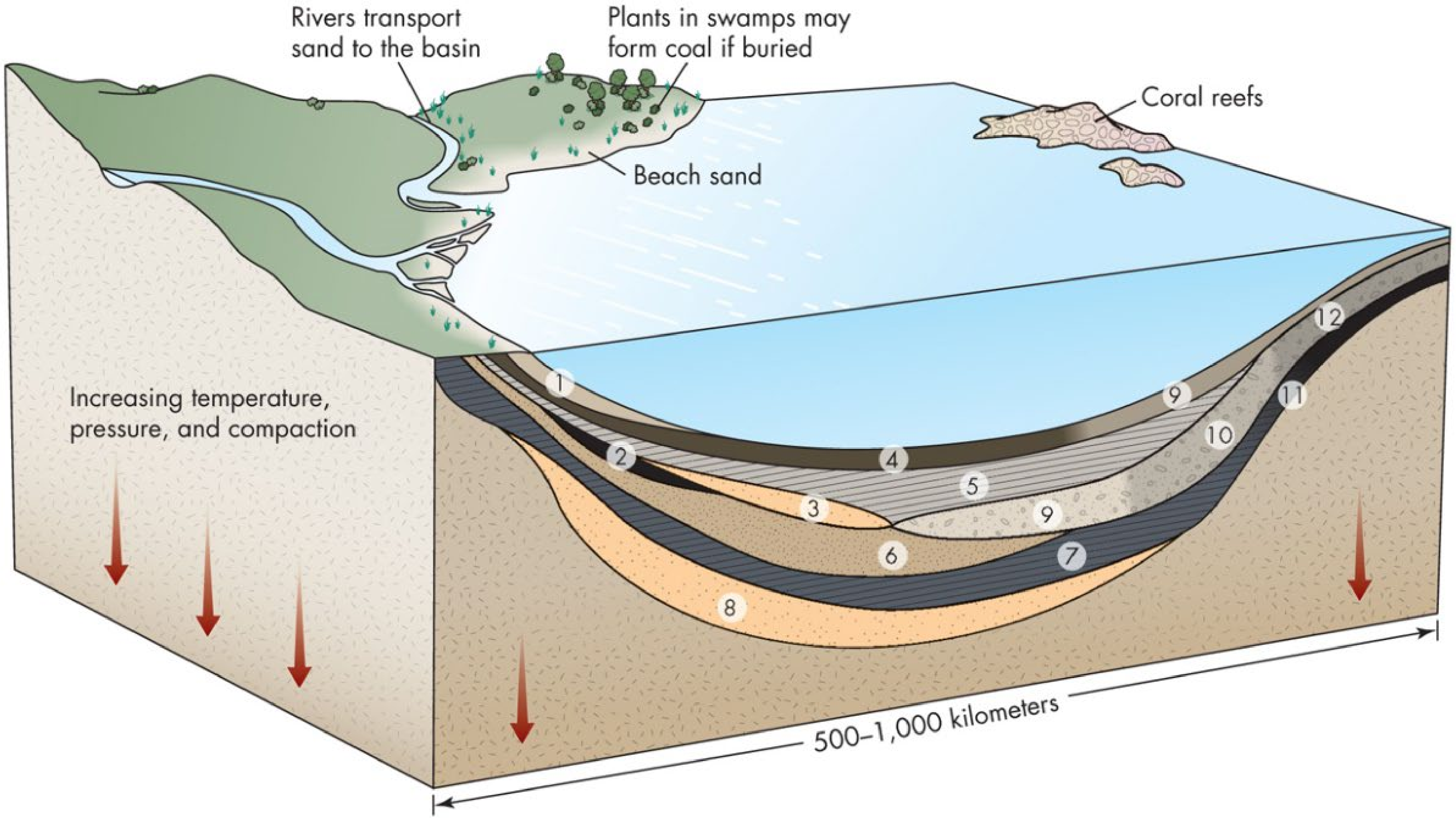
(a) Coal swamp forms.



(b) Rise in sea level buries swamp in sediment.

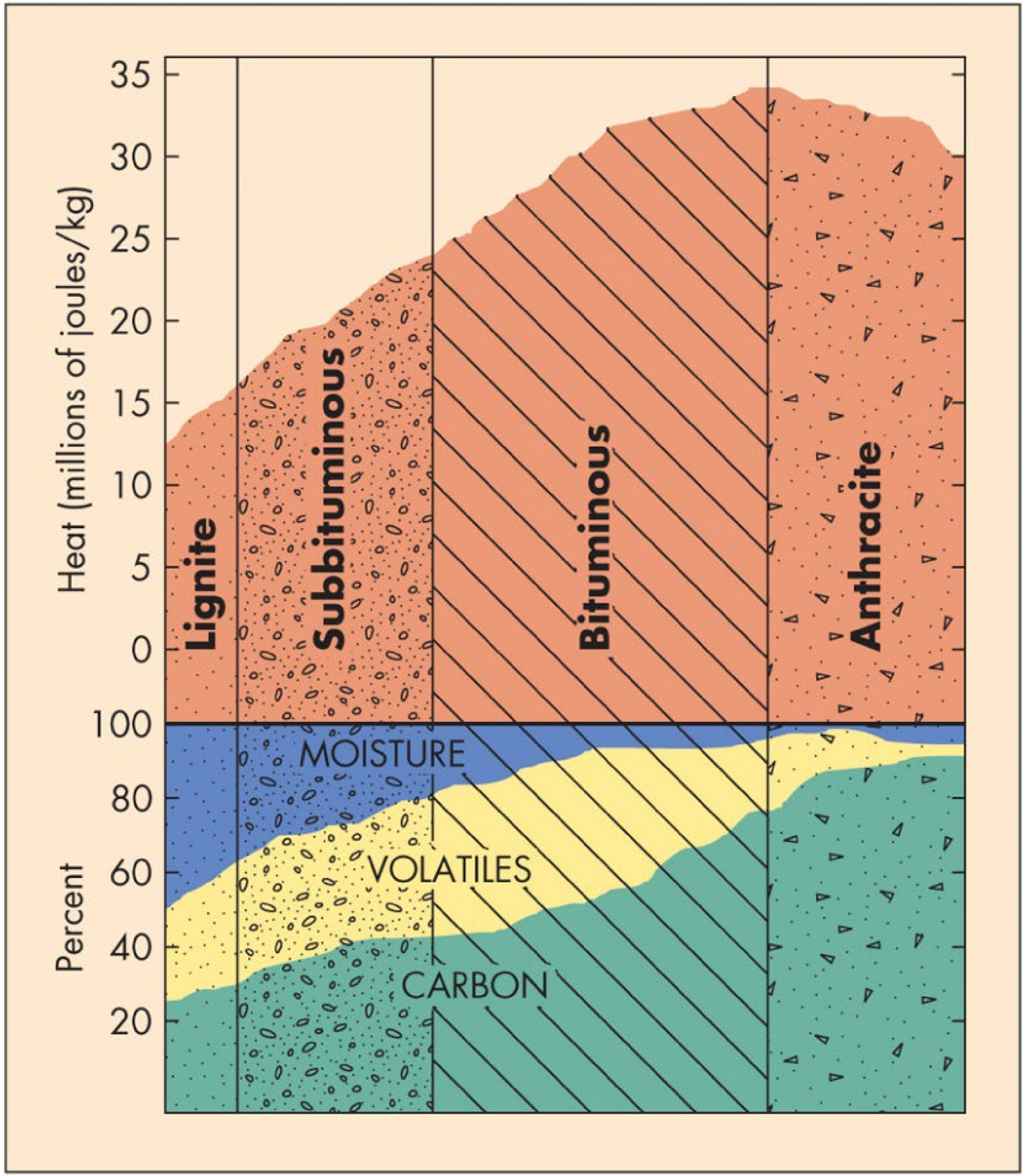


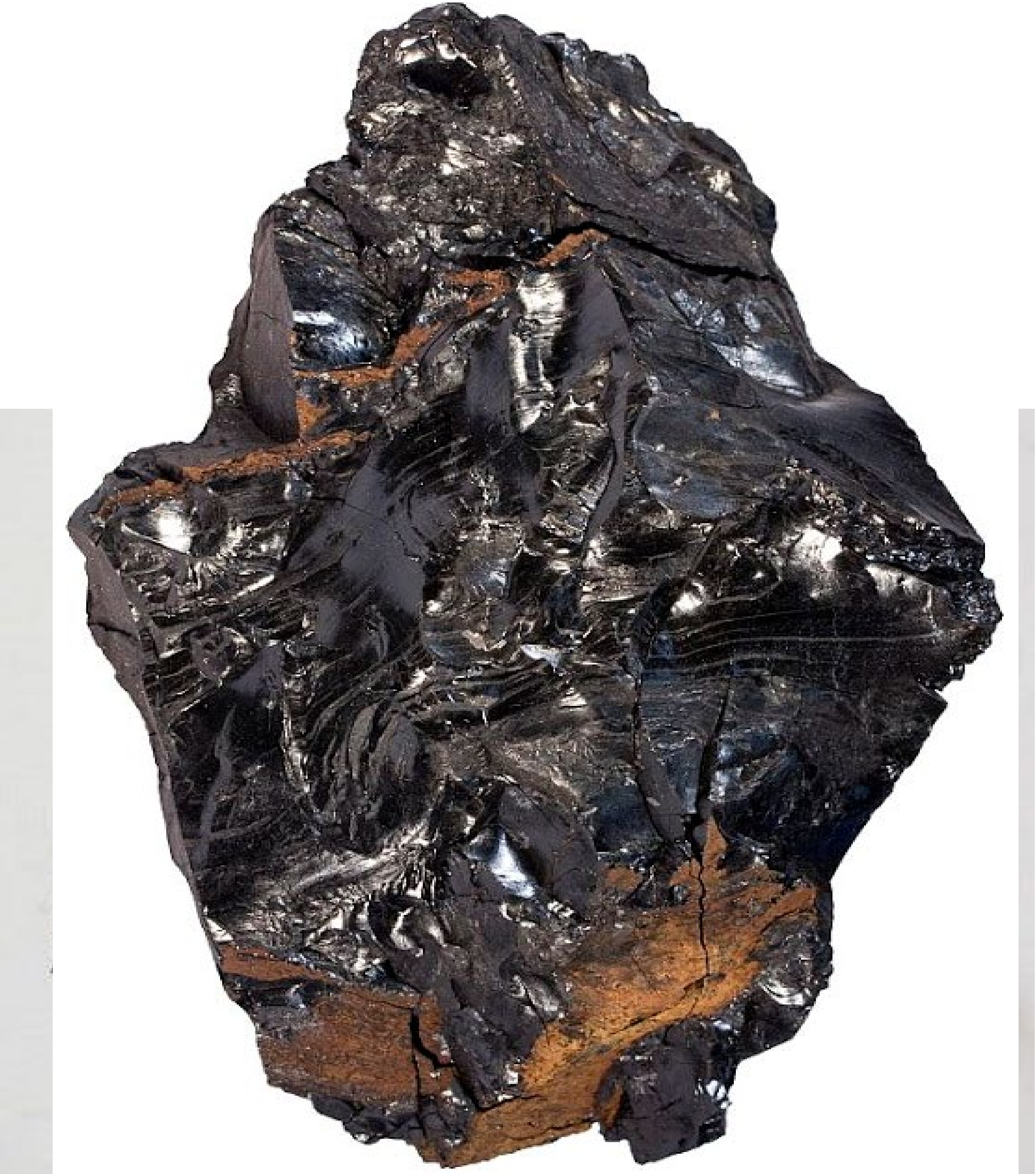
(c) Compression of peat forms coal.

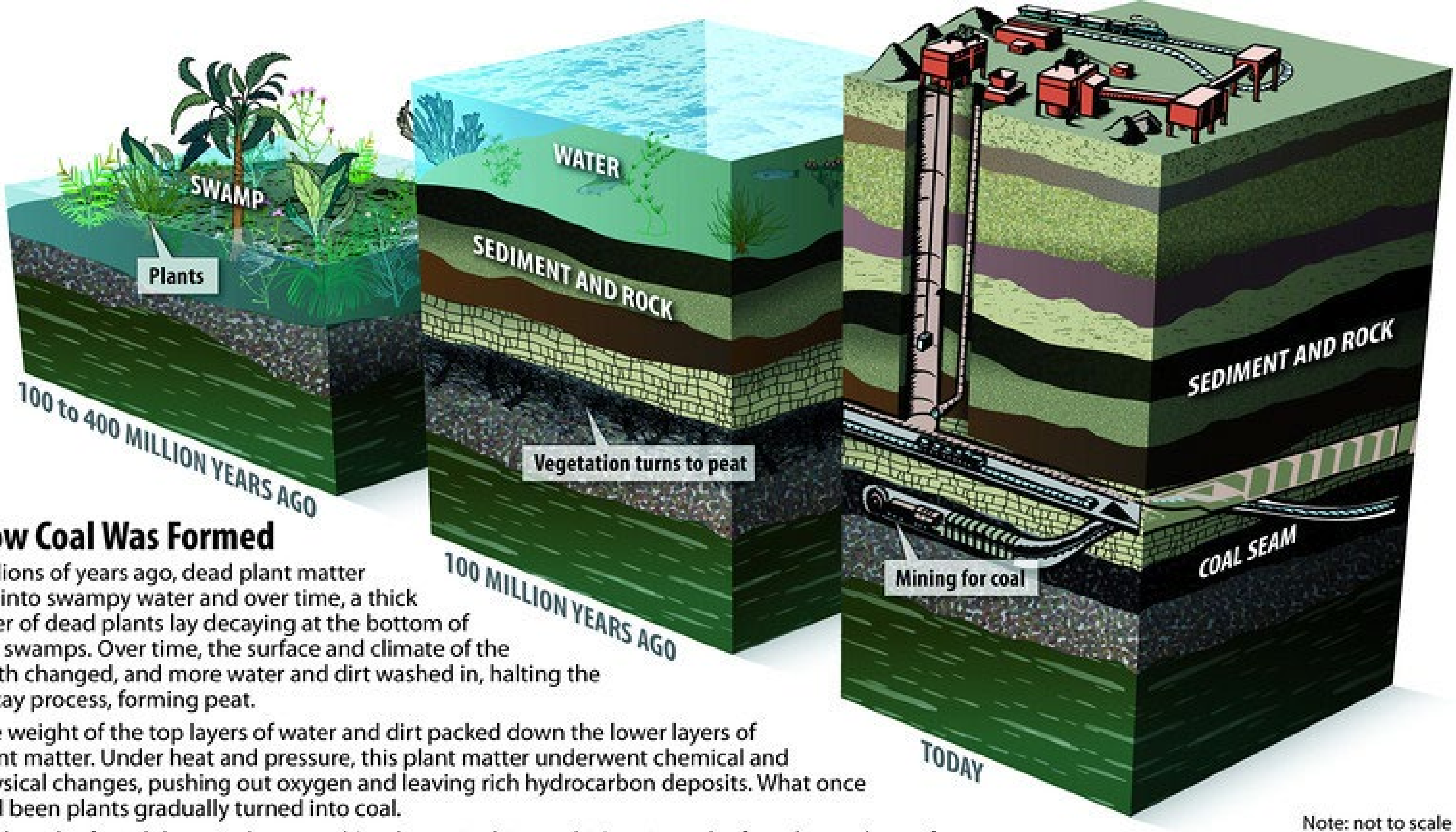


Explanation

1. Delta sand
2. Coal
3. Sandstone (compacted beach sand)*
4. Black mud settled from ocean water
5. Shale formed by compaction of mud
6. Brown sandstone (formed by compaction of river and delta sand)*
7. Ancient shale (the heat at this depth turns organic matter into oil)
8. Ancient sandstone*
9. Limestone*
10. Ancient reef*
11. Oil migrates from shale to the reef and forms an oil reservoir*
12. Dolomite formed by groundwater altering limestone*


Heat (millions of joules/kg)
35
30
25
20
15
10
5
0
Lignite
Subbituminous
Bituminous
Anthracite
100
80
60
40
20
Percent
MOISTURE
VOLATILES
CARBON



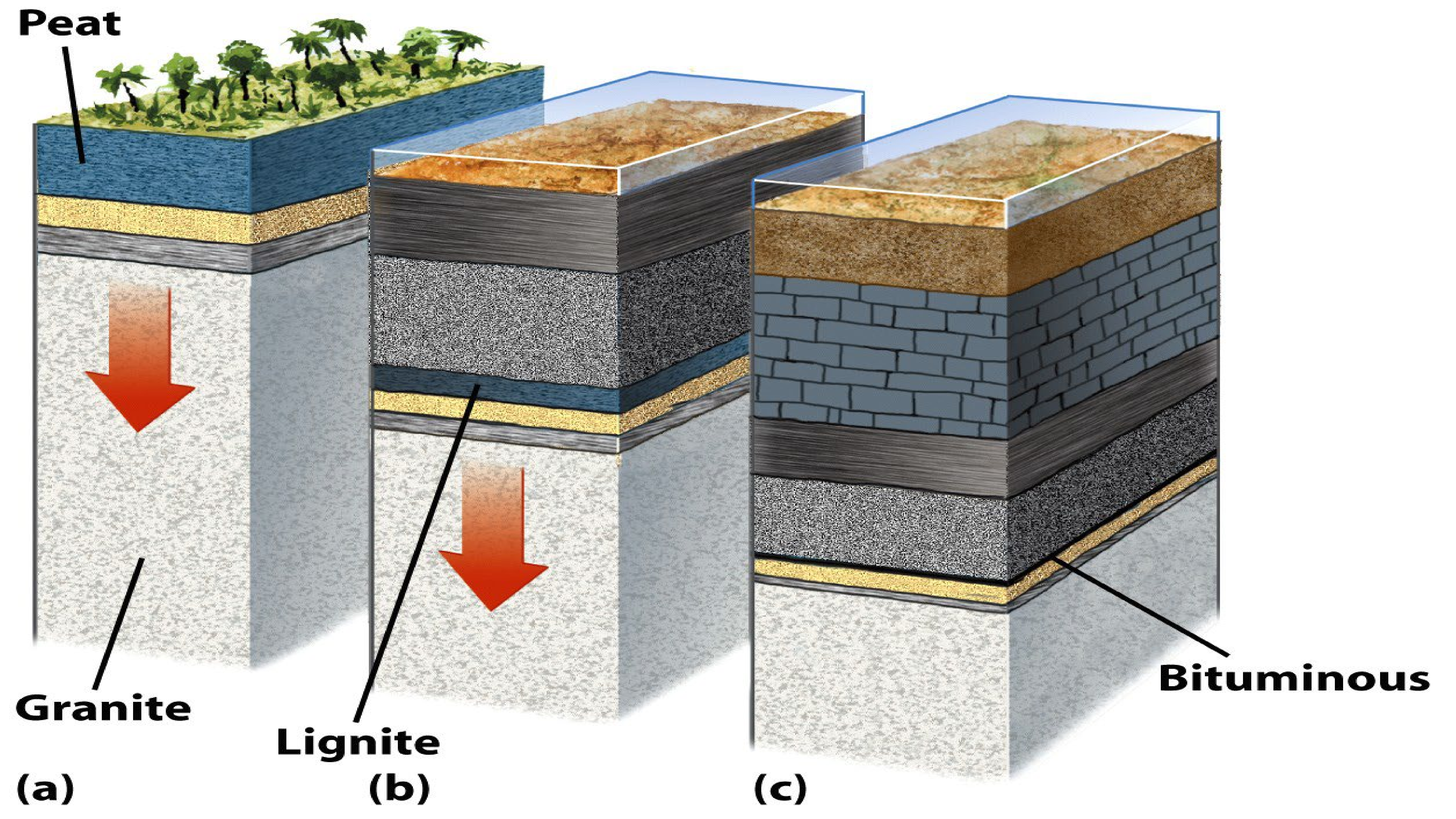


How Coal Was Formed

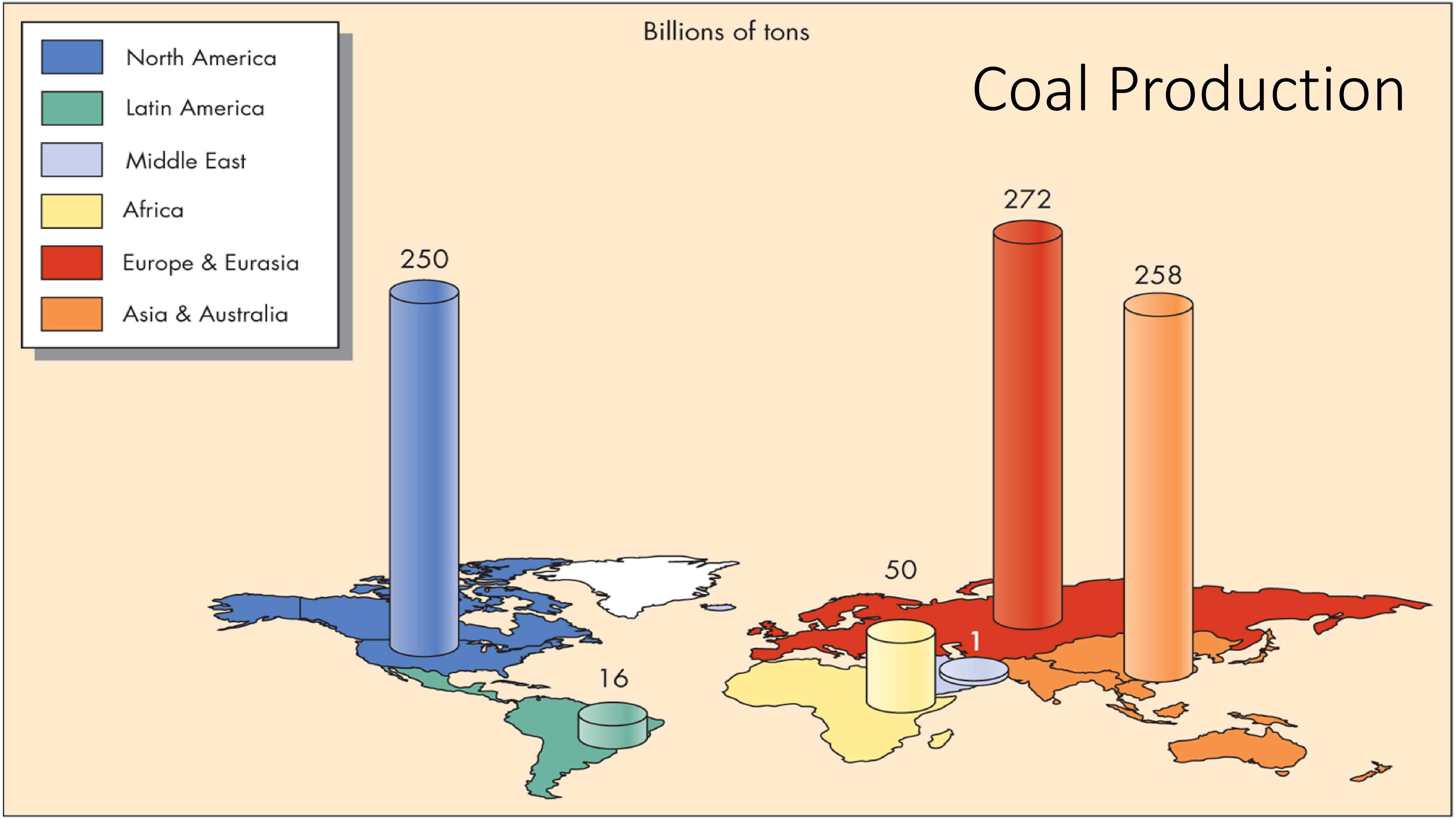
Millions of years ago, dead plant matter fell into swampy water and over time, a thick layer of dead plants lay decaying at the bottom of the swamps. Over time, the surface and climate of the Earth changed, and more water and dirt washed in, halting the decay process, forming peat.

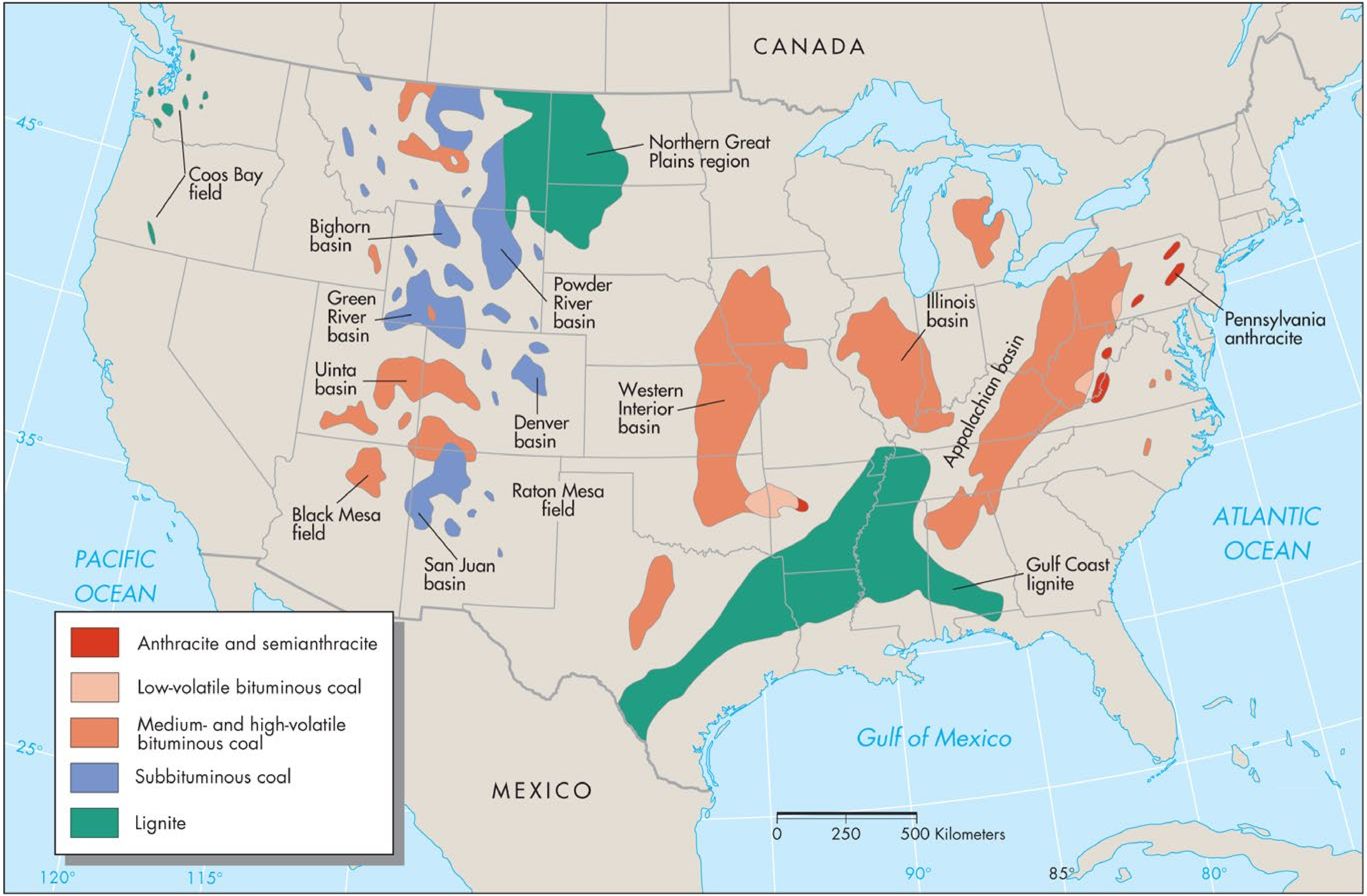
The weight of the top layers of water and dirt packed down the lower layers of plant matter. Under heat and pressure, this plant matter underwent chemical and physical changes, pushing out oxygen and leaving rich hydrocarbon deposits. What once had been plants gradually turned into coal.

Coal can be found deep underground (as shown in this graphic), or it can be found near the surface.


Peat
Granite
Lignite
Bituminous
(a)
(b)
(c)

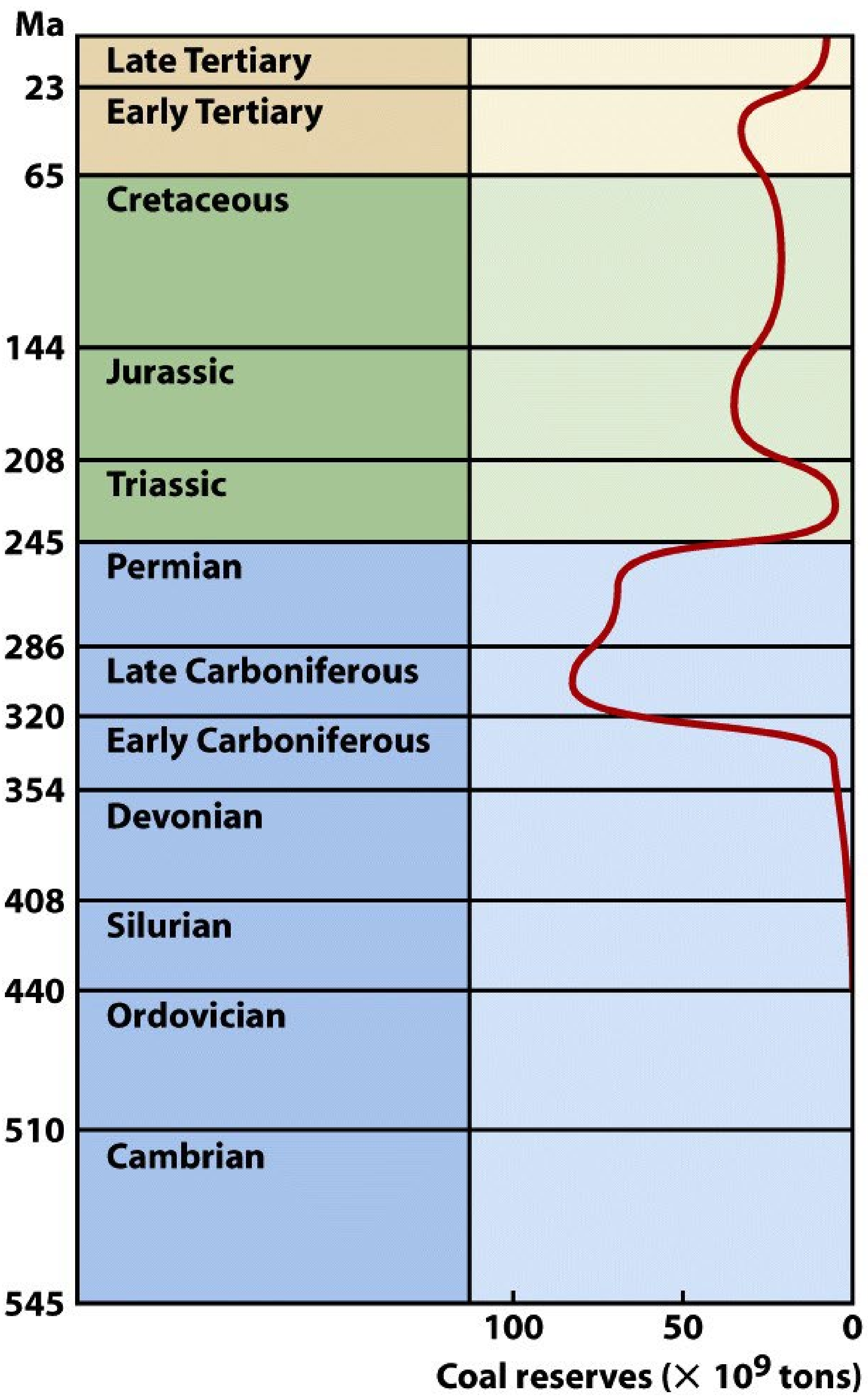
Coal Production




CANADA
Northern Great Plains region
Coos Bay field
Bighorn basin
Powder River basin
Green River basin
Uinta basin
Denver basin
Western Interior basin
Illinois basin
Appalachian basin
Pennsylvania anthracite
Black Mesa field
Raton Mesa field
San Juan basin
Gulf Coast lignite
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
MEXICO
Anthracite and semianthracite
Low-volatile bituminous coal
Medium- and high-volatile bituminous coal
Subbituminous coal
Lignite
0
250
500 Kilometers
45°
35°
25°
120°
115°
90°
85°
80°

Coal reserves & Geologic time

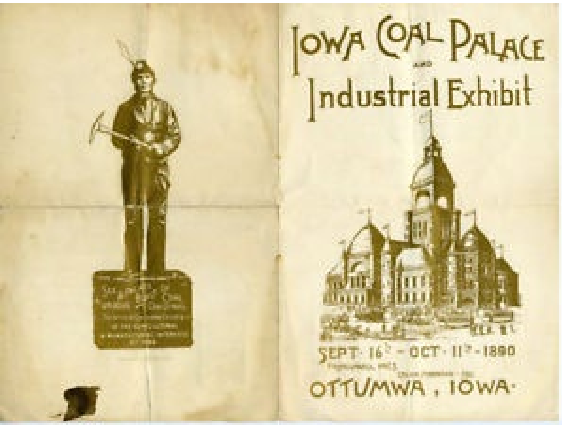
- Permian
- Carboniferous
  - Mississippian
  - Pennsylvanian

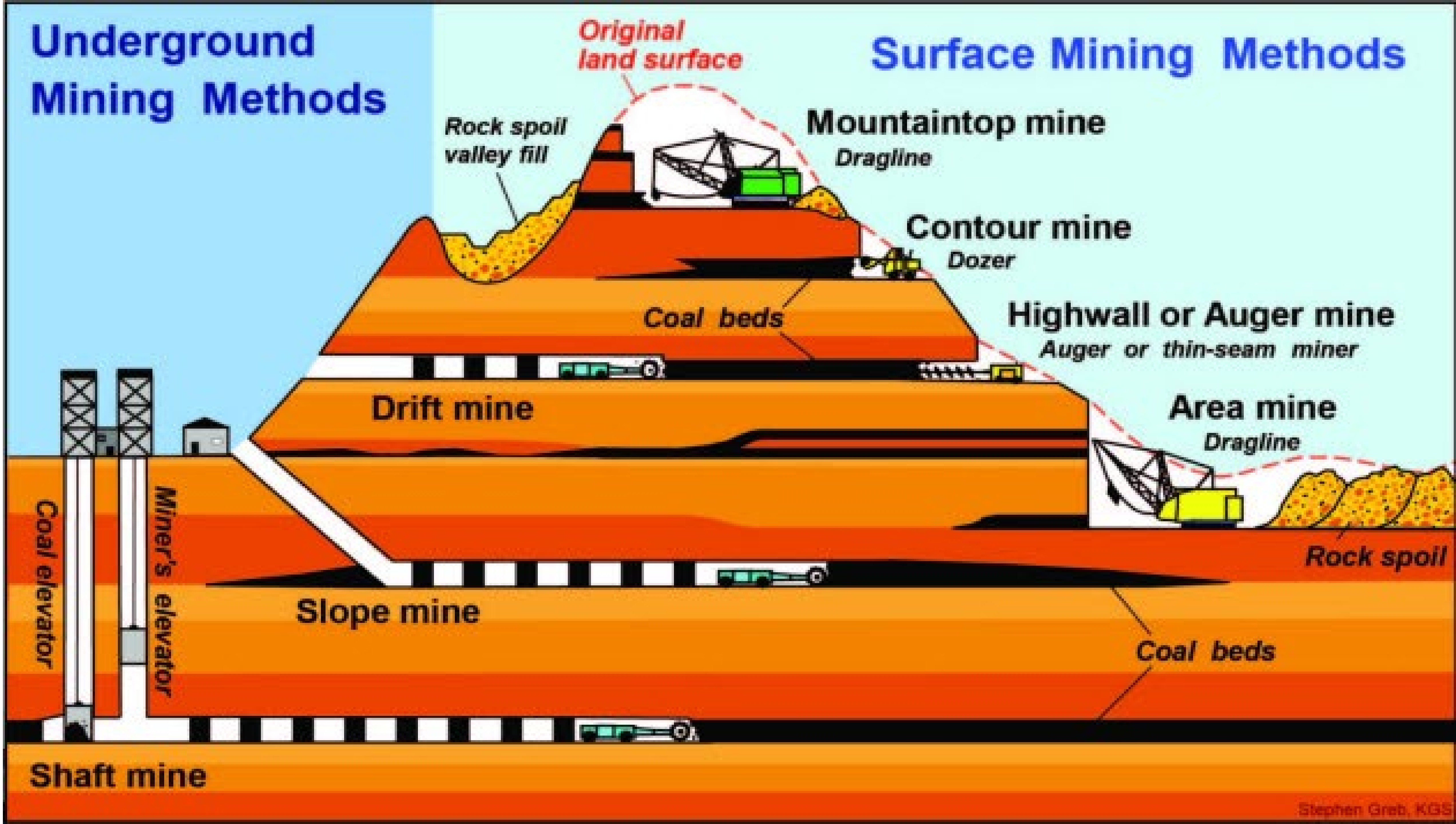


Iowa Coal

- Sub-Bituminous to Bituminous
- High ash and sulfur content (FeS_2)
  - Ash results from sediment (impurities) that were washed into the swamps

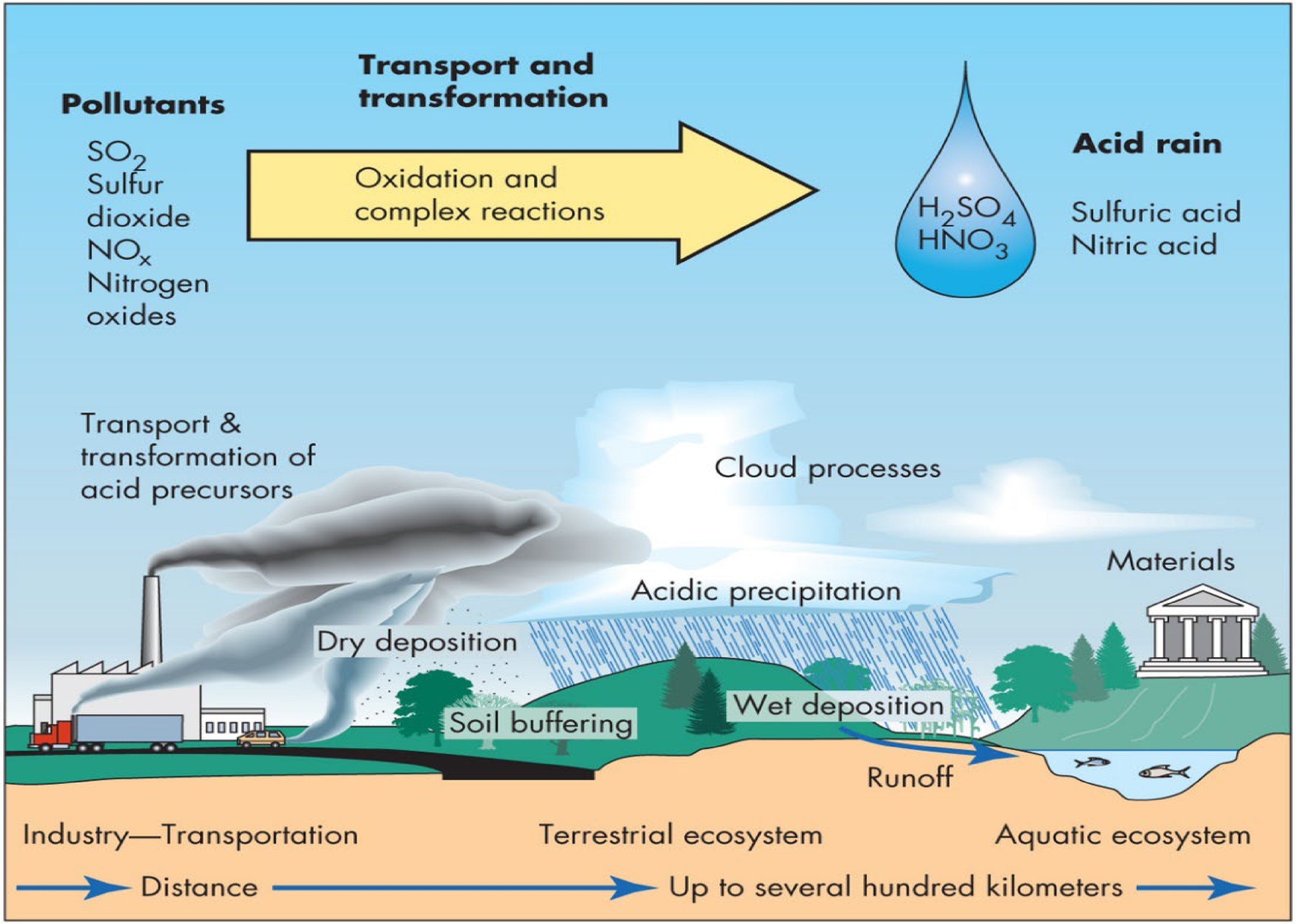
Ottumwa Coal Palace 1890

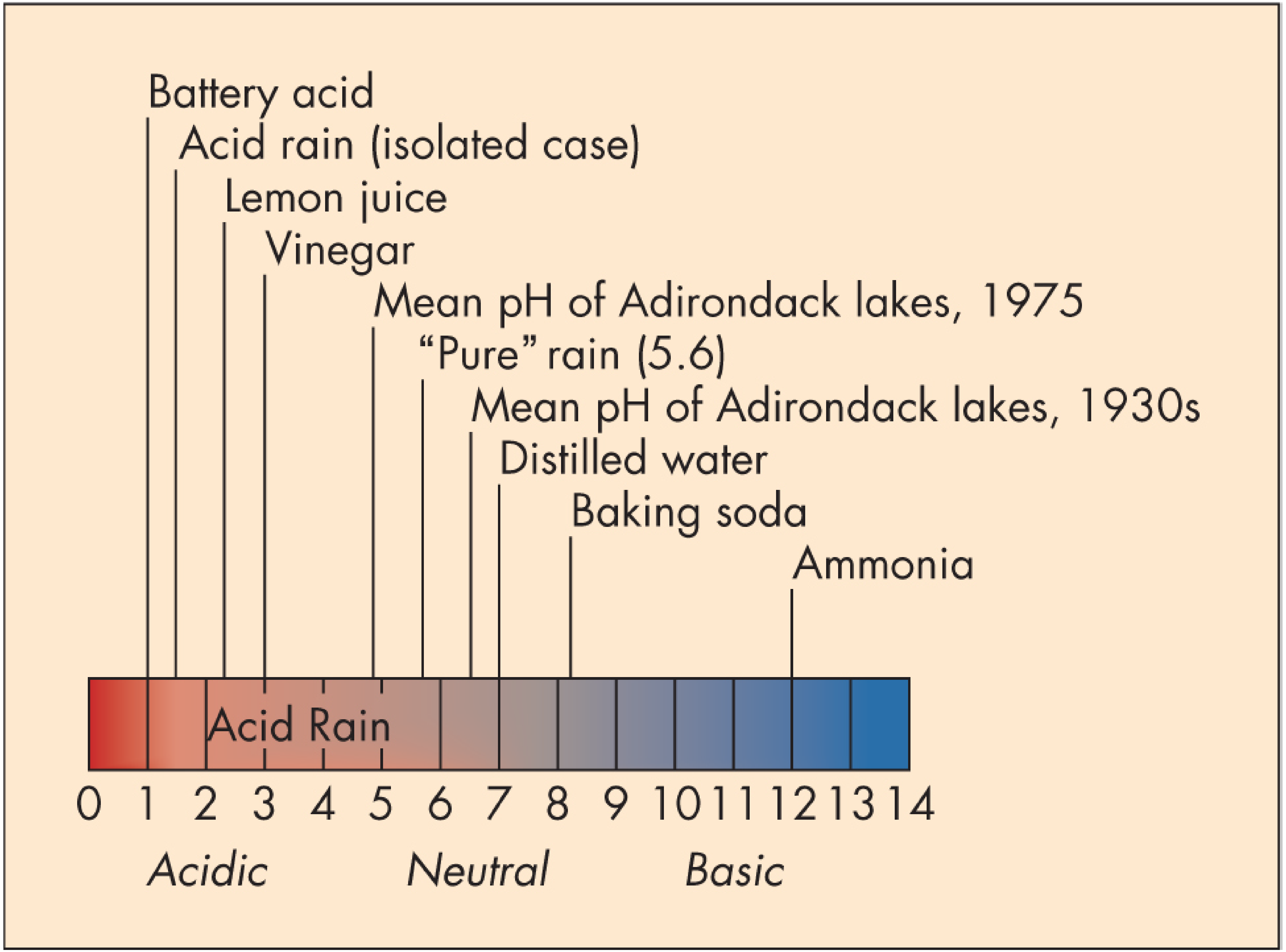



Underground Mining Methods
Original land surface
Surface Mining Methods
Rock spoil valley fill
Mountaintop mine
Dragline
Contour mine
Dozer
Coal beds
Highwall or Auger mine
Auger or thin-seam miner
Drift mine
Area mine
Dragline
Coal elevator
Miner's elevator
Rock spoil
Slope mine
Coal beds
Shaft mine
Stephen Greb, KGS


BLACK BEAUTY
COAL COMPANY

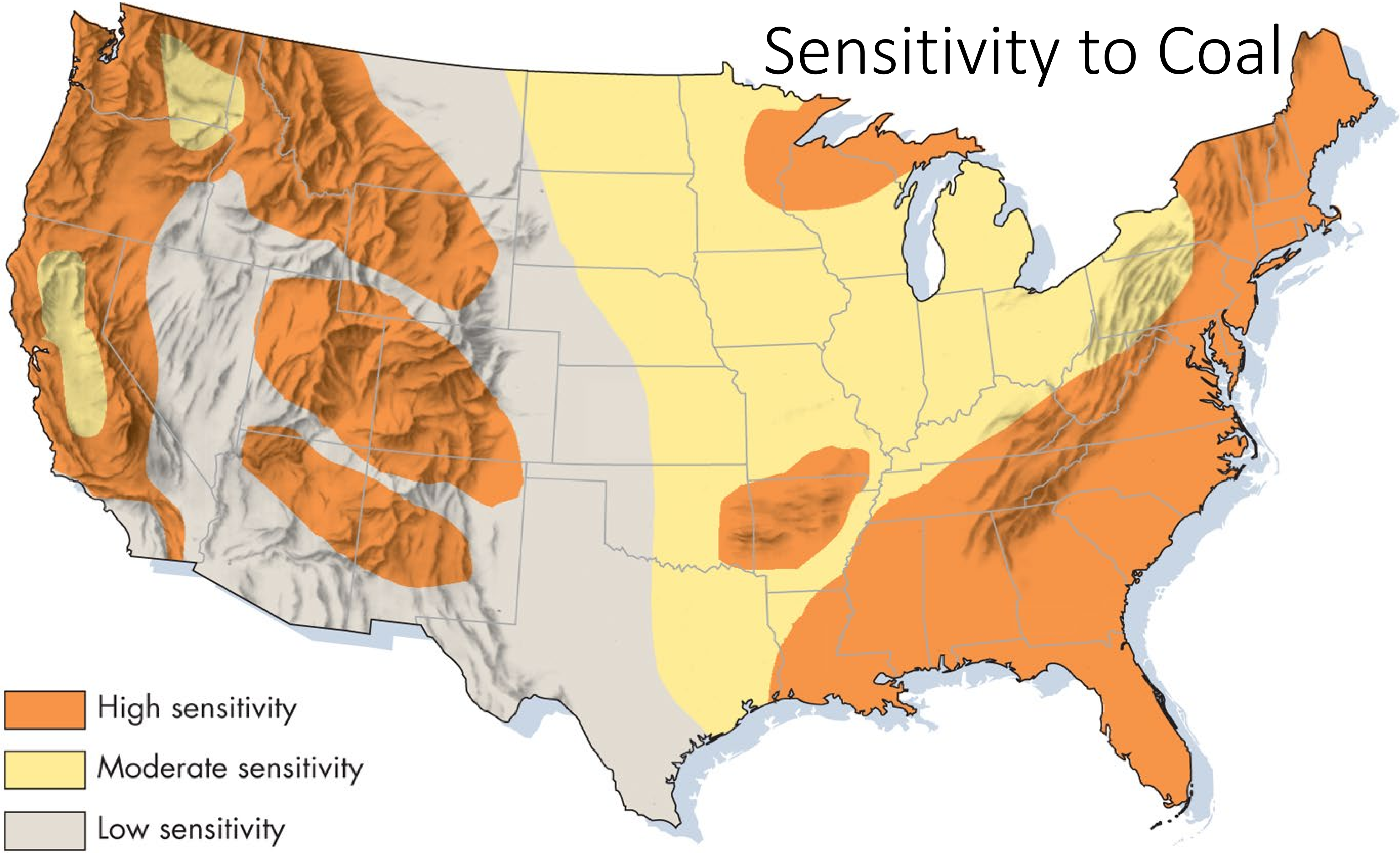
Reclamation


Pollutants
SO2
Sulfur
dioxide
NOx
Nitrogen
oxides
Transport and
transformation
Oxidation and
complex reactions
H2SO4
HNO3
Acid rain
Sulfuric acid
Nitric acid
Transport &
transformation of
acid precursors
Cloud processes
Materials
Acidic precipitation
Dry deposition
Soil buffering
Wet deposition
Runoff
Industry—Transportation
Terrestrial ecosystem
Aquatic ecosystem
Distance
Up to several hundred kilometers

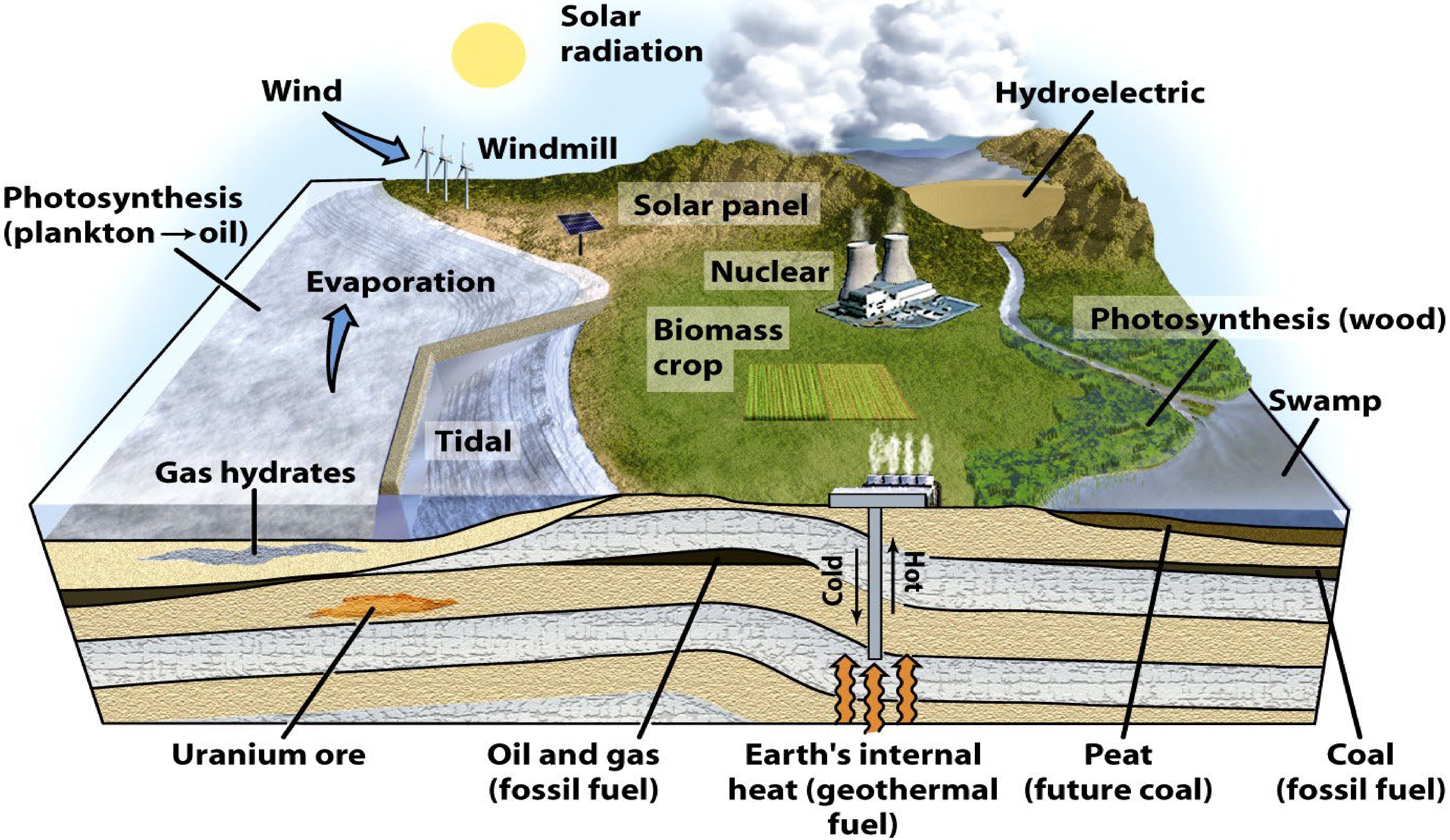


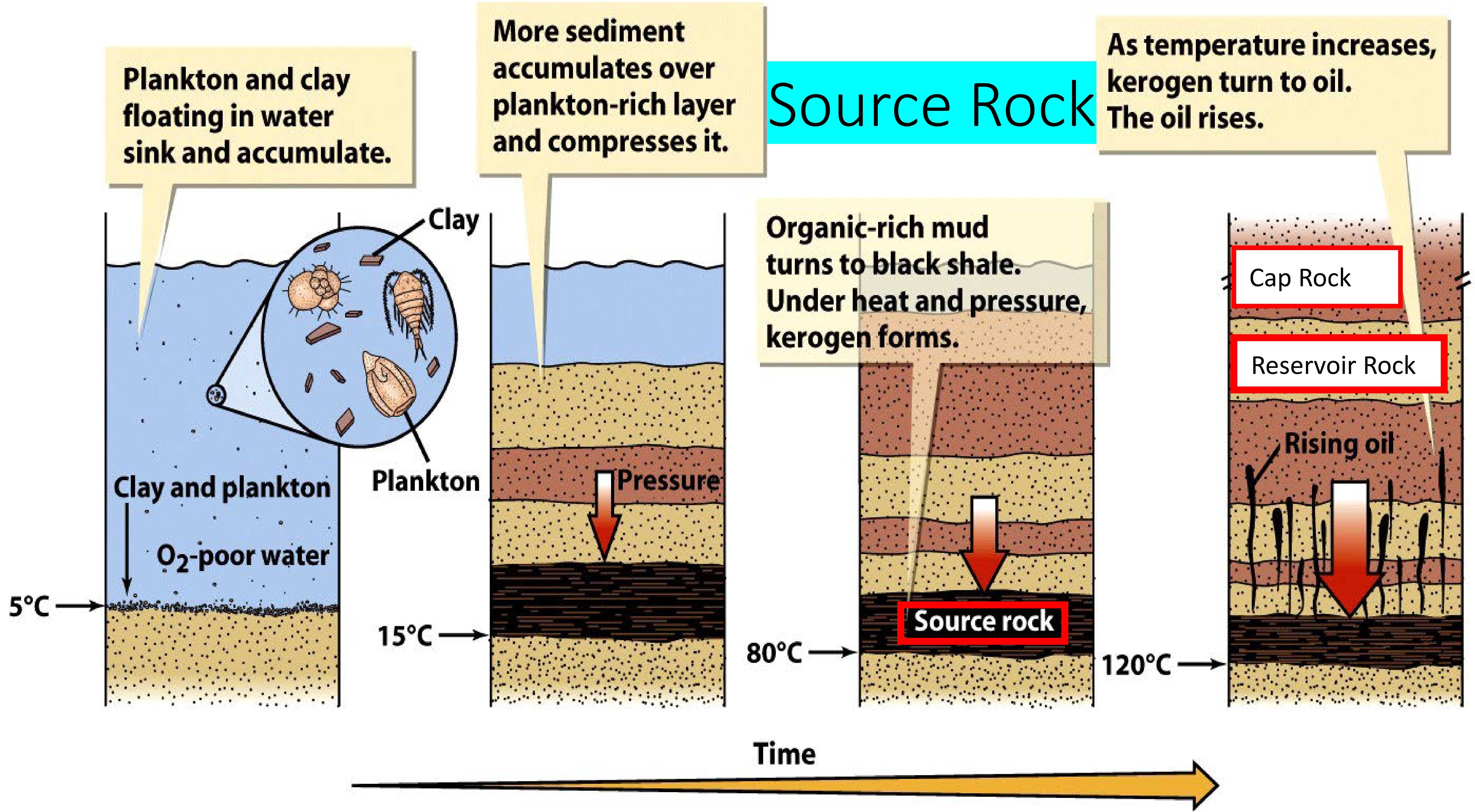
Battery acid
Acid rain (isolated case)
Lemon juice
Vinegar
Mean pH of Adirondack lakes, 1975
"Pure" rain (5.6)
Mean pH of Adirondack lakes, 1930s
Distilled water
Baking soda
Ammonia
Acid Rain
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Acidic
Neutral
Basic

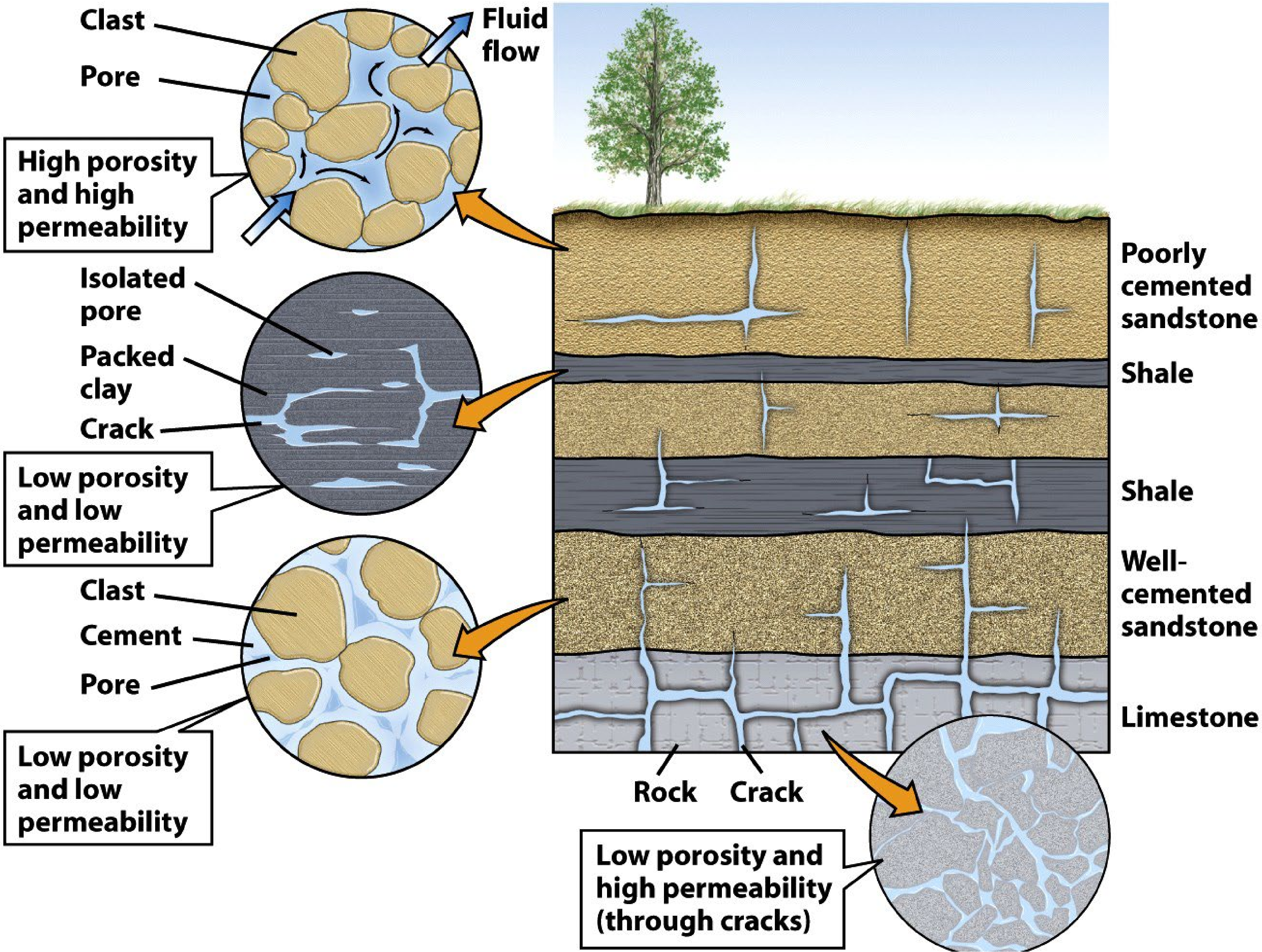
Sensitivity to Coal



Energy Resources




Plankton and clay floating in water sink and accumulate.
More sediment accumulates over plankton-rich layer and compresses it.
Source Rock
As temperature increases, kerogen turn to oil. The oil rises.
Clay
Plankton
Clay and plankton
O_2-poor water
5°C
Pressure
15°C
Organic-rich mud turns to black shale. Under heat and pressure, kerogen forms.
Source rock
80°C
Cap Rock
Reservoir Rock
Rising oil
120°C
Time

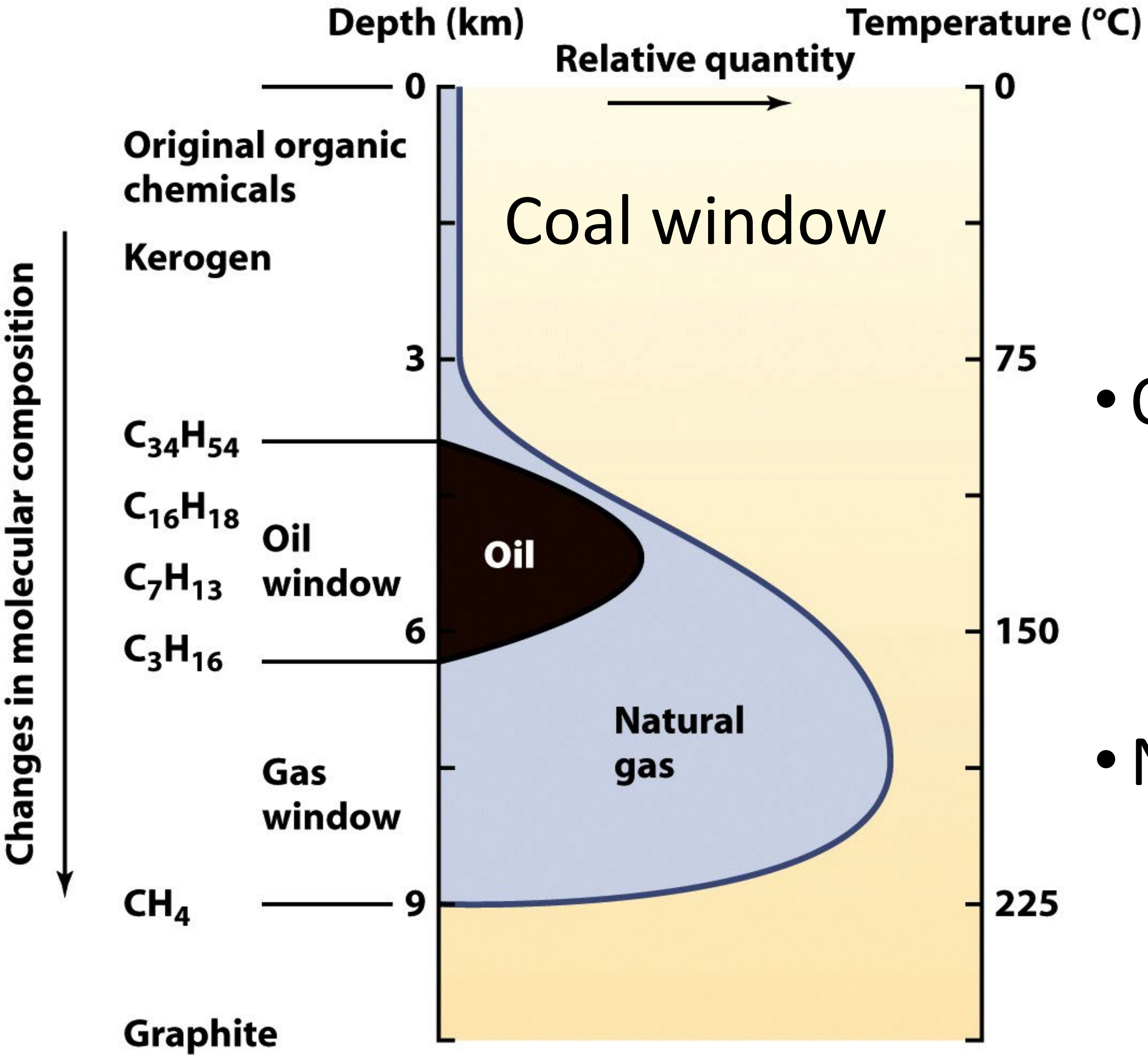


Porosity

Permeability

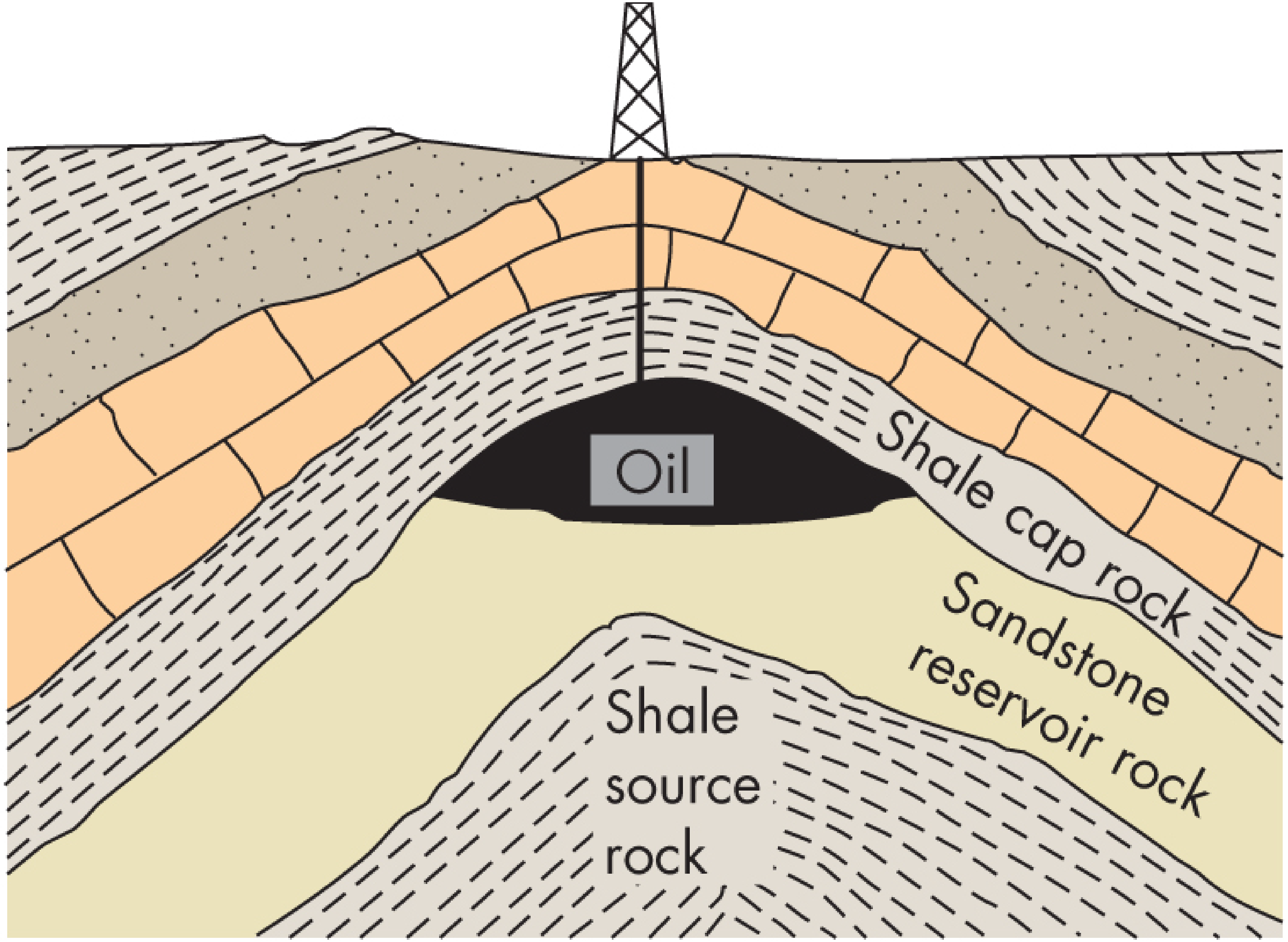
Reservoir vs. cap rocks

BioGeoChemcial Production Windows

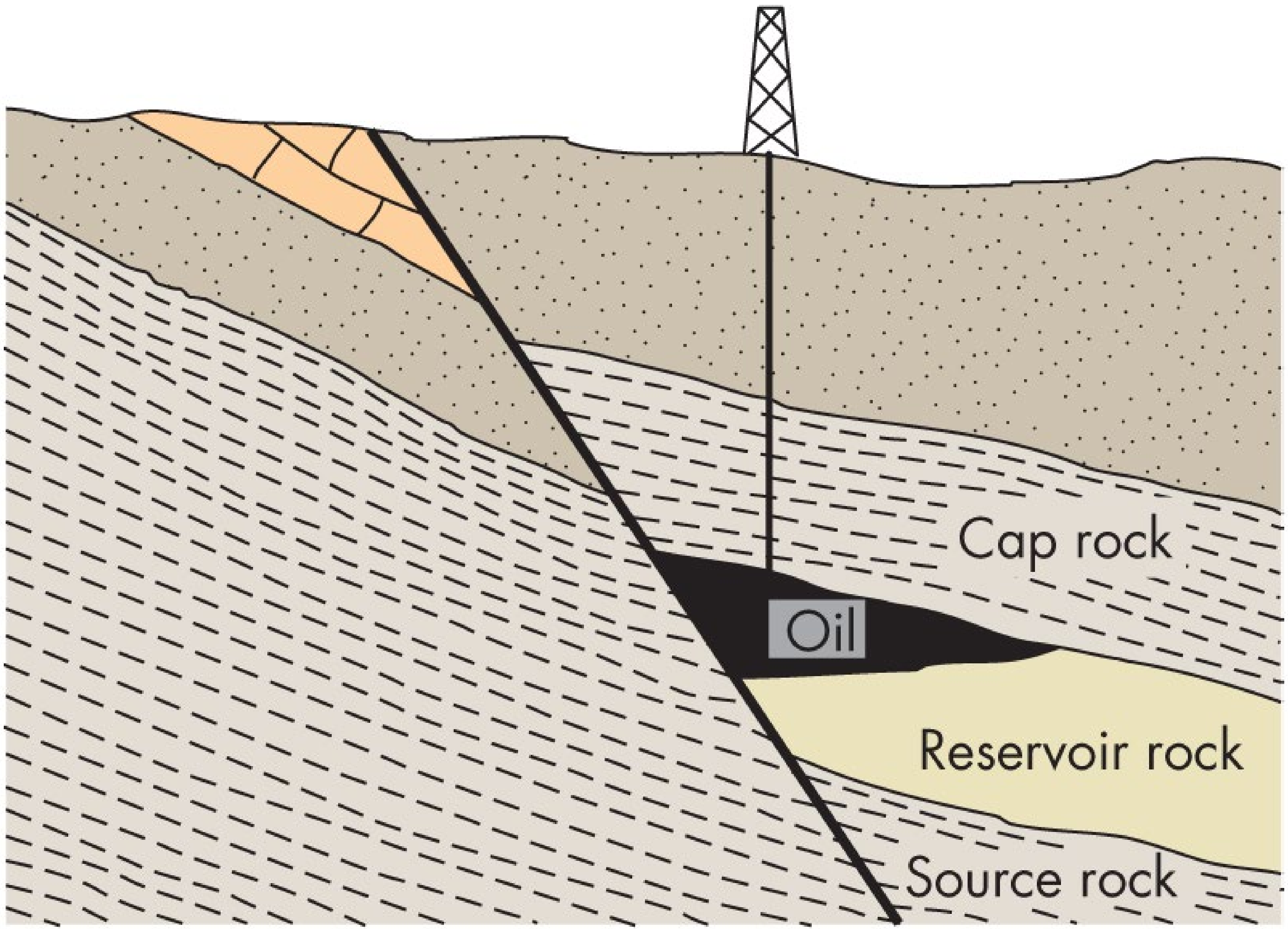


- Oil window
  - Depth 4 to 6 km
  - Temp. 125 to 160 C
- Natural gas window
  - Depth 6 to 9 km
  - 150 to 225 C

Geologic Structures



(a) Anticlinal trap



(b) Fault trap

A Geologic 'Miracle'

- Sun's Energy – Life – Photosynthesis
- Source Rock
- BioGeoChemical Trifecta
  - Biological accumulation
  - Specific Depth
  - Specific Heat
- Reservoir Rock
- Traps – Cap Rock
- Time – Millions of years
- Knowledge, Technology, Money

Mark Smith/Shutterstock

Gado Images/Alamy Stock Photo

(a)

(b)

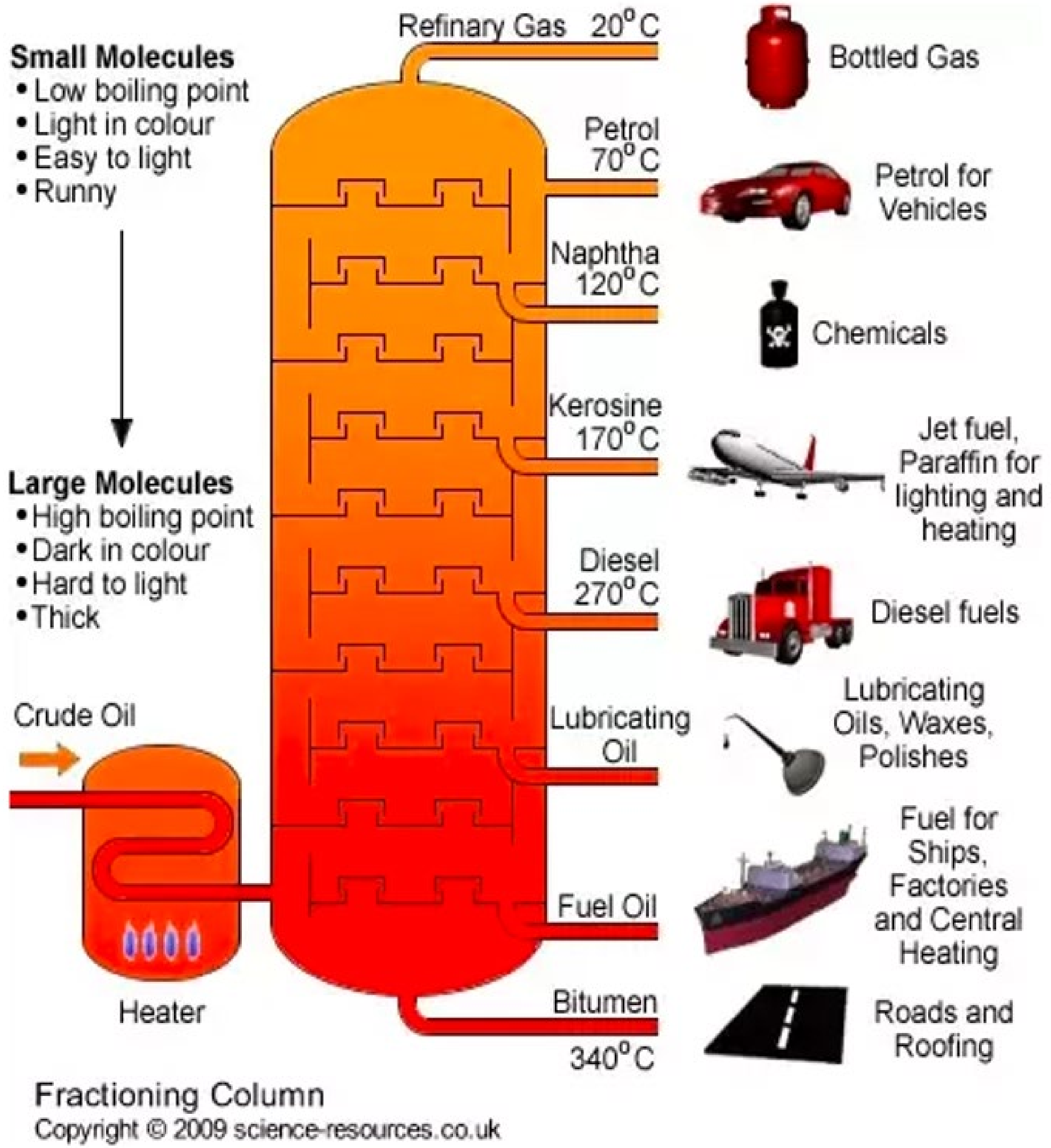
New well =
$5 to 8 million

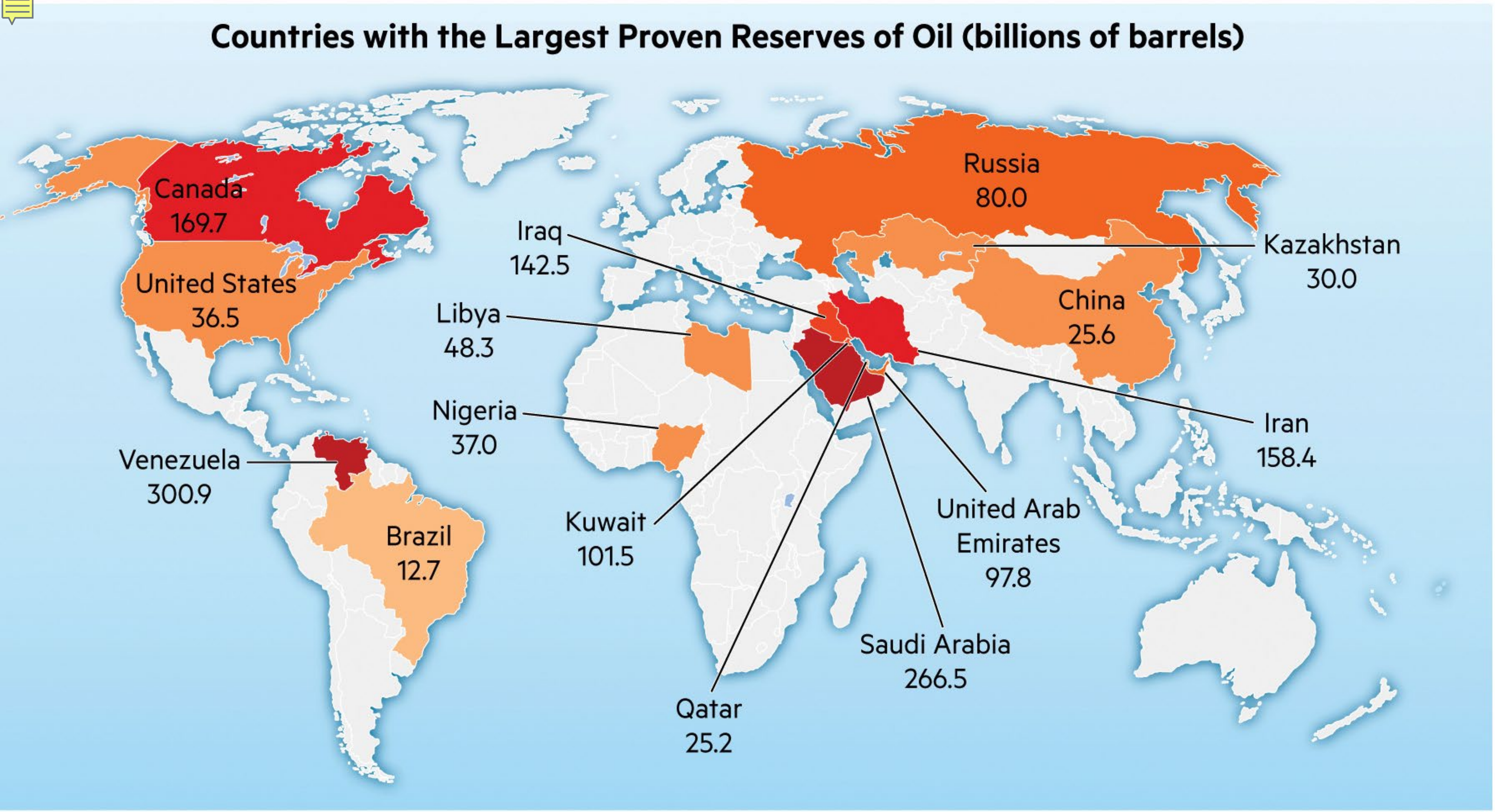
<u>Cost $30 to $50 per barrel of oil produced</u>

<u>$100 million annually</u>

2024 Global Revenue
$4.2 trillion

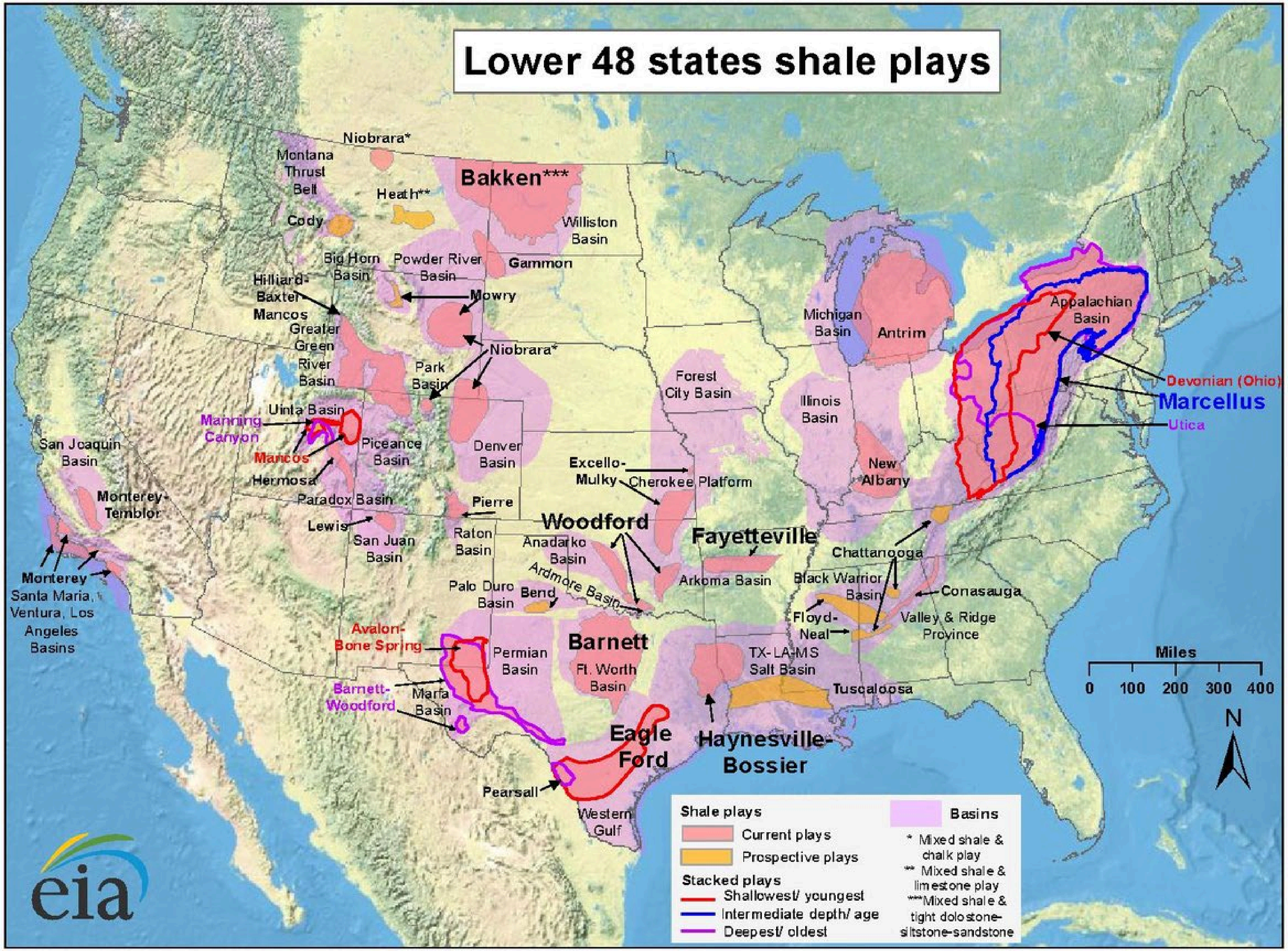
Oil and Gas Refineries





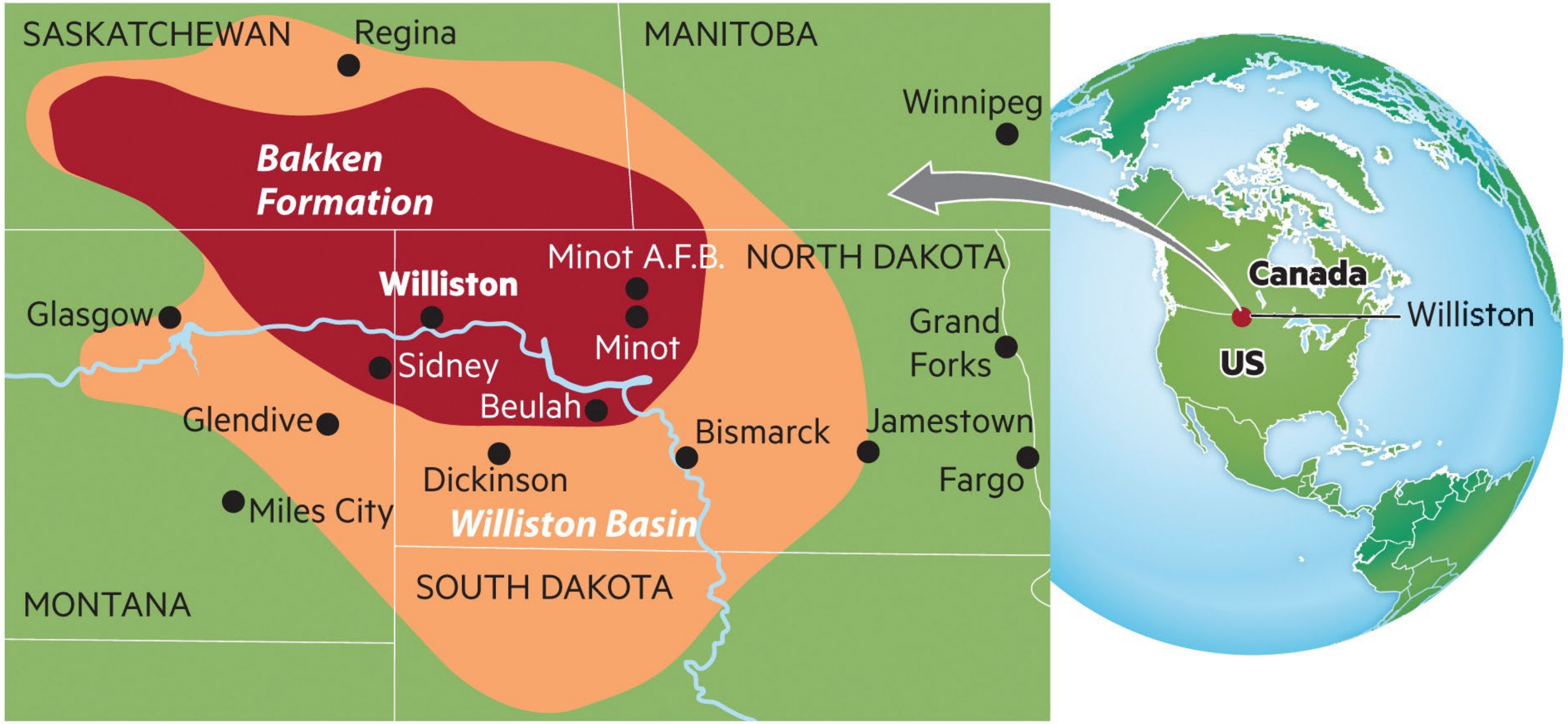
Adapted from Central Intelligence Agency (2019) and BP (2022)

Natural Gas

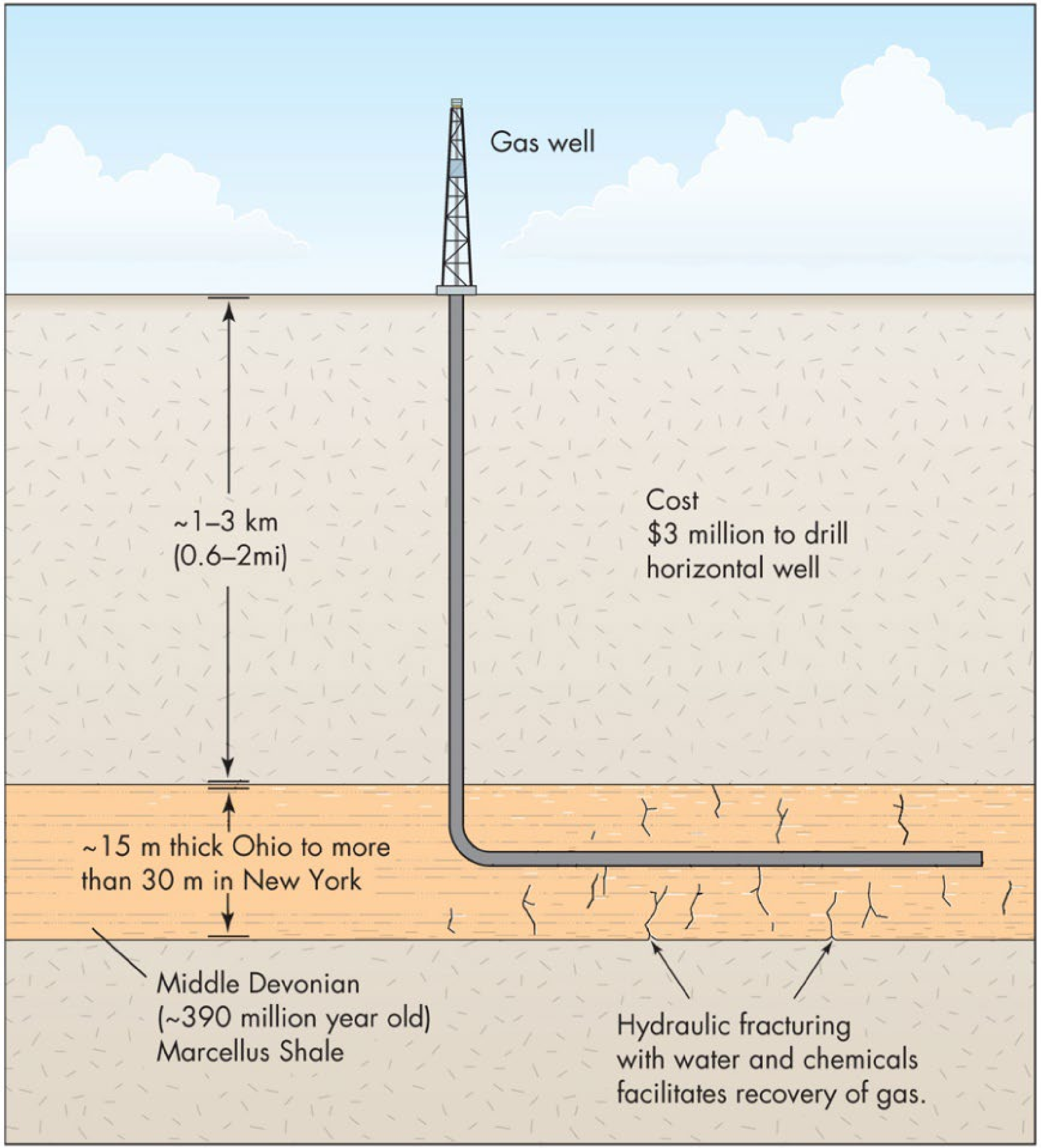


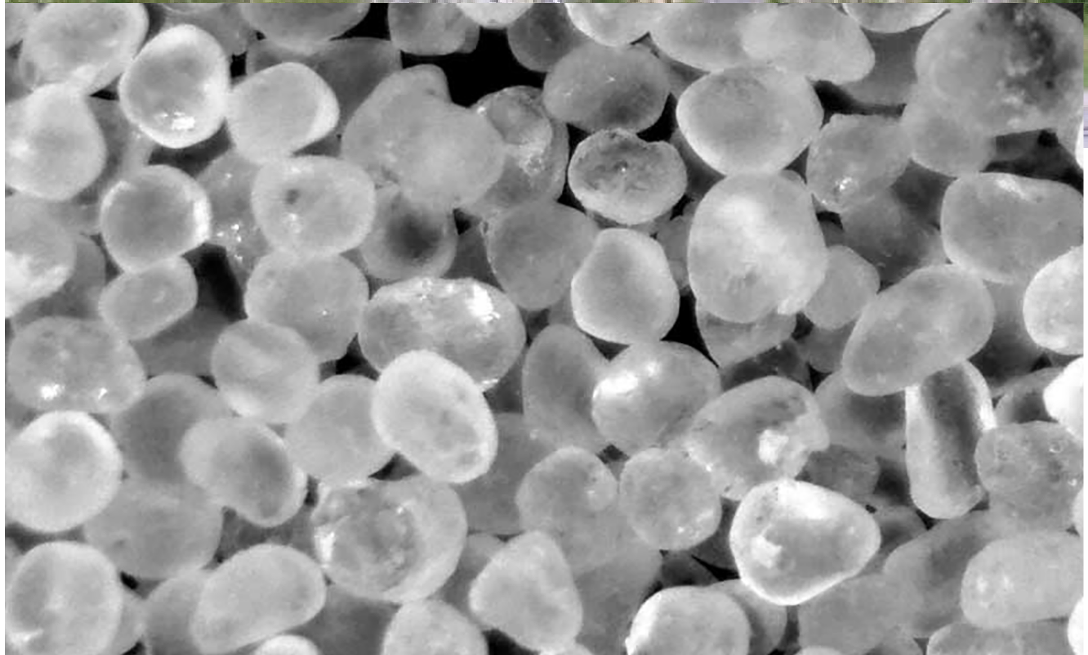
Source: Energy Information Administration based on data from various published studies

Natural Gas


SASKATCHEWAN
Regina
MANITOBA
Winnipeg
Bakken Formation
Minot A.F.B.
NORTH DAKOTA
Williston
Glasgow
Sidney
Minot
Grand Forks
Beulah
Glendive
Bismarck
Jamestown
Dickinson
Fargo
Miles City
Williston Basin
SOUTH DAKOTA
MONTANA
Canada
Williston
US


ME
VT
NH
NY
MA
CT
RI
WI
MI
PA
NJ
IL
IN
OH
MD
DE
WV
VA
KY
NC
TN
SC
ATLANTIC OCEAN
MS
AL
GA
0 200 mi
0 300 km
FL
Extent of Devonian Shale
Marcellus Shale


Gas well
~1–3 km
(0.6–2mi)
Cost
$3 million to drill
horizontal well
~15 m thick Ohio to more
than 30 m in New York
Middle Devonian
(~390 million year old)
Marcellus Shale
Hydraulic fracturing
with water and chemicals
facilitates recovery of gas.



Hydraulic Fracturing ‘Fracking’

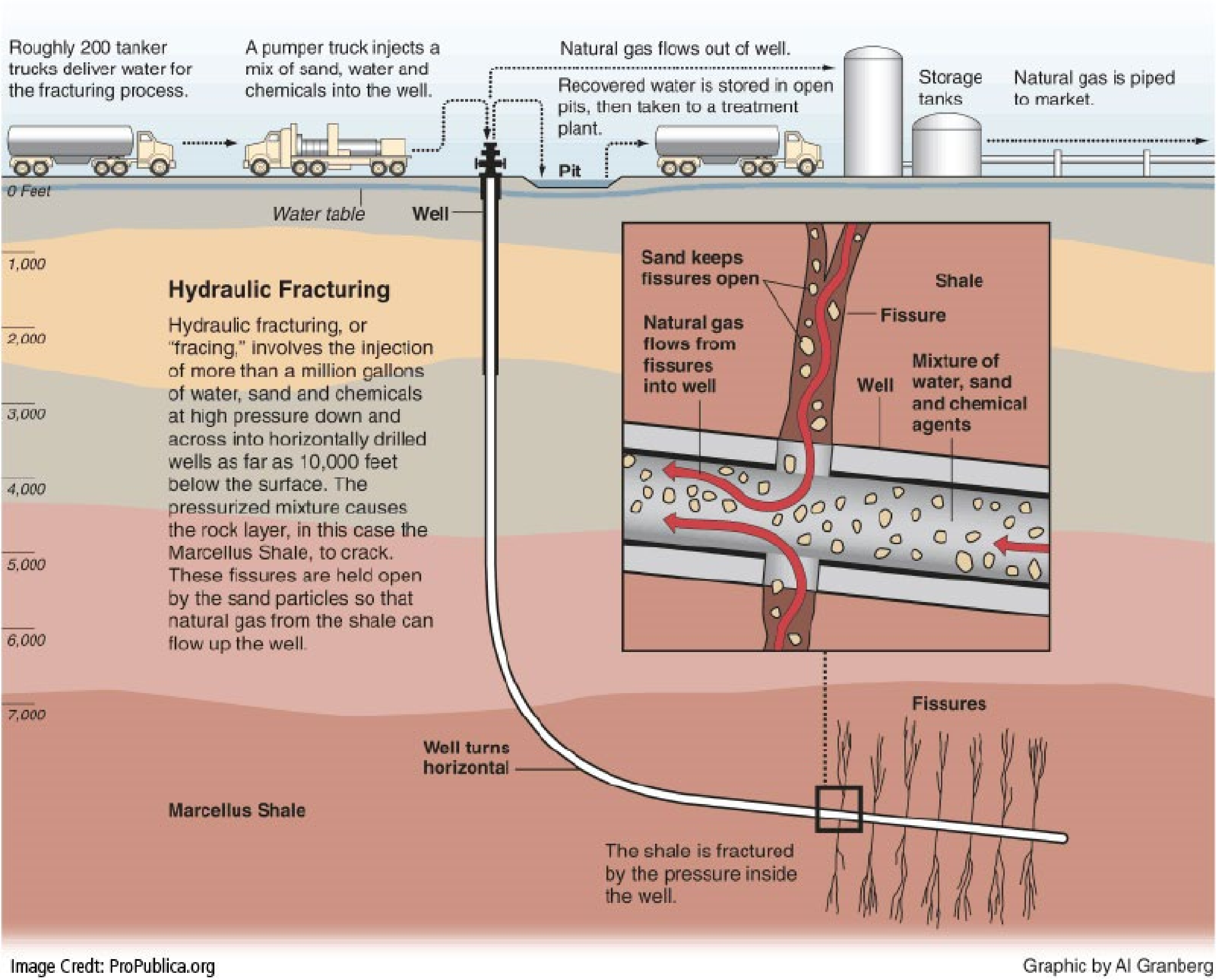
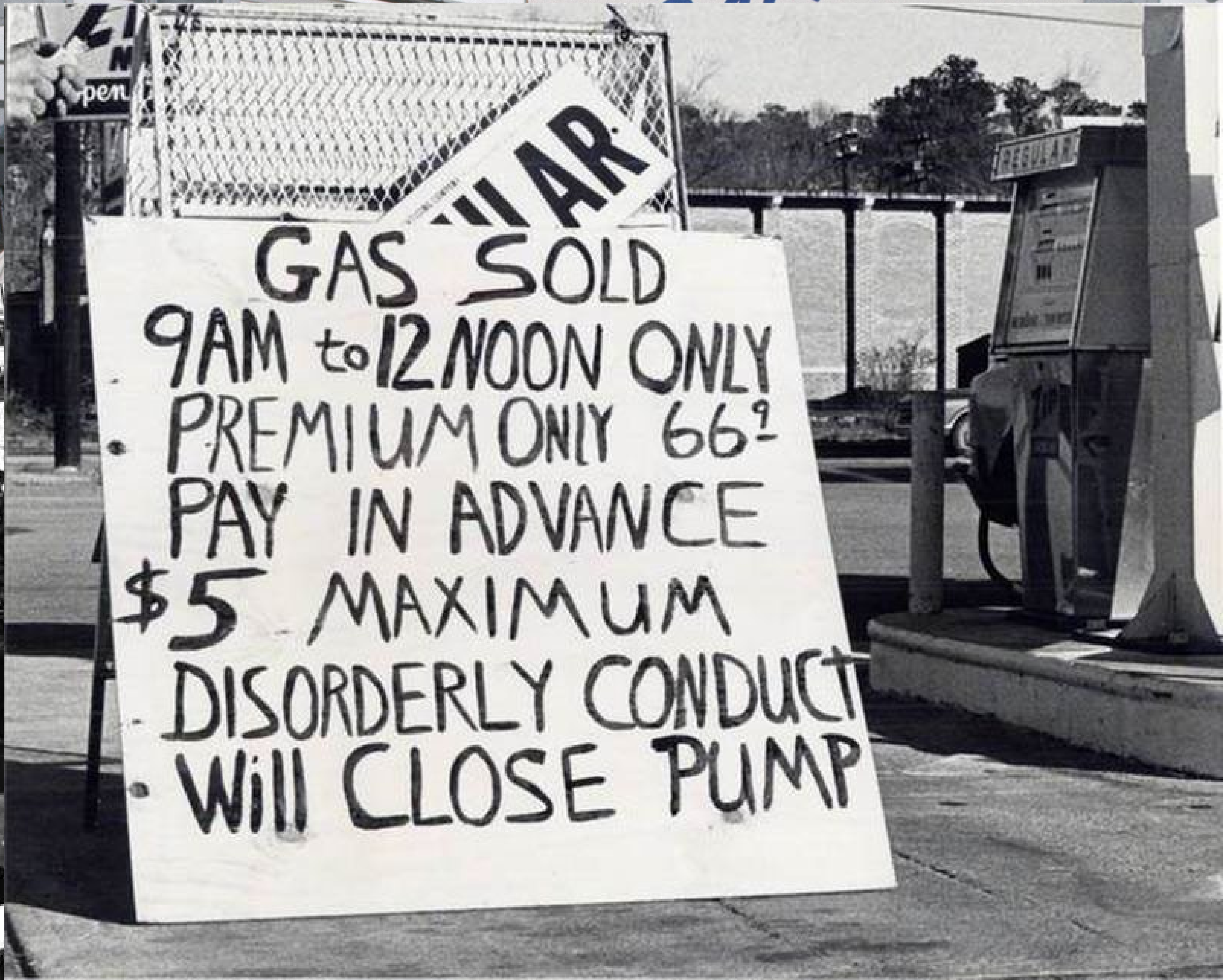
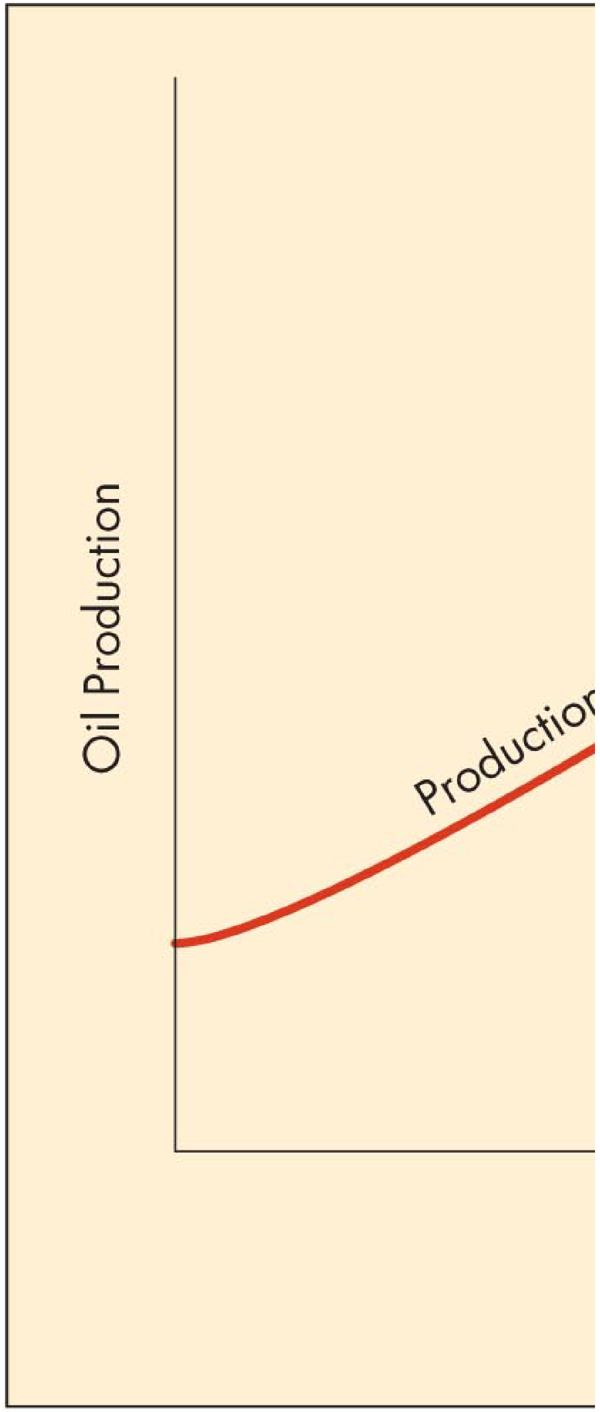


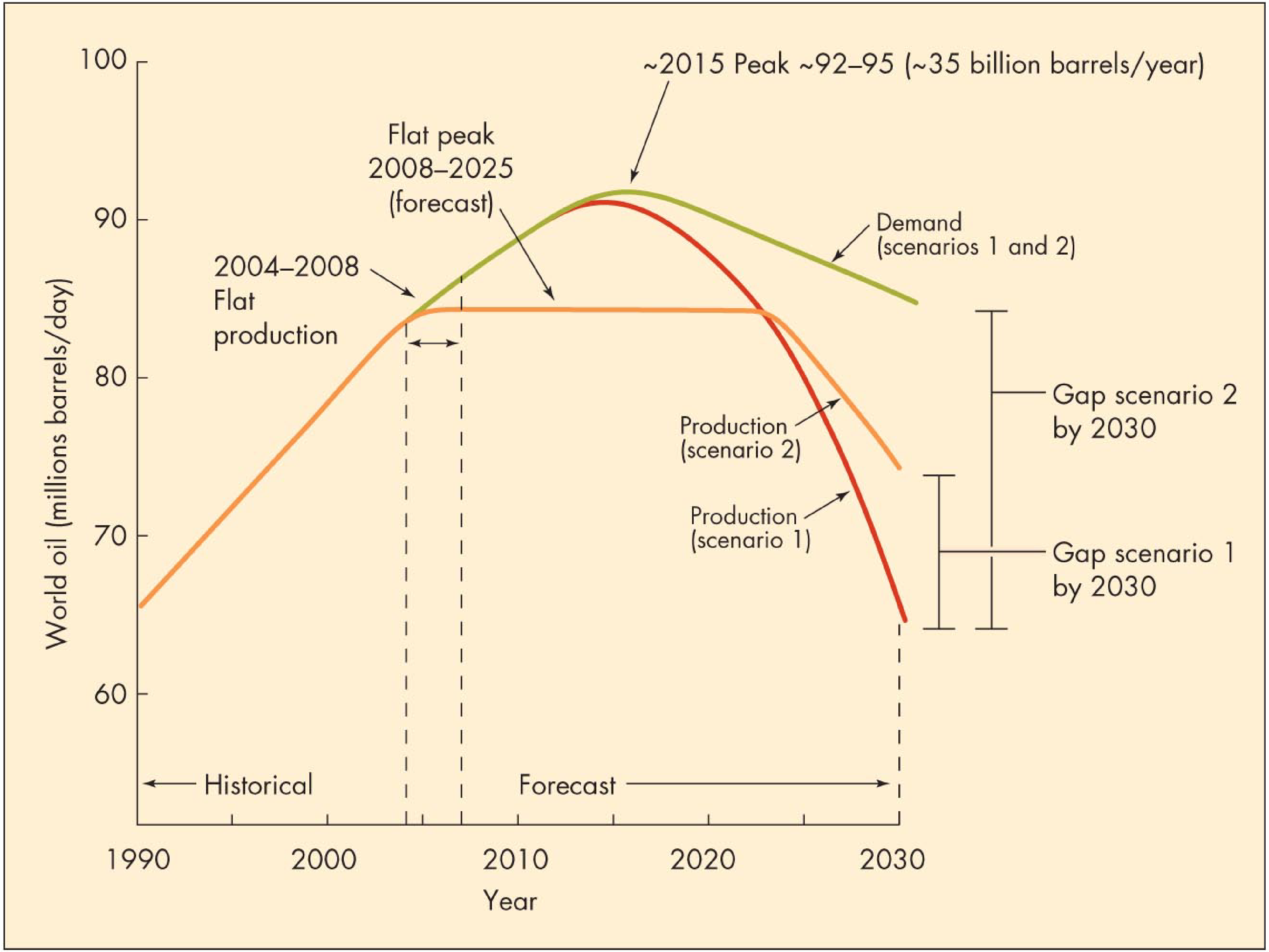
Image Credt: ProPublica.org

1974


STANDARD


GAS SOLD
9AM to 12 NOON ONLY
PREMIUM ONLY 66¢
PAY IN ADVANCE
$5 MAXIMUM
DISORDERLY CONDUCT
Will CLOSE PUMP
REGULAR


Oil Production


~2015 Peak ~92–95 (~35 billion barrels/year)
Flat peak 2008–2025 (forecast)
2004–2008 Flat production
Demand (scenarios 1 and 2)
Production (scenario 2)
Production (scenario 1)
Gap scenario 2 by 2030
Gap scenario 1 by 2030
World oil (millions barrels/day)
100
90
80
70
60
Historical
Forecast
1990
2000
2010
2020
2030
Year

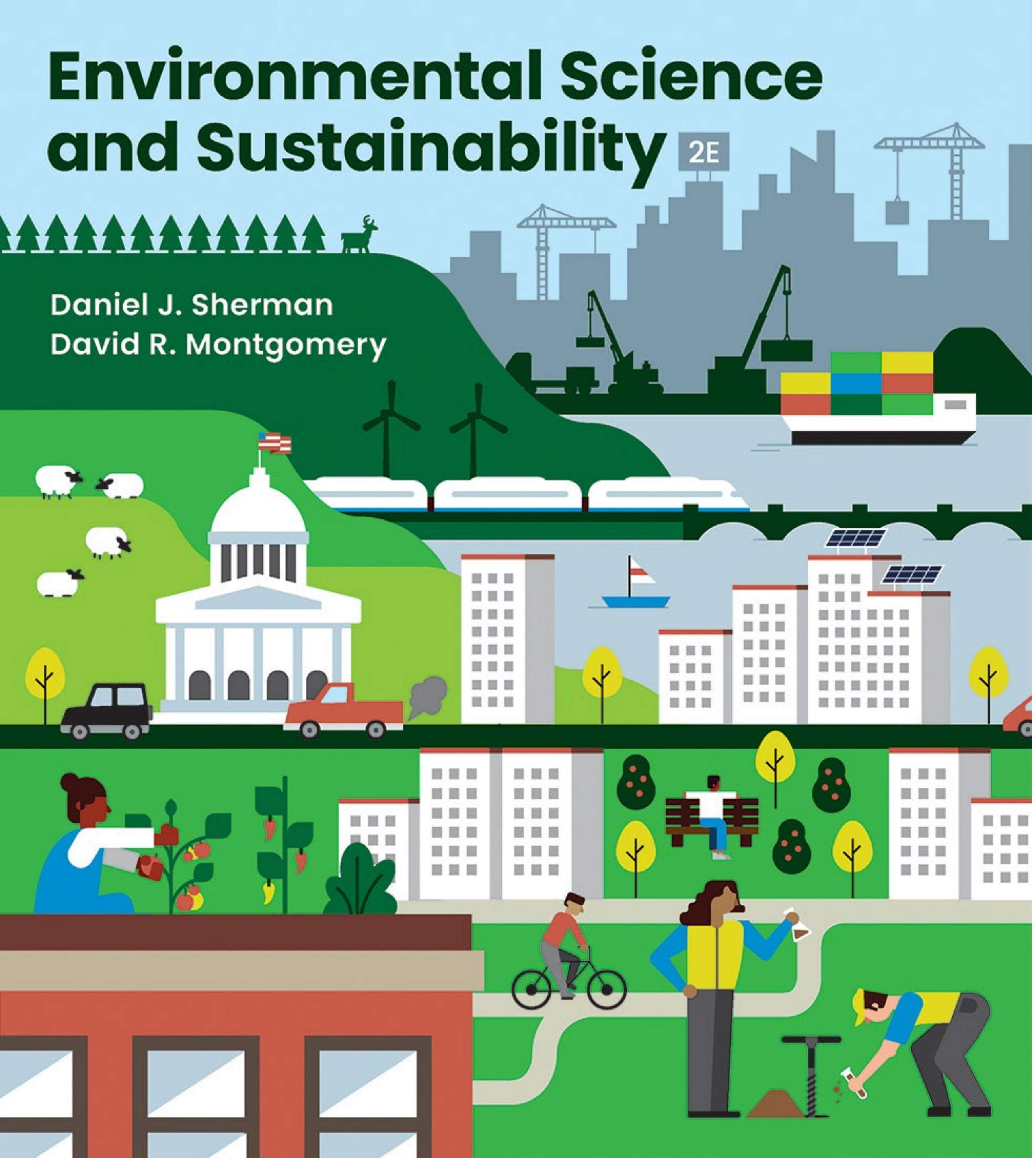
Organization of Petroleum Exporting Countries (OPEC)

- 1960 - Iran, Iraq, Kuwait, Saudi Arabia and Venezuela
- Qatar (1961), Indonesia (1962), Libya (1962), the United Arab Emirates (1967), Algeria (1969), Nigeria (1971), Ecuador (1973), Gabon (1975), Angola (2007), Equatorial Guinea (2017) and Congo (2018)
- Mission '*Coordinate and unify the petroleum policies of its member countries and ensure the stabilization of oil markets, in order to secure an efficient, economic and regular supply of petroleum to consumers, a steady income to producers, and a fair return on capital for those investing in the petroleum industry*'

The Great Way, Wu-Men Huikai

The Great way has no gate;
There are a thousand paths to it.
If you pass through the barrier,
You walk the universe alone.

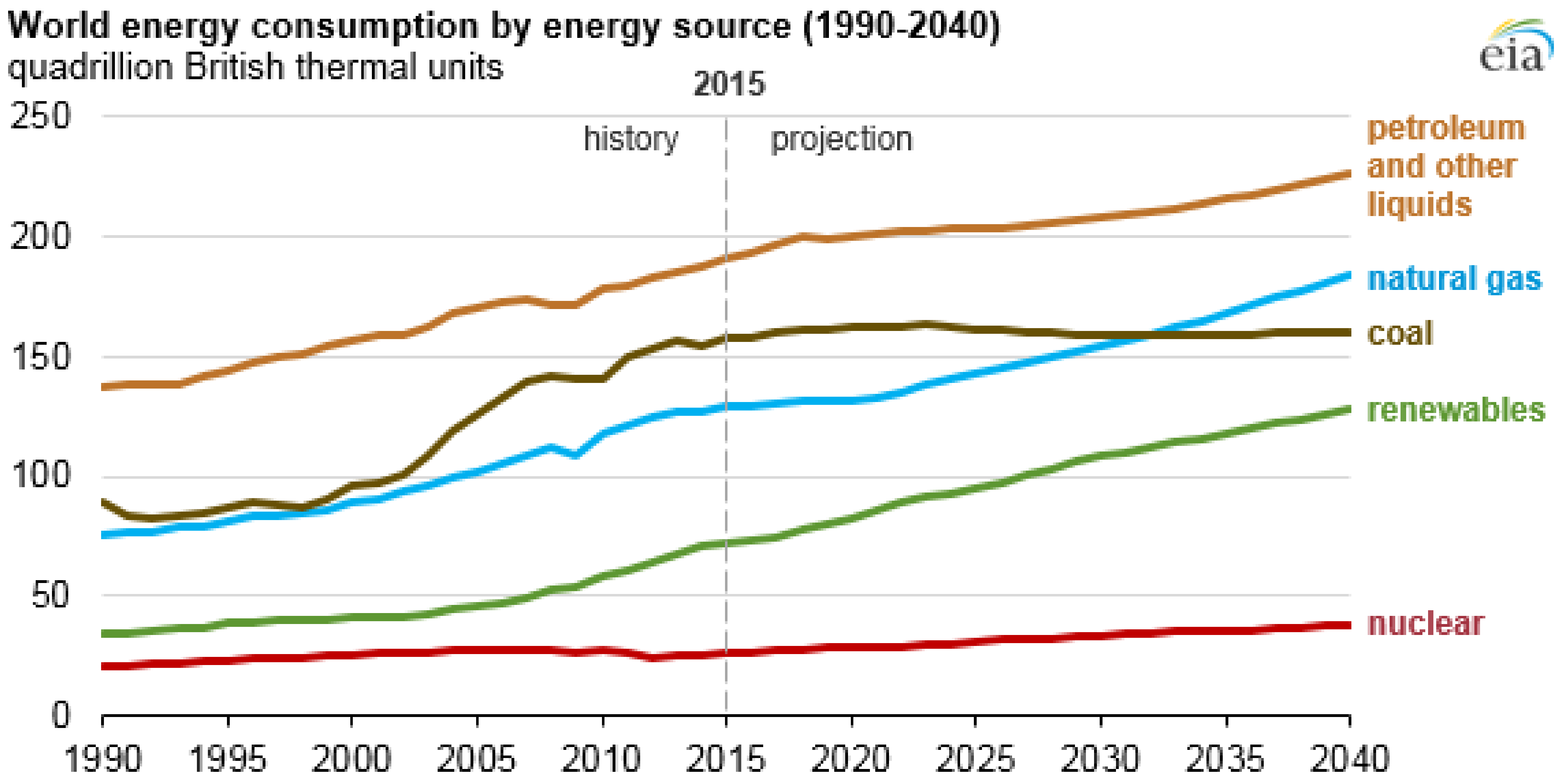
Change is Hard.

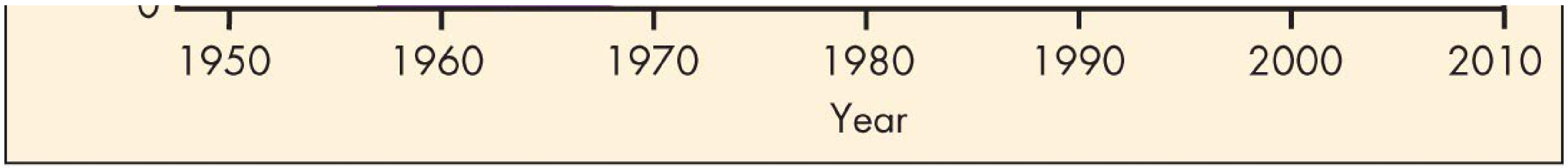


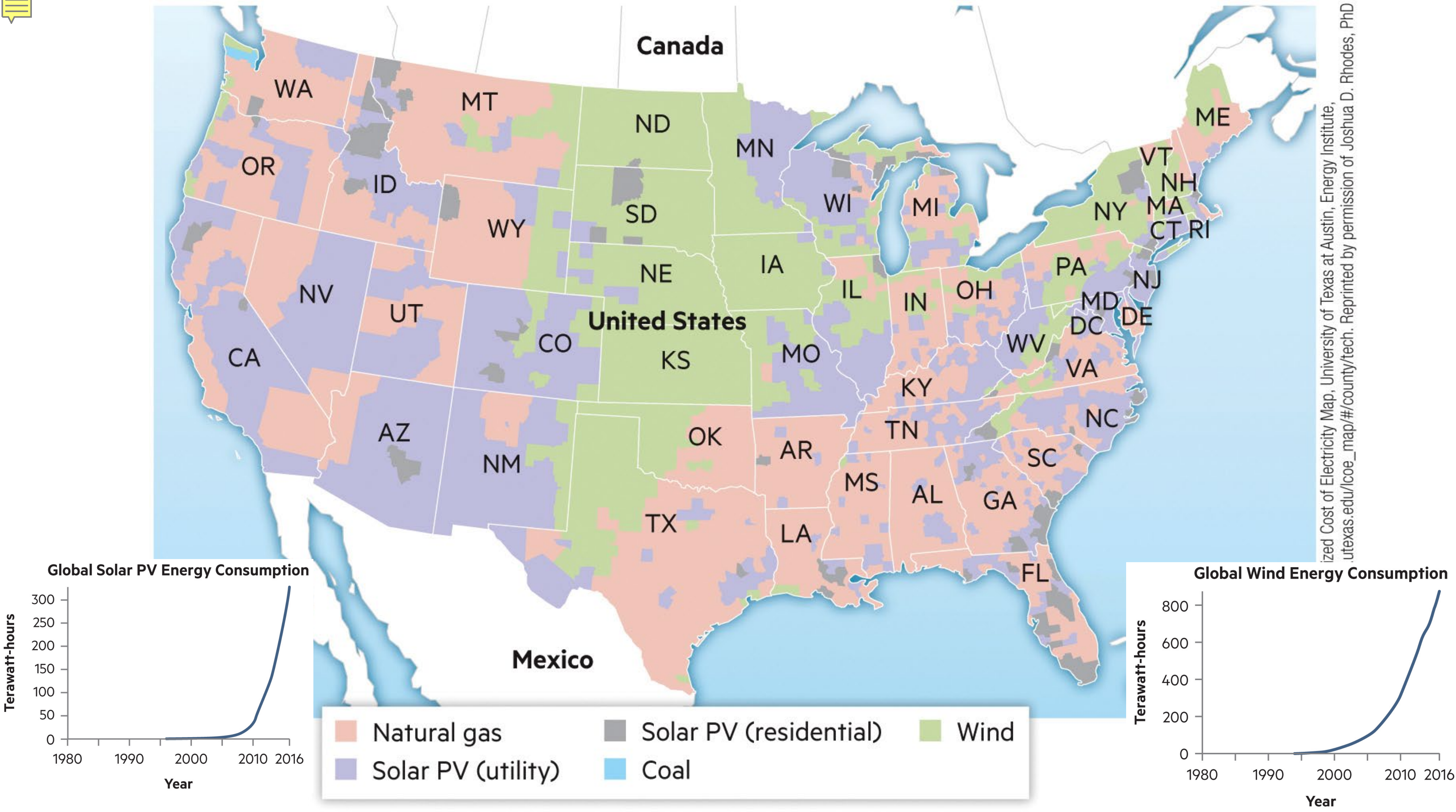
CHAPTER 14: Energy Alternatives

How Are Our Energy Decisions Changing?

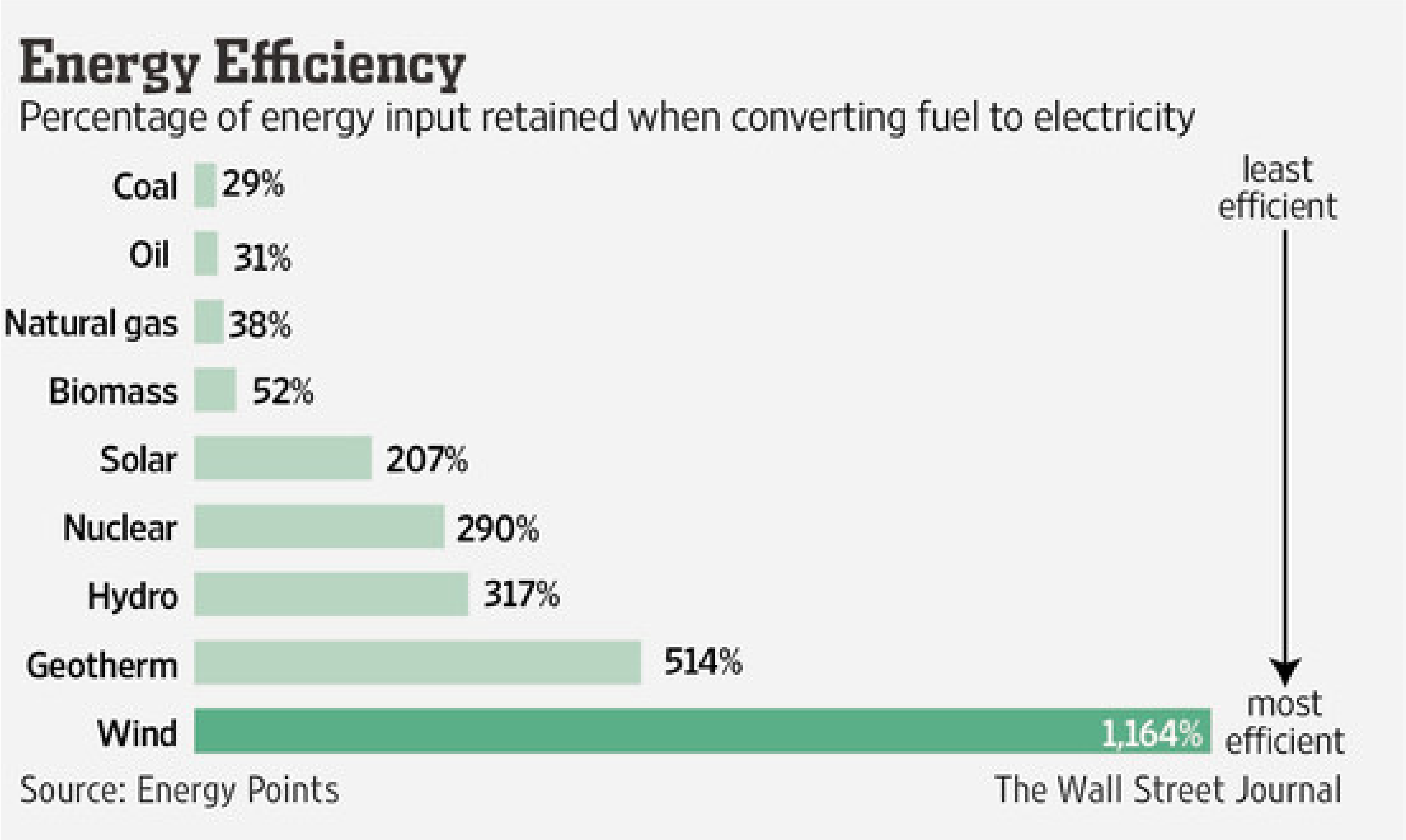
I'd put my money on the sun and solar energy. What a source of power. I hope we don't have to wait till oil and coal run out before we tackle that… - Thomas Edison


World energy consumption by energy source (1990-2040)
quadrillion British thermal units
eia
2015
history
projection
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
petroleum and other liquids
natural gas
coal
renewables
nuclear


1950
1960
1970
1980
1990
2000
2010
Year

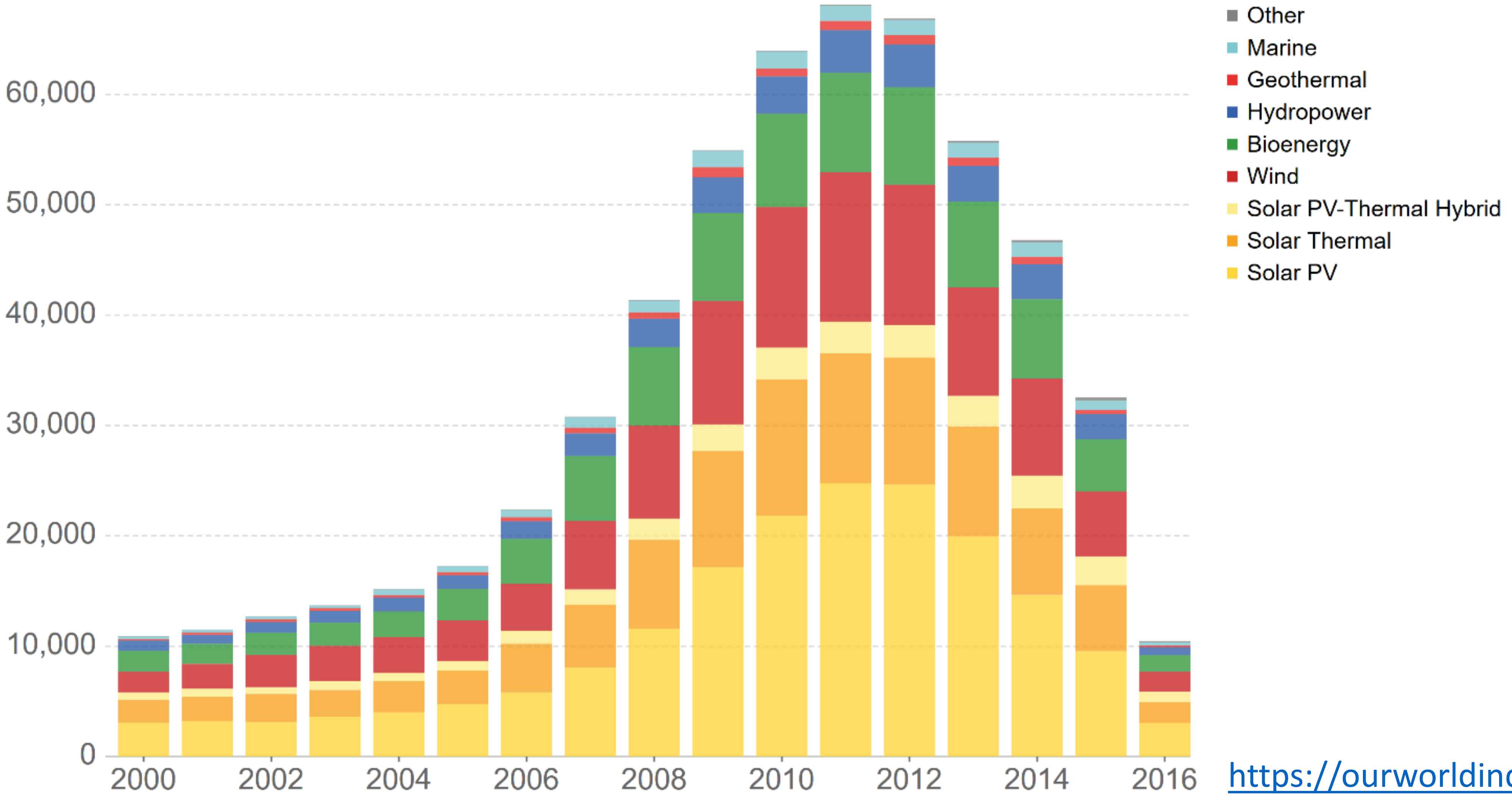


ized Cost of Electricity Map, University of Texas at Austin, Energy Institute, utexas.edu/lcoe_map/#/county/tech. Reprinted by permission of Joshua D. Rhodes, PhD


Energy Efficiency
Percentage of energy input retained when converting fuel to electricity
Coal 29%
Oil 31%
Natural gas 38%
Biomass 52%
Solar 207%
Nuclear 290%
Hydro 317%
Geotherm 514%
Wind 1,164%
least efficient
most efficient
Source: Energy Points
The Wall Street Journal

Number of patents filed for renewable energy technologies, World

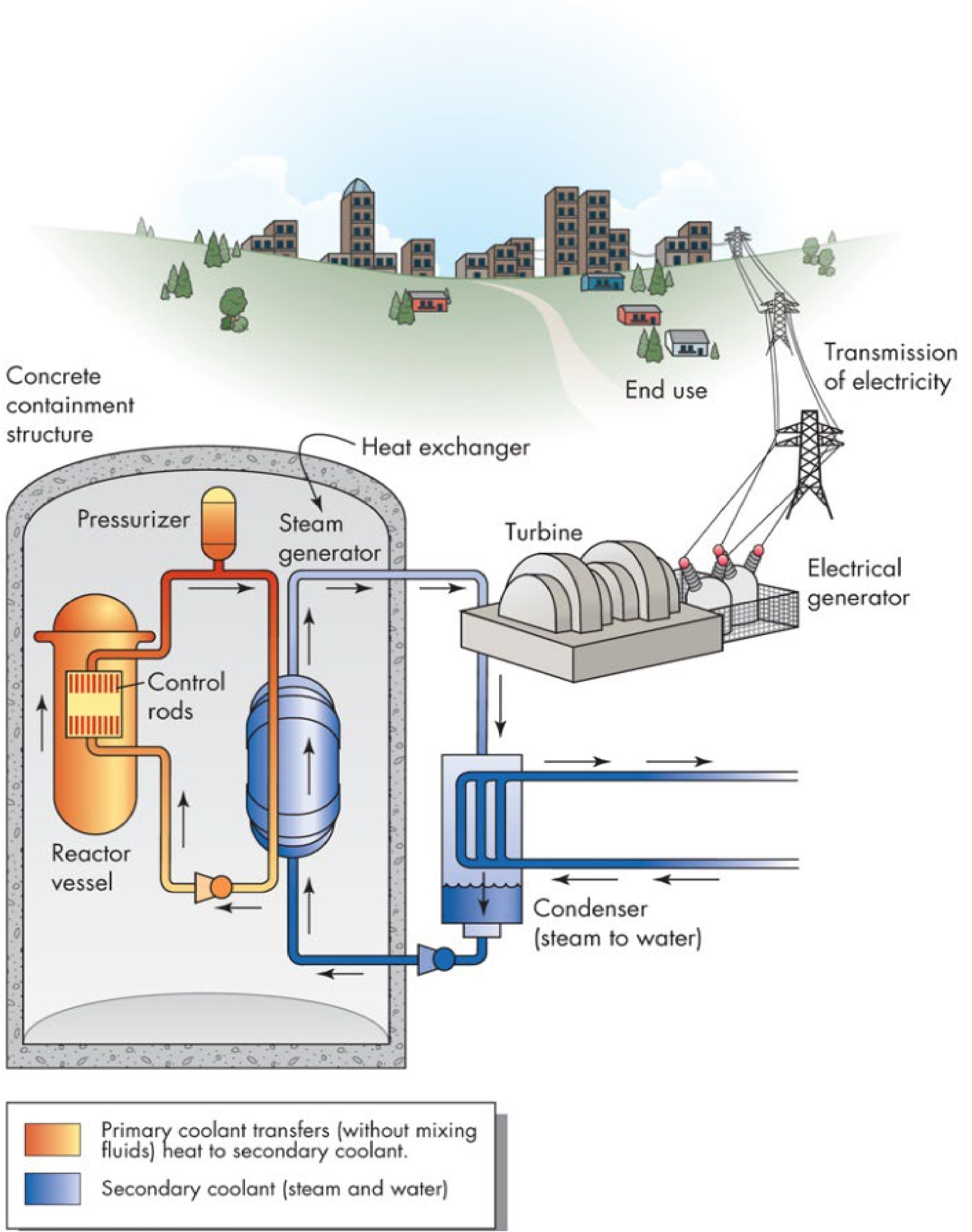
Global number of patents filed under each renewable technology category per year. Note that figures for 2014-16 may be subject to a time lag; processing times of patent applications vary and some patents submitted over this period may not yet be recorded in statistics. These figures will be updated with time if additional patent applications are recorded.

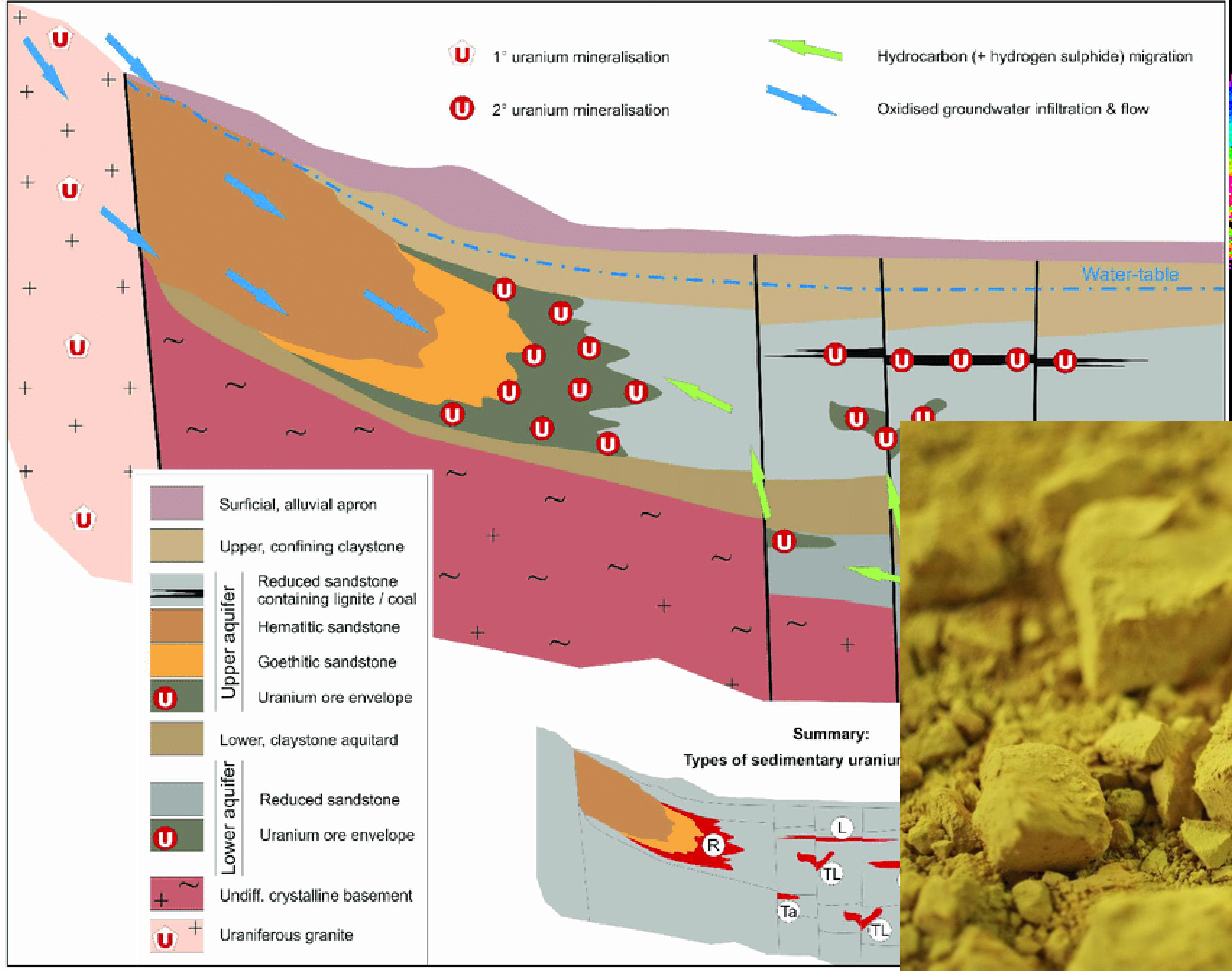
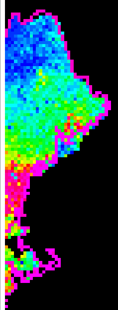


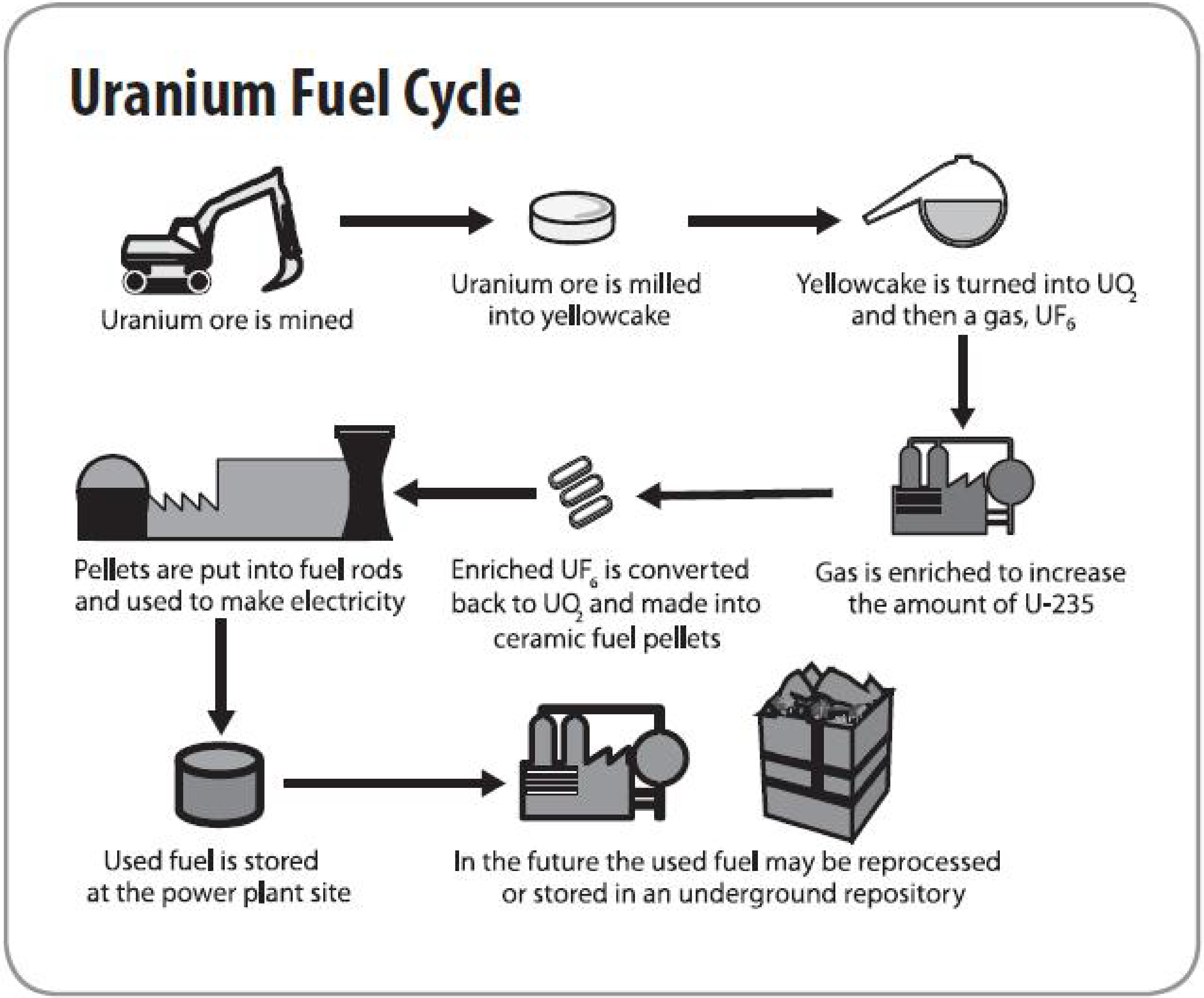
https://ourworldindata.org/renewable-energy

Source: IRENA (& EPO PATSTAT)

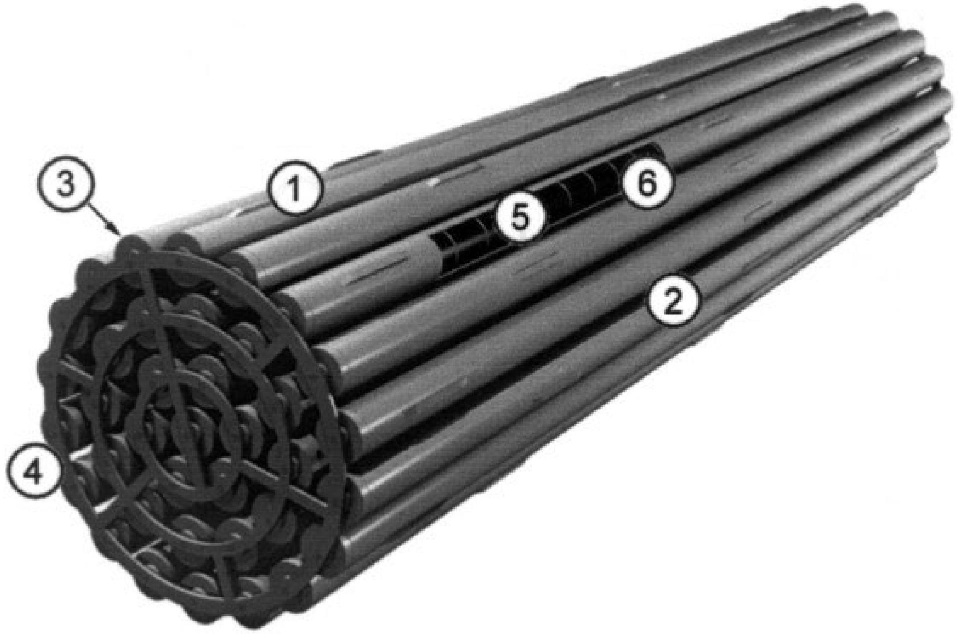
Nuclear Energy



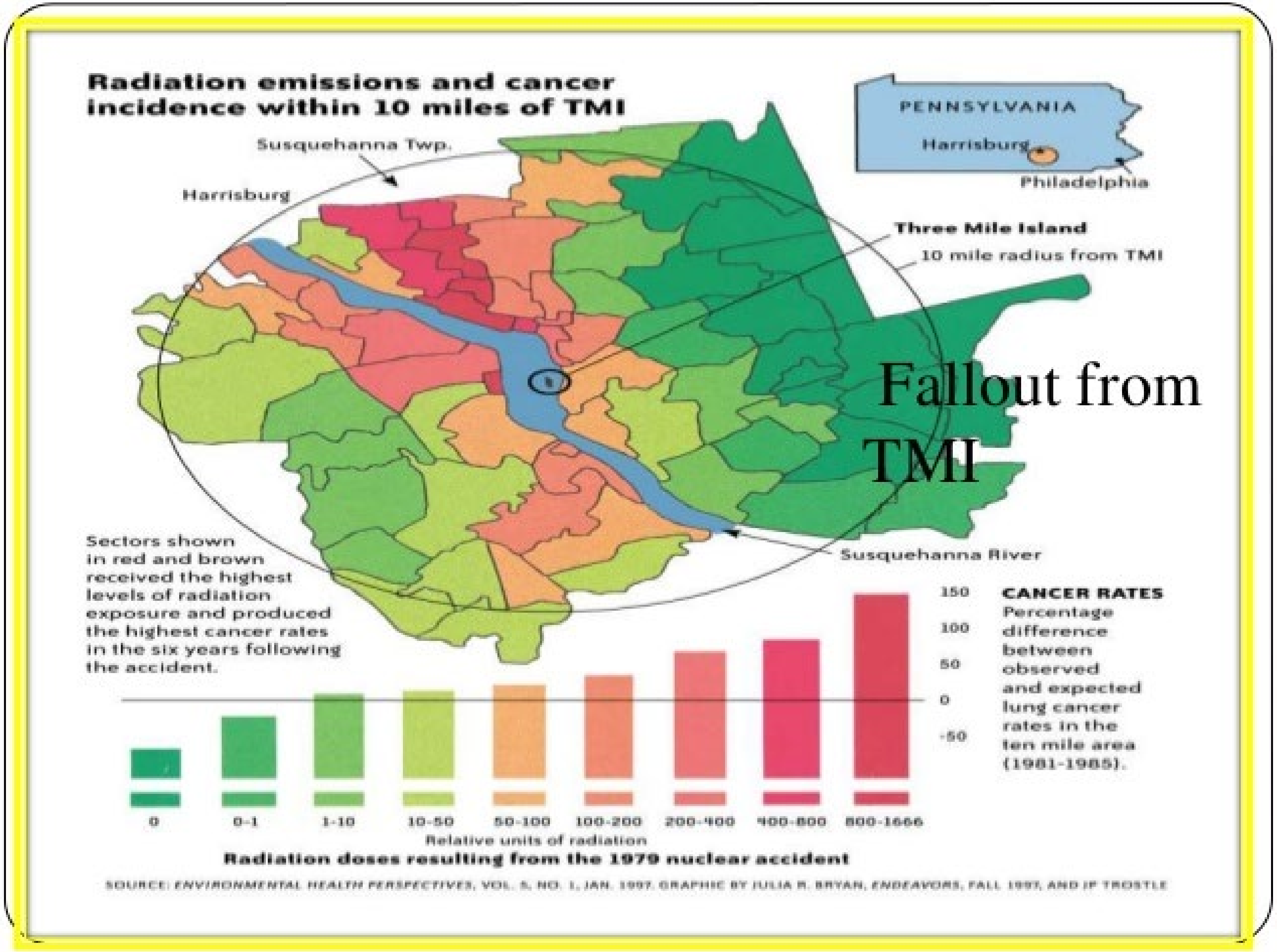

1° uranium mineralisation
2° uranium mineralisation
Hydrocarbon (+ hydrogen sulphide) migration
Oxidised groundwater infiltration & flow
Water-table
Surficial, alluvial apron
Upper, confining claystone
Upper aquifer
Reduced sandstone containing lignite / coal
Hematitic sandstone
Goethitic sandstone
Uranium ore envelope
Lower, claystone aquitard
Lower aquifer
Reduced sandstone
Uranium ore envelope
Undiff. crystalline basement
Uraniferous granite
Summary:
Types of sedimentary uraniu
R
L
TL
Ta
TL


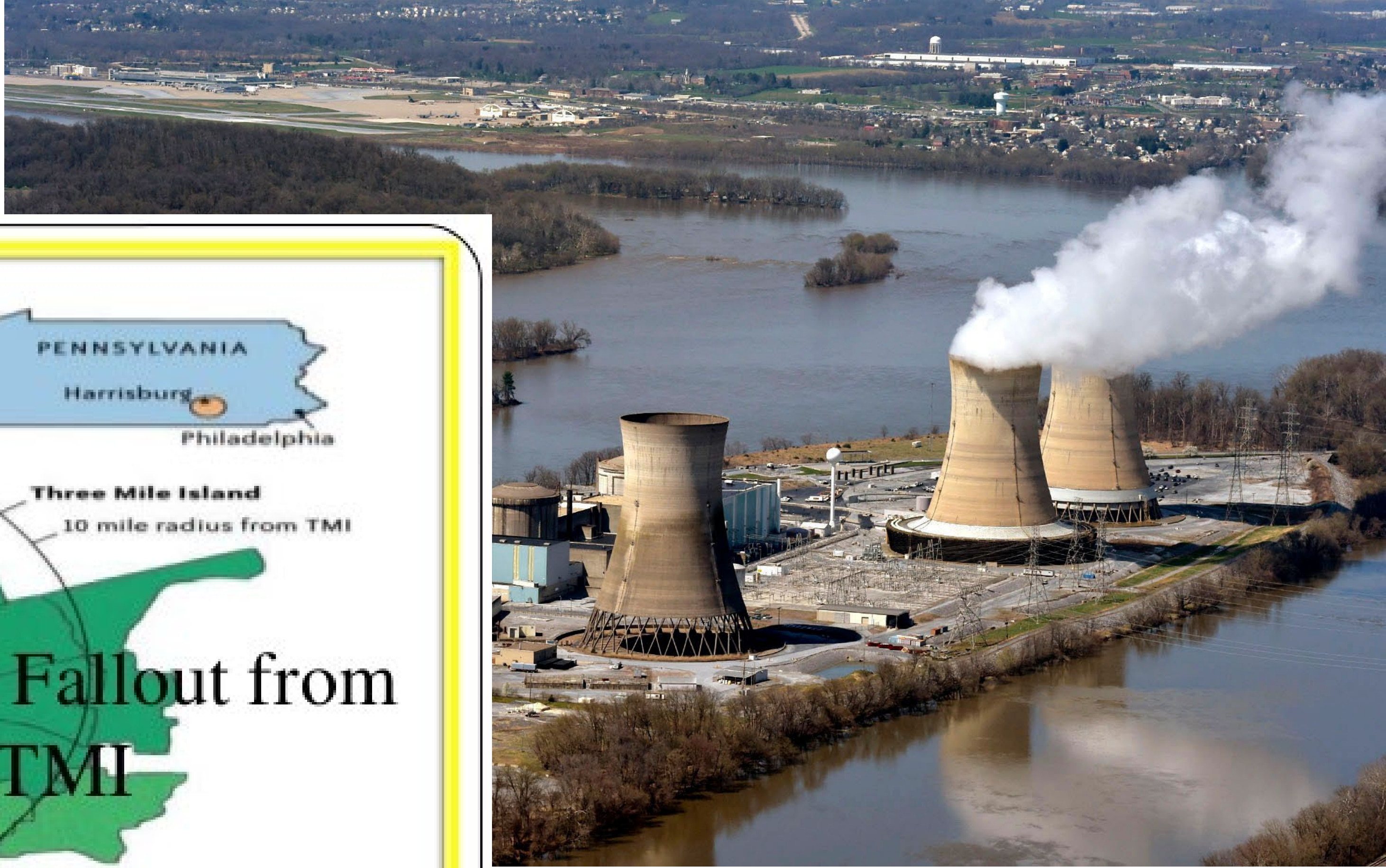



Isotope	Half-Life (Years)
U-234	2.455×10^5
U-235	7.038×10^8
U-238	4.468×10^9

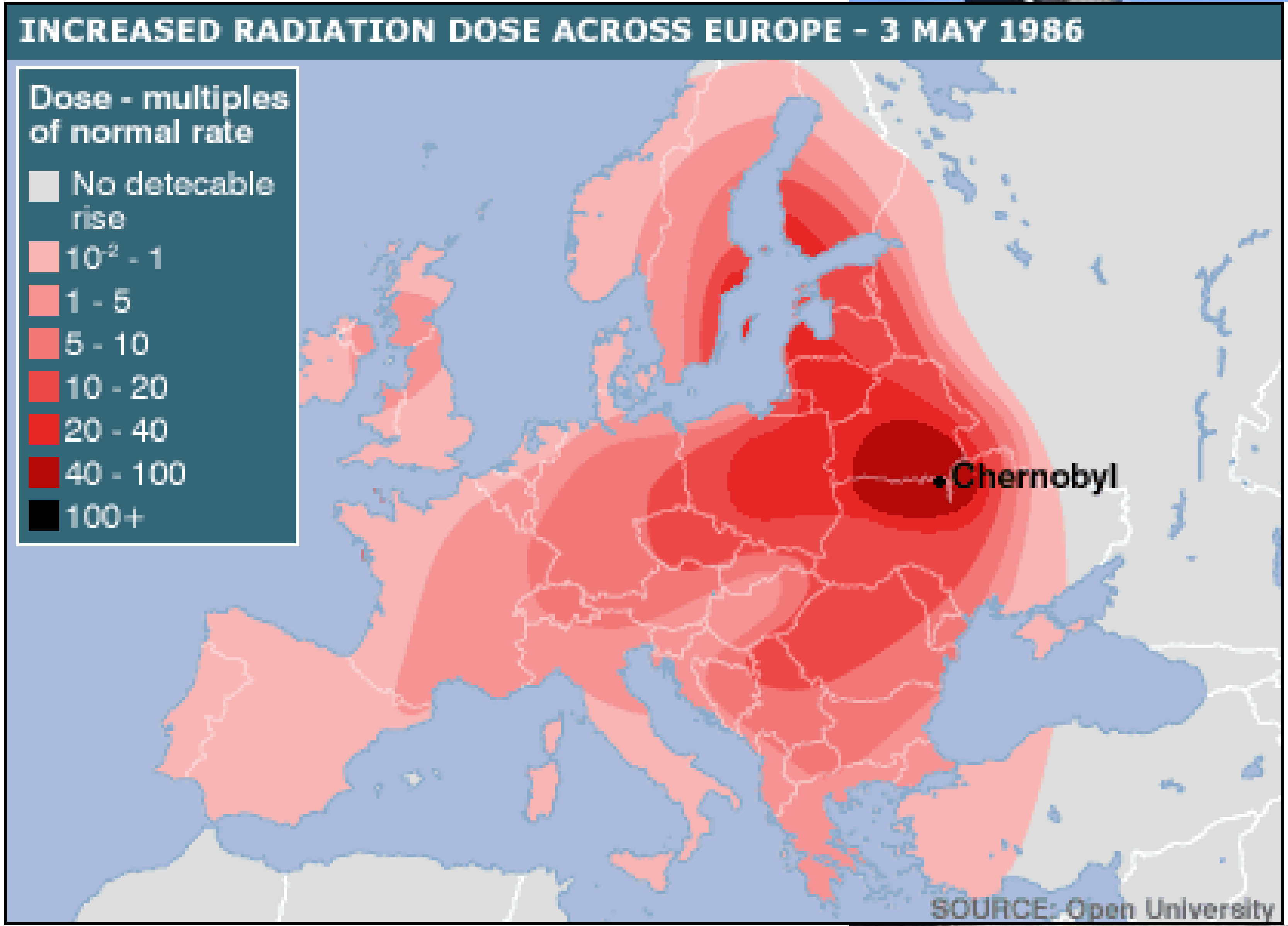


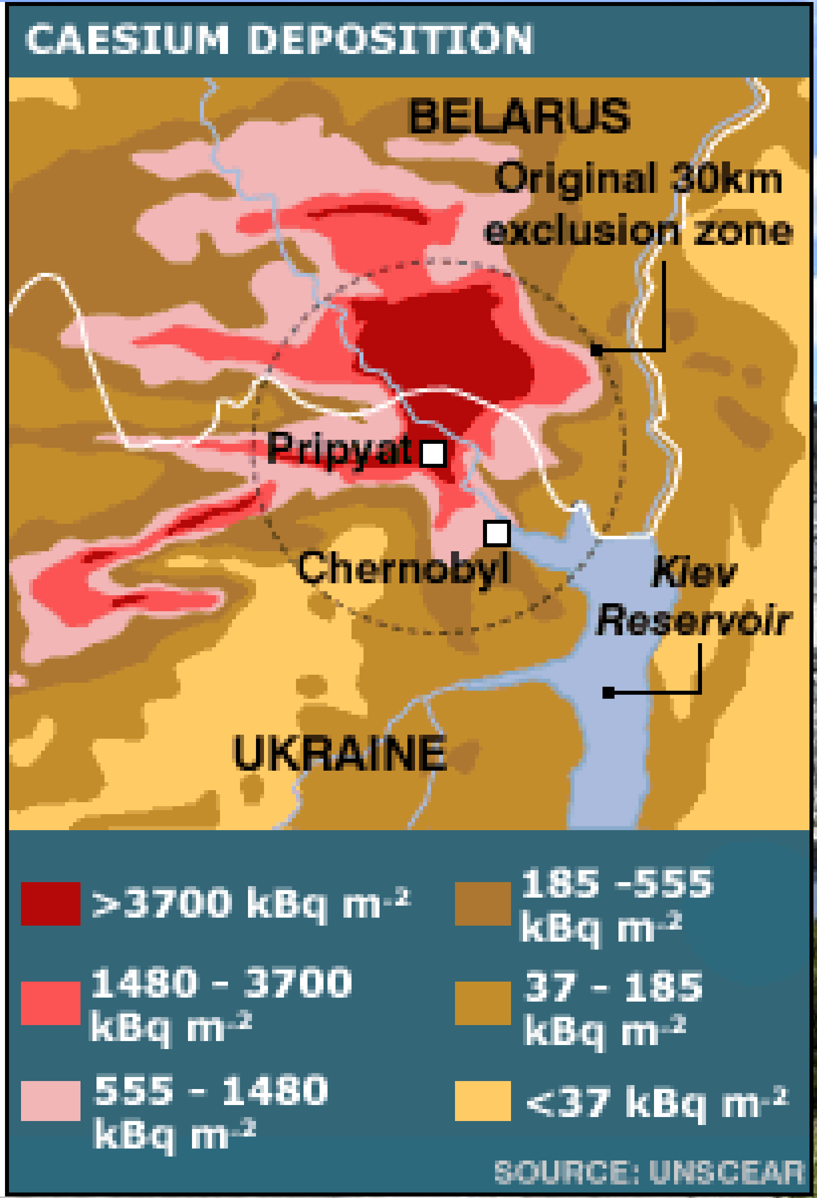
Three Mile Island



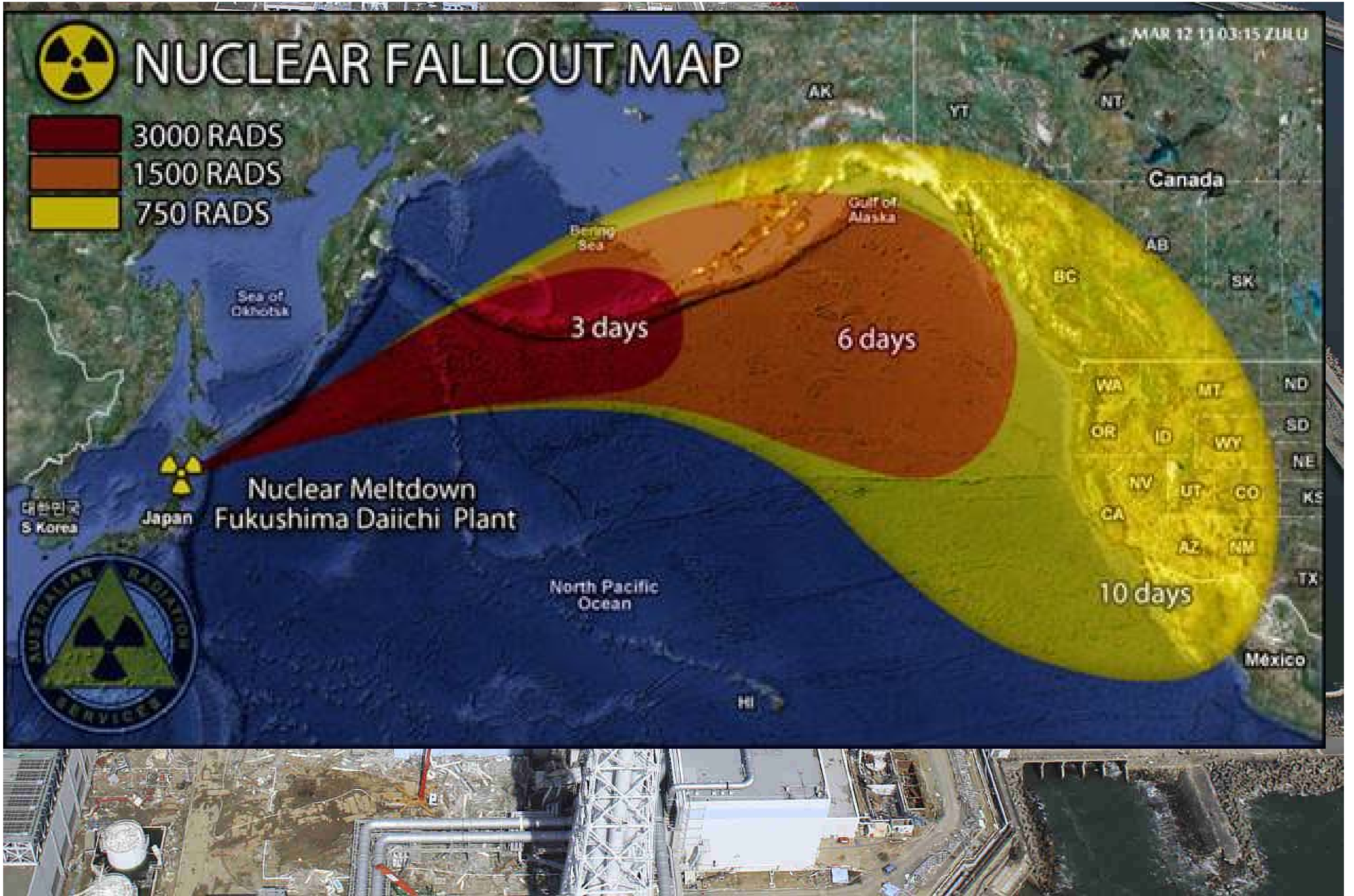


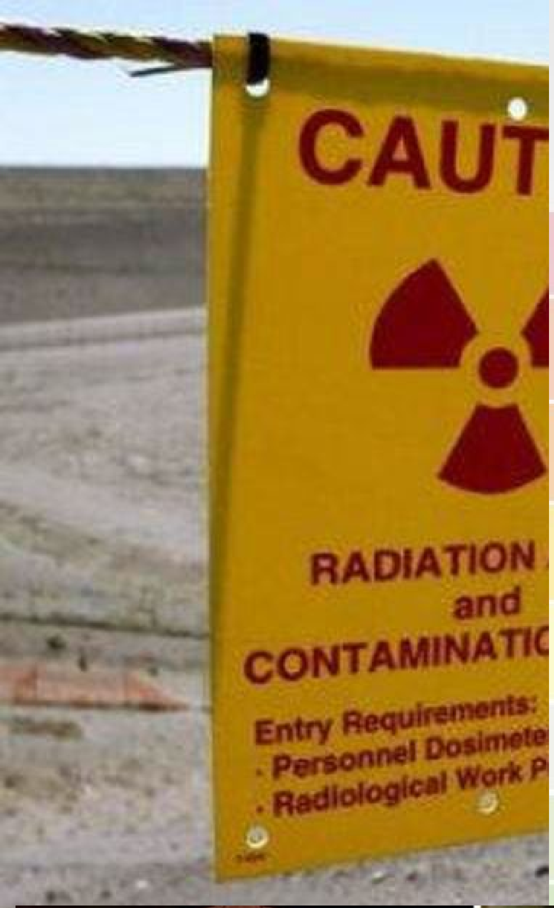
Chernobyl


INCREASED RADIATION DOSE ACROSS EUROPE - 3 MAY 1986
Dose - multiples of normal rate
No detecable rise
10^{-2} - 1
1 - 5
5 - 10
10 - 20
20 - 40
40 - 100
100+
Chernobyl
SOURCE: Open University

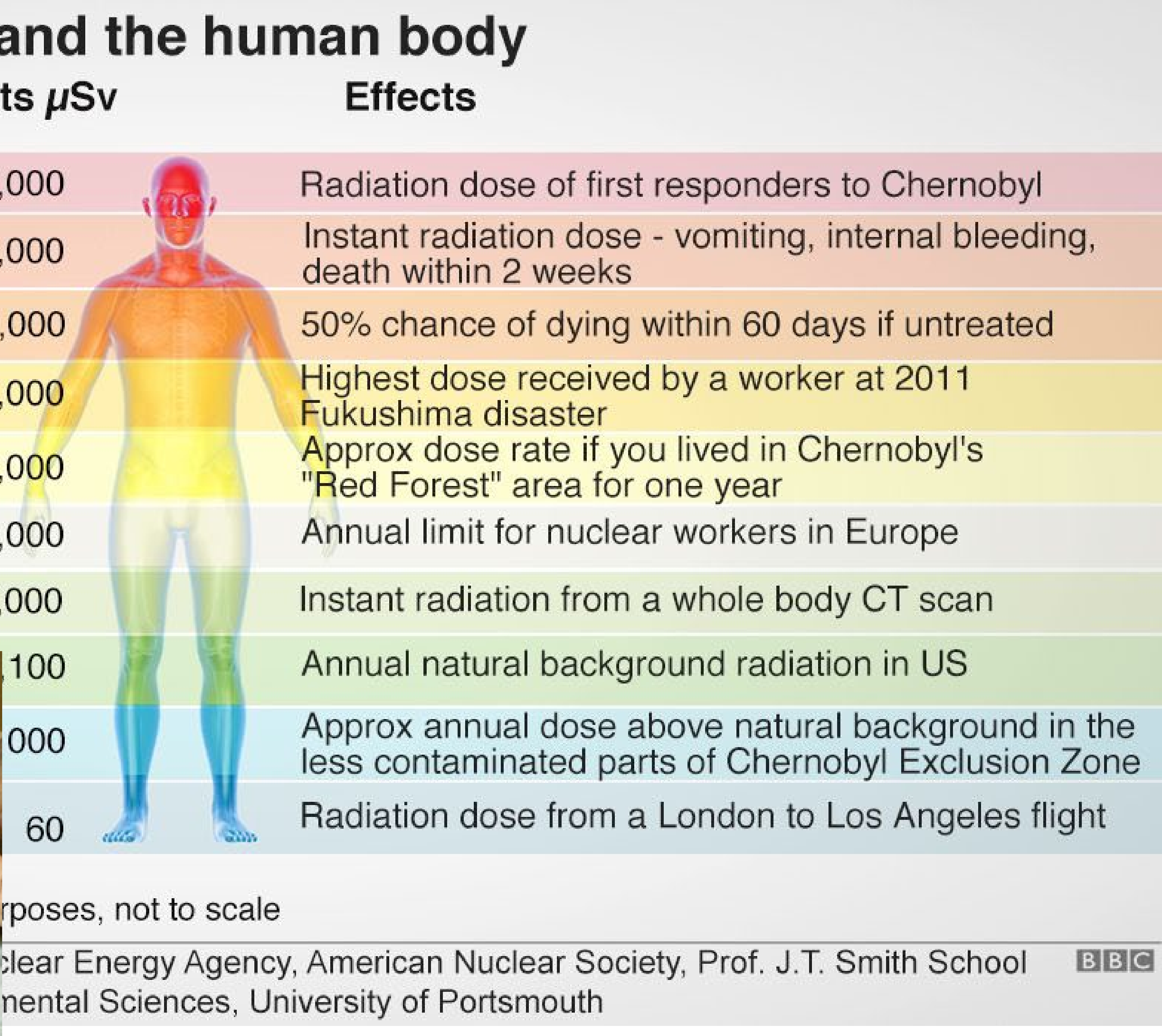

CAESIUM DEPOSITION
BELARUS
Original 30km exclusion zone
Pripyat
Chernobyl
Kiev Reservoir
UKRAINE
>3700 kBq m^{-2}
1480 - 3700 kBq m^{-2}
555 - 1480 kBq m^{-2}
185 -555 kBq m^{-2}
37 - 185 kBq m^{-2}
<37 kBq m^{-2}
SOURCE: UNSCEAR

Fukushima, Japan



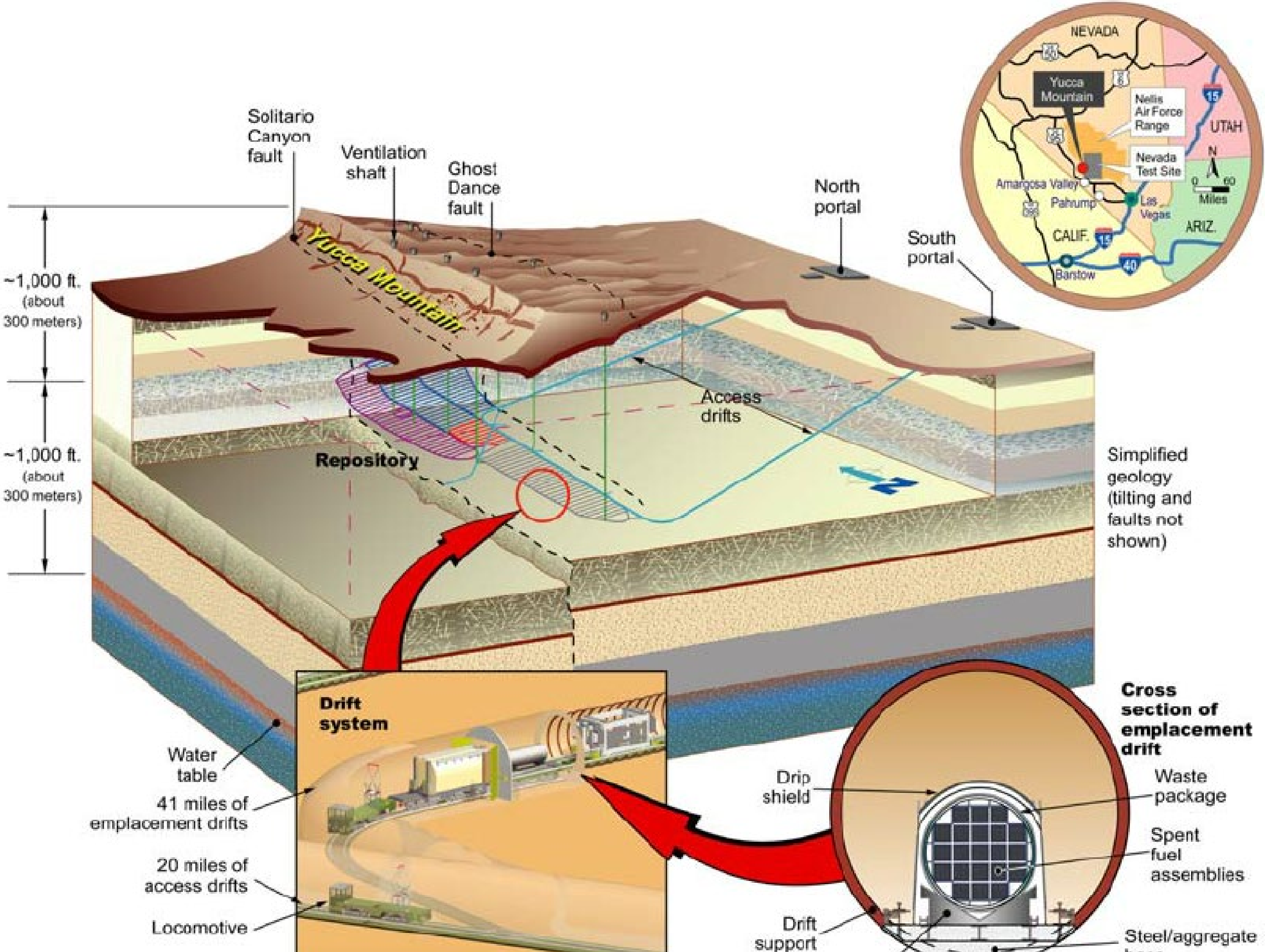


CAUT
RADIATION
and
CONTAMINATI
Entry Requirements:
· Personnel Dosimete
· Radiological Work P



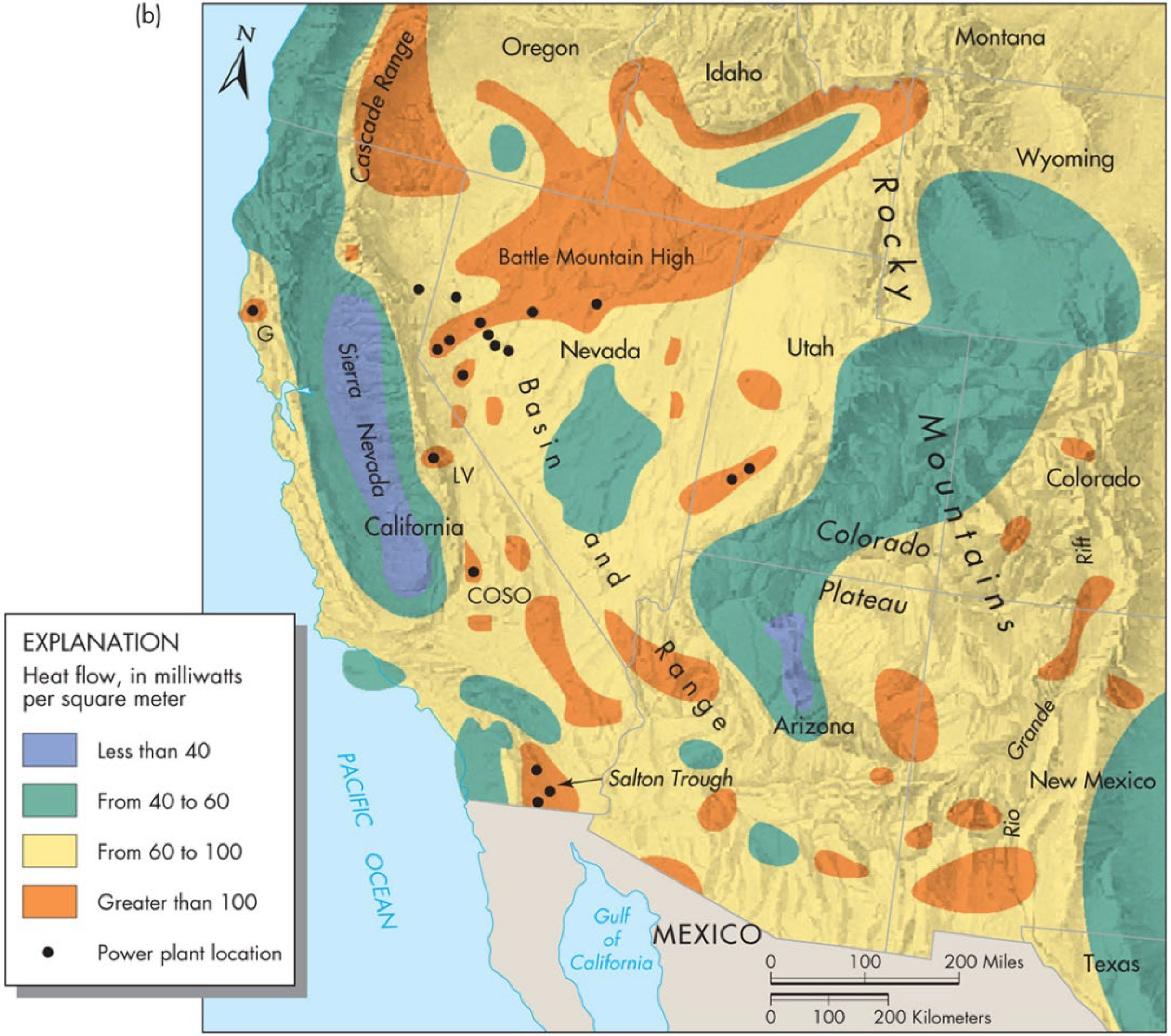
Radiation and the human body
In microsieverts μSv
Effects
800,000 - 16,000,000
Radiation dose of first responders to Chernobyl
Above 7,000,000
Instant radiation dose - vomiting, internal bleeding, death within 2 weeks
3,000,000
50% chance of dying within 60 days if untreated
680,000
Highest dose received by a worker at 2011 Fukushima disaster
350,000
Approx dose rate if you lived in Chernobyl's "Red Forest" area for one year
20,000
Annual limit for nuclear workers in Europe
10,000
Instant radiation from a whole body CT scan
100
Annual natural background radiation in US
000
Approx annual dose above natural background in the less contaminated parts of Chernobyl Exclusion Zone
60
Radiation dose from a London to Los Angeles flight
rposes, not to scale
clear Energy Agency, American Nuclear Society, Prof. J.T. Smith School
nental Sciences, University of Portsmouth
BBC


WA
Trojan
Columbia Generating Station
MT
OR
ID
Humboldt Bay
WY
Rancho Seco
NV
Yucca Mountain
UT
CA
CO
Diablo Canyon
San Onofre
AZ
Palo Verde
NM

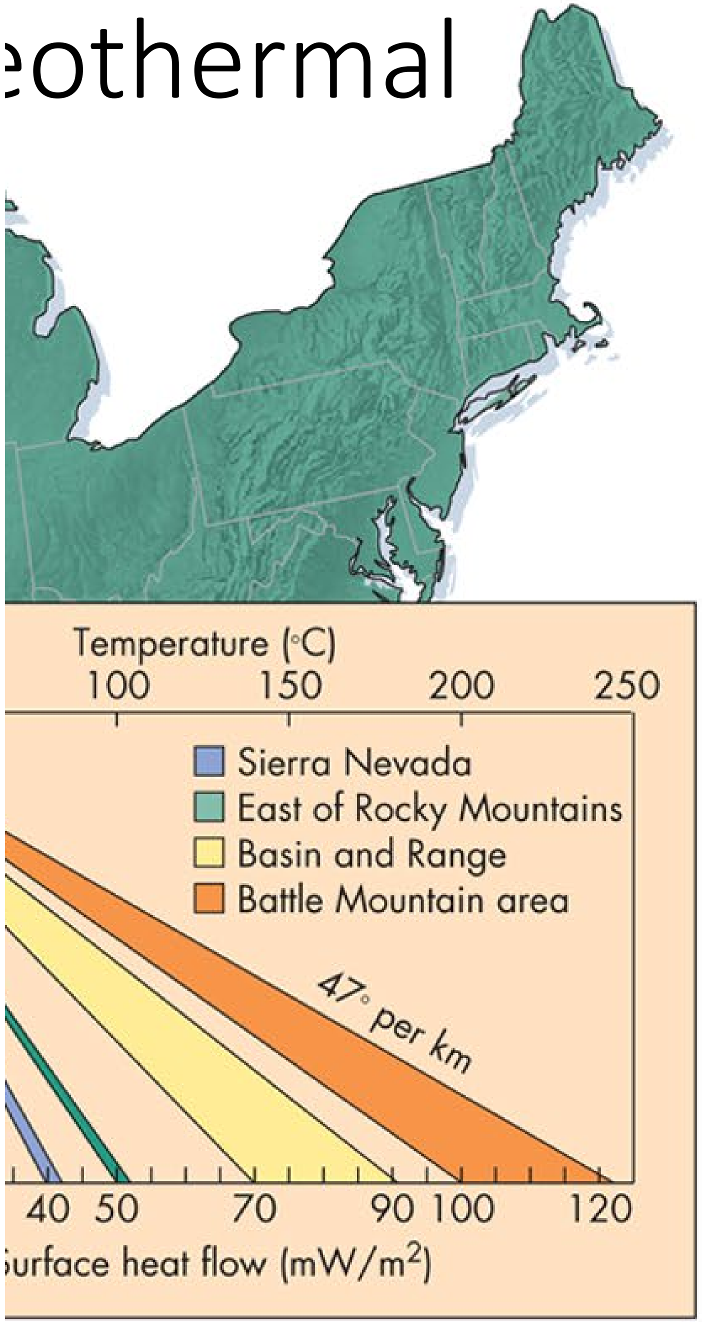

NEVADA
Yucca Mountain
Nellis Air Force Range
UTAH
Nevada Test Site
Amargosa Valley
Pahrump
Las Vegas
Miles
CALIF.
ARIZ.
Barstow
Solitario Canyon fault
Ventilation shaft
Ghost Dance fault
North portal
South portal
Yucca Mountain
~1,000 ft. (about 300 meters)
~1,000 ft. (about 300 meters)
Access drifts
Repository
Simplified geology (tilting and faults not shown)
Drift system
Water table
41 miles of emplacement drifts
20 miles of access drifts
Locomotive
Cross section of emplacement drift
Drip shield
Waste package
Spent fuel assemblies
Drift support
Steel/aggregate

eothermal

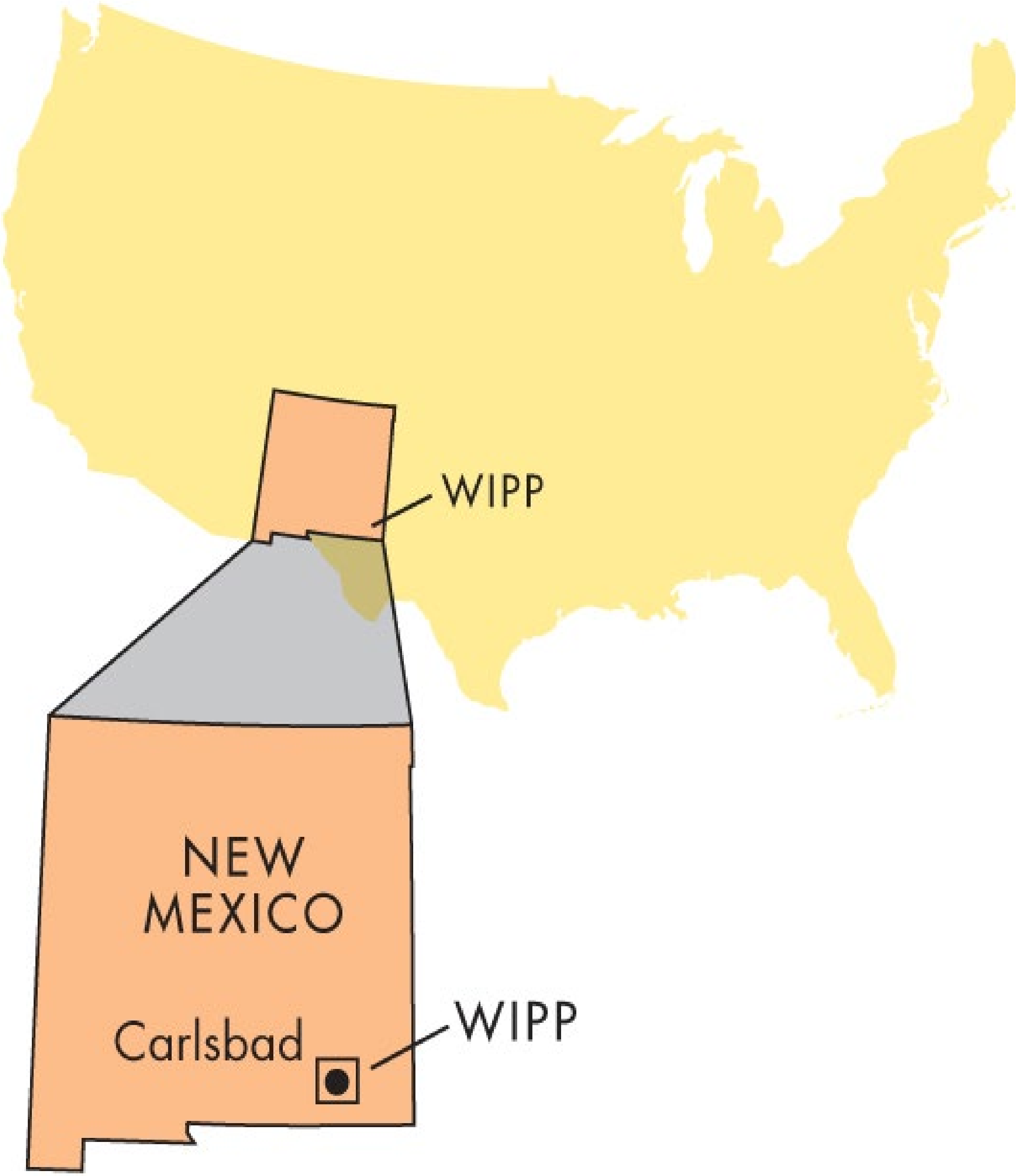
(b)

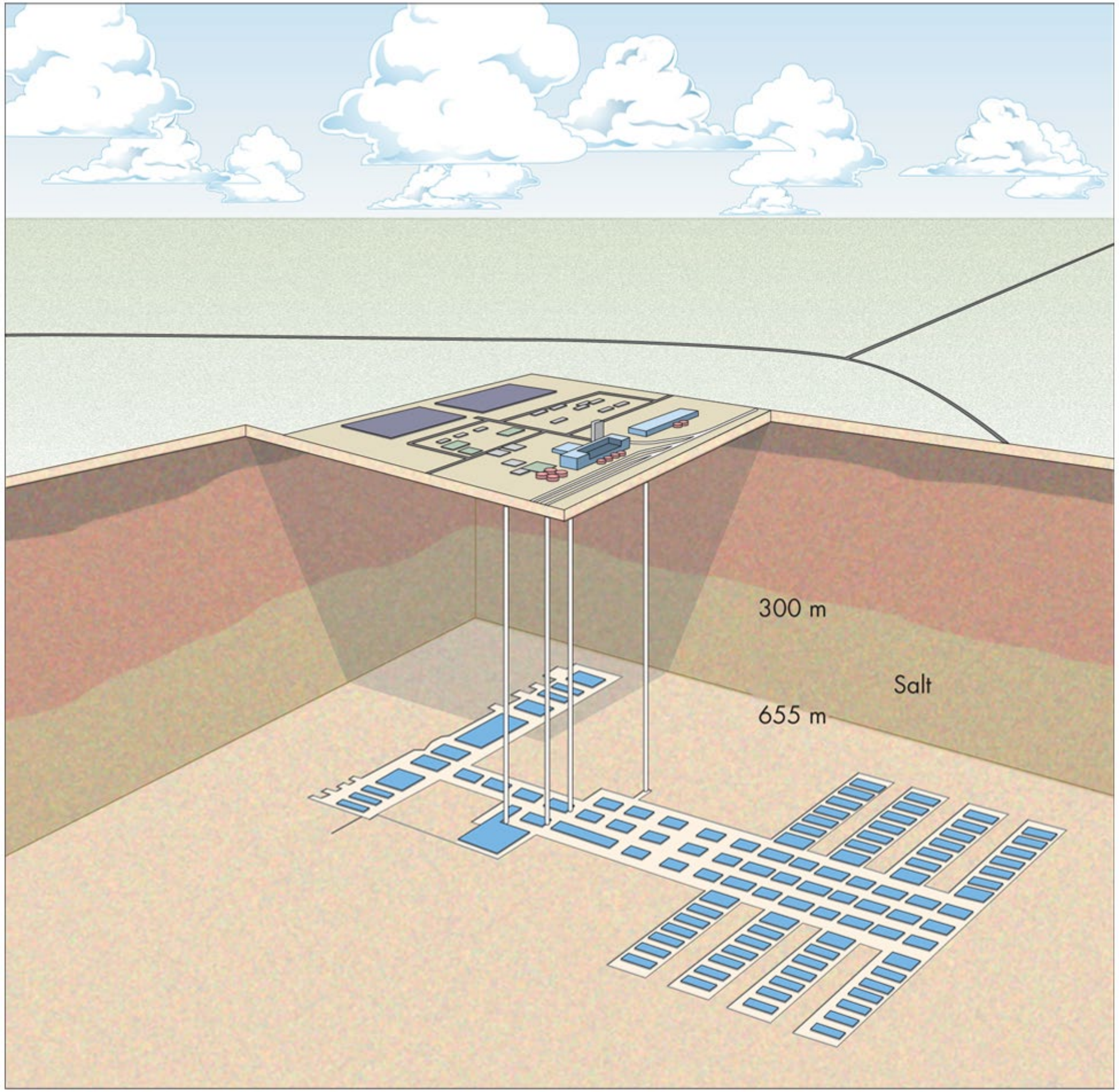


N
Oregon
Idaho
Montana
Wyoming
Cascade Range
Battle Mountain High
Rocky Mountains
Nevada
Utah
Colorado
Basin and Range
Sierra Nevada
G
LV
California
COSO
Colorado Plateau
Rio Grande Rift
Arizona
New Mexico
Salton Trough
PACIFIC OCEAN
Gulf of California
MEXICO
Texas
0 100 200 Miles
0 100 200 Kilometers
EXPLANATION
Heat flow, in milliwatts per square meter
Less than 40
From 40 to 60
From 60 to 100
Greater than 100
Power plant location

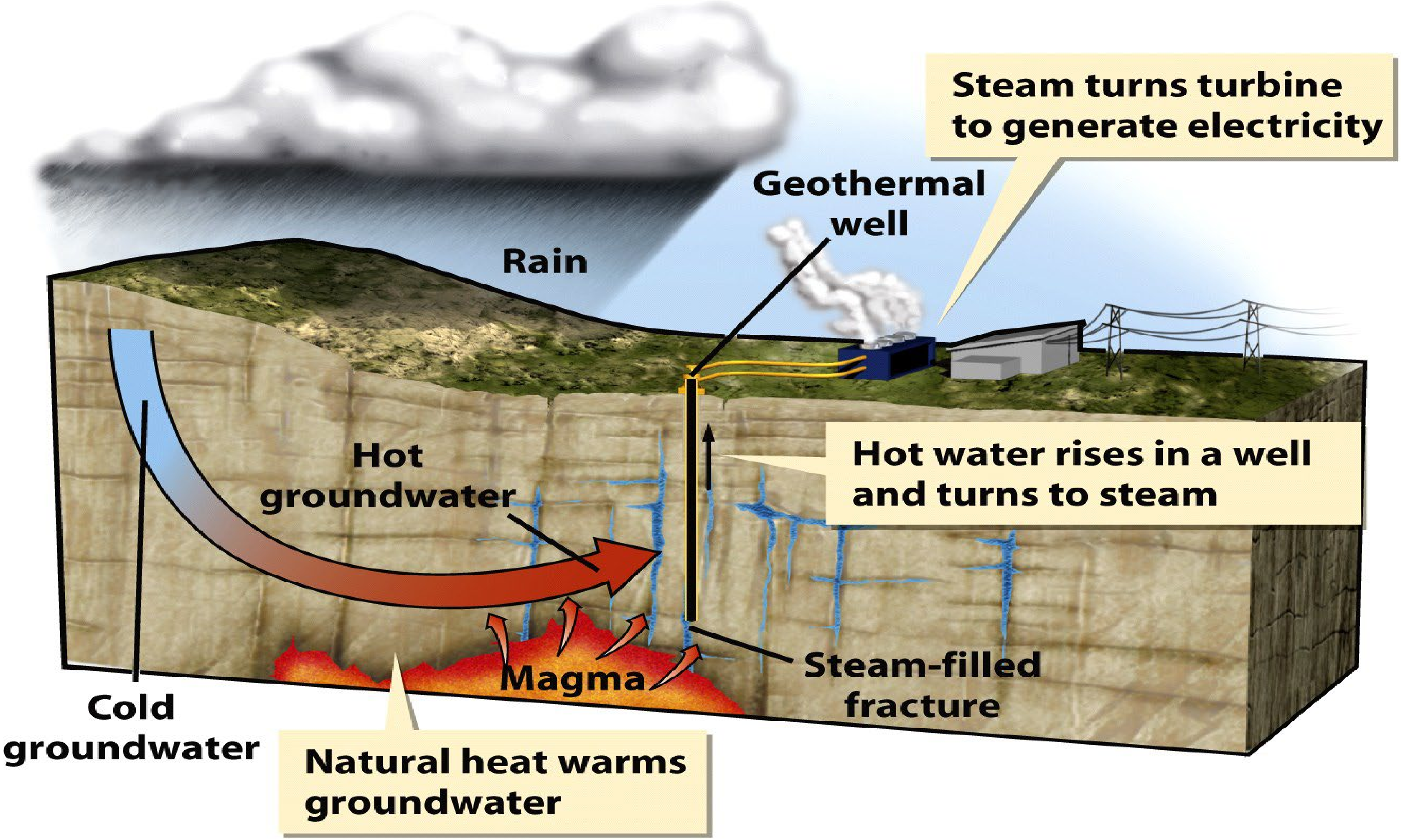


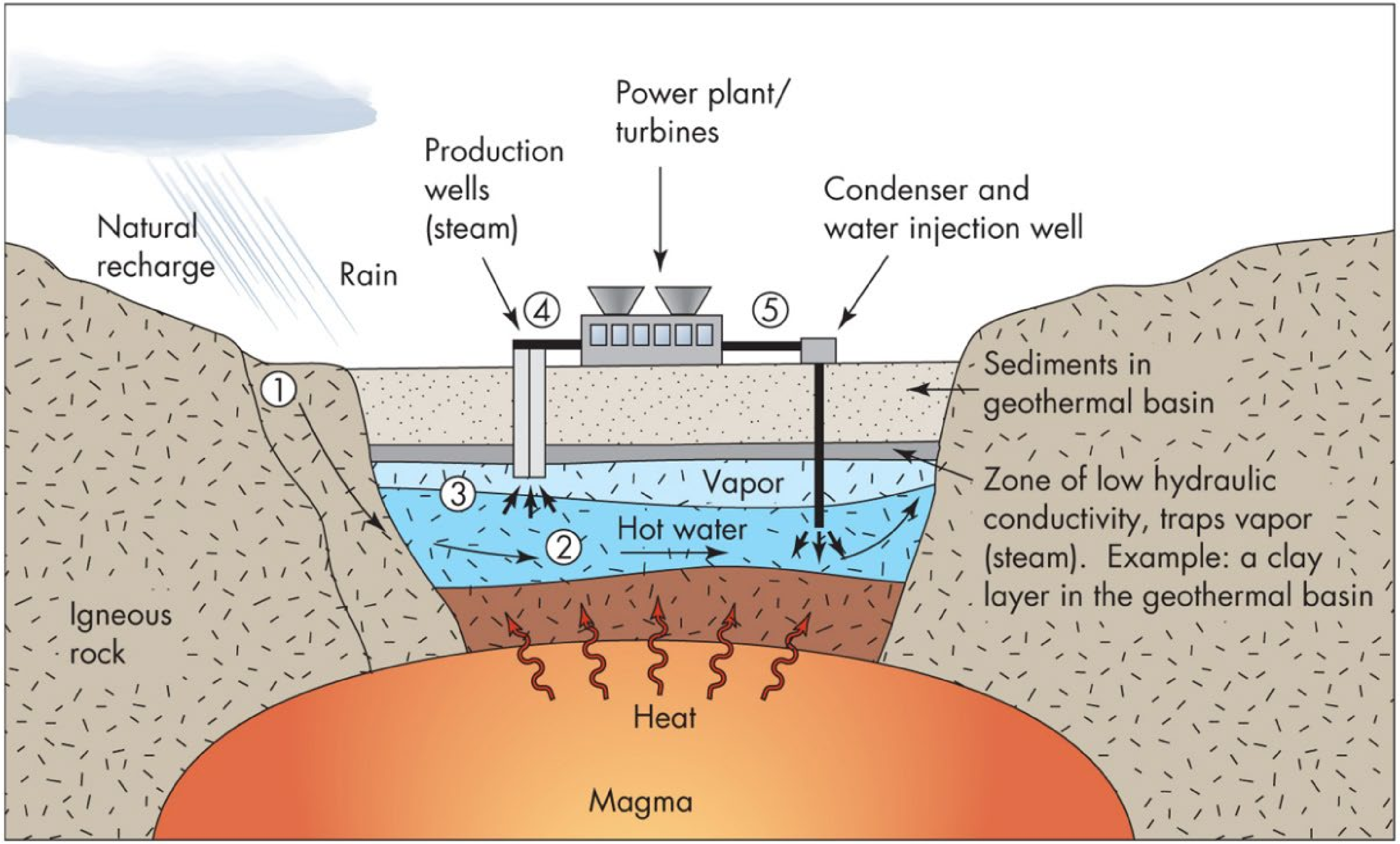
Temperature (°C)
100
150
200
250
Sierra Nevada
East of Rocky Mountains
Basin and Range
Battle Mountain area
47° per km
40
50
70
90
100
120
urface heat flow (mW/m²)


WIPP
NEW
MEXICO
Carlsbad
WIPP


300 m
Salt
655 m

Renewable energies

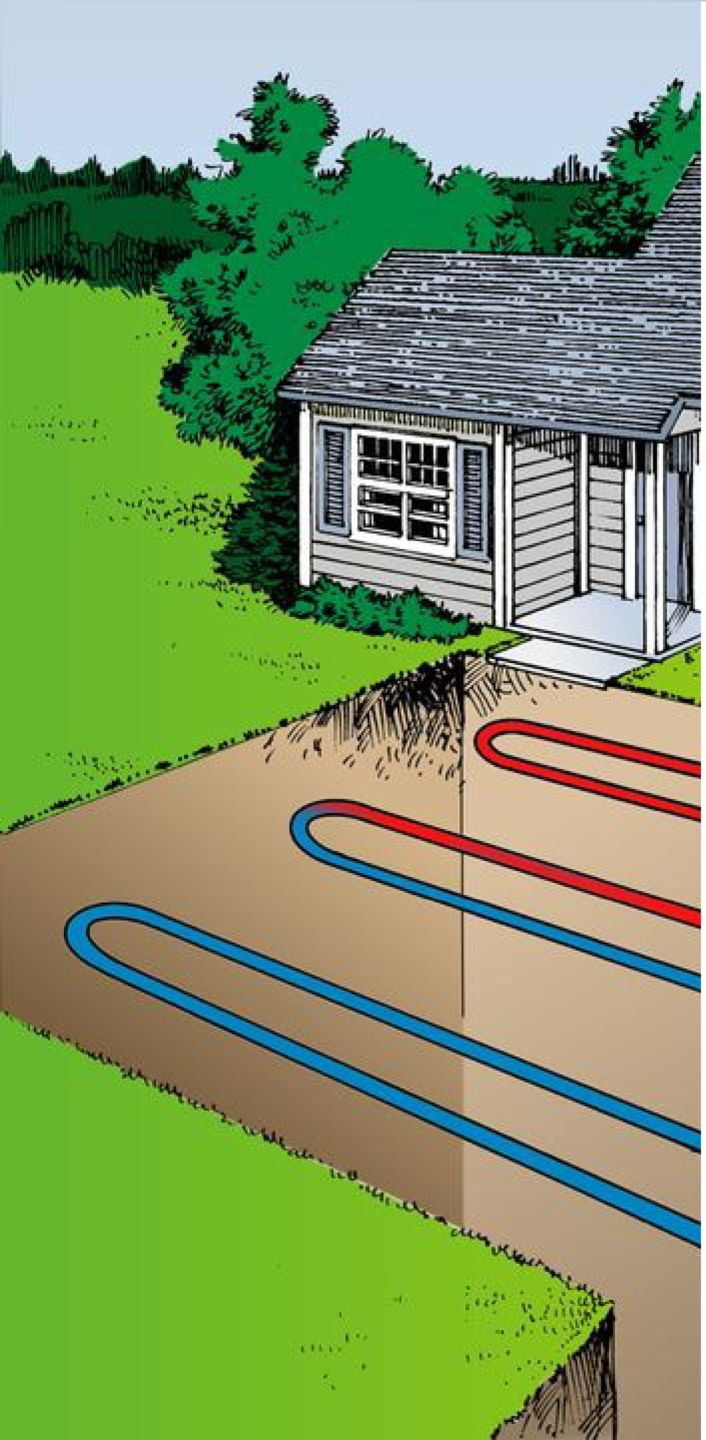


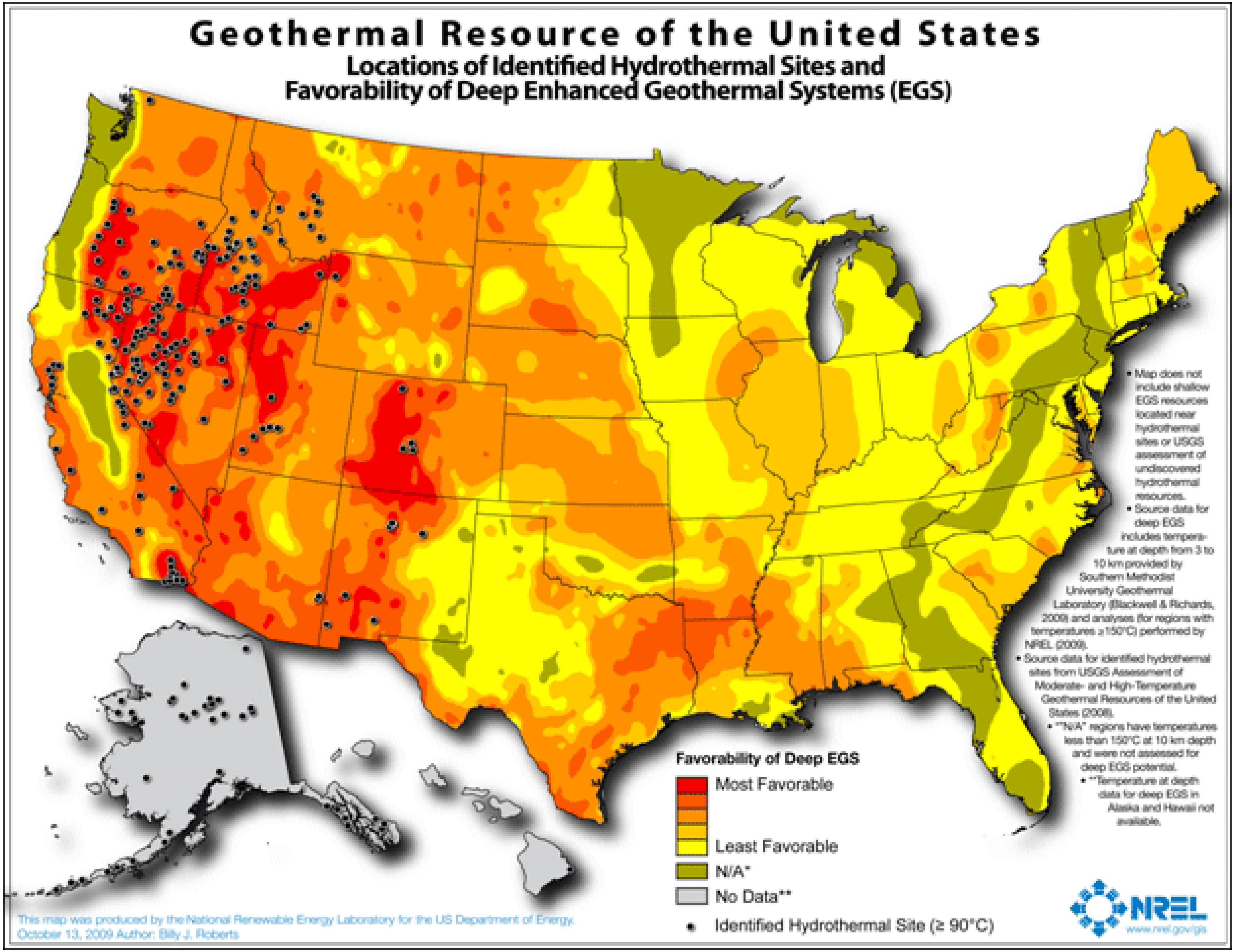


Direction of water flow

1. Natural recharge of water from rain
2. Hot water produced by Earth processes
3. Steam to production well
4. Steam to turbines to produce electricity
5. Water is injected back into ground



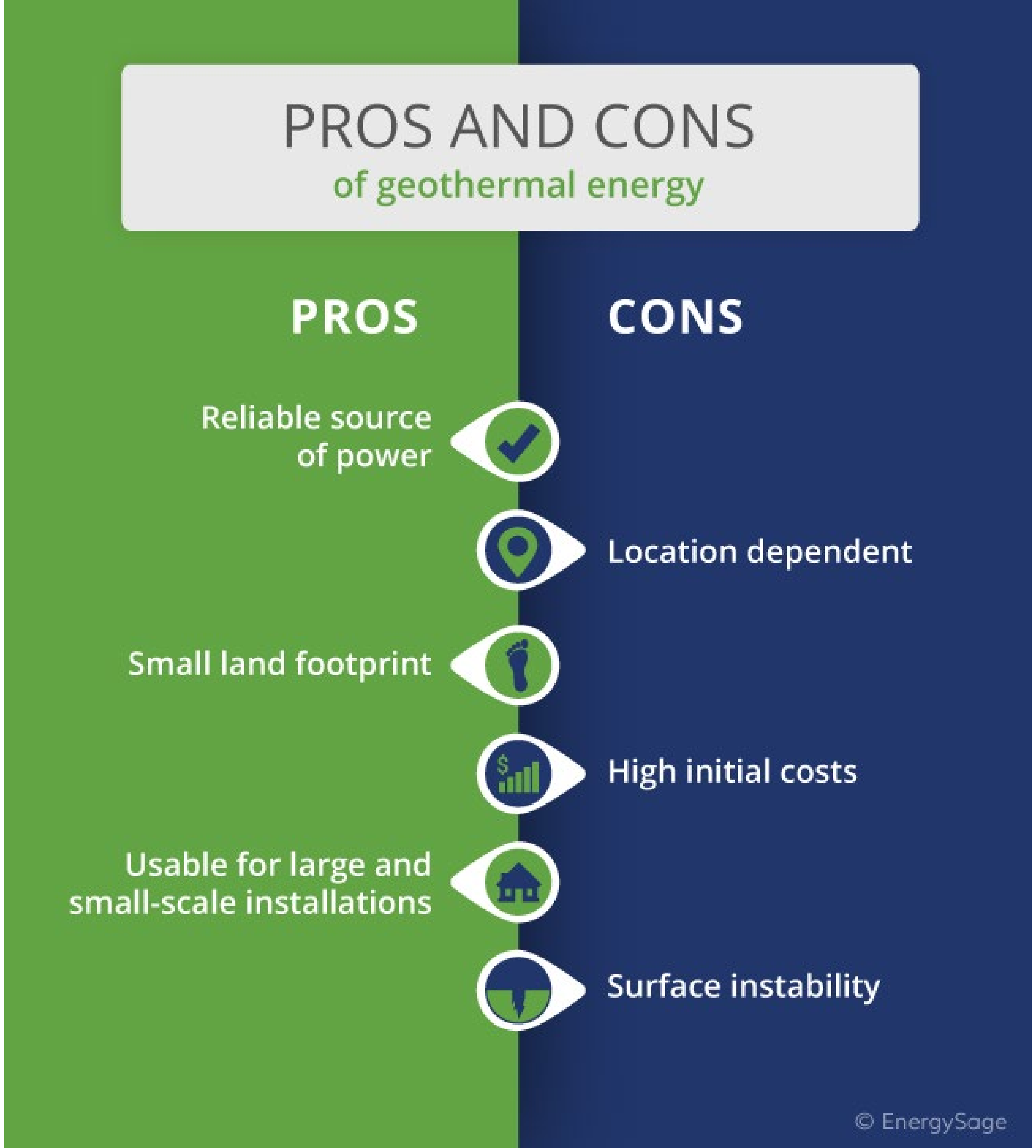


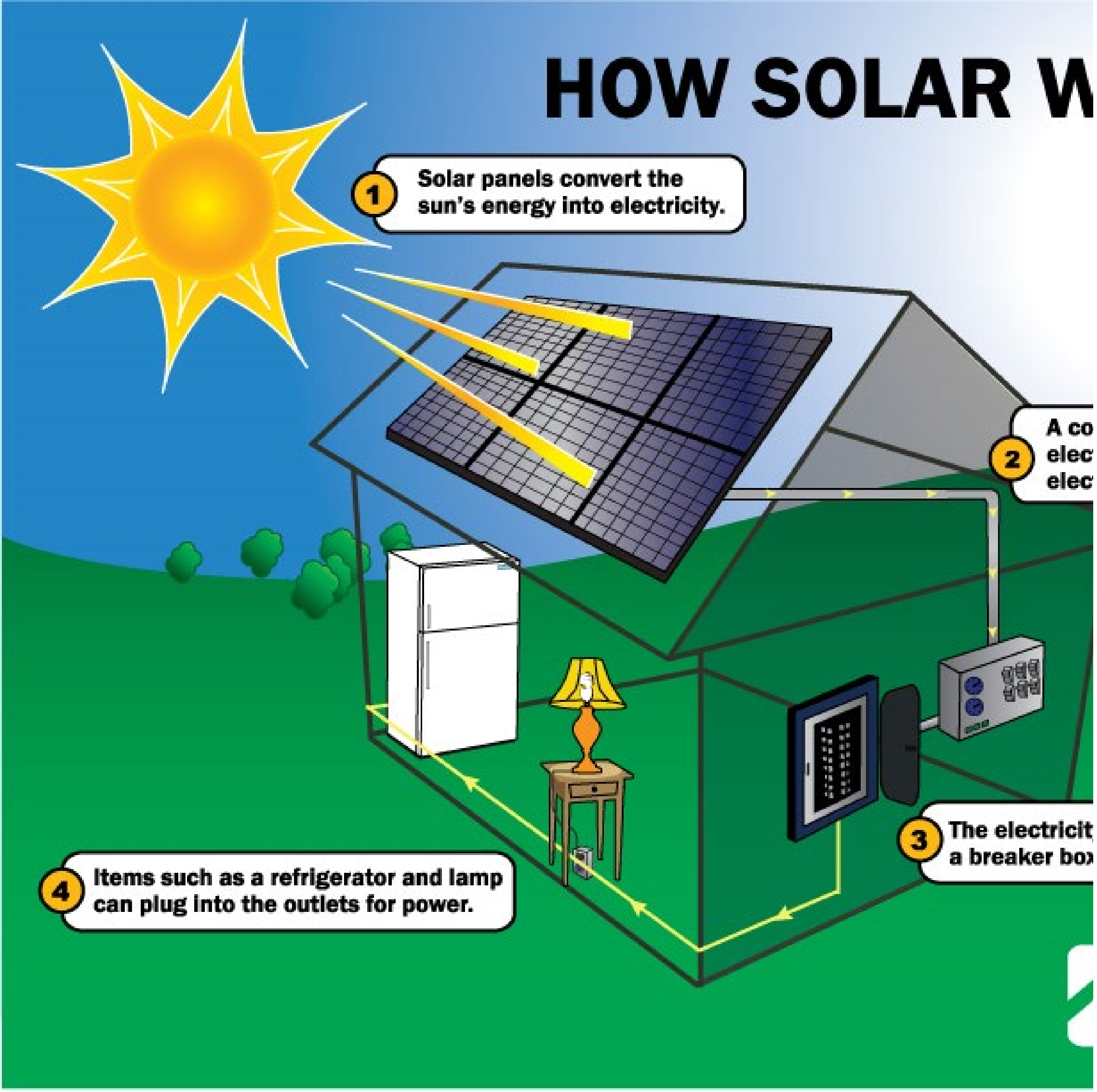

Geothermal Resource of the United States
Locations of Identified Hydrothermal Sites and
Favorability of Deep Enhanced Geothermal Systems (EGS)
• Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources.
• Source data for deep EGS includes temperature at depth from 3 to 10 km provided by Southern Methodist University Geothermal Laboratory (Blackwell & Richards, 2009) and analyses (for regions with temperatures ≥150°C) performed by NREL (2009).
• Source data for identified hydrothermal sites from USGS Assessment of Moderate- and High-Temperature Geothermal Resources of the United States (2008).
• *"N/A" regions have temperatures less than 150°C at 10 km depth and were not assessed for deep EGS potential.
• **Temperature at depth data for deep EGS in Alaska and Hawaii not available.
Favorability of Deep EGS
Most Favorable
Least Favorable
N/A*
No Data**
Identified Hydrothermal Site (≥ 90°C)
This map was produced by the National Renewable Energy Laboratory for the US Department of Energy.
October 13, 2009 Author: Billy J. Roberts
NREL
www.nrel.gov/gis

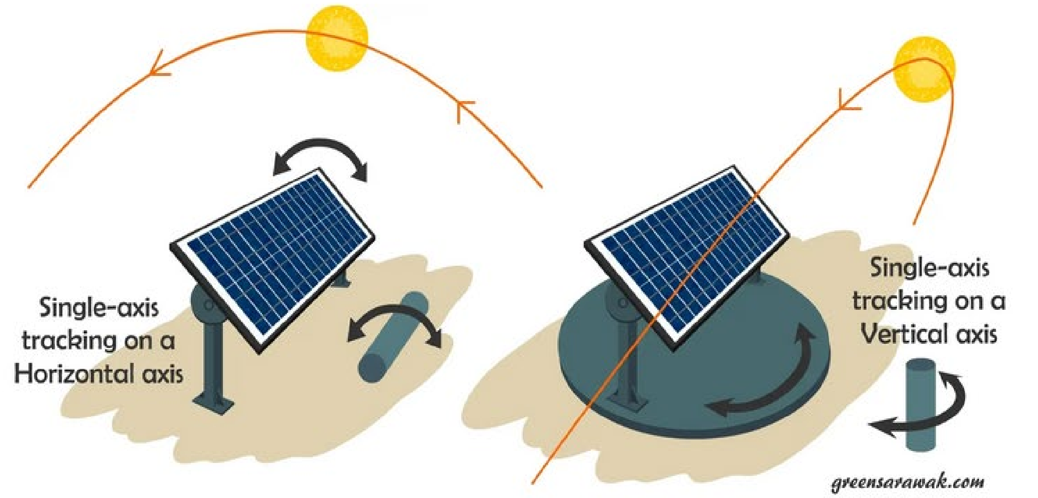
Geothermal issues – Open vs. Closed systems

- Water use and contamination
- Air contamination
- Land use
- Emissions – Climate change

https://www.ucsusa.org/resources/environmental-impacts-geothermal-energy

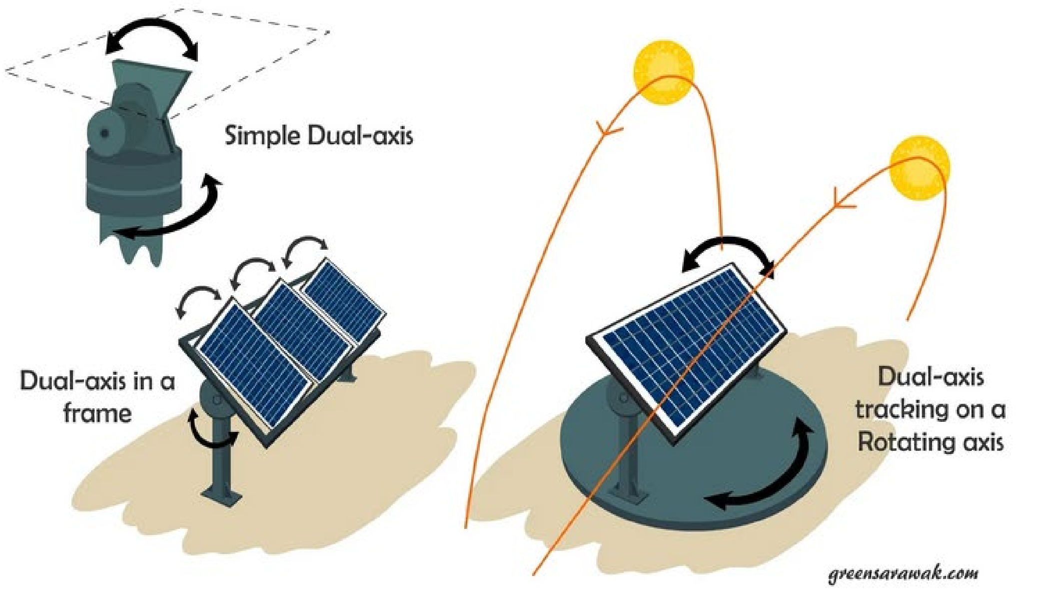


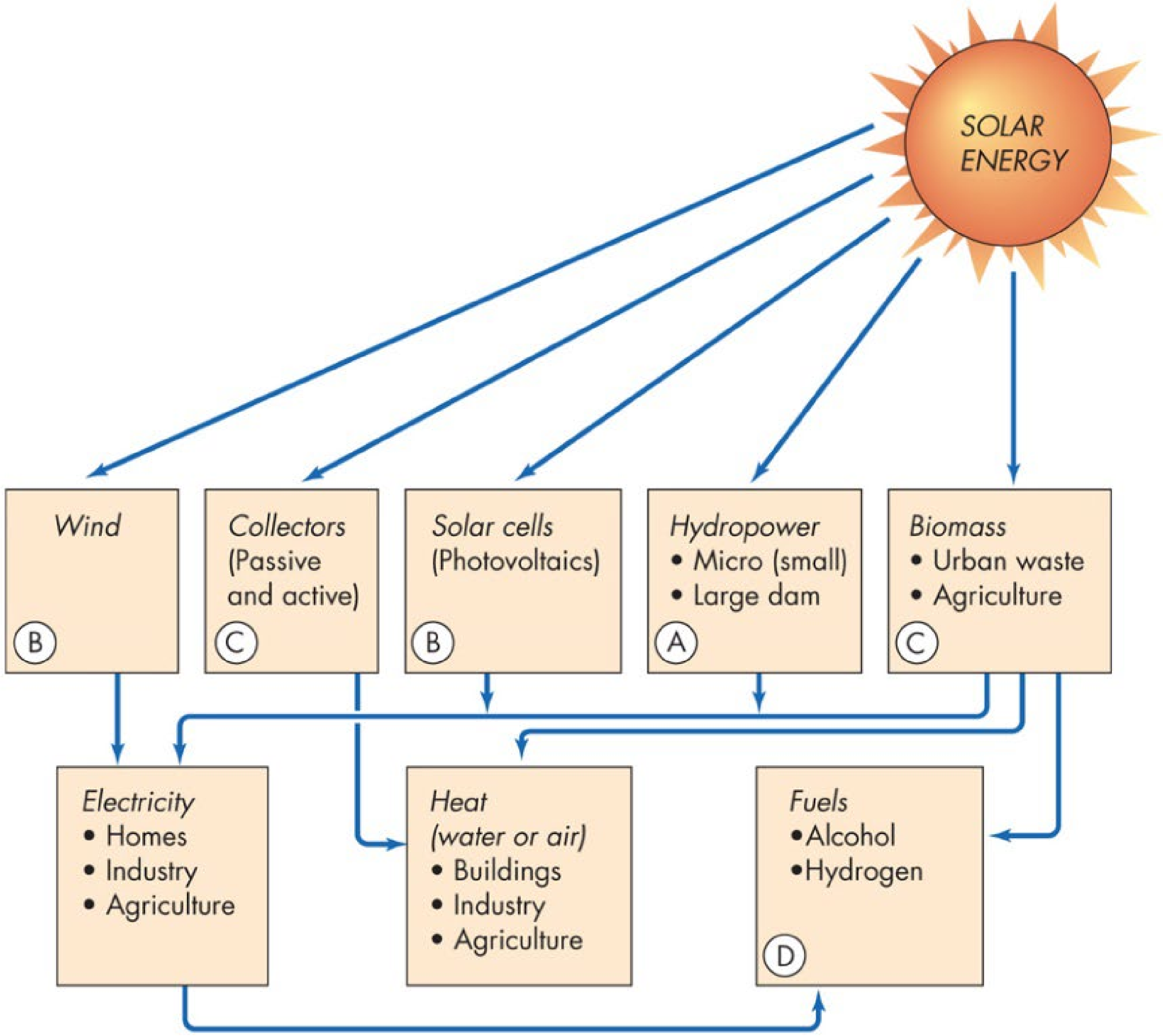




Dual axis solar tracker

This tracker not only tracks the sun as it moves east to west, but also follows it as it moves from north to south. Two axis trackers are more common among residential and small commercial solar projects that have limited space, so they can produce enough power to meet their energy needs.





(A) Produces most electricity from renewable solar energy

(B) Rapidly growing, strong potential; wind and solar are growing at 30% per year!

(C) Used today; important energy source

(D) Potentially a very important fuel to transition from fossil fuels

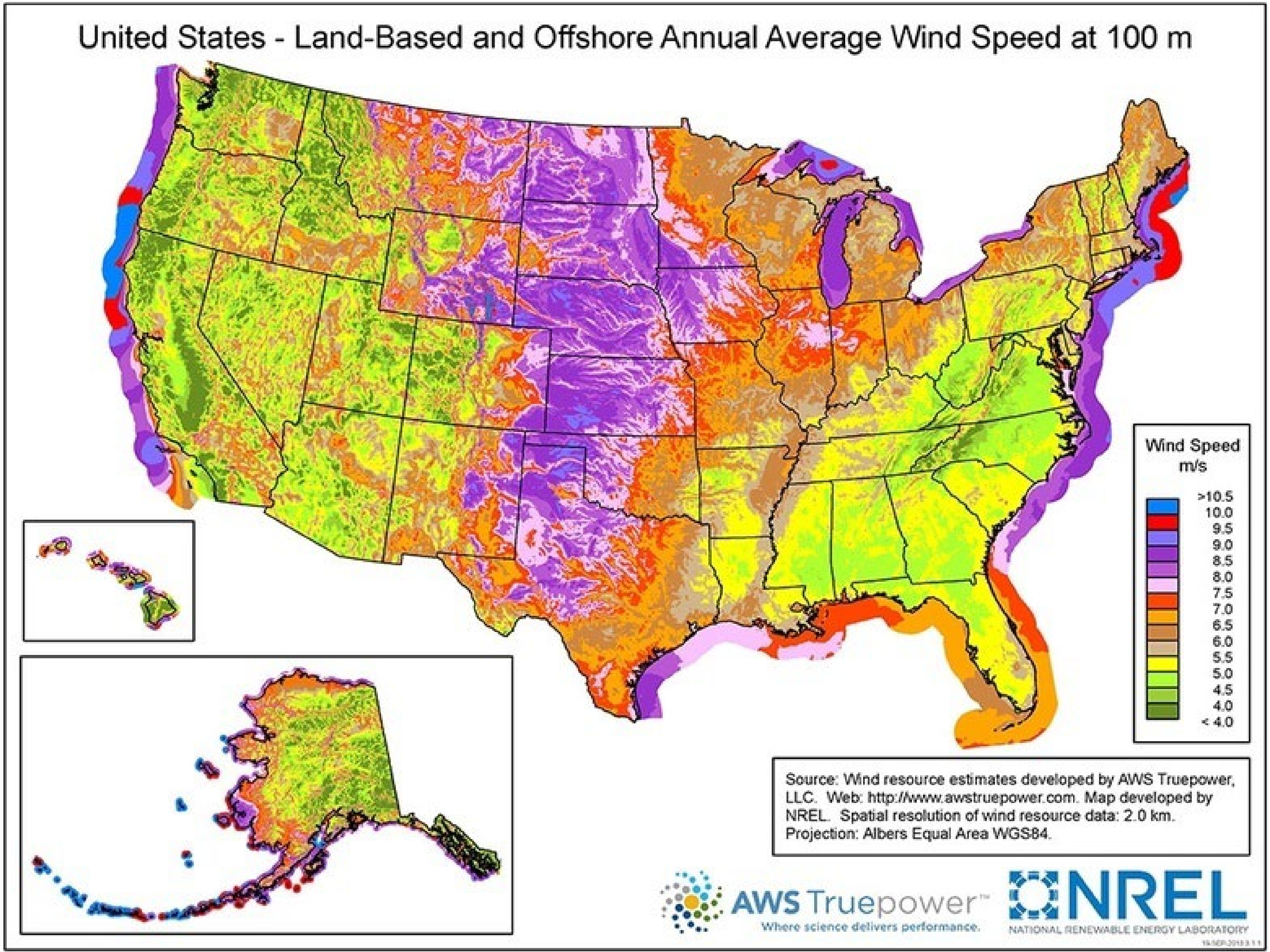

sunrun
TESLA
TESLA


RIVIAN

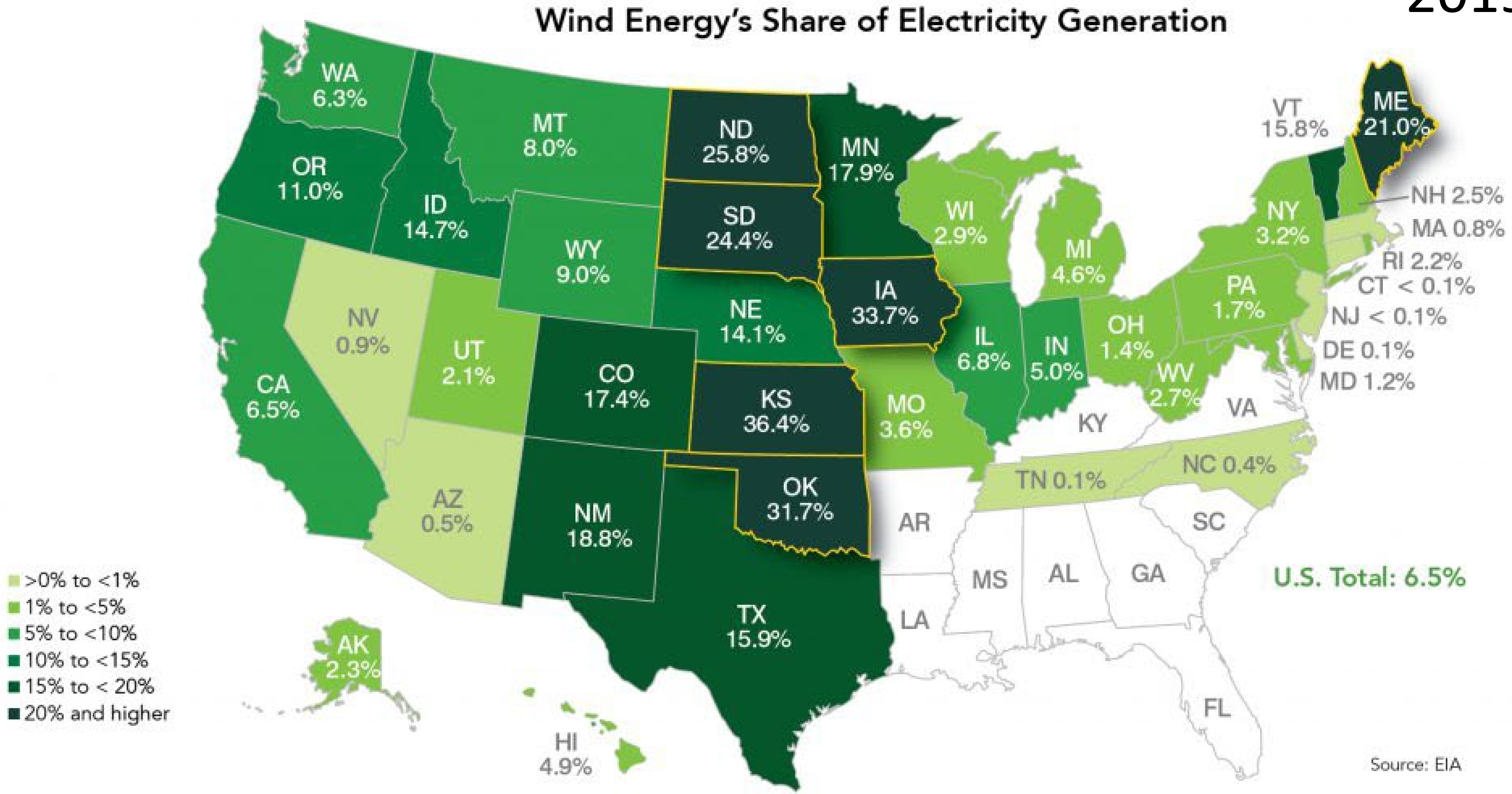
Tengger Desert Solar Park – 1500MW – China

Solar

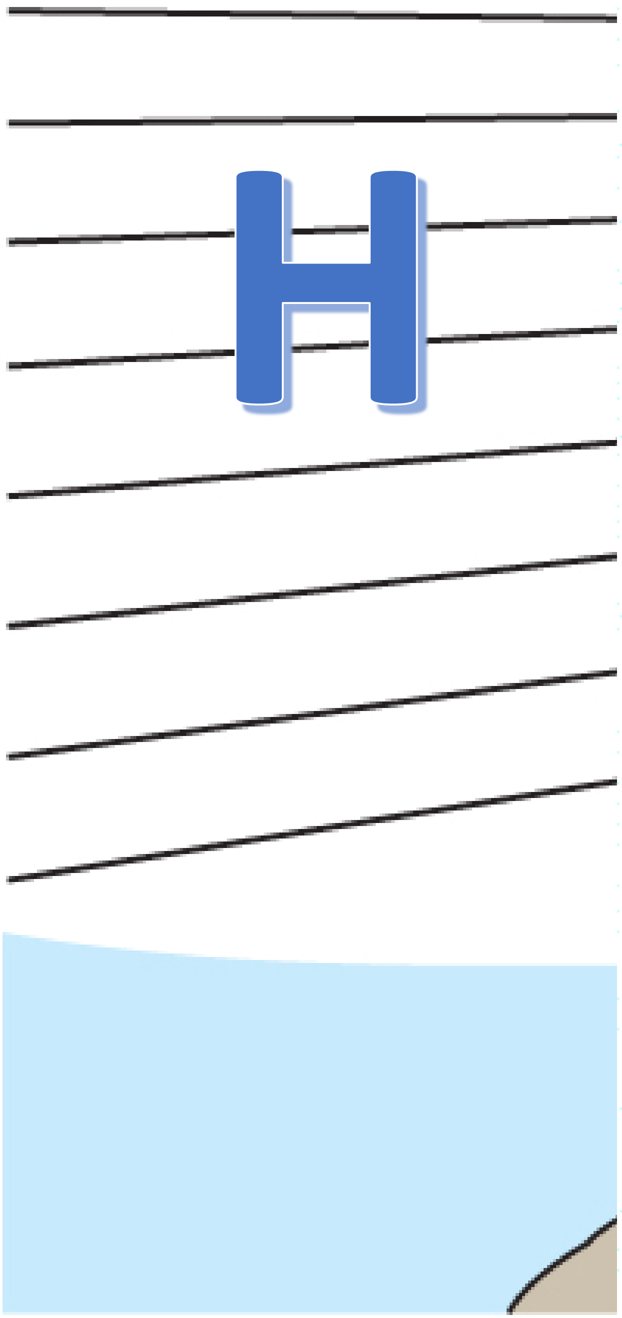
- Resources - REEs
- Battery storage

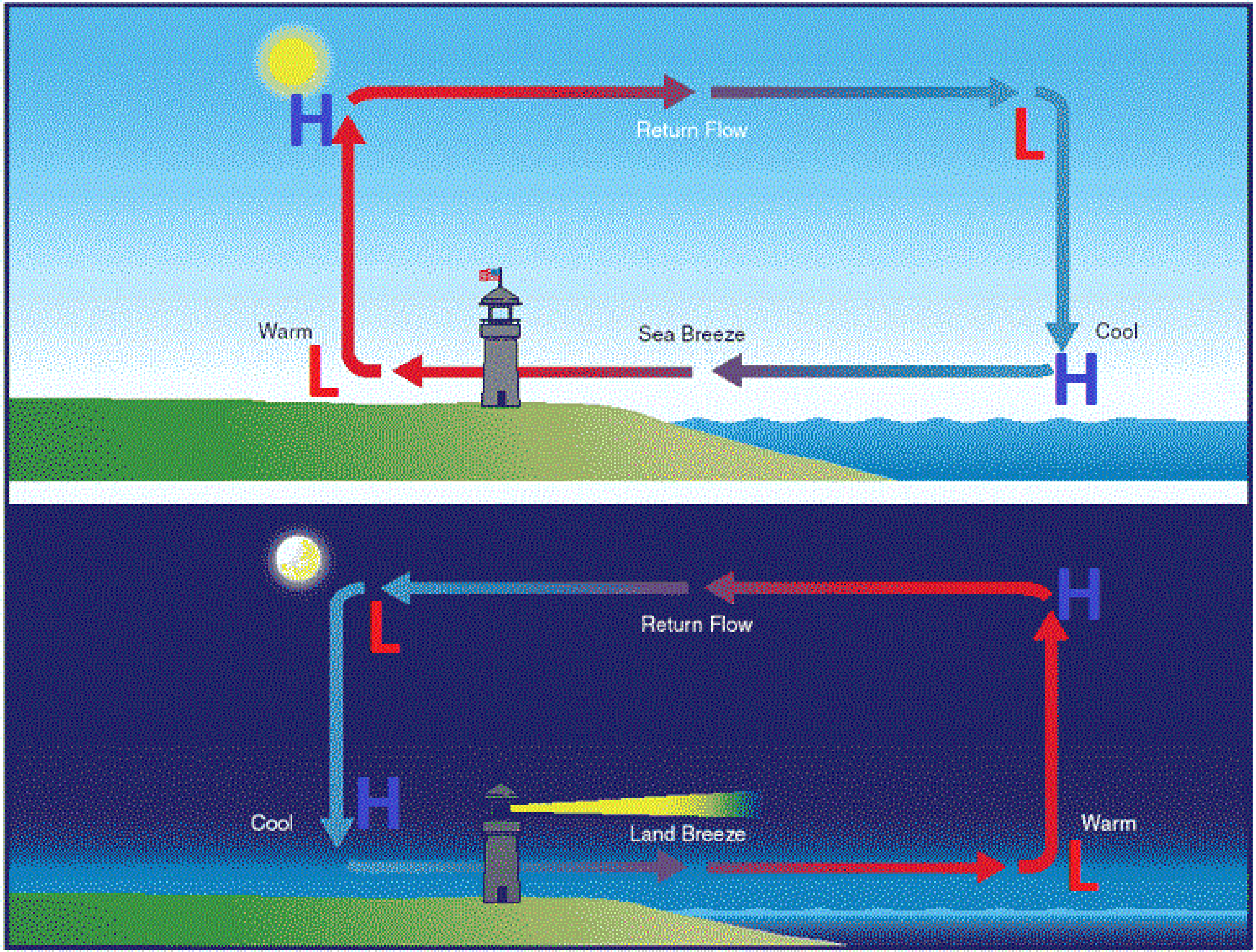

United States - Land-Based and Offshore Annual Average Wind Speed at 100 m
Wind Speed m/s
>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0
Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.
AWS Truepower™
Where science delivers performance.
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

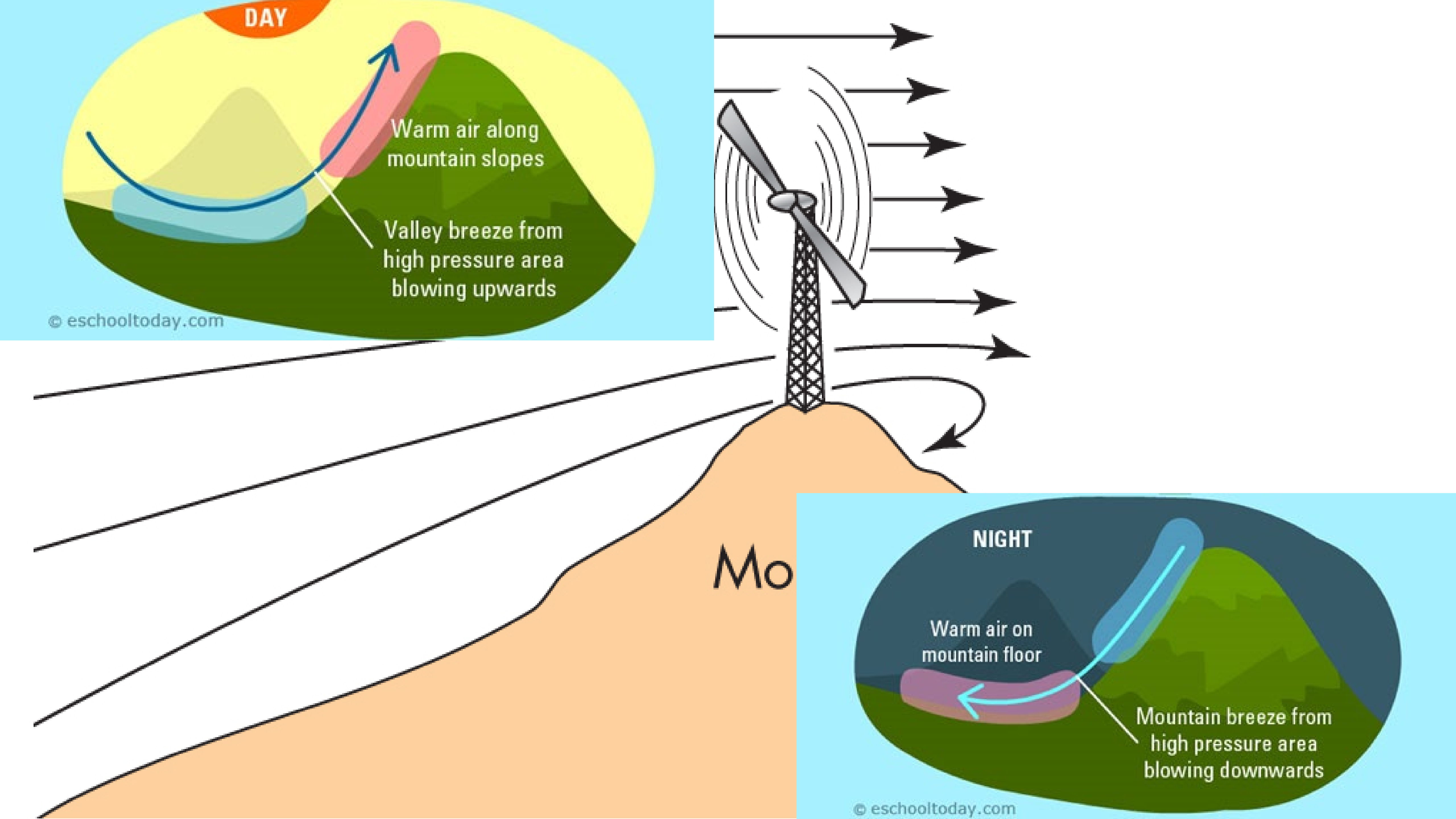
2019

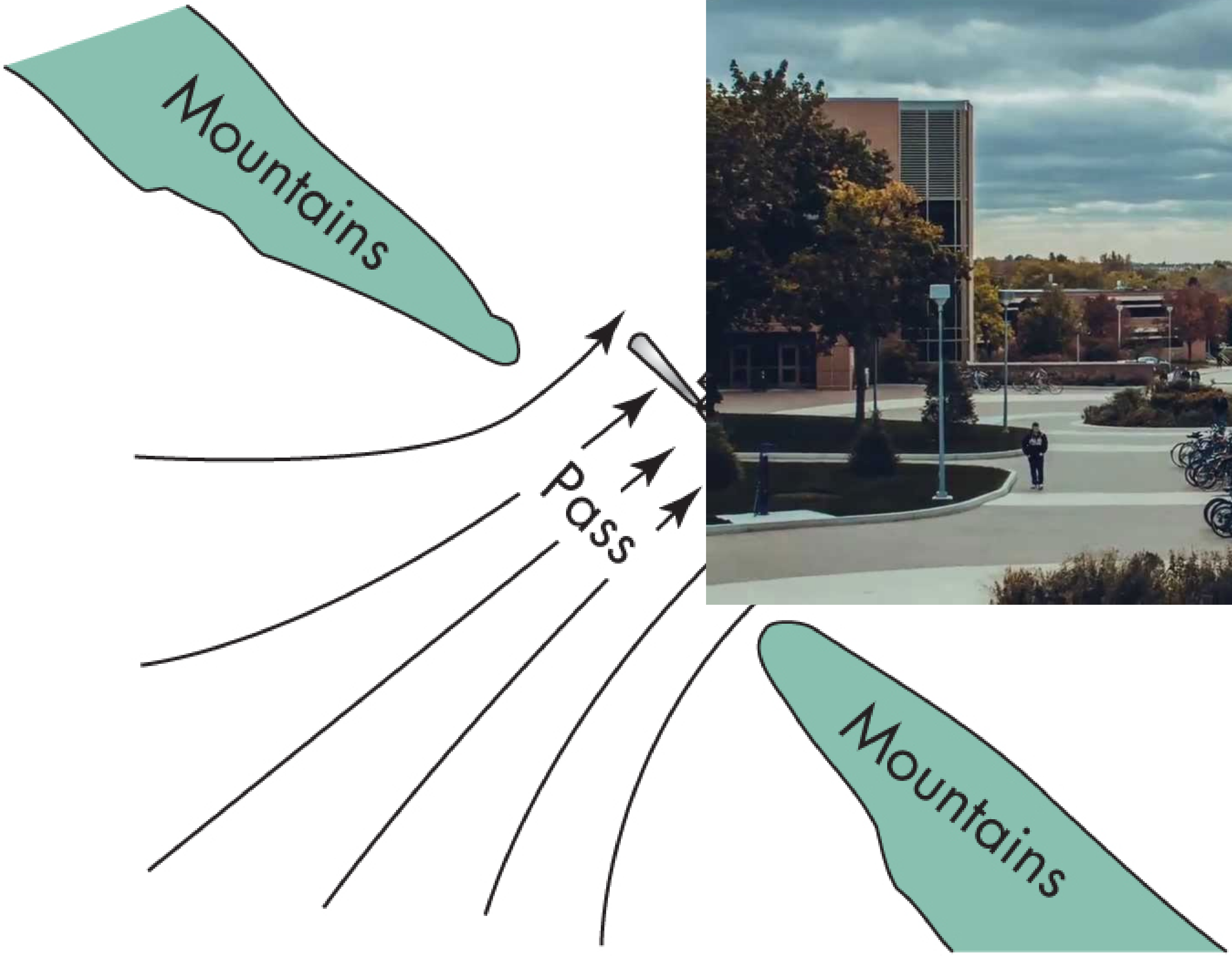


Wind Energy's Share of Electricity Generation
WA 6.3%
MT 8.0%
ND 25.8%
MN 17.9%
OR 11.0%
ID 14.7%
SD 24.4%
WY 9.0%
WI 2.9%
MI 4.6%
NY 3.2%
VT 15.8%
ME 21.0%
NH 2.5%
MA 0.8%
RI 2.2%
CT < 0.1%
NJ < 0.1%
DE 0.1%
MD 1.2%
PA 1.7%
OH 1.4%
WV 2.7%
VA
IN 5.0%
IL 6.8%
IA 33.7%
NE 14.1%
NV 0.9%
UT 2.1%
CO 17.4%
KS 36.4%
MO 3.6%
KY
CA 6.5%
AZ 0.5%
NM 18.8%
OK 31.7%
AR
TN 0.1%
NC 0.4%
SC
MS
AL
GA
LA
TX 15.9%
FL
AK 2.3%
HI 4.9%
>0% to <1%
1% to <5%
5% to <10%
10% to <15%
15% to < 20%
20% and higher
U.S. Total: 6.5%
Source: EIA


H

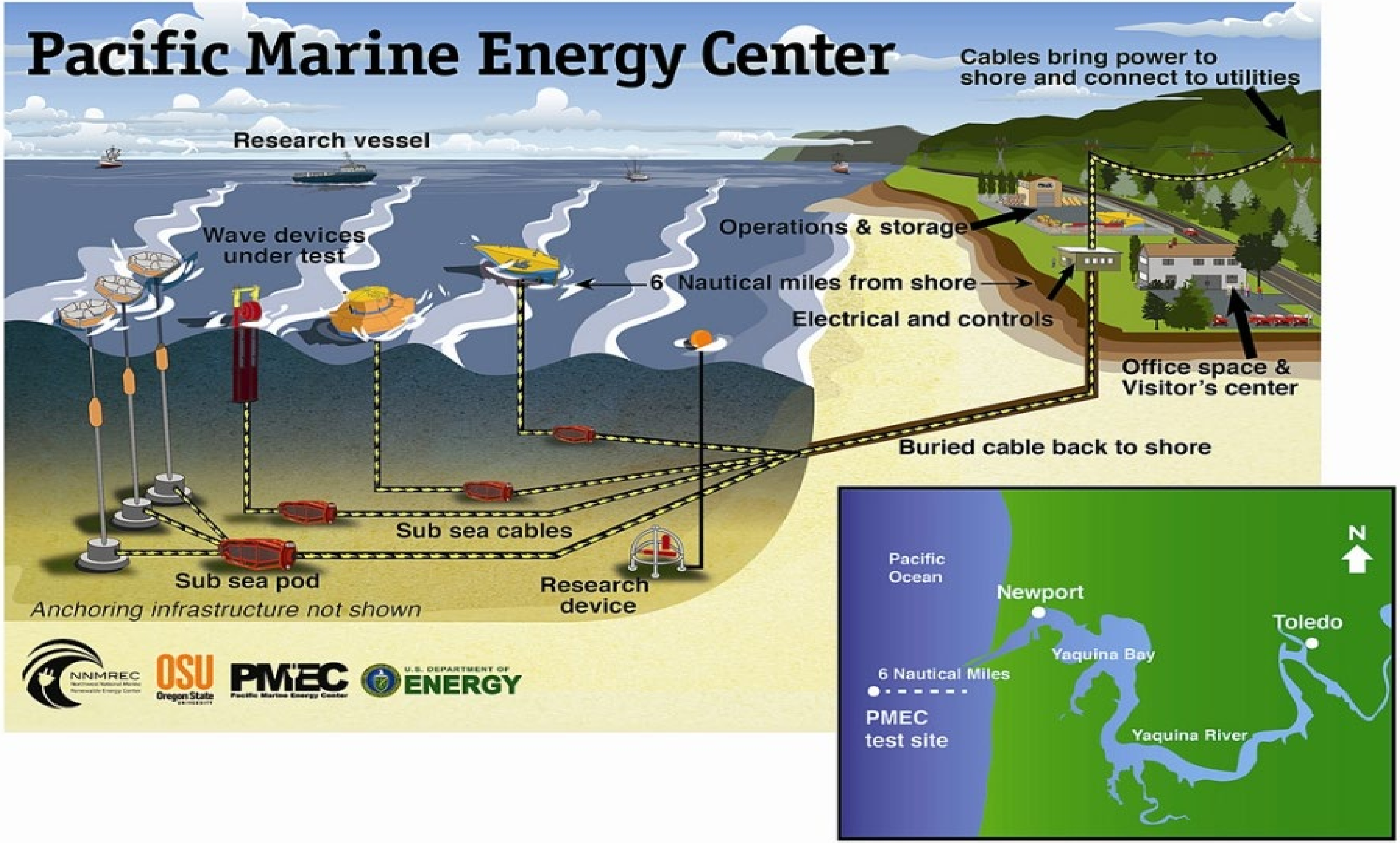

H
Return Flow
L
Warm
L
Sea Breeze
Cool
H
L
Return Flow
H
Cool
H
Land Breeze
Warm
L


DAY
Warm air along mountain slopes
Valley breeze from high pressure area blowing upwards
© eschooltoday.com
Mo
NIGHT
Warm air on mountain floor
Mountain breeze from high pressure area blowing downwards
© eschooltoday.com


Mountains
Pass
Mountains

Wind

Resources and Recycling?


Pacific Marine Energy Center
Cables bring power to shore and connect to utilities
Research vessel
Operations & storage
Wave devices under test
6 Nautical miles from shore
Electrical and controls
Office space & Visitor's center
Buried cable back to shore
Sub sea cables
Sub sea pod
Research device
Anchoring infrastructure not shown
NNMREC
OSU
Oregon State
PMEC
Pacific Marine Energy Center
U.S. DEPARTMENT OF ENERGY
Pacific Ocean
Newport
Toledo
Yaquina Bay
6 Nautical Miles
PMEC test site
Yaquina River
N

PROS AND CONS
of hydropower

PROS	CONS
Renewable source of energy	
	Some adverse environmental impact
Pairs well with other renewables	
	Expensive up-front
Can meet peak electricity demand	
	Lack of available reservoirs

TABLE 15.1 Energy Policy: What Is Being Discussed

1. Promote conventional energy sources: Use much more natural gas, with the objective to reduce our reliance on energy from foreign countries.
2. Encourage alternative energy: Support subsidies for wind energy and other alternative energy sources such as solar geothermal, hydrogen, and biofuels (ethanol and biodiesel). Increase the amount of biofuel (ethanol) mixed with gasoline sold in the United States.
3. Provide for energy infrastructure: Ensure that electricity is received over a dependable modern infrastructure.
4. Promote conservation measures: Set higher efficiency standards for federal buildings and for household products. Require what is now waste heat from power generation and industrial processes be used to produce electricity or other products . Recommend fuel-efficiency standards for cars, trucks, and SUVs. Provide new tax credits to install energy-efficient windows and appliances in homes. Provide a tax credit for purchasing a fuel-efficient hybrid or clean-diesel vehicle.
5. Seriously consider nuclear power: Recognize that nuclear power plants can generate large amounts of electricity without emitting air pollution or contributing to climate change (global warming).
6. Promote research: Develop alternative energy sources; find innovative ways to improve coal plants and help construct cleaner coal plants; determine how to safely tap into the vast amounts of oil trapped in oil shale and tar sands; and develop pollution-free automobiles.