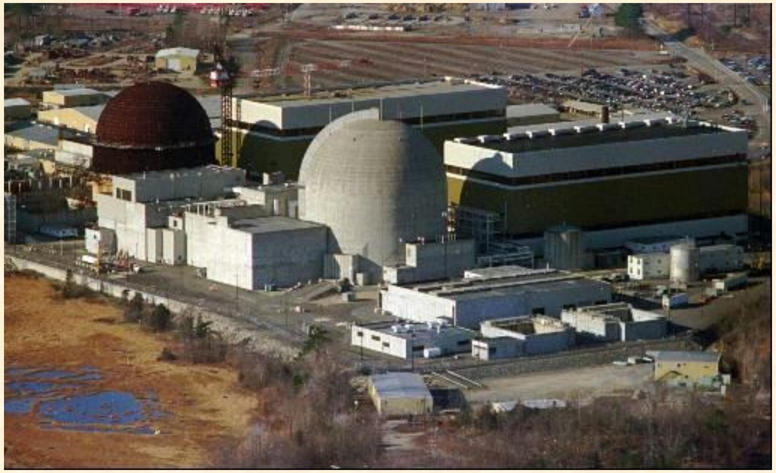
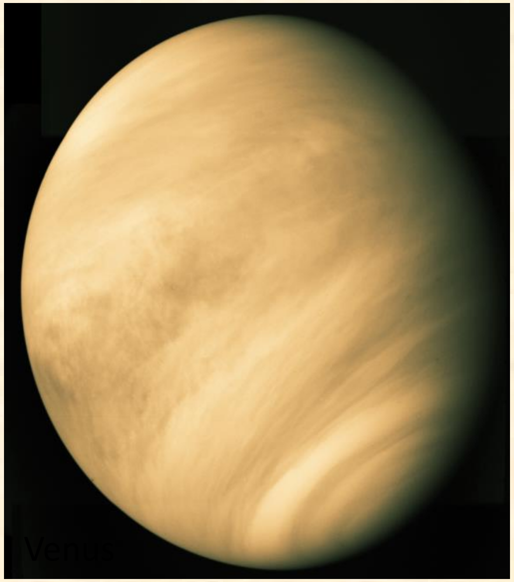
ENVI.5720 – Energy and Environment



The Terrestrial Planets, Life Cycle, and Atmosphere

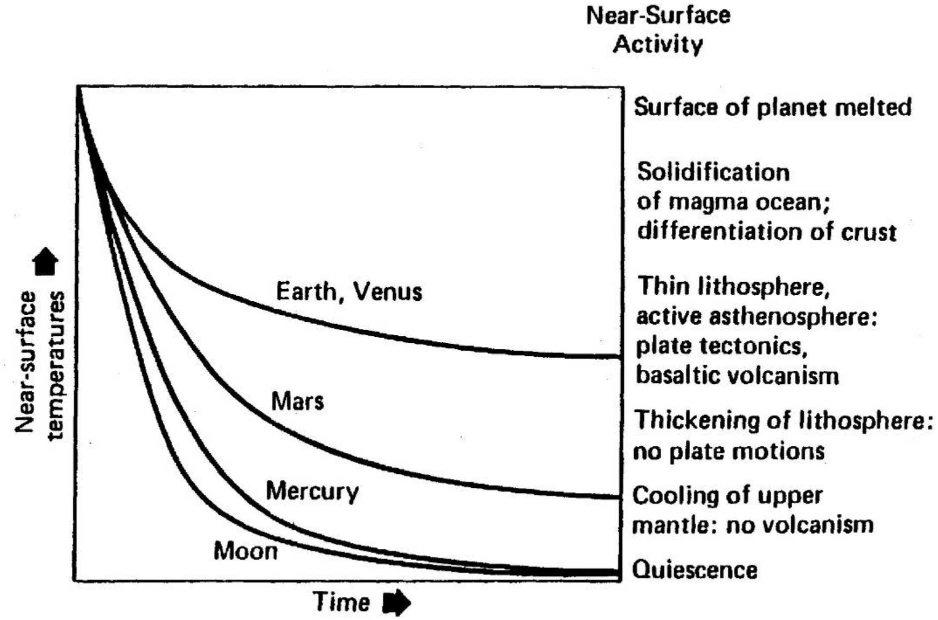


Thermal History of the Terrestrial Planets

Heat sources for early Earth

- Accretion – material added to earth causes heating due to conversion of kinetic energy
- Radioactive decay (U, Th, and K)
- Core formation – conversion of potential gravitational energy to heat

FIG. 7-13 A first-order explanation for differences in the present geologic state of the planets, based on the proposition that cooling of the outer layers of planets brings on different stages of geologic activity (right edge of diagram), and small planets cool faster than large ones.



Characteristics of the Atmospheres of Venus, Earth and Mars

			Composition of Atmosphere (Vol %)				
	Surface T (^{o}C)	Surface P (Atm)	CO_2	N_2	H_2O	Ar	O_2
Venus	468	99	96.4	3.4	0.14	18.6 ppm	69.3 ppm
Earth	15	1	0.033	78.084	Var	0.934	20.946
Mars	-63	0.0052	95.32	2.7	0.03	1.6	0.13

Origin of the Atmospheres

- Primary – left over from the formation of the solar system
- Secondary – formed after construction of the planet

Holland's Three Stage Model for the Origin of the Earth's Atmosphere

1) First Stage – prior to core formation. Native iron present. Volcanic gases are highly reduced. H_2, CH_4, NH_3. 4.5 to 4.0 Ga.

2) Second Stage – after core formation. Atmosphere becomes less reducing. Major changes are CO_2 replacing CH_4 and N_2 replacing NH_3. 4.0 to 2.0 Ga.

3) Third Stage – photosynthesis initiated and free oxygen builds up. Large banded iron formations do not form after 2.0 Ga which indicates a build-up in oxygen which inhibits the transport of iron in solution. 2.0 Ga to present

Other patterns deduced from the geologic record:

1) The concentration of various gases in the atmosphere has varied throughout geologic time.

2) There have been times in the past when oxygen content has been much greater than today (30% versus 21%) and spontaneous wildfires have occurred.

3) Carbon dioxide concentrations in the atmosphere have been both significantly lower and significantly greater than at present.

Venus and Earth are very similar planets in terms of size and density. Why are their atmospheres so different?

- Total amount of C, H, and N in the surface reservoirs for both planets are very similar but they are found in different reservoirs – atmosphere for Venus; hydrosphere, polar caps and sediments for Earth.

Table 4-3 Carbon, Hydrogen, and Nitrogen Contained in Combined Atmospheres, Hydrosphere, Polar Caps, and Sediments of Planets

Planet	CARBON (kg/cm²)	HYDROGEN (kg/cm²)	NITROGEN (kg/cm²)
VENUS	30	<0.06	<1.5
EARTH	20.4	50	0.8
MARS	~0.004	~0.06	$\sim 4 \times 10^{-4}$

- Relative to Venus and Earth, very little C, H, and N in Mars surface reservoirs. Because Mars is smaller than Earth and Venus its active thermal history is much shorter. A lot less degassing.

So why are Venus and Earth different? It all has to do with liquid water versus water vapor. Liquid water formed on Earth, not on Venus. Carbon dioxide was removed from the Earth's atmosphere by photosynthesis and oxygen was added. Life did not develop on Venus. Mars may be a different story, but the limited amount of degassing inhibited the process.

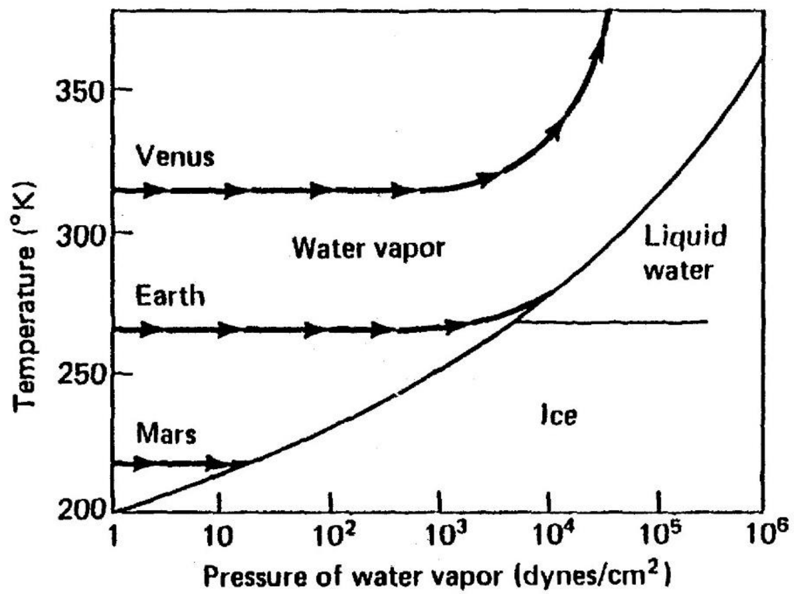


FIG. 4-10 A model that rationalizes differences in the evolution of atmospheres of Venus, Earth, and Mars. As H_2O vapor was evolved from the interiors of the three planets, the H_2O vapor pressure in their atmospheres built to higher and higher values (three tracks with arrows). Differences in starting temperatures for the three atmospheres are due to differences in proximity to the sun. When atmospheres accumulate more than $\sim 10^3$ dynes/cm^2 of H_2O vapor, the greenhouse effect begins to operate, raising the temperature of the atmosphere. But no more than ~ 20 dynes/cm^2 of H_2O vapor could accumulate in the Martian atmosphere; any additional H_2O vapor evolved from the interior of Mars froze out as ice on the surface. Similarly, H_2O vapor in excess of $\sim 10^4$ dynes/cm^2 in the terrestrial atmosphere condensed as liquid water. In the case of Venus, however, it has been suggested that increasing efficiency of the greenhouse effect (a "runaway greenhouse") prevented H_2O from ever condensing, no matter how much was added to the atmosphere. After S. I. Rasool and C. de Bergh, *Nature*, v. 226, 1970, 1037–1039.

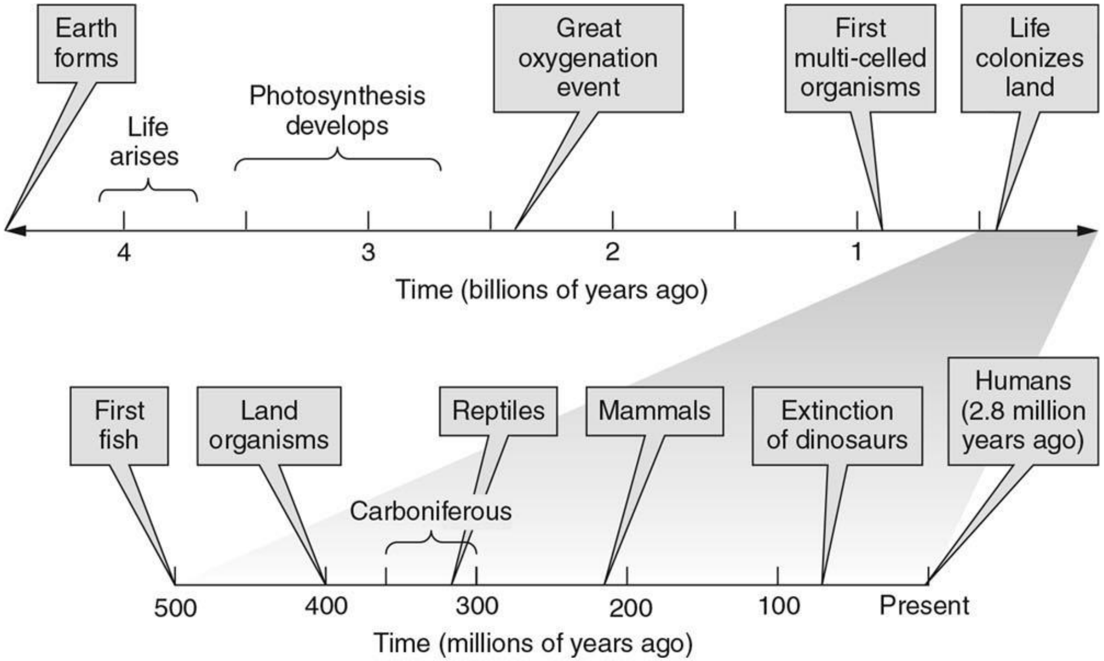


FIGURE 1.4

Some major events in the history of life on Earth. The origins of life and photosynthesis are uncertain, and the dates given for the last 500 million years represent the earliest definitive fossil evidence.

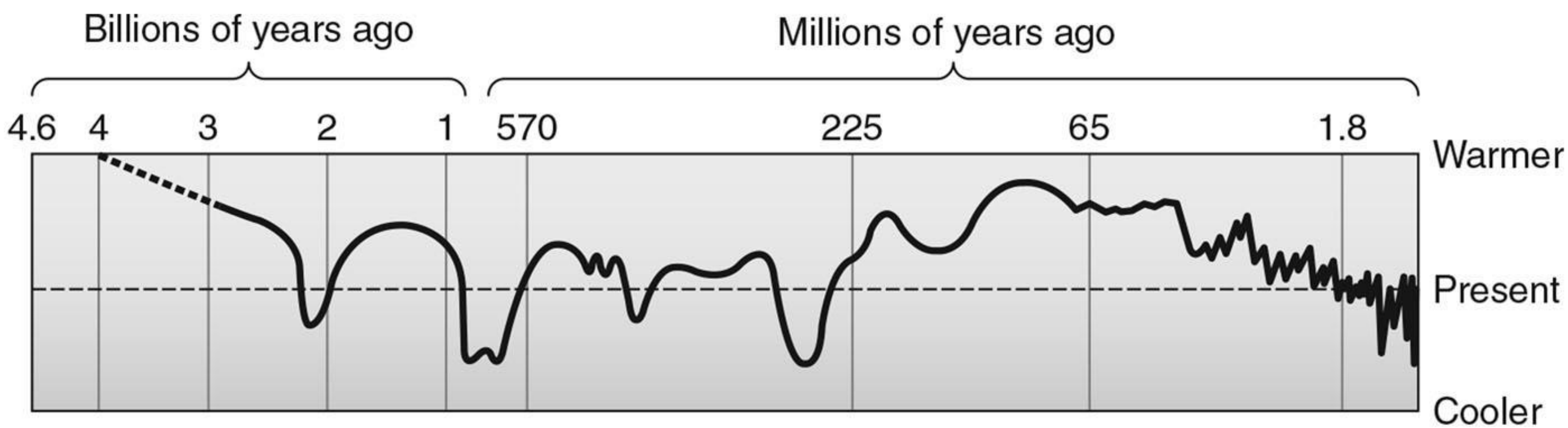


FIGURE 1.5

A rough estimate of Earth's temperature history over the past 3 billion years shows that much of the time it has been warmer than the present, despite the Sun's steadily increasing energy output. The temperature scale is only semiquantitative, with the overall variation shown being about 30°C—comparable to winter–summer differences in today's temperate climates. Note that the horizontal timescale is not uniform.

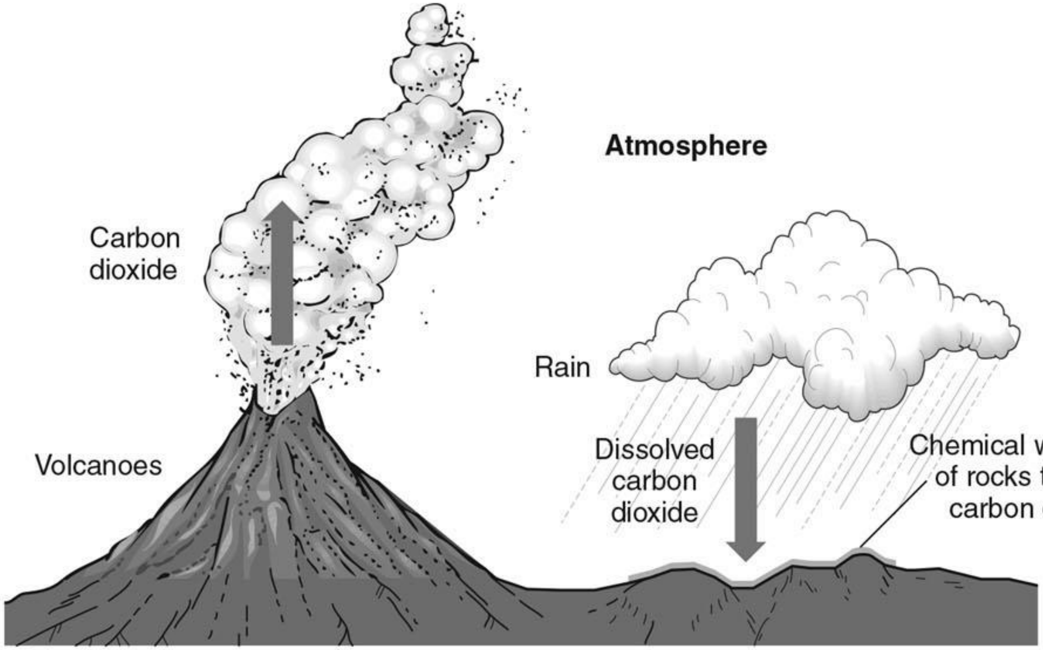
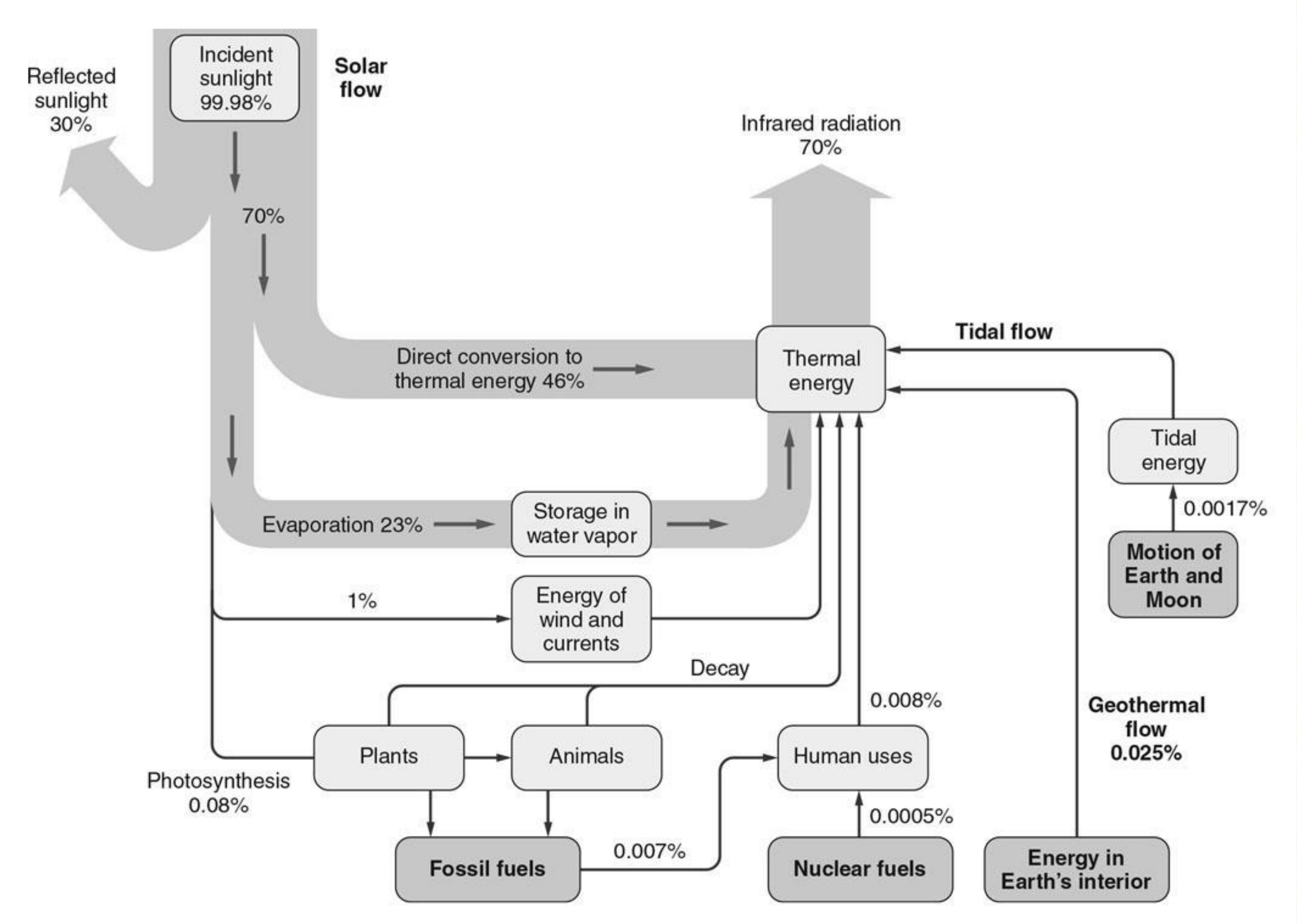
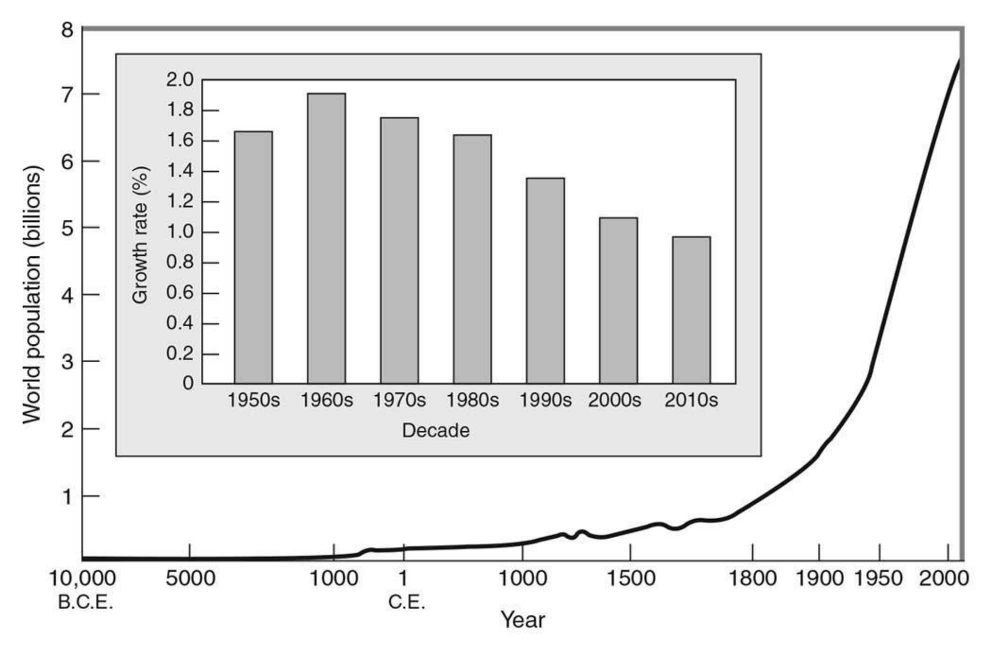
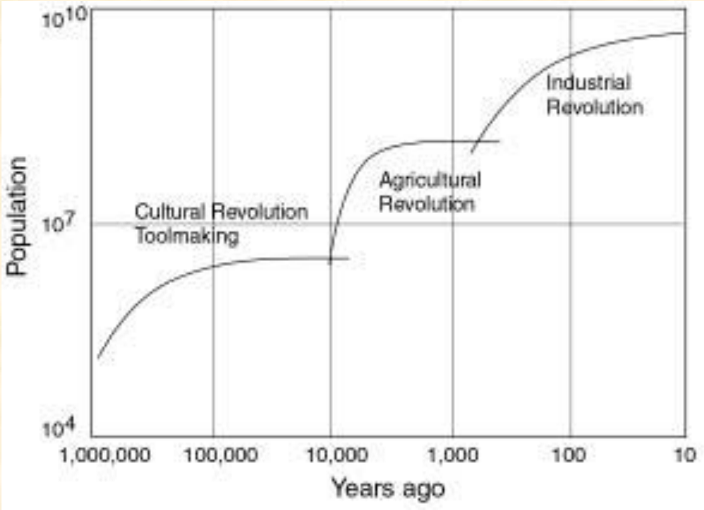


FIGURE 1.6

Over geological time, removal of CO_2 by precipitation and chemical weathering of rocks balances volcanic CO_2 emissions. Carbon dioxide removal increases with temperature, providing a negative feedback that regulates Earth's temperature.

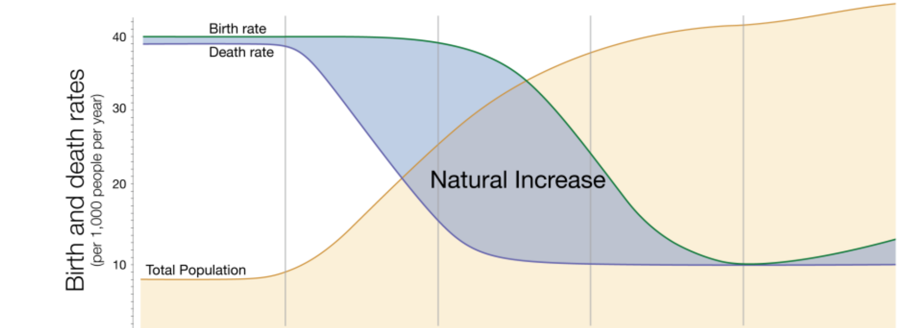

Reflected sunlight 30%
Incident sunlight 99.98%
Solar flow
70%
Infrared radiation 70%
Direct conversion to thermal energy 46%
Thermal energy
Tidal flow
Tidal energy
0.0017%
Motion of Earth and Moon
Evaporation 23%
Storage in water vapor
1%
Energy of wind and currents
Decay
0.008%
Geothermal flow 0.025%
Plants
Animals
Human uses
Photosynthesis 0.08%
0.0005%
Fossil fuels
0.007%
Nuclear fuels
Energy in Earth's interior





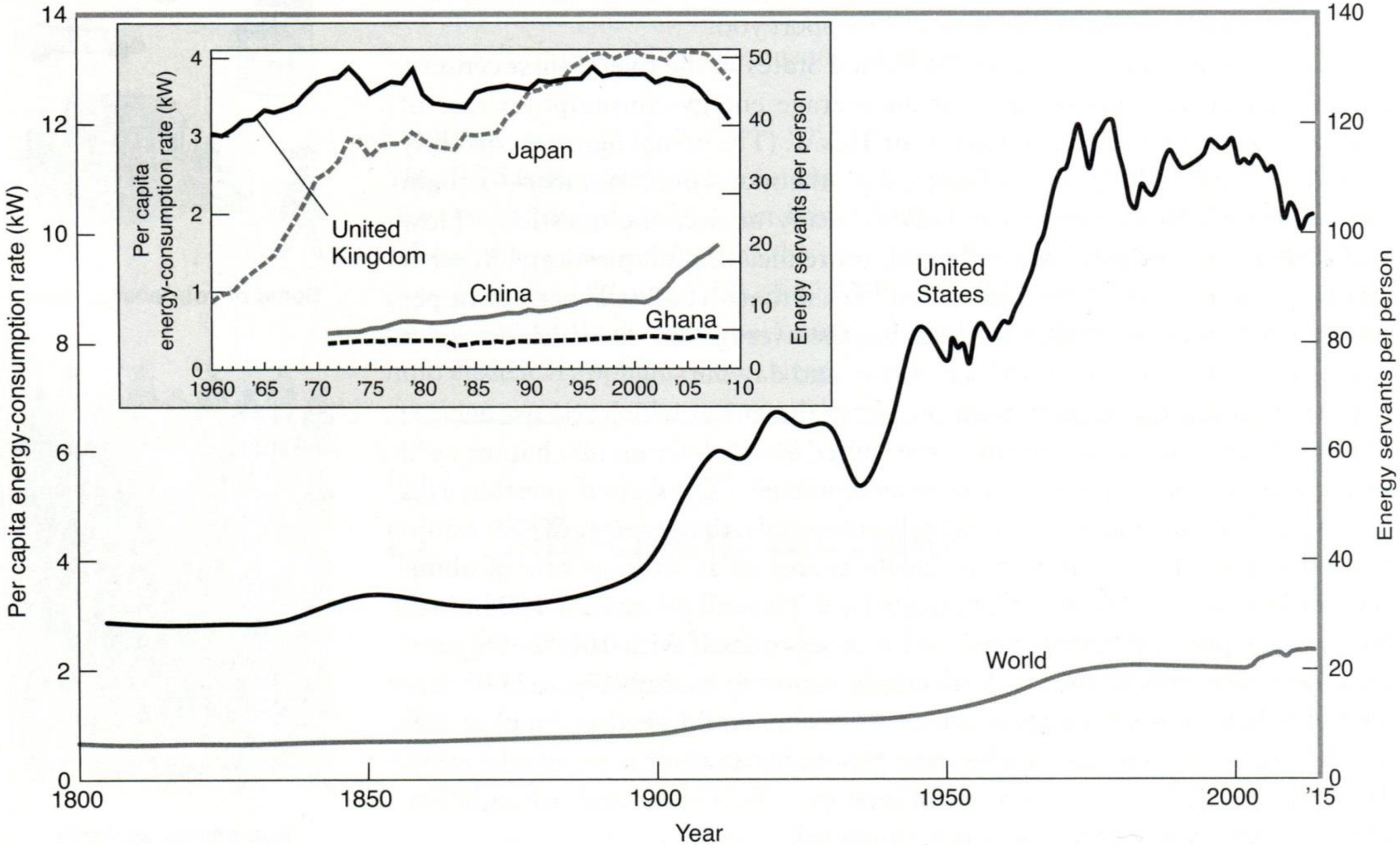
The demographic transition in 5 stages

Our World in Data



	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Birth rate	High	High	Falling	Low	Rising again
Death rate	High	Falls rapidly	Falls more slowly	Low	Low
Natural increase	Stable or slow increase	Very rapid increase	Increase slows down	Falling and then stable	Stable or slow increase

Population Pyramid



Per capita energy-consumption rate (kW)
Energy servants per person
Year
United States
World
Per capita energy-consumption rate (kW)
Energy servants per person
Japan
United Kingdom
China
Ghana
1960
'65
'70
'75
'80
'85
'90
'95
2000
'05
'10
1800
1850
1900
1950
2000
'15

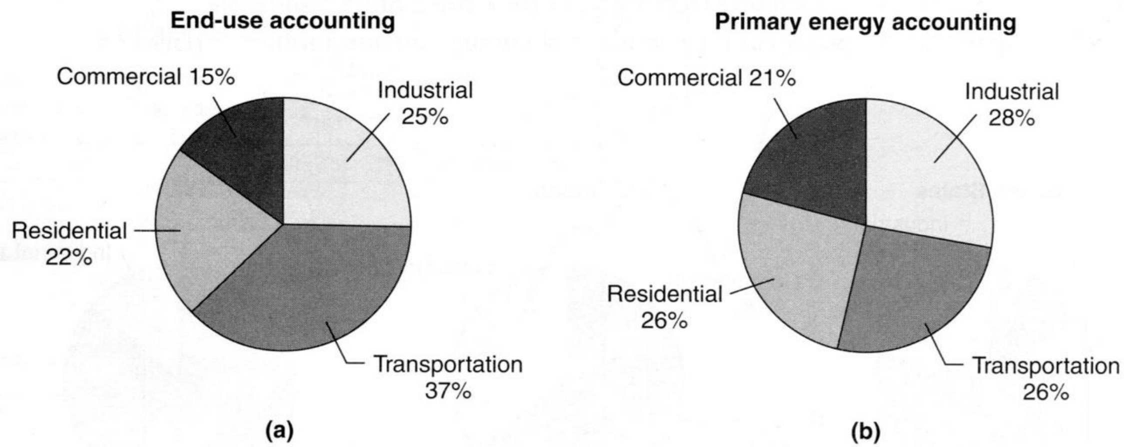


FIGURE 2.5

Energy consumption by sector for the 34 countries that constitute the Organization for Economic Cooperation and Development (OECD), with (a) end-use accounting and (b) accounting for primary energy. Inefficiencies in electric power generation explain most of the difference.

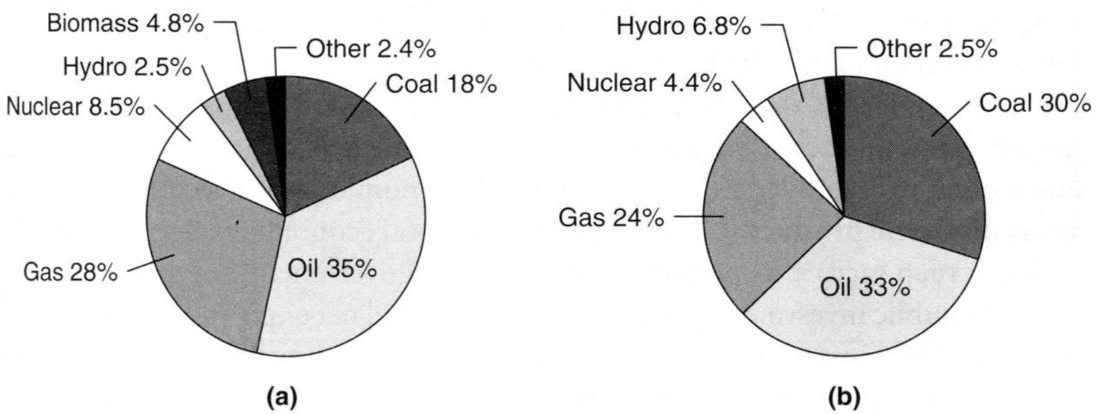


FIGURE 2.6

Sources of energy in the mid-2010s, shown as percentages. (a) Some 82% of U.S. energy comes from fossil fuels. The "Other" category includes geothermal, wind, and solar energy. (b) Fossil fuels supply about 86% of the world's energy. Here the "Other" category includes biomass, geothermal, wind, and solar energy.

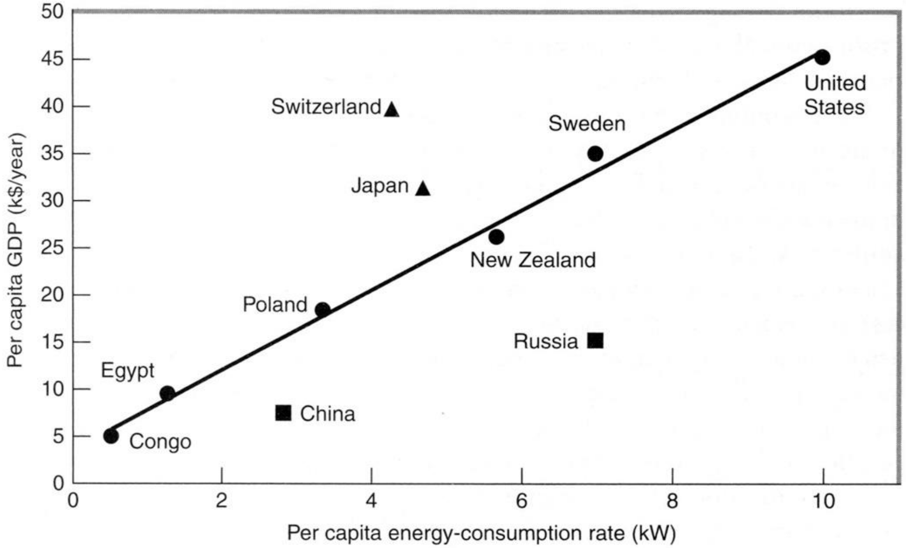
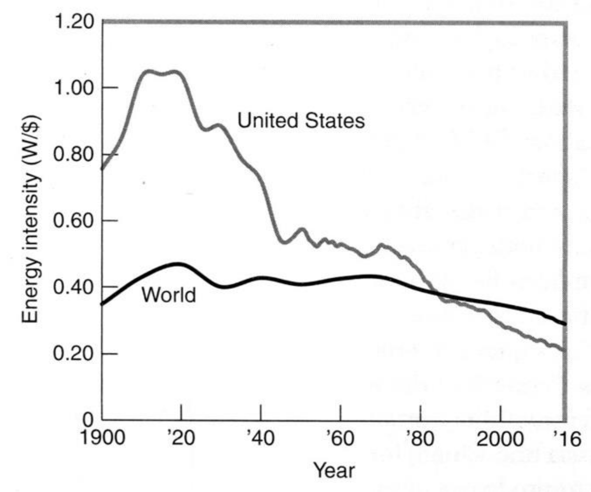


FIGURE 2.7

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.



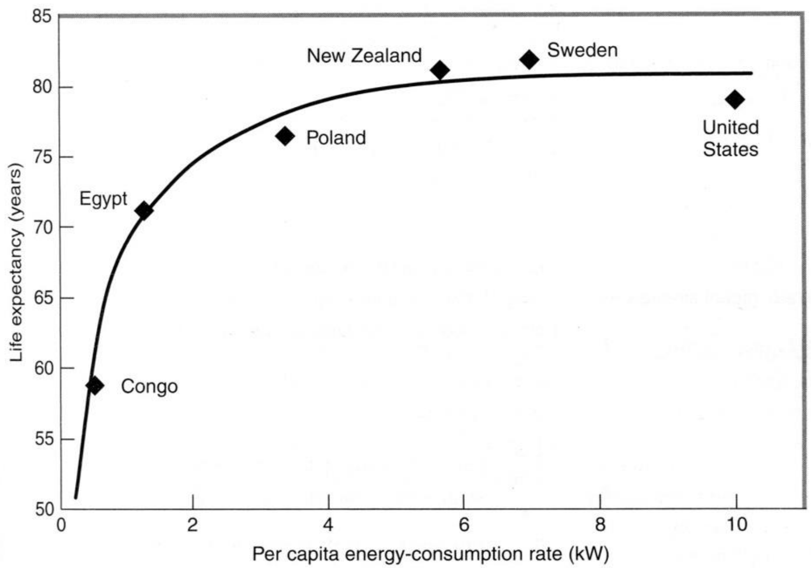
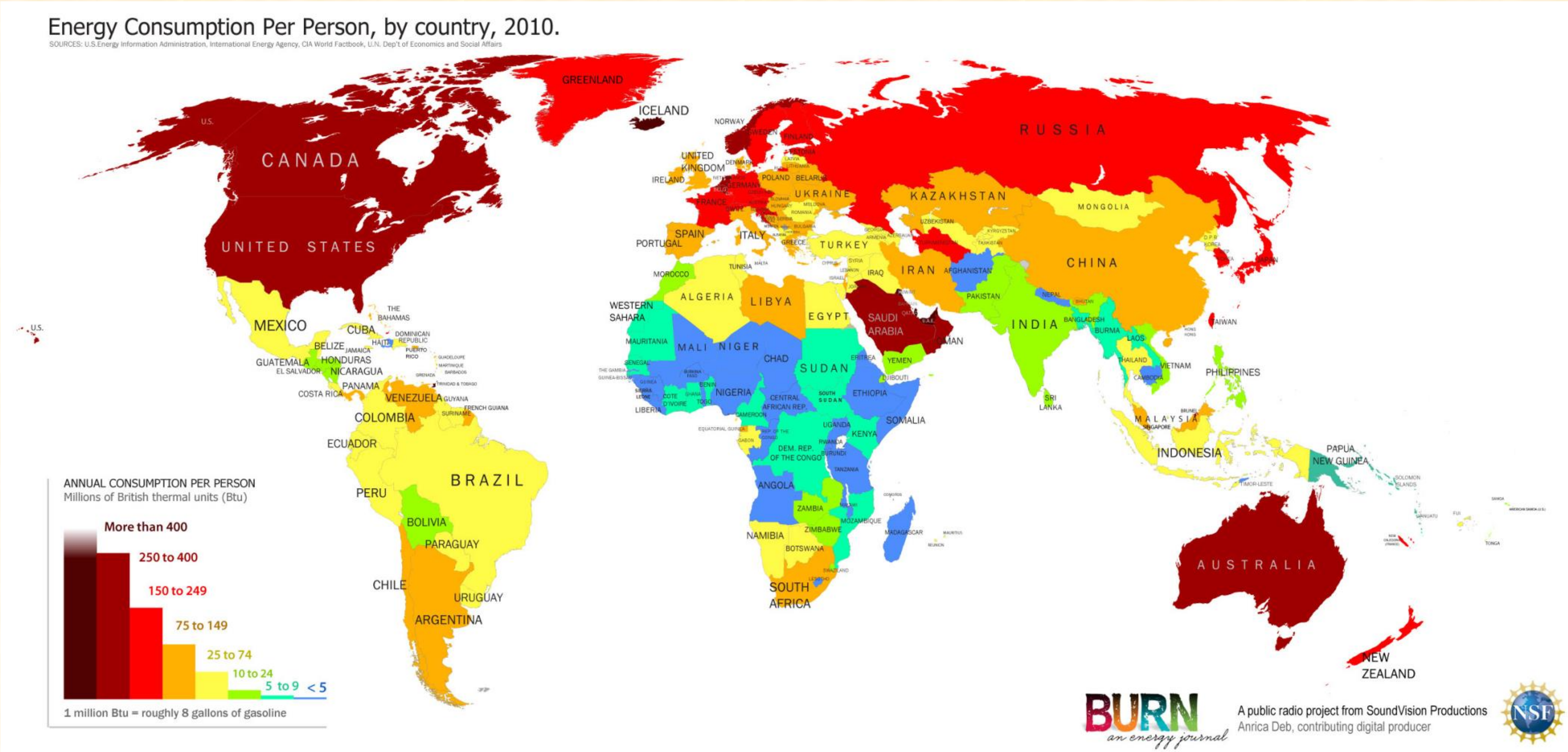


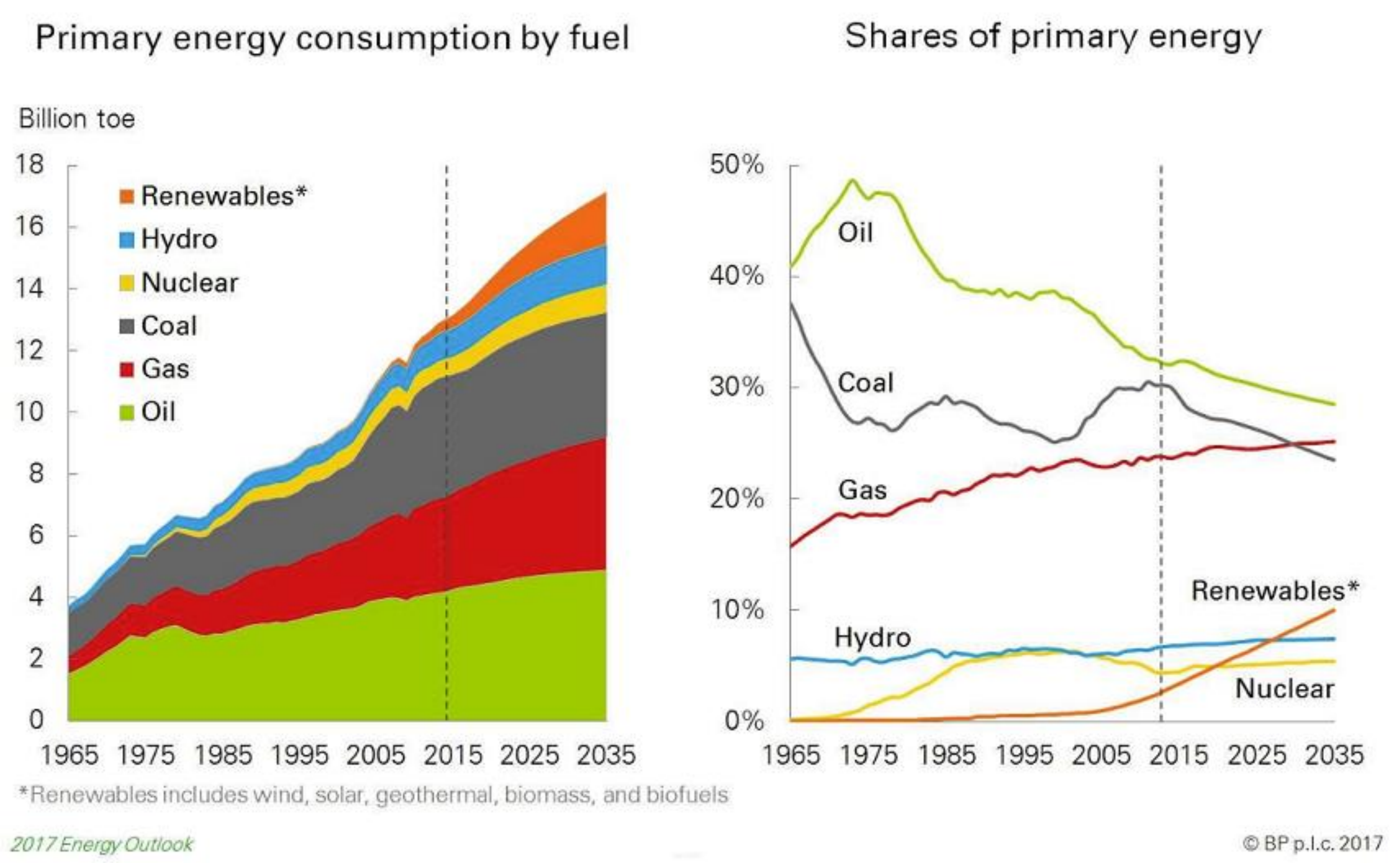
FIGURE 2.9

Life expectancy versus energy consumption for the six countries that lie near the line in Figure 2.7. Only at very low energy-consumption rates is there a correlation; at higher energy-consumption rates, the life expectancy curve saturates. Many other quality-of-life indicators show similar behavior in relation to energy consumption.



British thermal unit (Btu) = amount of heat needed to raise one pound of water at maximum density through one degree Fahrenheit.

1Btu = 1.054×10^3 joules

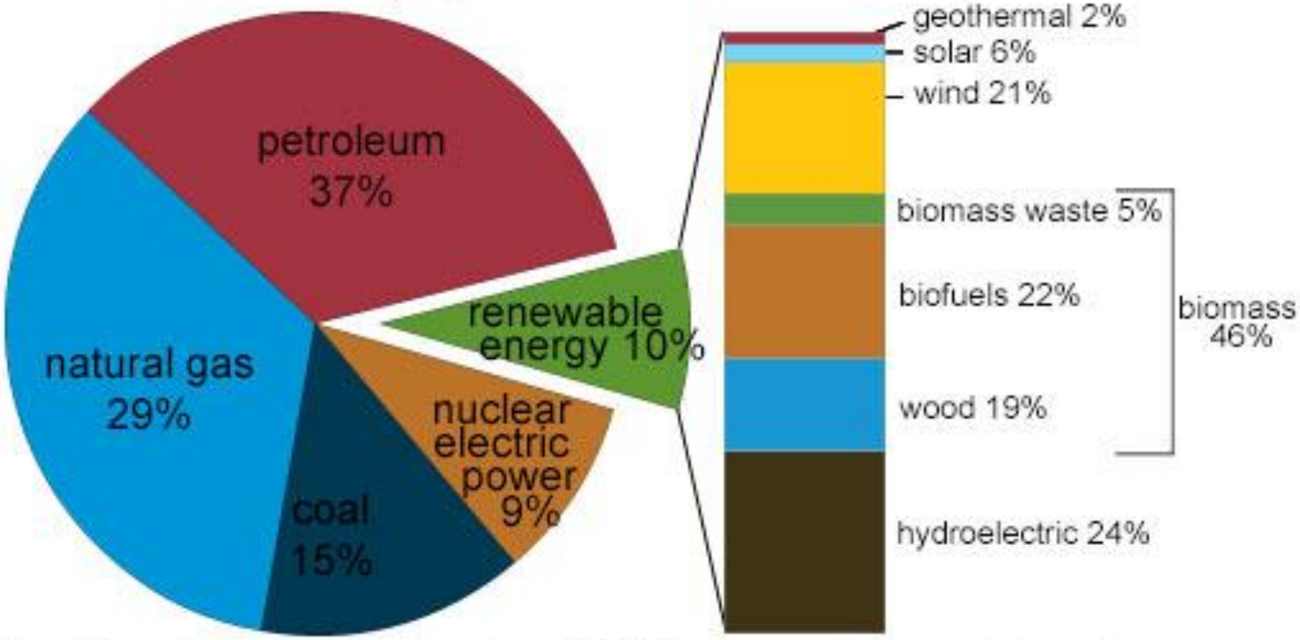


tonne of oil equivalent (toe) = the amount of energy released by burning one tonne of crude oil. It is approximately 42 gigajoules or 11,630 kilowatt hours.

U.S. energy consumption by energy source, 2016

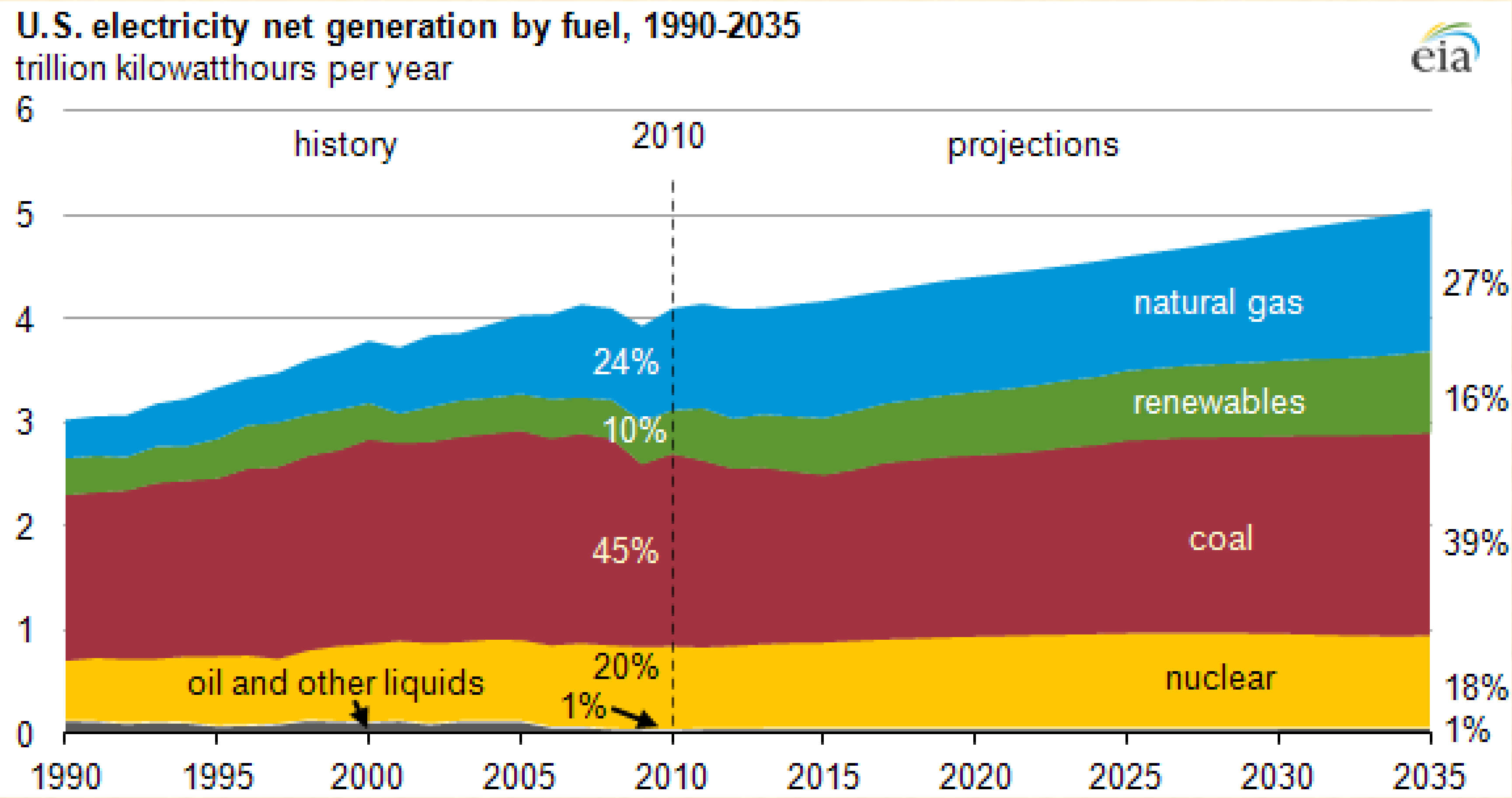
Total = 97.4 quadrillion British thermal units (Btu)

Total = 10.2 quadrillion Btu



Note: Sum of components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2017, preliminary data



1 watt = 1 joule s^{-1}

1 kilowatt-hour = 1000W x 3600 s = 3.6×10^6 J