Spring Semester, 2011
Energy Engineering
에너지공학

Basic information, unit & concept of energy

Ref. Textbook (AJ), Ch. 1. Introduction
SS, Ch. 1

Definition & forms of energy

Energy: the capacity or capability to do work

Forms of energy

biofuels (e.g., wood)	mass
chemical	mechanical-kinetic
electrical	mechanical-potential
gravitational	nuclear
heat (thermal)	radiation
magnetic	sound

Energy conversion: transformations between different forms of energy

conversion efficiency → input > output : < 100%

e.g., solar cell ~ 10% (radiant to electrical)

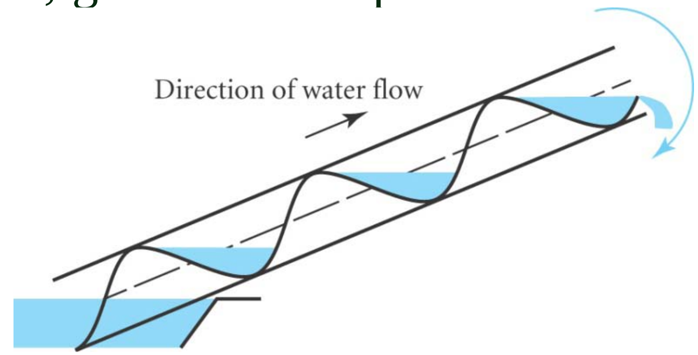
automobile engine ~25% (chemical to thermal, thermal to mechanical)

fuel cell ~60% (chemical to electrical)

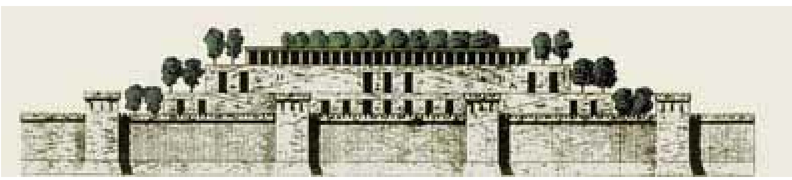
secondary battery ~75% (chemical to electrical, electrical to chemical)

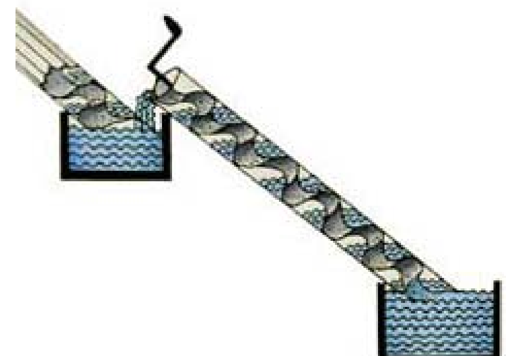
History of energy technology

Archimedes' screw: water from river/flooded mine, grain from ship…

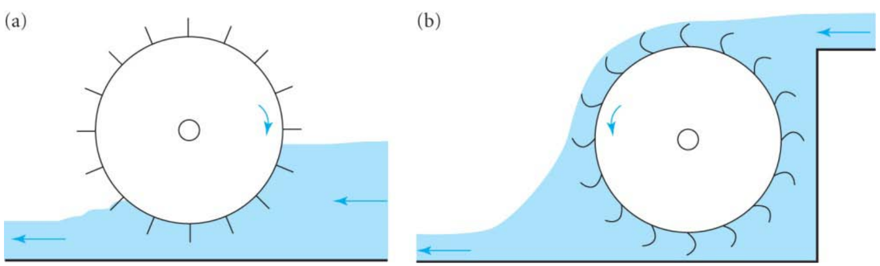


Hanging garden of Babylon (하늘정원)

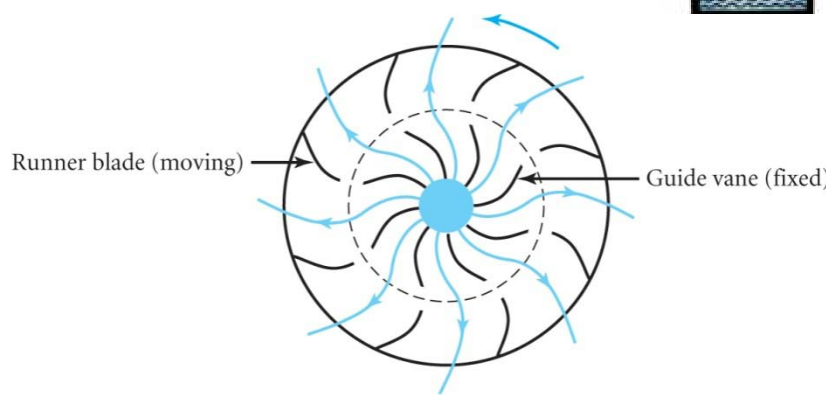




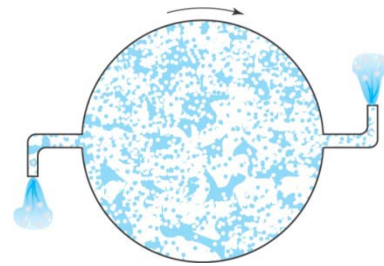
Waterwheels: ancient, common in Europe by 1000 AD



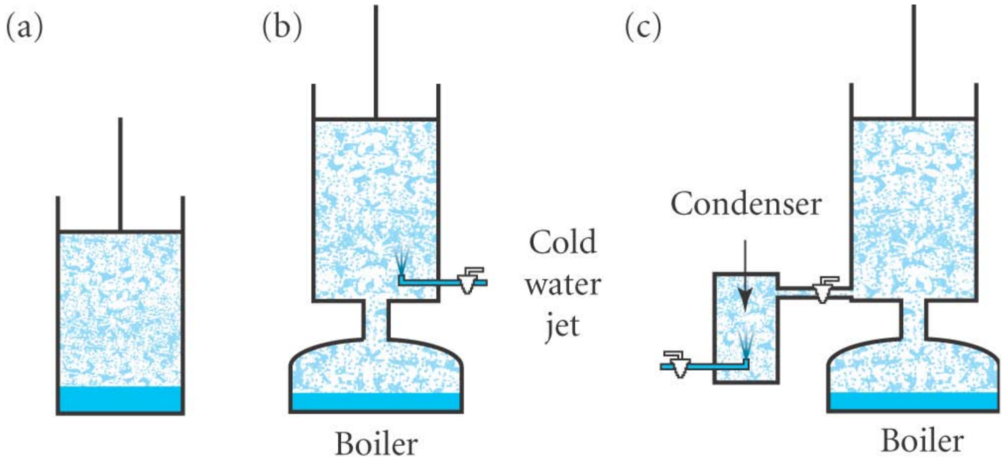
Fourneyron turbine (ch. 4): 1832



Hero's steam engine: 1 century AD



<u>**Steam engines**</u>:



Papin   Newcomen (1712)   Watt (1769)

James Watt: reduce heat loss in the piston chamber (~80%)

James Joule: heat & mechanical energy are equivalent, energy is conserved (1840s)

Nicholas Carnot (1824): maximum possible efficiency of an ideal heat engine depends only on hot & cold temperatures between which it operates

Thermodynamics and heat energy

Heat: a form of energy

Quantity of heat (Q)

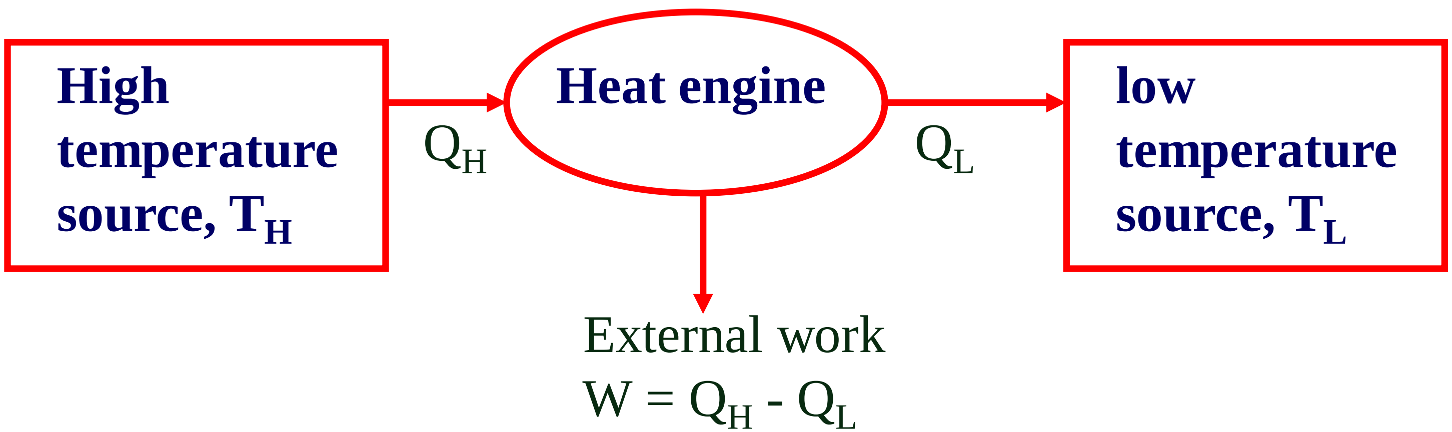
1 calorie: heat to raise 1 g of water through 1°C

1 BTU (British thermal unit): 1 pound (lb) of water through 1°F

Mechanical equivalent of heat

1 cal = 4.186 J   1 BTU = 7718 ft lb = 252 cal = 1054.7 J ~ 0.293 kWh

Ideal heat engine (heat-work converter)



$$Q_H - Q_L = W \text{ (1}^{st}\text{ law of thermodynamics)}$$

Efficiency η = work output / work input = $W/Q_H = 1 - Q_L/Q_H$

2nd law of thermodynamics: no system in a closed cycle can convert all the heat from a heat reservoir into the same amount of work

"Carnot efficiency" (theoretical maximum efficiency) (Carnot cycle)

$$\eta_{carn} = 1 - T_L/T_H$$

T: absolute temperature (K)

e.g., 600ºC fluid to 100ºC via mechanical work converter

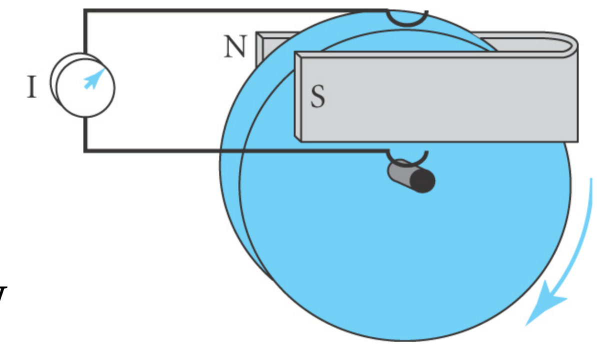
max. efficiency = 1 – 373/873 = 57.3%

Practical heat engine: most efficient engine ~2/3 of Carnot efficiency

automobile petrol engine ~25%, diesel engine ~35%

Michael Faraday (early 19 centruey)

Electromagnetic induction: current is induced across a rotating copper disk between a strong magnet



→ introducing of electric lighting

Joseph Swan (1860), Thomas Edison (1879)

1881, 1st world electric power station (Edison): 160 kW

Intense rivalry between Edison's direct current system(직류) & AC system(교류) (George Westinghouse) → AC system became adopted worldwide

1st large-scale hydroelectric power station (1895): Niagara Falls using Fourneyron turbines

Nuclear power station (late 1950s): more popular after Arab-Israeli War (1973). Slow down after incidents at Three-Mile Island (USA, 1979) & Chernobyl (Ukraine, 1986)

Alternating energy technologies after oil price shocks of the 1970s

Power

Power: the time rate of doing work or of expending energy

Power = energy/time = work/time

Instantaneous power $P = dW/dt$

Average power $P = W/t$

Unit: watt (W) = J/s

1 horsepower (HP) = 746 W

Power ratings of various devices & animals

10^{18} W solar power input to earth

10^{12} W electricity capacity in USA (2000)

10^{9} W large electric power plant

10^{7} W train

10^{5} W automobile

1000 W horse

100 W man/woman resting

0.1~1 W Si solar cell

0.01 W human heart

e.g., 5933000 BTU = 6259 MJ = 6259 MWs = 6259/3600 MWh (1.739 MWh)

1 kWh = 1000 x 60 x 60 = 3.6 x 10^6 J ~ 3411 BTU ~ 859.6 Kcal

cf. 1 barrel = 42 US gallons ~ 0.136 tonnes ~ 159 L

Fuel equivalence: 1 tonnes oil ~ 1.5 tonnes hard coal ~ 3 tonnes lignite ~ 12000 kWh

Million tonnes of oil equivalent (1 Mtoe = 41.9 PJ)

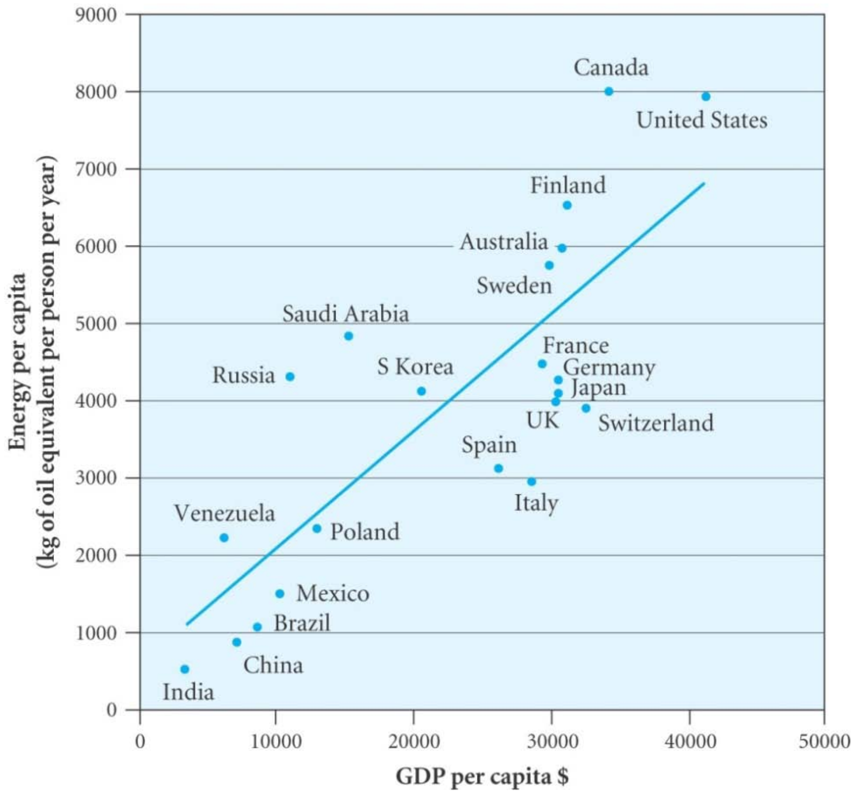
MW(mega-), GW,(giga-) TW(tera-), PW(peta-), EW(exa-):

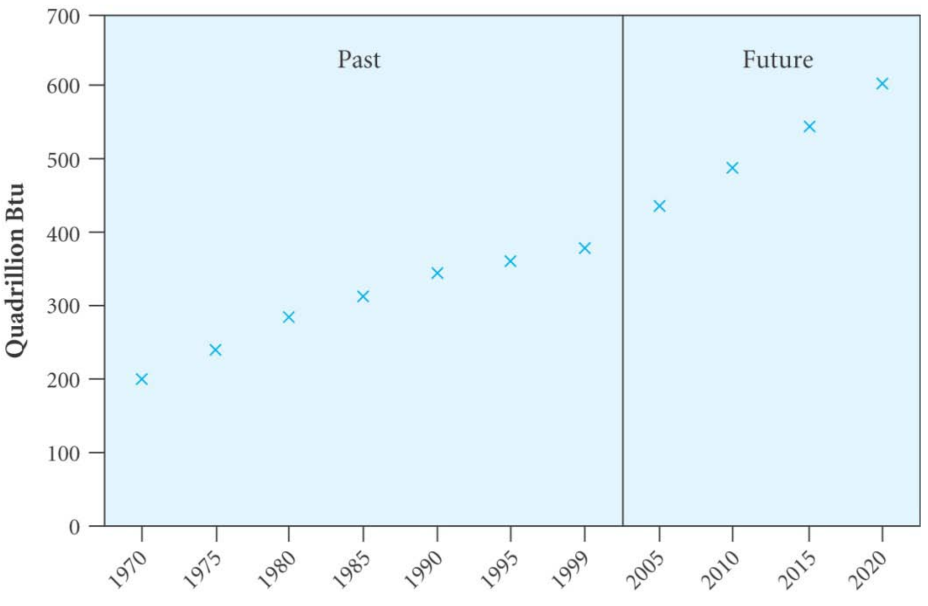
10^6, 10^9, 10^{12}, 10^{15}, 10^{18} W

History of energy technology: Power scales

Treadwheel (AD 0)	0.2 kW
Strong horse	0.7 kW
Newcomen steam engine (1712)	4 kW
Fourneyron water turbine (1832)	30 kW
Steam engine (1900)	1000 kW
Wind turbine (1942)	1300 kW
Boeing 747 gas turbine (1969)	60000 kW
Nuclear power station (1992)	1.2 x 10^6 kW
Coal power station (1986)	3.9 x 10^6 kW

Global energy trends





		Population(x 109)	Power per capita (kW)	Total power (kW)
1992	Developed countries	1.2	7.5	9.0
	Less developed	4.1	1.1	4.5
	Total	5.3		13.5
2025	Developed	1.4	3.8	5.3
	Less developed	6.8	2.2	15.0
	Total	8.2		20.3

Energy stored within the fossil fuels

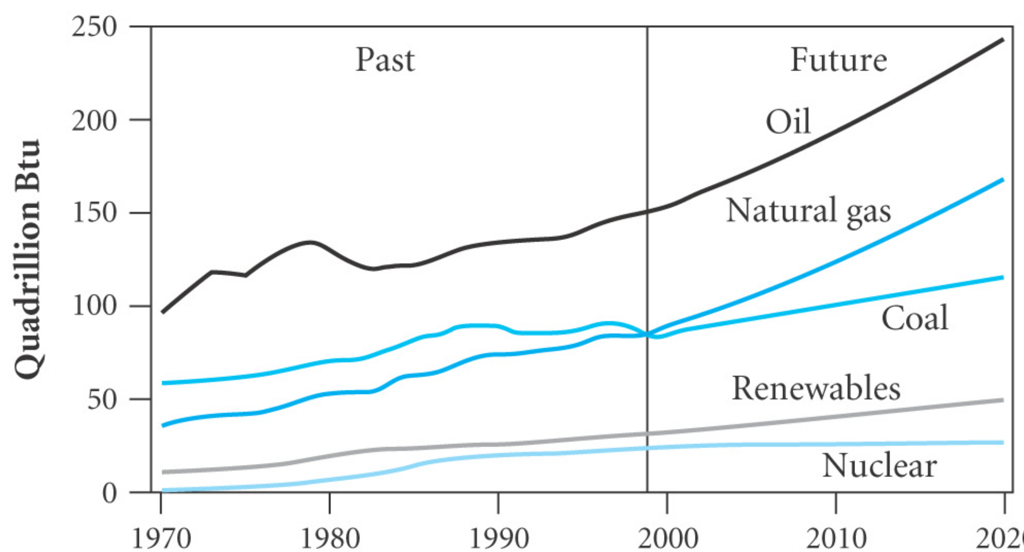
Fossil fuels: coal, oil-shale, petroleum, natural gas
Estimates of the rates of use and the years of fossil-fuel reserves remaining: reserve/production (R/P) ratio
Increased R/P ratio: new discovery

Primary fuel shares (% of total)

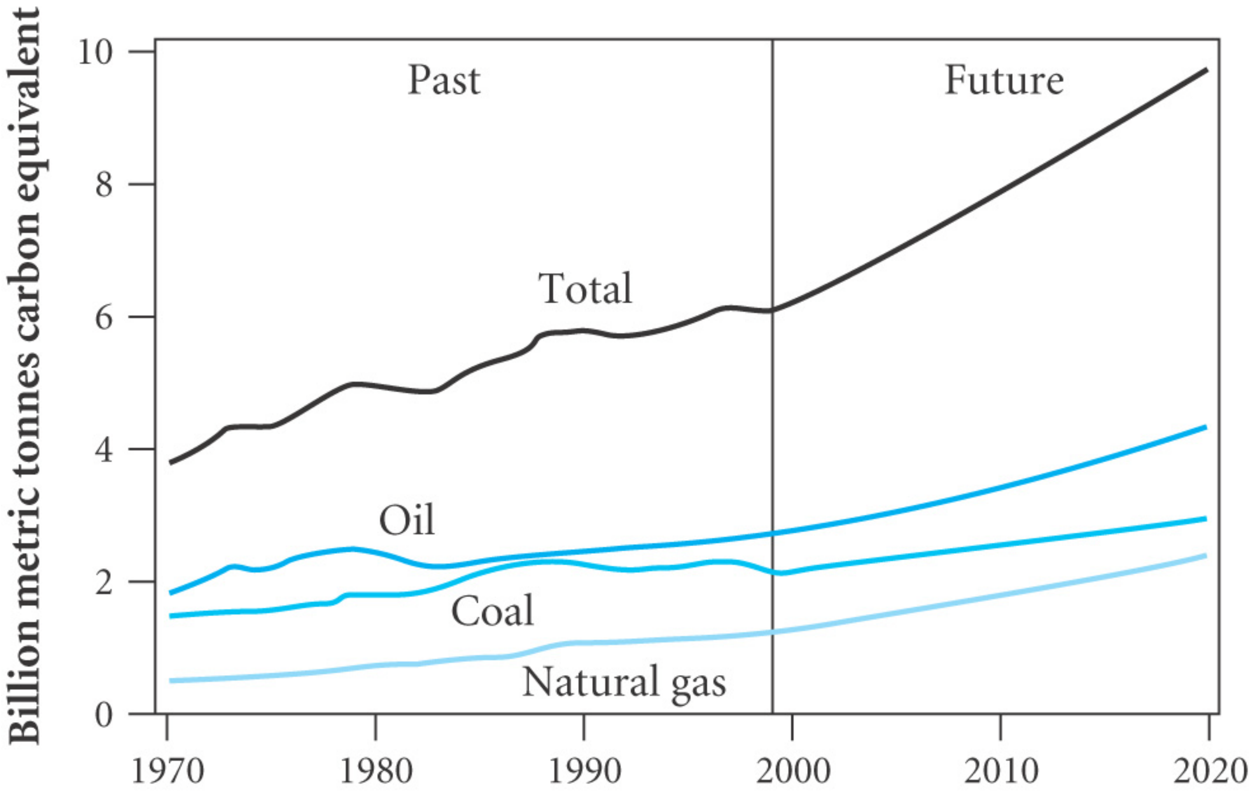
	2000	2010	2020
Oil	39.2	36.4	34.4
Gas	23.0	23.8	25.5
Coal	23.8	25.3	26.1
Nuclear	6.5	5.7	5.4
Renewables	7.6	8.9	8.7

Remaining:
Oil 40 yrs
Gas 70 yrs
Coal 250 yrs

Hubbert's peak: oil production peak at 1970s. Bell-shaped peak



CO_2 emission



Risks associated with energy systems

Annual CO_2 emission: 8 billion tonnes (2010), 9.8 billion (2020)
56%↑ & 100%↑ than 1990 level

1998 Kyoto Protocol agreement

CO_2 emission from various sources (life cycle analysis)

	CO_2 emission (kg/kWh)
Wood	1.5
Coal	0.8-1.05
Natural gas	0.43
Nuclear power	0.006
Photovoltaic	0.06-0.15
Hydroelectric	0.004
wind power	0.003-0.022

CO_2 emission: oil > coal

Gases emissions and the greenhouse effect

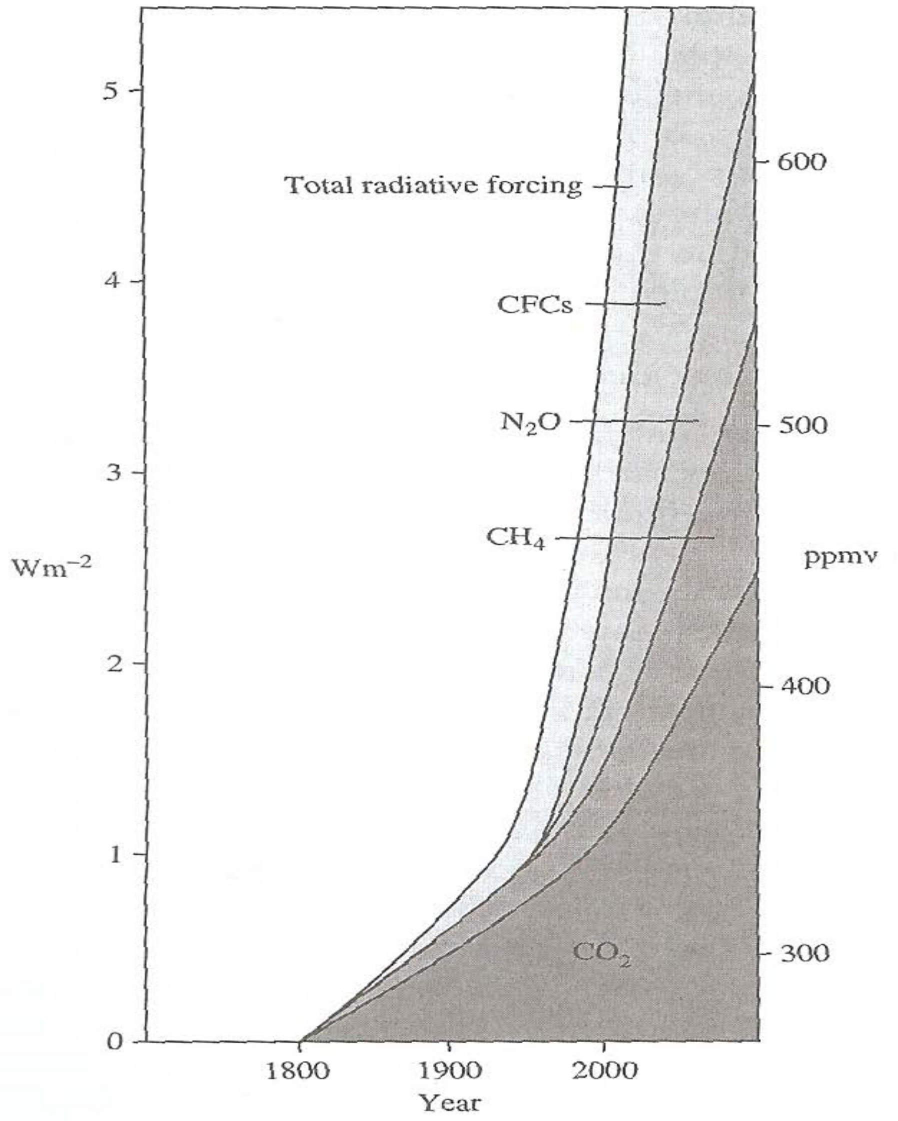
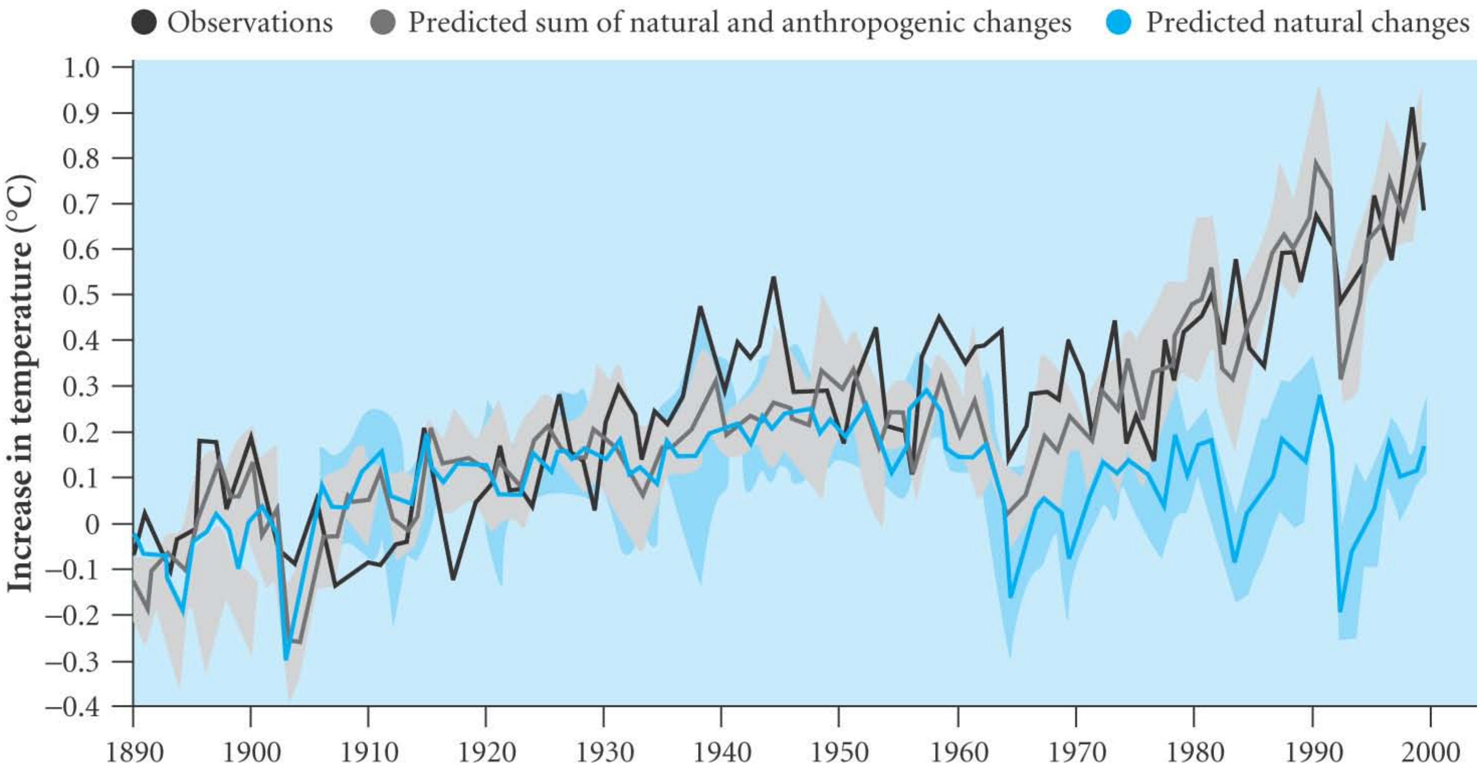


Fig. 2.21. World greenhouse gas emissions [12]. CH_4 = methane; N_2O = nitrogen oxide; CO_2 = carbon dioxide; CFCs = chlorofluorocarbons.

Global warming



Energy Resources and Energy Use

Energy input to the earth

Solar radiation and annual variation

-solar constant (at atmospheric boundary): 1377 W/m^2 (Jan. & July 3-4% difference)

-Earth radiation rate = $1377 \times \pi \times r^2 = 1377 \times \pi \times (6.324 \times 10^6)^2 = 1.73 \times 10^{17}$ W

-Total input radiation(W_{annual}) = $365.25 \times 24 \times 3600 \times 1.73 \times 10^{17} = 5.46 \times 10^{24}$ J

-Year 2000, $W_{world\ consumption}$ = 8752.4 mtoes = $8752.4 \times 12 \times 10^9$ kWh =

= $8752.4 \times 12 \times 10^9 \times 3.6 \times 10^6$ J = 3.781×10^{20} J

-Year 2000: energy input > primary energy consumption (14,440 times)

Terrestrial energy from inside the earth

-energy flow from the interior earth to its surface: 0.063 W/m2

-Total: $0.063 \times 4\pi r^2 \sim 3.2 \times 10^{13}$ W

Tidal (gravitational) input energy: 3×10^{12} W

Energy flow upon the earth from natural sources

~47% of incoming solar radiation (8.1 x 10^{16} W): absorbed by oceans, land, atmosphere
~23% (4 x 10^{16} W): hydrological cycle (evaporation, rivers…)
~0.21% (3.7 x 10^{14} W): ocean and atmospheric convection and circulations → wind, wave, ocean current motion
~0.0023% (4 x 10^{13} W): photosynthesis
(cf. annual energy of photosynthesis ~ world commercial energy consumption (~10^{20} J))

Energy outflow from the Earth

~30% of the incoming solar radiation (5.2 x 10^{16} W): reflected back into space in the form of short-wave radiation
~47% (8.1 x 10^{16} W): converted to low-grade heat & then re-radiated as long-wavelength radiation

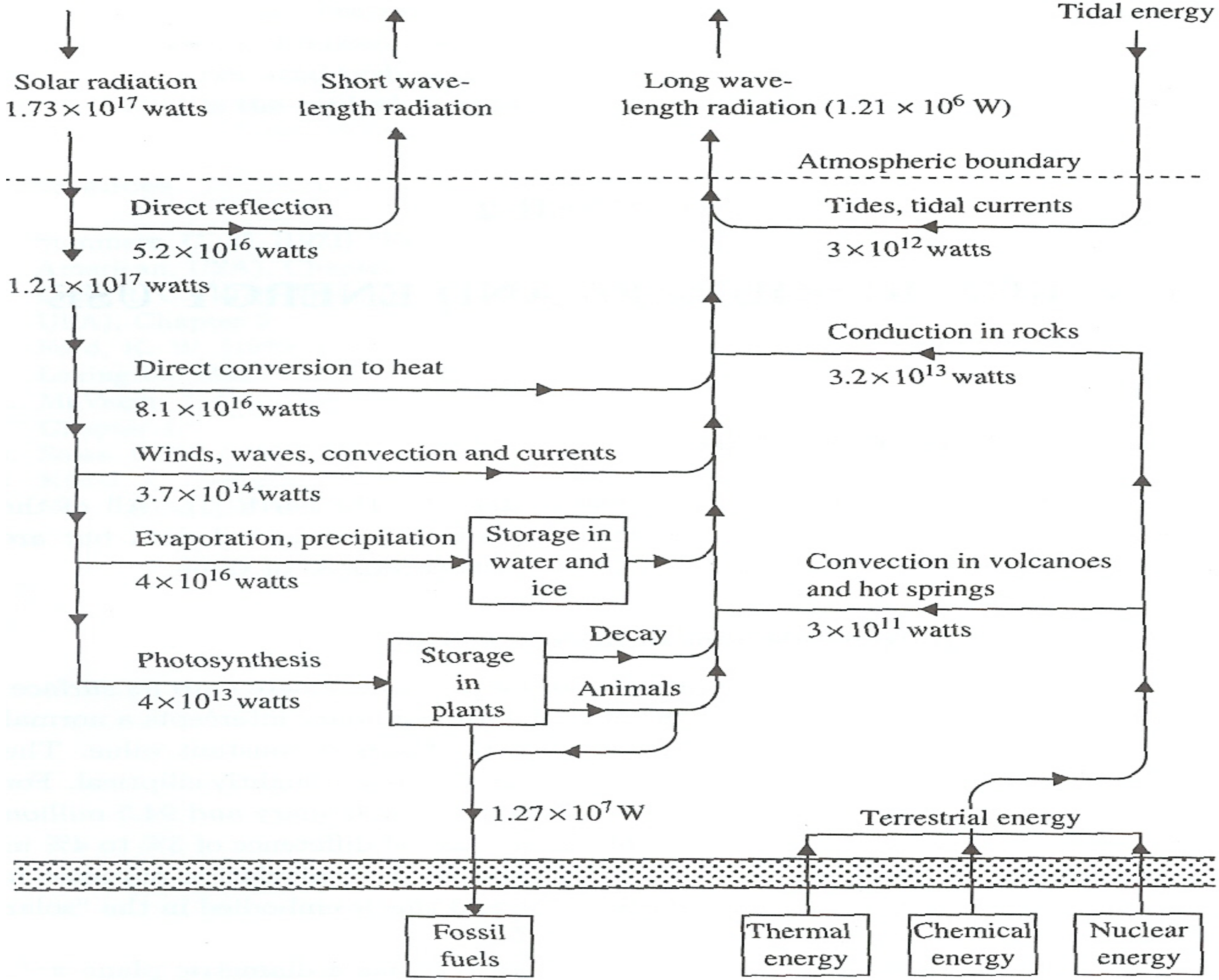


Fig. 2.1. Rate of energy flow diagram for the earth [1].

Units and dimensional analysis