Renewable Energy MSc Lecture Notes

By

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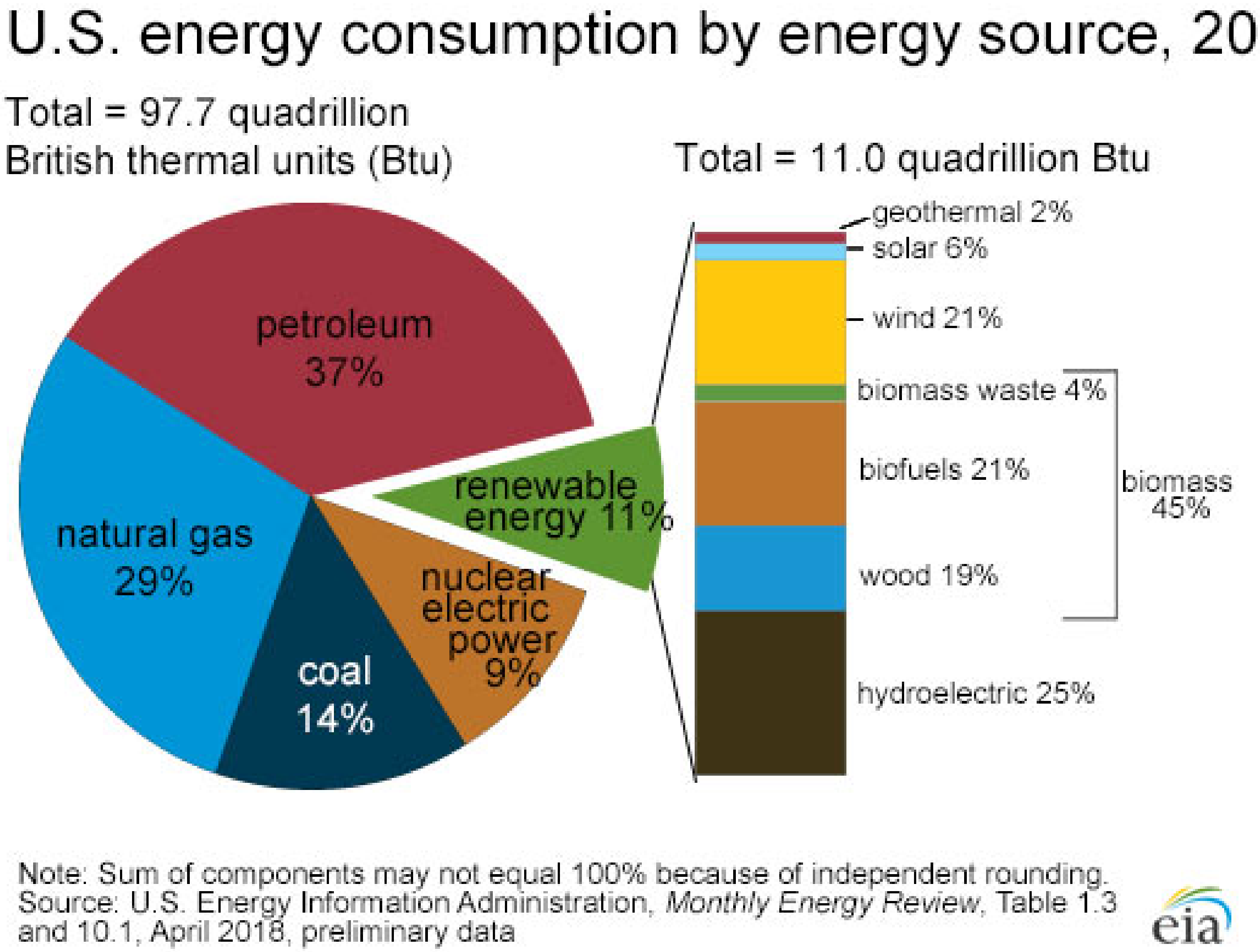
Course Contains:

- **Renewable Energy Overview**
- **Basic of Renewable Energy Supply**
- **Solar Thermal Heat Utilization**
- **Photovoltaic Power Generation**
- **Wind Power Generation**
- **Hydroelectric Power Generation**

Renewable Energy Overview

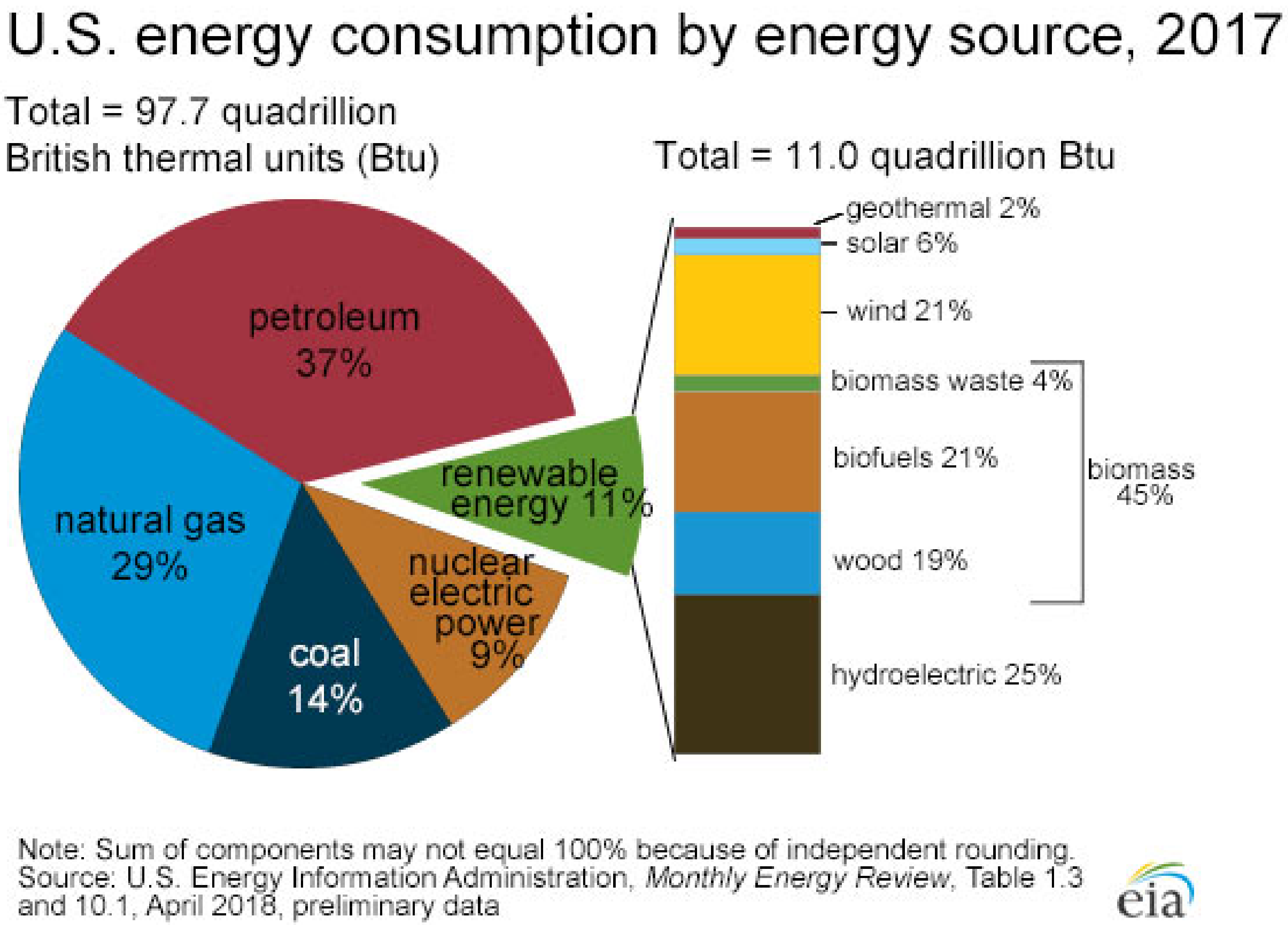
(Lecture 1)

Energy Consumption –US (is an example)

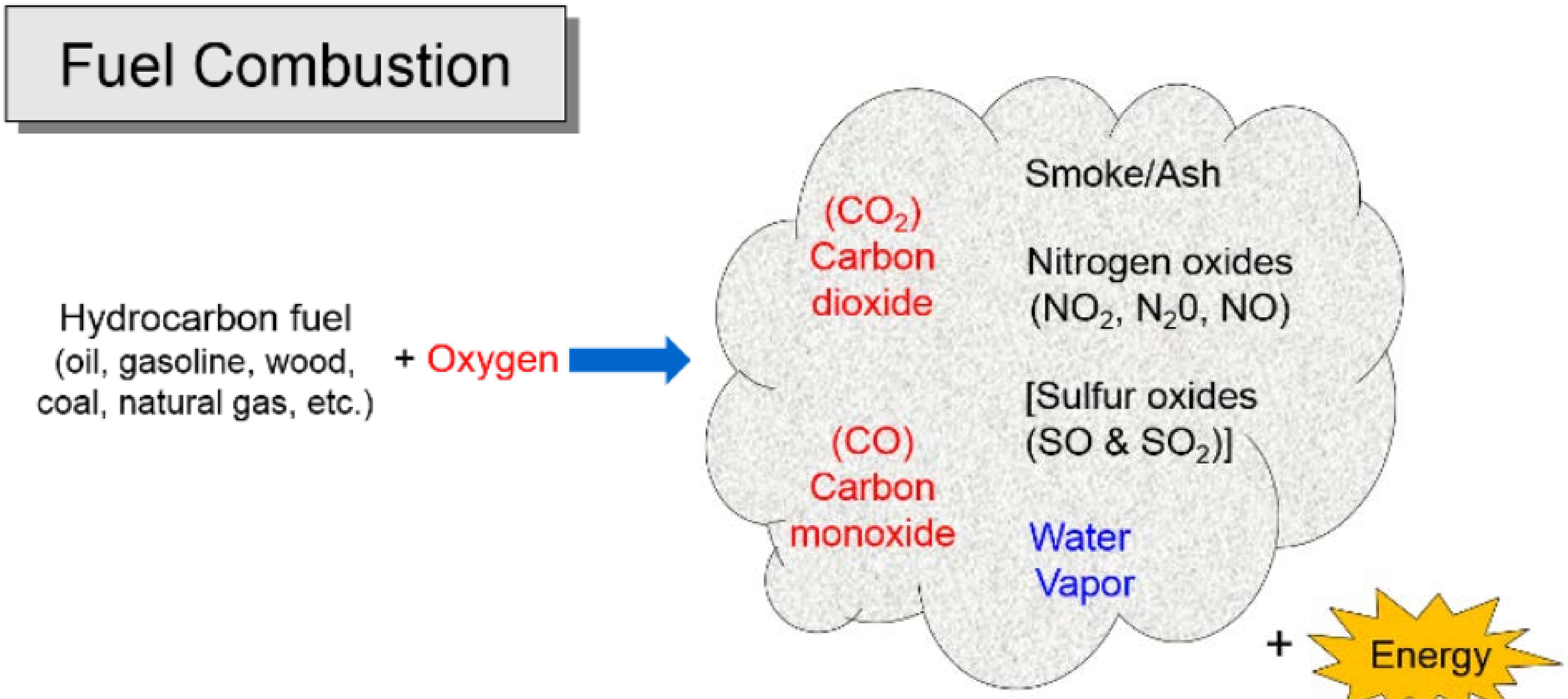


Problems of Non-renewable Energy

- Nonrenewable energy, including fossil fuels and nuclear power
- This is not sustainable , due to issues with supply and pollution.
- Climate change due to natural causes (solar variations, volcanoes, etc.)
- CO_2 Concentration, Temperature, and Sea Level Continue to Rise Long after Emissions are Reduced



Problems of Non-renewable Energy



Problems of Non-renewable Energy

- Industrial Revolution changed the energy trend
  (lignite and hard coal became increasingly more important)

↓

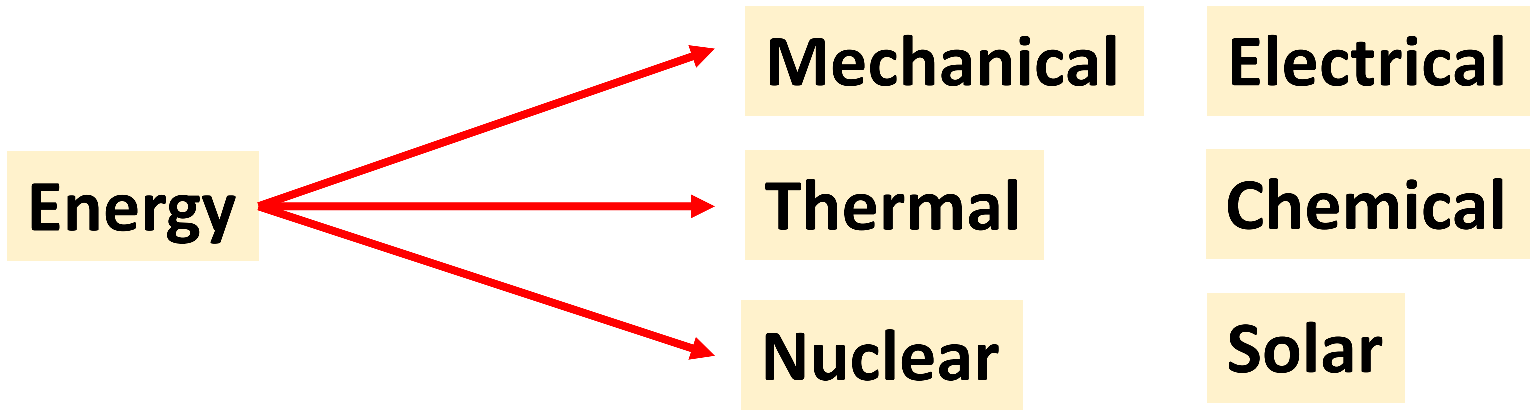
As fossil energy carriers increase for energy generation in Industrial

↓

This can cause environmental problem such as greenhouse effect is only one example

→ The solution is stop using non-renewable energy and swatch to alternative energy source (Renewable energy)

Energy system



- The ability to perform work becomes visible by force, heat and light

- The ability to perform work from chemical energy, nuclear and solar energy is only given if these forms of energy are transformed into mechanical and/or thermal energy

Energy Conversion Chain

Have not yet undergone any technical conversion

Energy carriers that are produced from primary energy or other secondary energy carriers.

Last stage of energy conversion process can be consumed by user.

Energy available to user to consume after last conversion process to satisfy the energy demands.

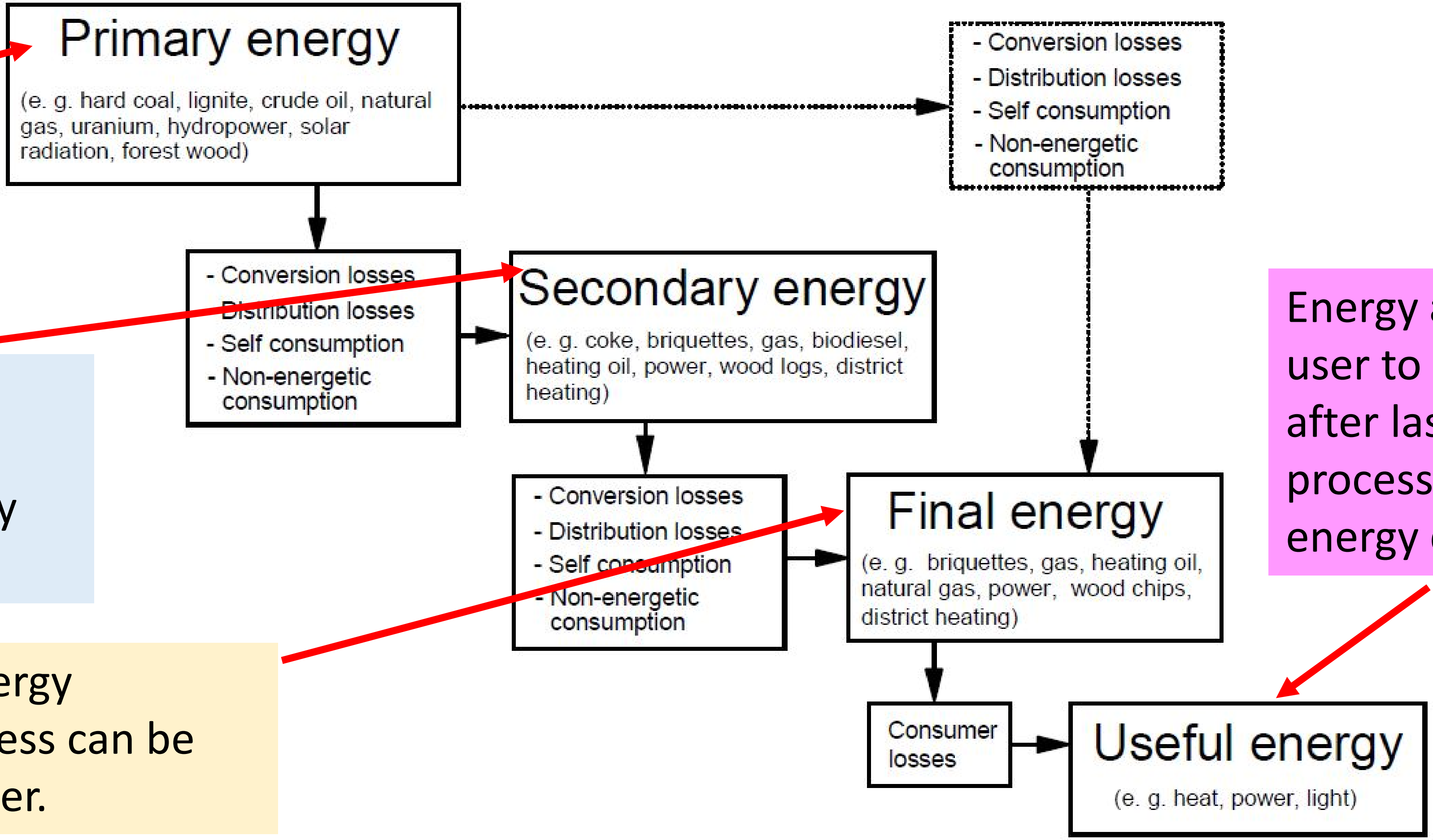


Fig. 1.1 Energy conversion chain (see /1-1/)

Energy Resources

Fossil energy resources are stocks of energy that have formed during ancient geologic ages by biologic and/or geologic processes.
-fossil biogenous energy resources (i.e. stocks of energy carrier of biological origin) E.g: hard coal, natural gas, crude oil deposits
-fossil mineral energy resources (i.e. stocks of energy carrier of mineral origin or non-biological origin) E.g: energy contents of uranium deposits and resources to be used for nuclear fusion processes.

Recent resources are energy resources that are currently generated, for instance, by biological processes; E.g: the energy contents of biomass and the potential energy of a natural reservoir.

The term renewable energy : are continuously generated by the energy sources solar energy, geothermal energy and tidal energy. The energy produced within the sun is responsible for a multitude of other renewable energies (such as wind and hydropower) as well as renewable energy carriers (such as solid or liquid biofuels).

Energy Consumption

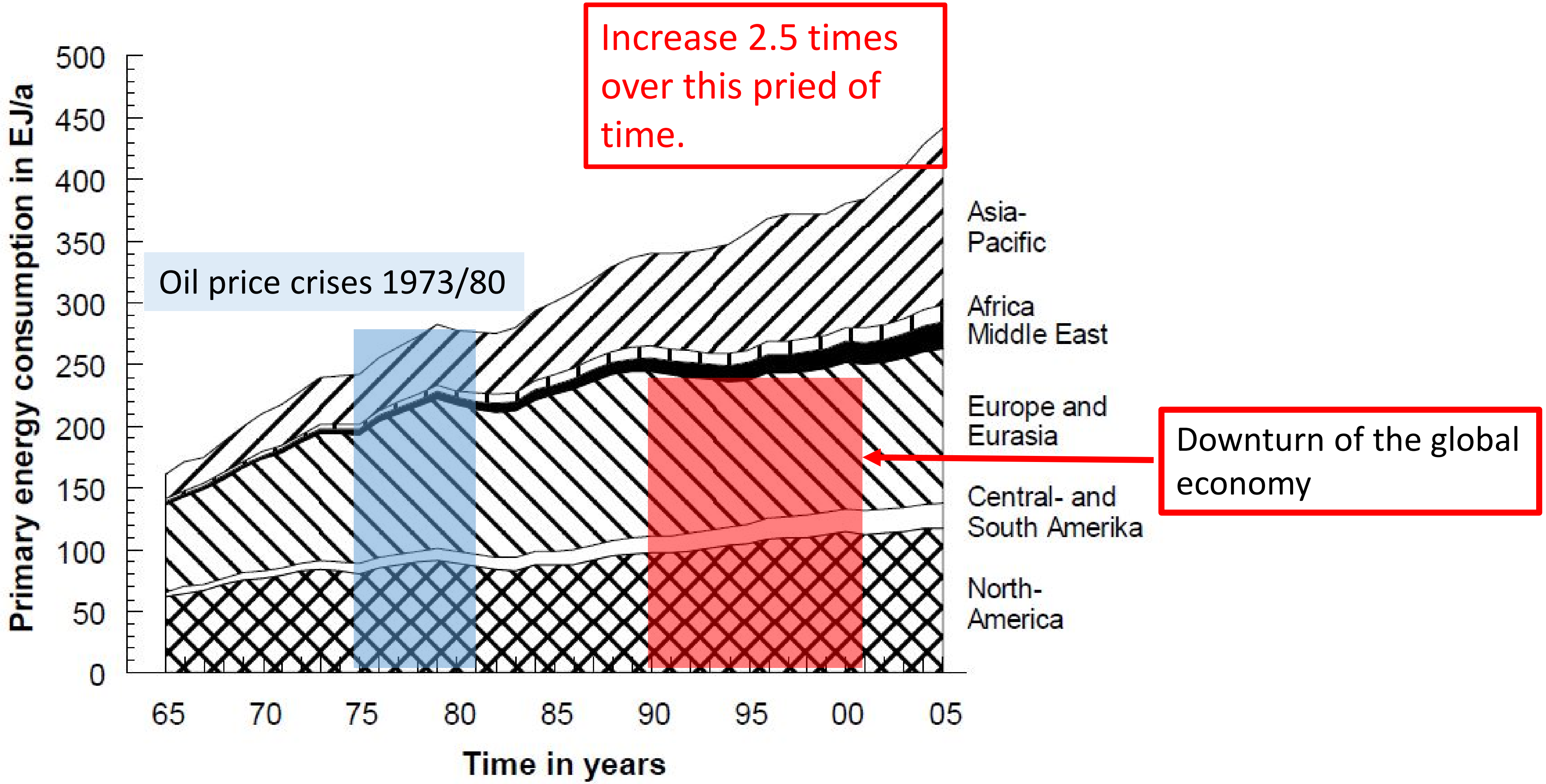
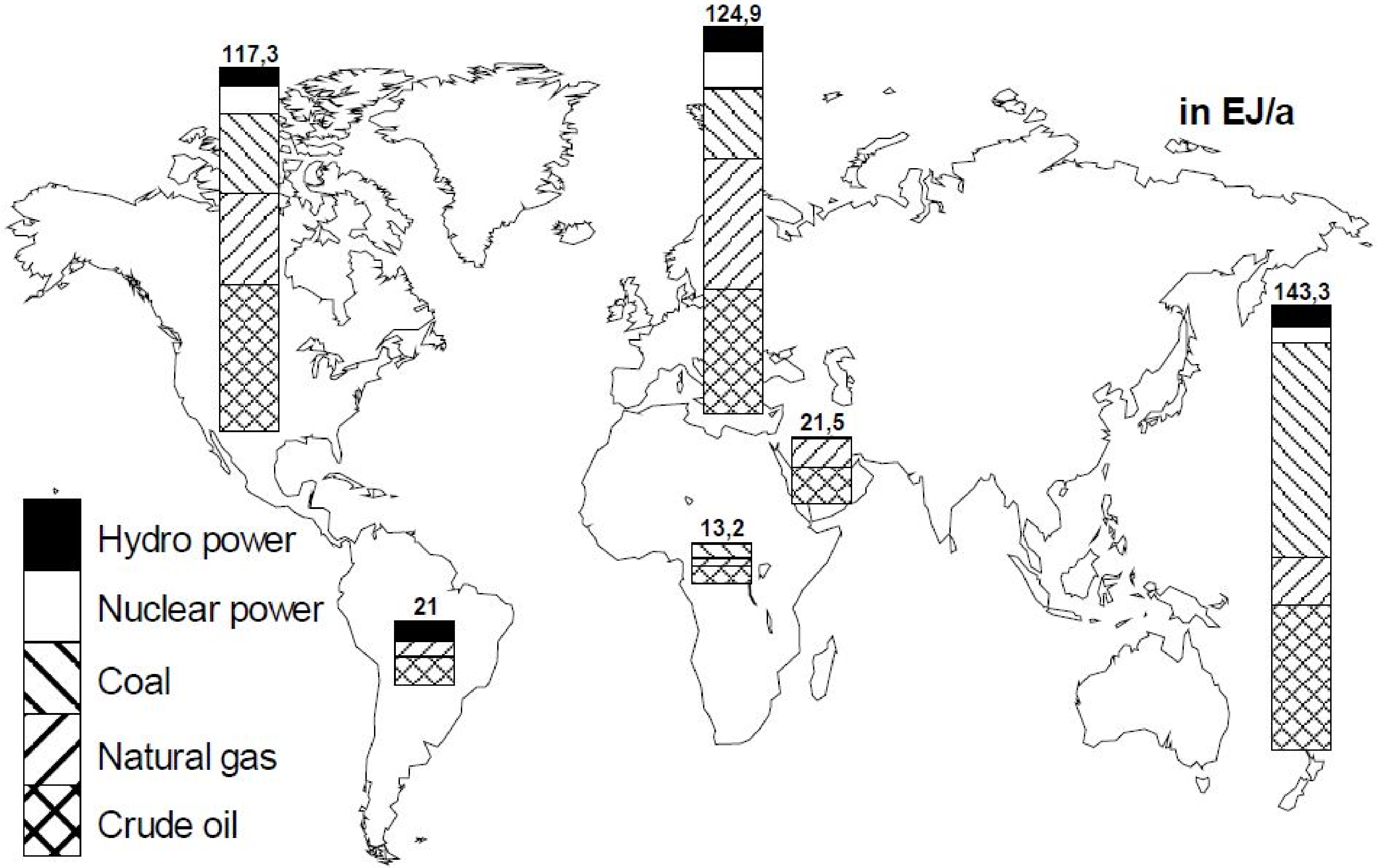


Fig. 1.2 Evolution of the worldwide consumption by regions of fossil primary energy carriers and hydropower (data according to /1-3/)



Asia-demand for primary energy carriers is covered by coal

Fig. 1.3 Worldwide consumption of fossil primary energy carriers and hydropower according to regions and energy carriers in the year 2005 (data according to /1-3/)

In 1965, nuclear energy had still no importance on a global scale; in the year 2005; however, it covered roughly 6 % of the global primary energy demand and still has a strong tendency to increase.

Coal consumption diminished from 40 % in the year 1965 to scarcely 28 % in 2005

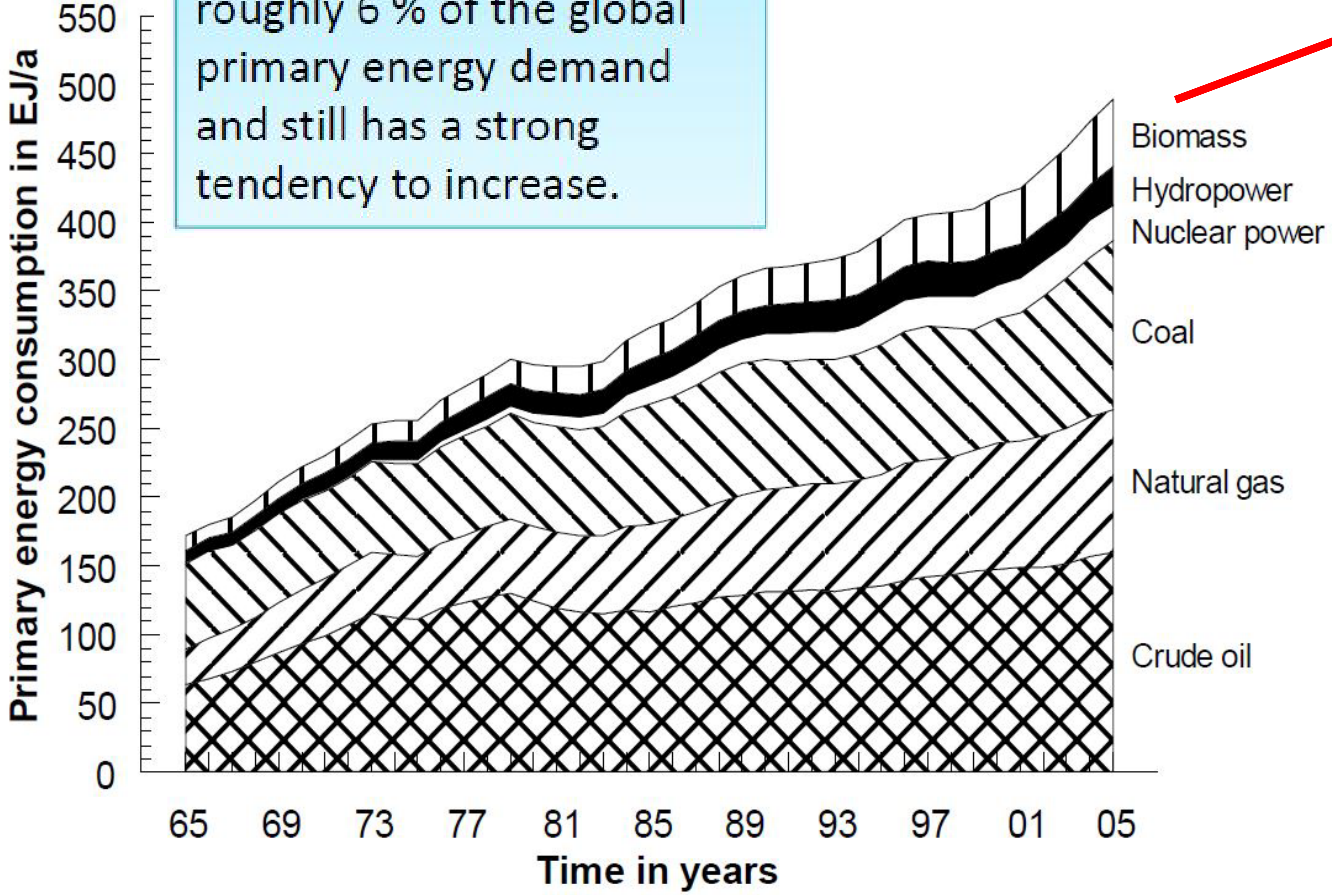


Fig. 1.4. Worldwide consumption of fossil primary energy carriers, hydropower and biomass according to energy carriers (for data also refer among others to /1-3/)

Application of Renewable Energy

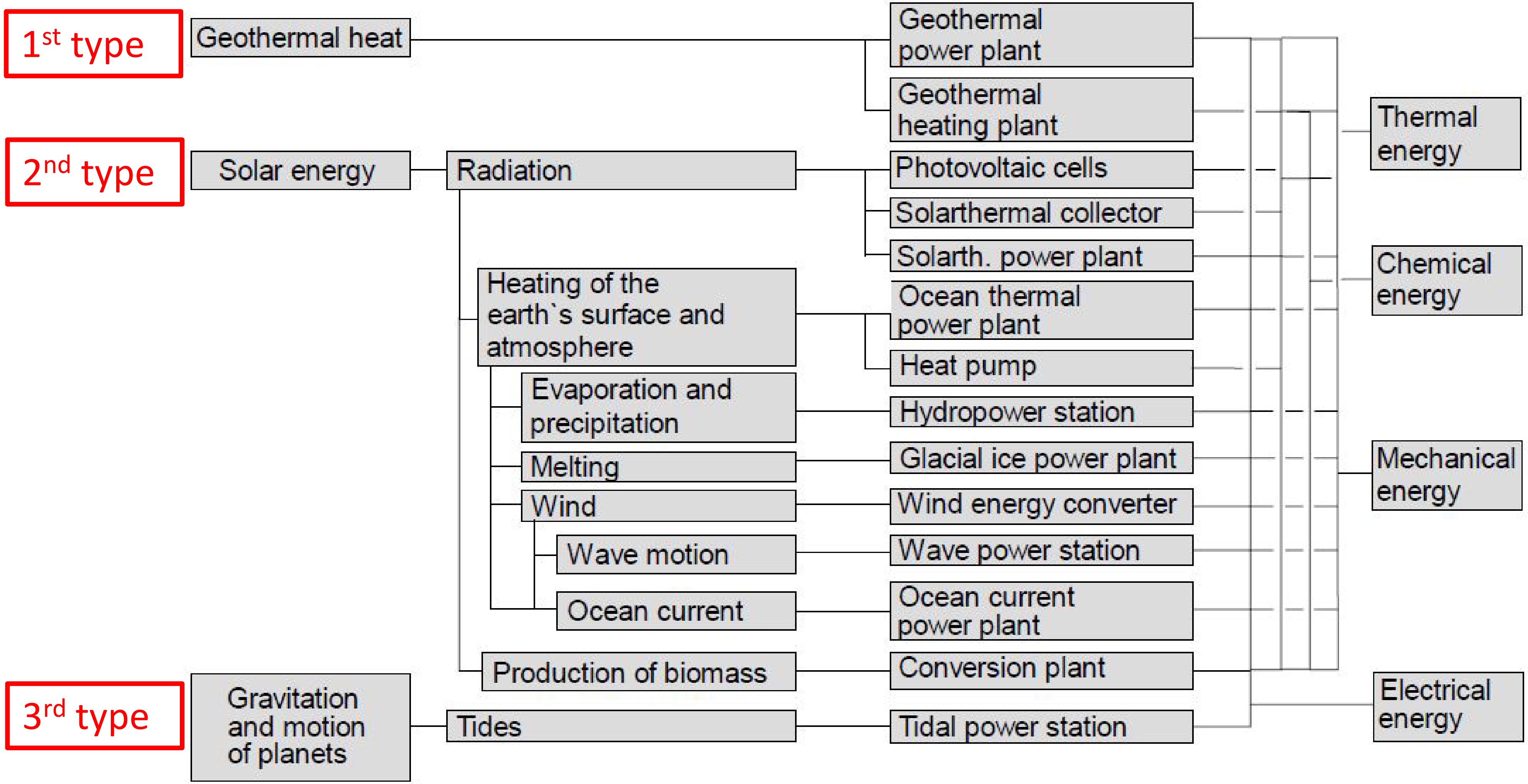


Fig. 1.5 Options of using renewable energies for the provision of useful energy (Solarth. Solarthermal) (see /1-1/)

Basic of Renewable Energy Supply

Energy Balance of the Earth

Introduction

- Solar energy has a share of more than 99.9 %of all the energy converted on earth.

- The solar radiation incident on the earth is weakened within the atmosphere and partially converted into other energy forms (e.g. wind, hydro power)

Solar Energy

- The sun is the central body of our planetary system; it is the star closest to the earth

- The nucleus has temperatures of approximately 15 Mio. K (~15.7×106 K)
- Energy is released by nuclear fusion where hydrogen is melted to helium

- Approximately 650 Mio. t/s of hydrogen are converted into approximately 646 Mio. t/s of helium

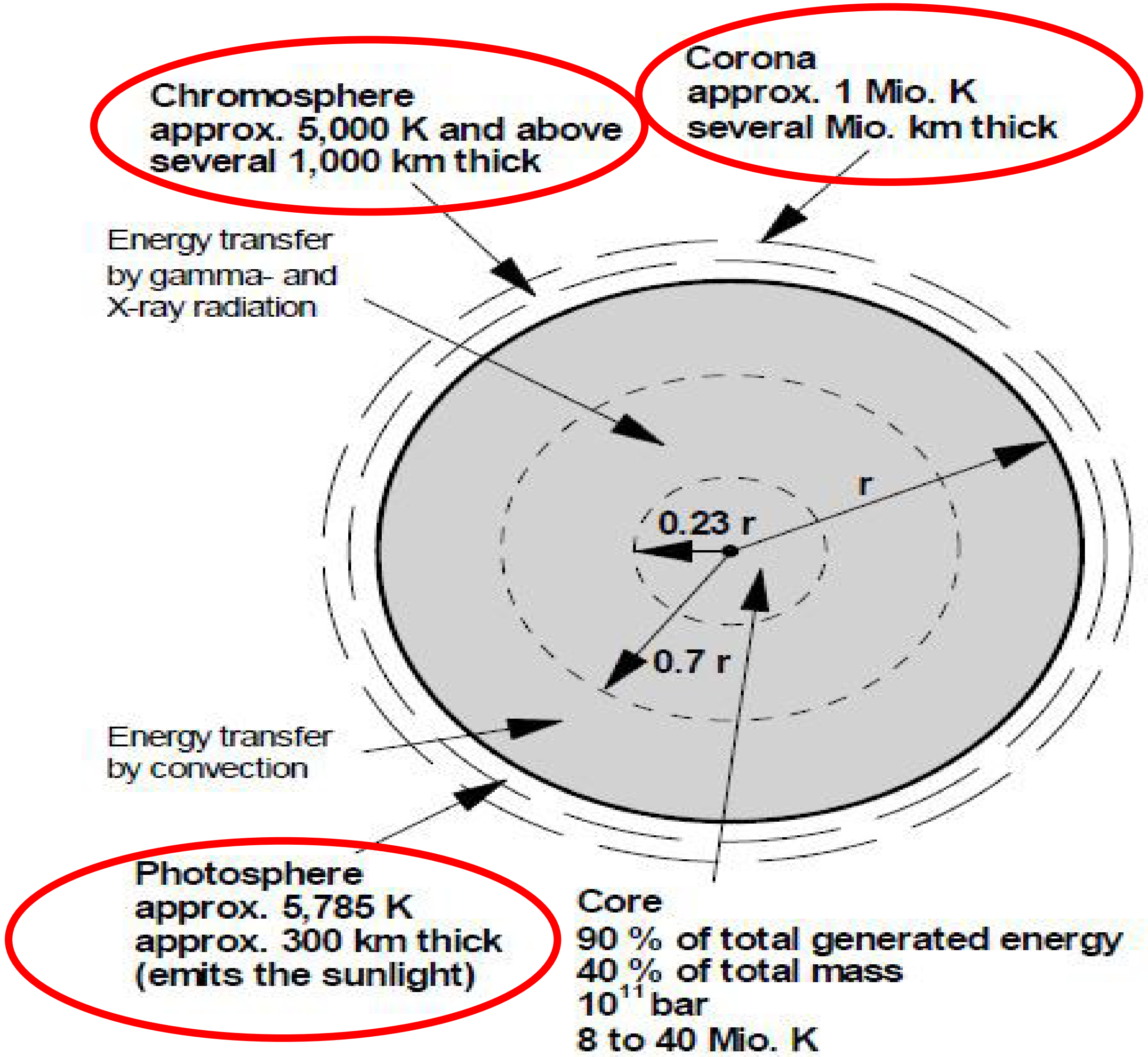
- According to Einstein, it can be calculated multiplying mass m and the square of the speed of light vc

$$E = mvc^2$$

Solar Energy

- The energy released within the nucleus of the sun is initially transported by radiation to approximately 0.7 times the solar radius
- Further transport to the surface of the sun takes place through convection.
- Afterwards, the energy is released into space

Solar Energy-The properties of Sun



Parameters	
Diameter	1,390,000 km (approx. 109 times the diameter of the earth)
Mean density	1.4 g/cm³
Core density	80 bis 100 g/cm³
Mass	$2\ 10^{33}$ g (approx. 330,000 times the mass of the earth)
Gravitational acceleration	approx. 275 m/s (approx. 28 times earth gravity)
Components	75 % hydrogen (H_2) 23 % helium (He) 2 % other components
Condition	gaseous

Solar Energy-The properties of Sun

The energy stream released by the sun:

The radiation of matter:

- consists of protons and electrons ~ 500 km/s.
- few of these electrically charged particles reach the earth's surface, as most of them are deflected by the terrestrial magnetic field
- *This is of particular importance for life on earth*, as this harsh matter radiation would not allow organic life in its current form.

Electromagnetic radiation

- Released by the photosphere covers
- Entire frequency from short-wave to long-wave radiation
- This type of solar radiation ≈ black body.

Solar Energy-Continue

The radiant flux density at the outer rim of the earth atmosphere *Esc can be calculated:*

$$E_{SC} = \frac{M_S \, \pi \, d_S^2}{\pi (2 L_{ES})^2}$$

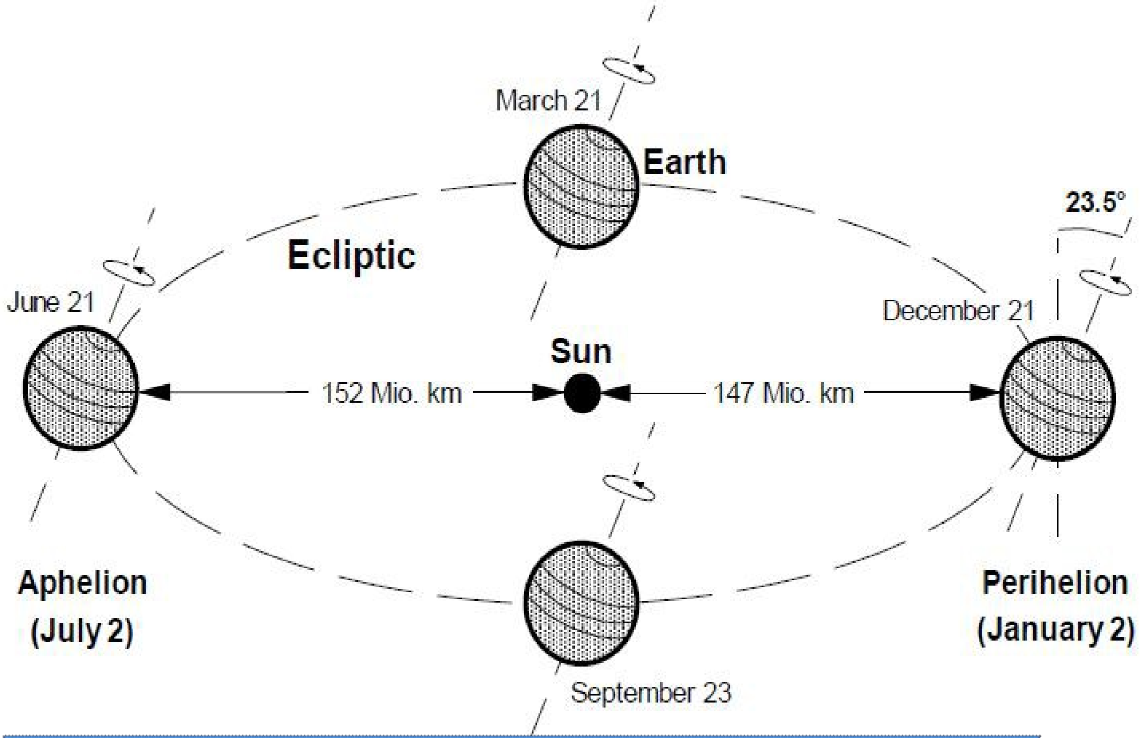
Radiant flux density

Diameter of the sun *is assumed up to the photosphere (approximately* 1.39 x10^9 m) ;

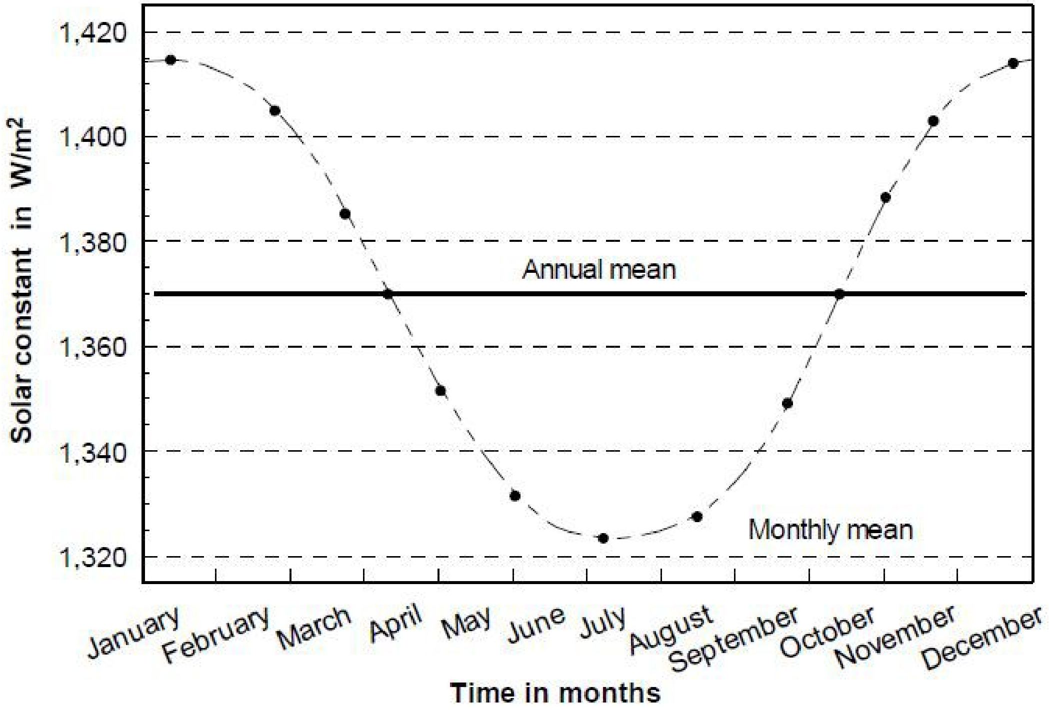
a mean distance between the sun and the earth *of approximately* 1.5 x10^{11} m is taken into consideration,

Esc ~**1,370 W/m²** at the top rim of the earth atmosphere , this mean value called ***the solar constant***

Solar Energy-Continue



Elliptical orbit of the earth around the sun



Solar constant in the course of one year

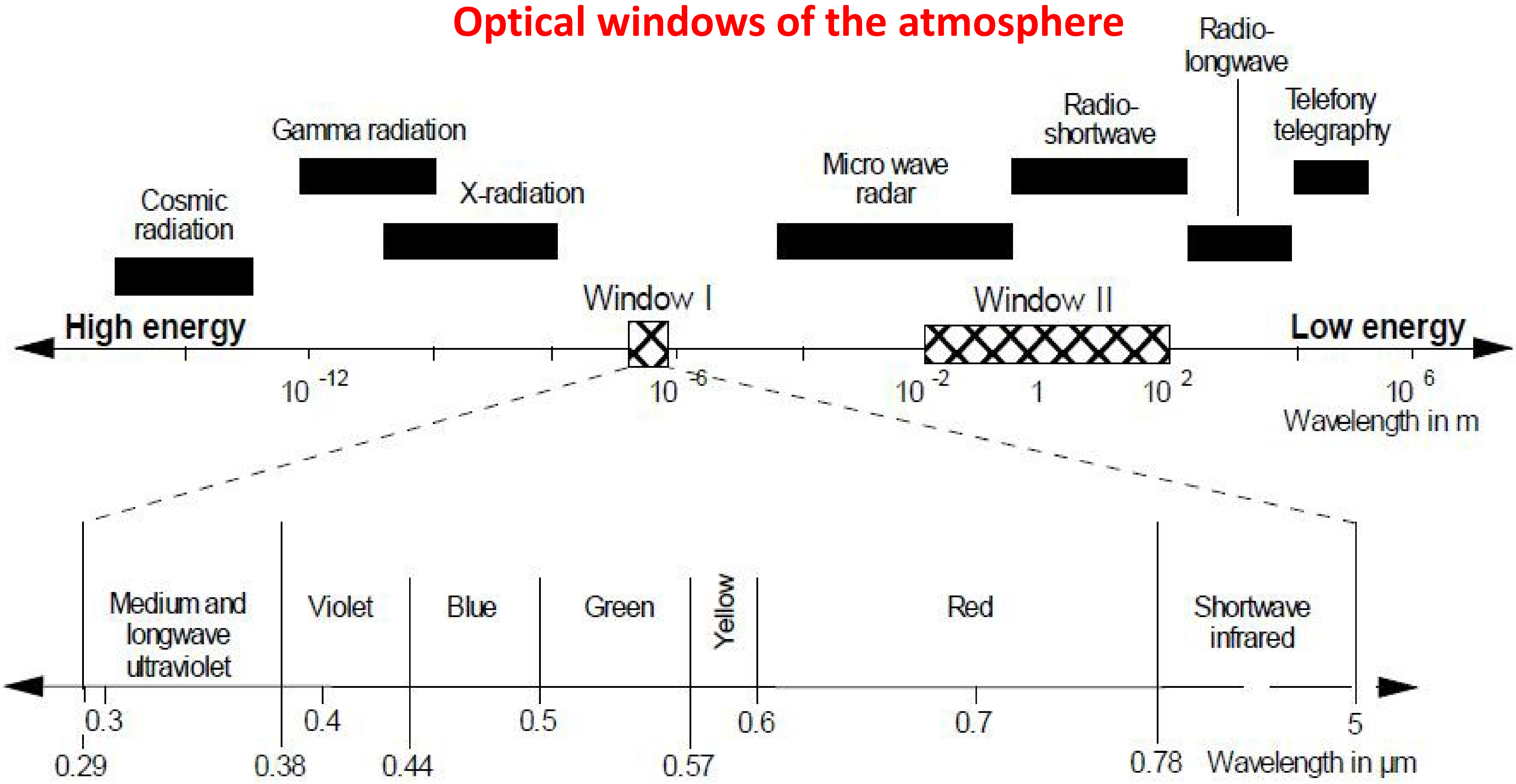
The solar constant reaches its maximum in January at almost **1,420 W/m2,** due to reaching the **shortest distance between the sun and the earth (Perihelion) on January, 2nd**. The opposite takes place on July, 2nd, when it reaches its minimum with approximately 1,330 W/m2 (Aphelion).

Solar Radiation

Optical windows: The atmosphere is to a large extent opaque for solar radiation.

- Only within the optical spectral range (0.3 to 5.0 µm; **window I**) and
- within the low-frequency range (10^{-2} to 10^{2} m, **window II**) radiation can pass the atmosphere (so-called optical windows of the atmosphere).
- Due to energetic reasons only *window I* is relevant for the technical use of solar energy. The most important part of the optical window I covers the range of visible light between 0.38 and 0.78 µm.

Solar Radiation



Solar Radiation: **Weakening of radiation → extinction process**

1-Diffusion: diversion of radiation from its original radiation angle without energy transfer and thus without a loss of energy. Such diffusion takes place i.e. in air molecules, water drops, ice crystals, and aerosol particles.

Rayleigh diffusion

(Particles with a radius significantly smaller than the wavelength of the incident light (e.g. air molecules).)

Mie diffusion

(Takes place at particles with a radius within the wavelength of the incident light and larger (e.g. aerosol particles).)

Diffraction

The larger particles at which the sunlight is diffused into a forward direction

Solar Radiation: **Weakening of radiation → extinction process**

2-Absorption is the conversion process the solar radiation to other form of energy -

Solar radiation → Heat during this process (aerosol, cloud and precipitation particles)

- Additionally, a selective absorption is possible; here selected spectral and wave-length ranges of solar radiation are absorbed by some gases existing within the atmosphere.
- This is especially the case for ozone (O_3) and water vapor (H_2O). Ozone, for example, almost completely absorbs the spectral range between 0.22 and 0.31 µm. Carbon dioxide (CO2), in comparison, only minimally absorbs solar radiation.

Solar Radiation: **Weakening of radiation → extinction process**

This weakening is described by the so-called transmission factor τ_G ; it covers all weakening effects affecting solar global radiation incident on the outer atmospheric layer passing through the atmosphere. *Gg is the global radiation* and *E_{SC} the solar constant.*

$$G_g = E_{SC}\,\tau_G$$

$$\tau_G = \tau_{RD}\,\tau_{MD}\,\tau_{GA}\,\tau_{PA}$$

Rayleigh diffusion

Mie diffusion

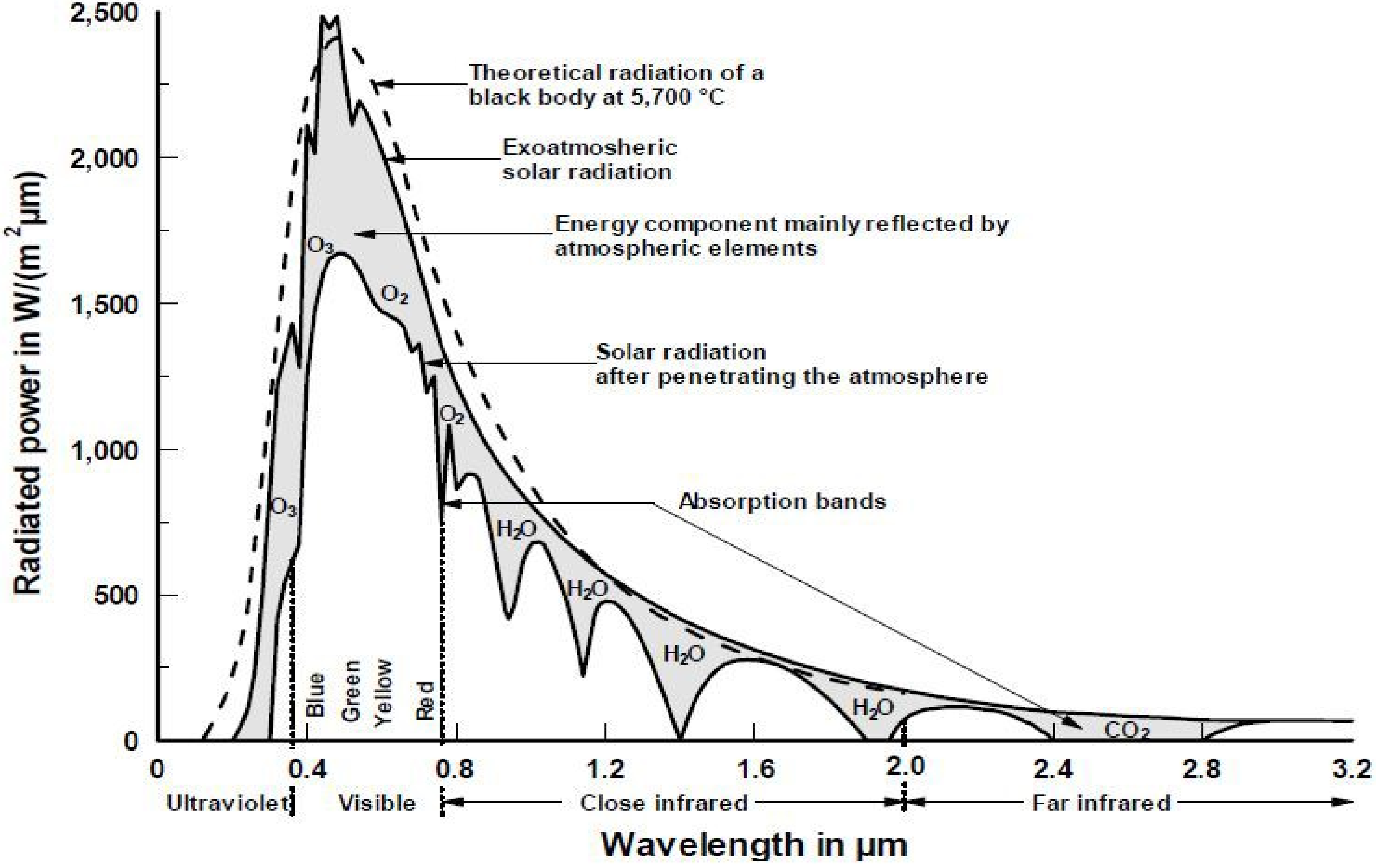
Absorption within gases

Absorption within particles

Solar Radiation: Spectral Range

- Due to the weakening of the radiation within the atmosphere of the earth, the energy distribution spectrum of sunlight is changed

- The spectrum of the solar radiation before & after passing through the earth's atmosphere:



Solar Radiation: Spectral Range

Solar radiation reaching the earth shows the following characteristics:

- The energy maximum in range 0.5 and 0.6 µm (green to yellow light).
- With a decreasing wavelength (i.e. in the ultraviolet spectrum) the radiated power decreases rapidly.
- With an increasing spectral range (i.e. in the infrared spectrum) the radiation decreases more slowly.
- Some specific wave lengths show deep cuts in the energy distribution curve ("dark ranges"). They are caused by selective absorption of the sunlight by selected elements within the atmosphere.

Solar Radiation: Direct, diffuse and global radiation

The diffusion mechanisms within the atmosphere cause diffuse and direct radiation to incident on the surface of the earth.

Direct radiation: the radiation incident on a particular spot, having travelled a straight path from the sun.
Diffuse radiation: the radiation emerged by diffusion in the atmosphere and thus indirectly reaching a particular spot on the earth's surface.

The sum of direct (beam) radiation G_b *and* diffuse radiation G_d, always related to the horizontal receiving surface, is called **global radiation** *Gg*

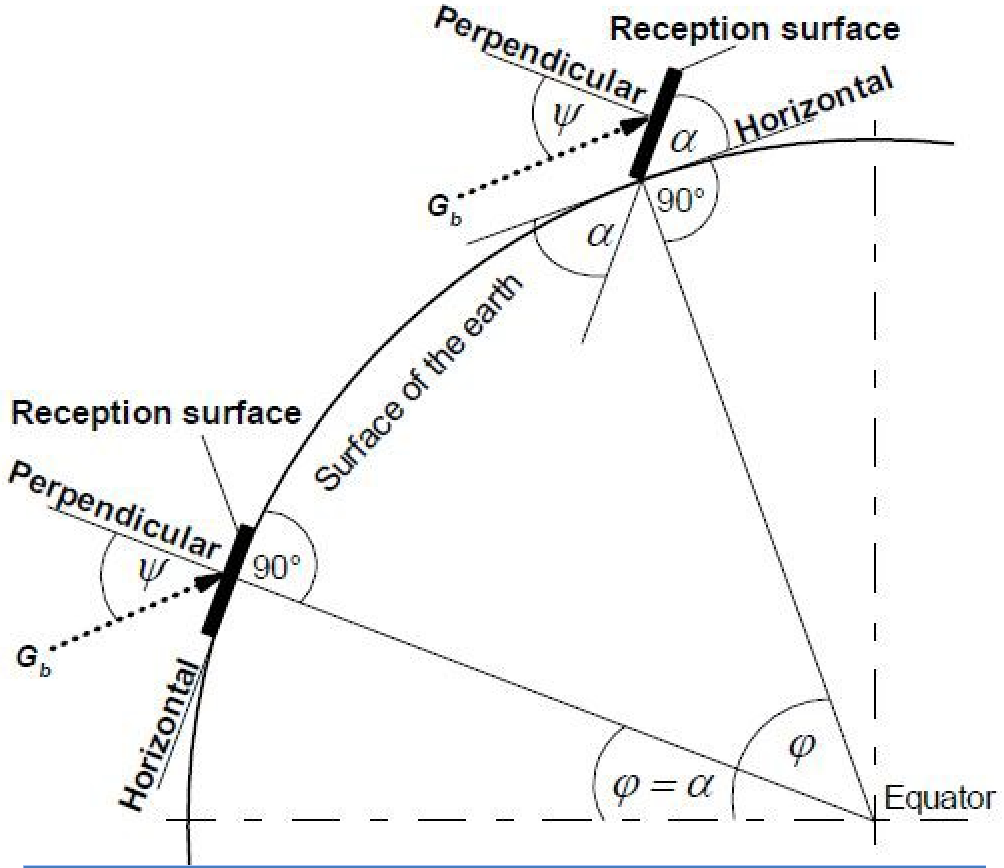
$$G_g = G_b + G_d$$

The diffuse radiation G_d consists of the radiation diffused in the atmosphere, the atmospheric counter-radiation, and the radiation reflected by the neighborhood.

Solar Radiation: Direct radiation on tilted, aligned surfaces

- The direct radiation incident on a tilted surface is determined by its incident angle ψ. This angle in turn is dependent on the alignment and the location of the receiving surface and the position of the sun

α : the slope or tilt angle of the surface (horizontal 0),
β : the surface azimuth angle (i.e. diversion from the South alignment, south 0, west positive), ϕ : the latitude (north positive),
δ : the solar declination and wh: the hourly angle of the sun; this angle is at 0°when the sun is at its highest position and is negative in the morning and positive in the afternoon.



Geometric interrelationships of radiation incident on tilted surfaces