LABORATORIUM
FOTOWOLTAICZNE
IMIM - PAN

„Introduction to photovoltaics”

Institute of Metallurgy and Materials Science of Polish Academy of Sciences

Photovoltaic Laboratory

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Institute of Metallurgy and Materials Science

Photovoltaic Laboratory

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Mgr inż. Grażyna Kulesza
Mgr inż. Zbigniew Starowicz

Institute of Metallurgy and Materials Science
Photovoltaic Laboratory

35 years of experience in a solar cell technology

The first silicon solar cell in Poland (1977)

Unique laboratory in Poland (performing solar cells)

The main areas of research:

Crystalline silicon solar cells technology

Comprehensive characterization of solar cell parameters

Advantages and disadvantages of photovoltaics

Generating electric power from sources of energy

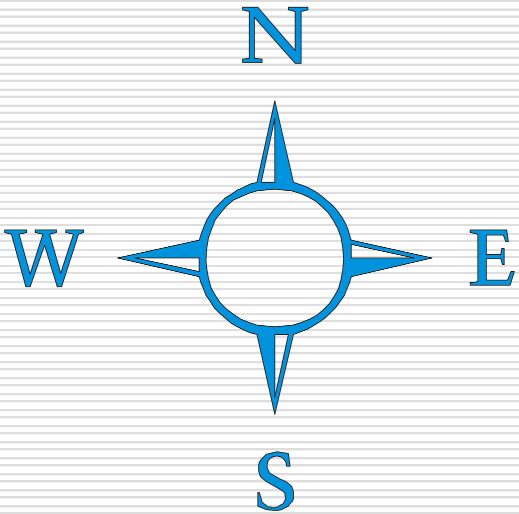
Conventional energy sources

COMBUSTION

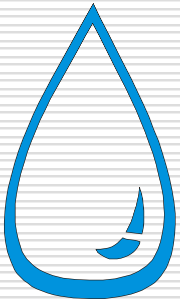
Generating power from sources of energy

Conventional energy sources

Wind



Water



Generating electric power from sources of energy

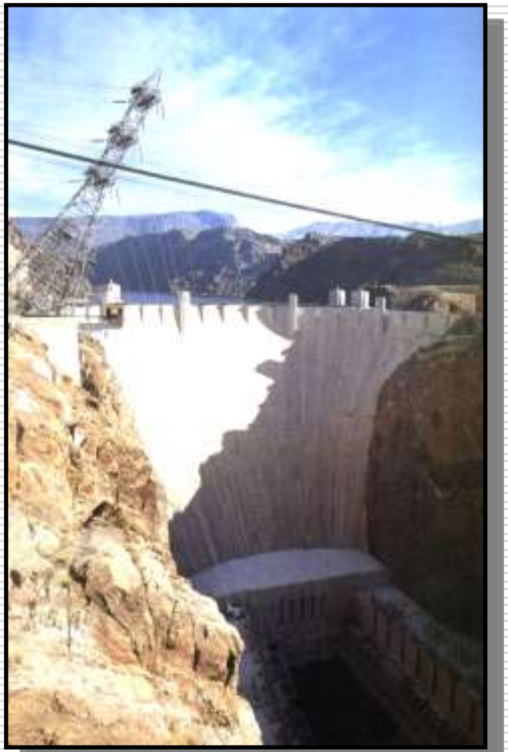
Conventional energy sources – wind

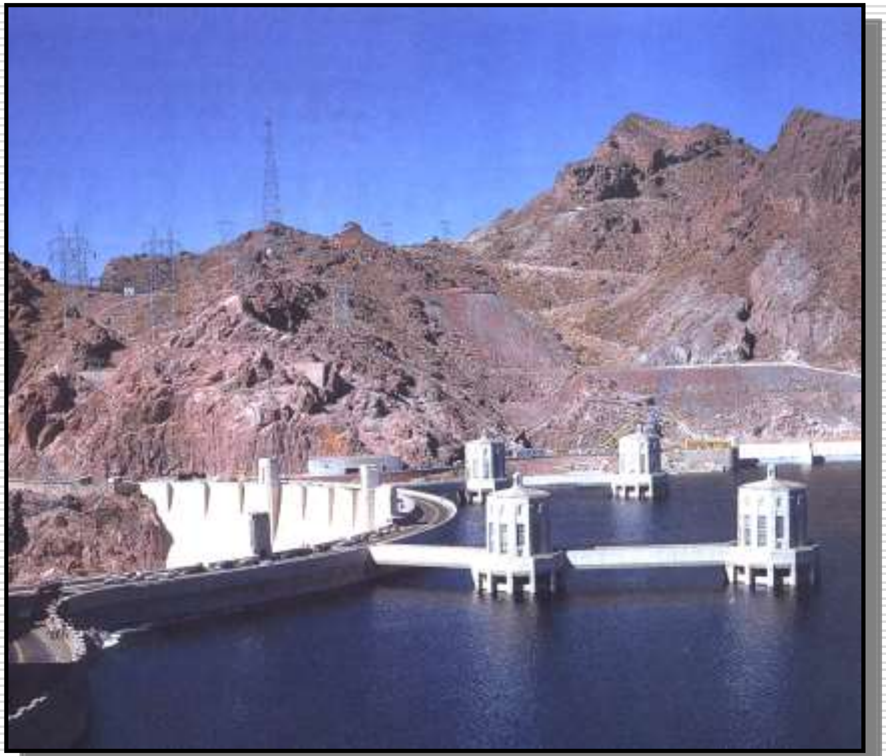
Wind - Most wind turbines generate electricity from naturally occurring wind.

Generating electric power from sources of energy

Conventional energy sources - water

Water (hydroelectric) - Turbine blades are acted upon by flowing water, produced by hydroelectric dams or tidal forces.

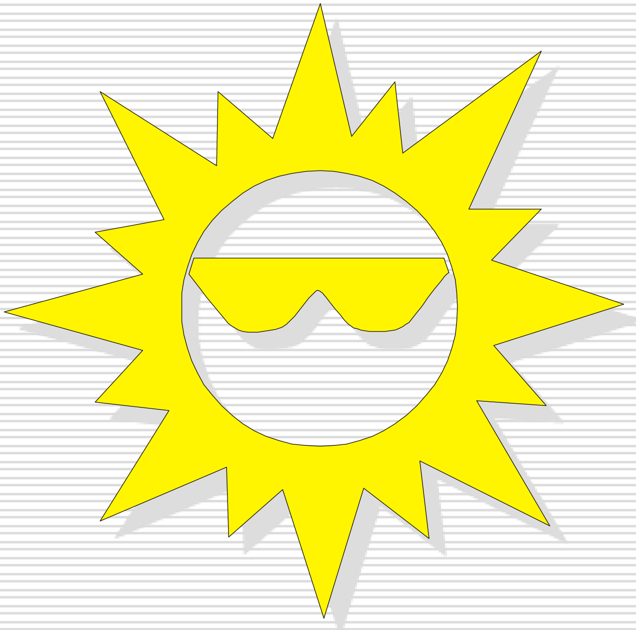




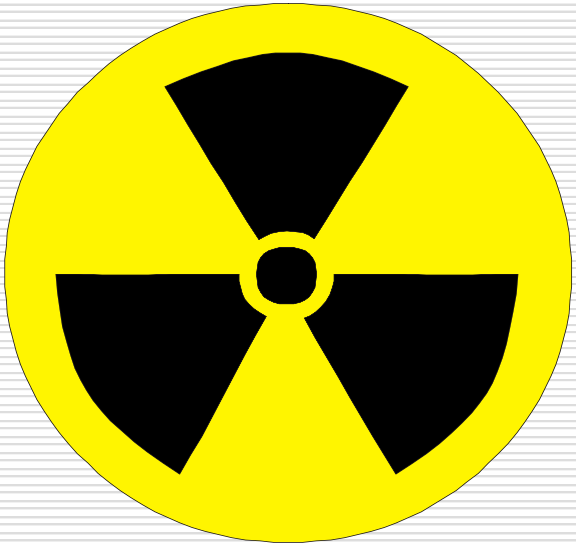
Generating electric power from sources of energy

New energy sources – sun and nuclear power

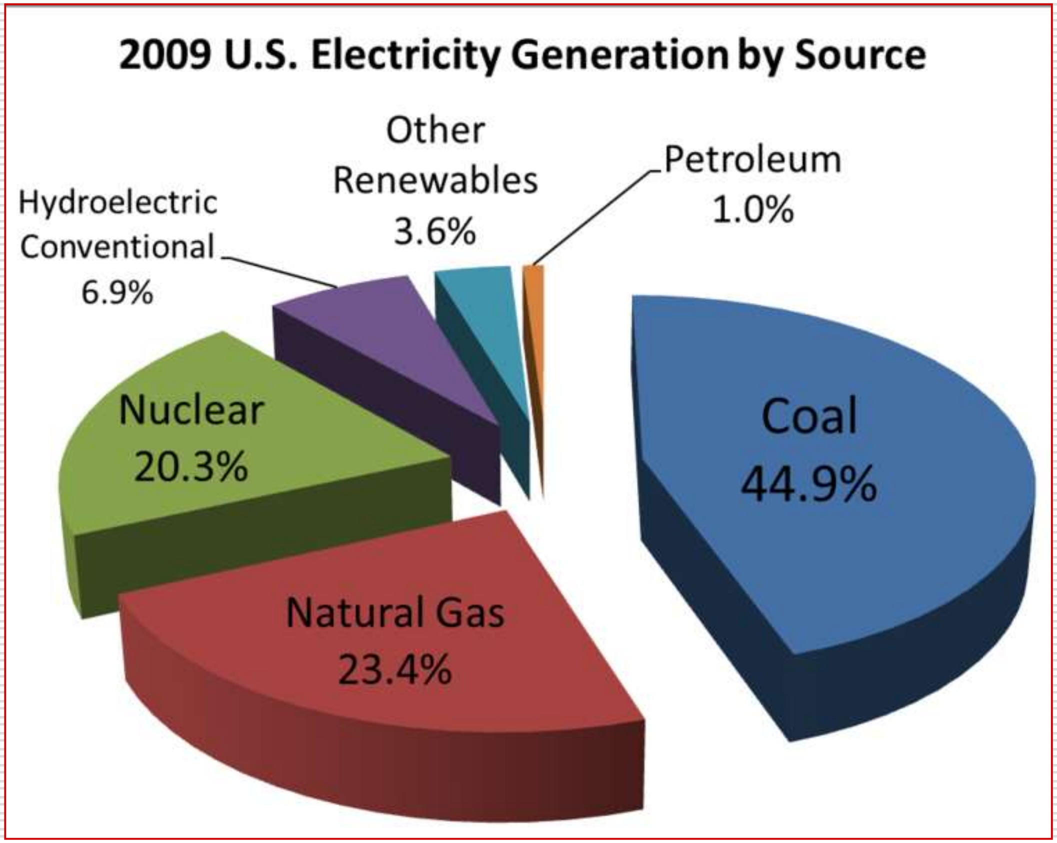
SUN



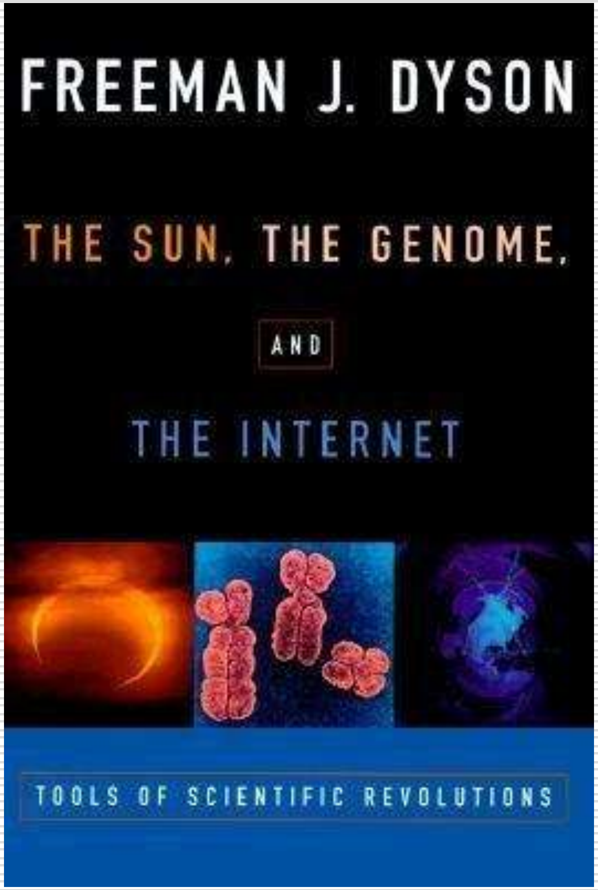
NUCLEAR POWER



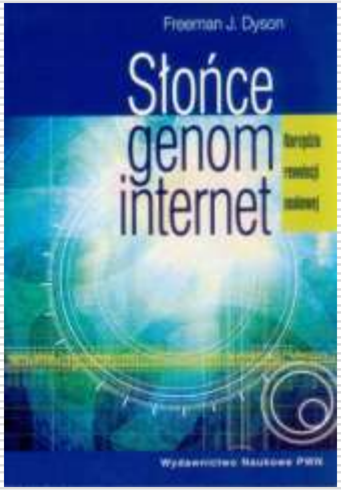
Electricity Generation by Source



The Sun, the Genome, and the Internet is a non-fiction scientific book by renowned physicist Freeman J. Dyson



Professor Dyson suggests that three rapidly advancing technologies, Solar Energy, Genetic Engineering and World-Wide Communication together have the potential to create a more equal distribution of the world's wealth.



Advantages of solar cells

1. Do not contain toxic liquid and gas
2. Do not have moving parts – no noise and durability
3. Very quick response
4. They can work in extremely different conditions

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Advantages of solar cells

DOES NOT POLLUTE DURING WORK

THEY ARE MADE FROM SILICON (VERY WIDE-ELEMENT)

ALLOW THE CONSTRUCTION OF SYSTEMS FROM MW TO MW

CAN BE ASSOCIATED WITH VARIOUS SURFACES WITHOUT SPECIAL CONSTRUCTION

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PV SYSTEMS APPLICATIONS

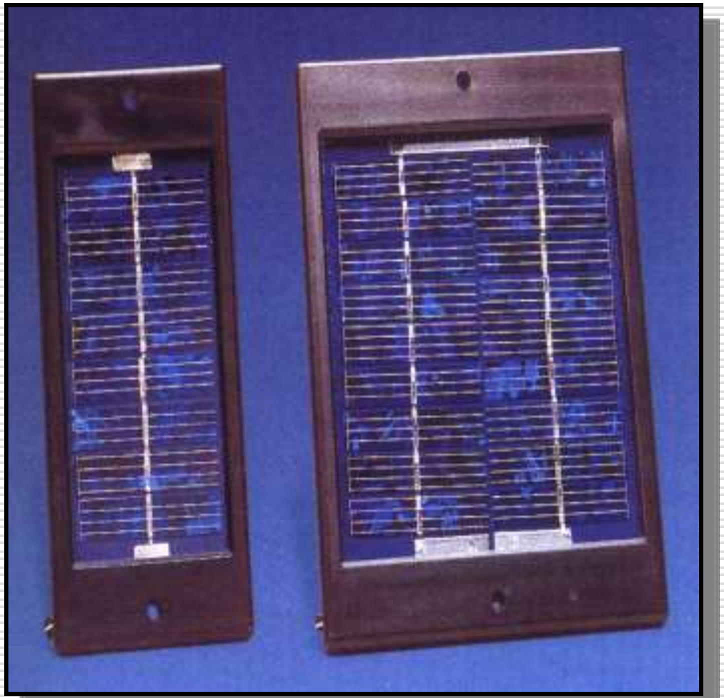
- IN ARMY - electric power field devices (radios, stations leads, measuring equipment, lighting equipment, etc.).
  IN METEOROLOGY - power remote weather stations.
  IN HOUSEHOLDS - power household appliances from calculators and watches as through radio and television etc.
  IN MEDICINE - supply of complete field of medical clinics in third world countries (especially important supply cold storage of vaccines and drugs).
  TOURISM - stand-alone power systems for mobile homes, mountain chalets.

PV SYSTEMS APPLICATIONS

- In the NAVIGATION - power marine waterways and aviation beacons, battery charging on yachts.
  In agriculture and forestry - protection of electrical power pastures and forests, irrigation and drainage, fire protection equipment.
  IN TELECOMMUNICATIONS - power radio communications relay stations, radio stations, mobile phones.
  SHIPPING - Power marks on the road and rail ropes.

SMALL SOLAR MODULES

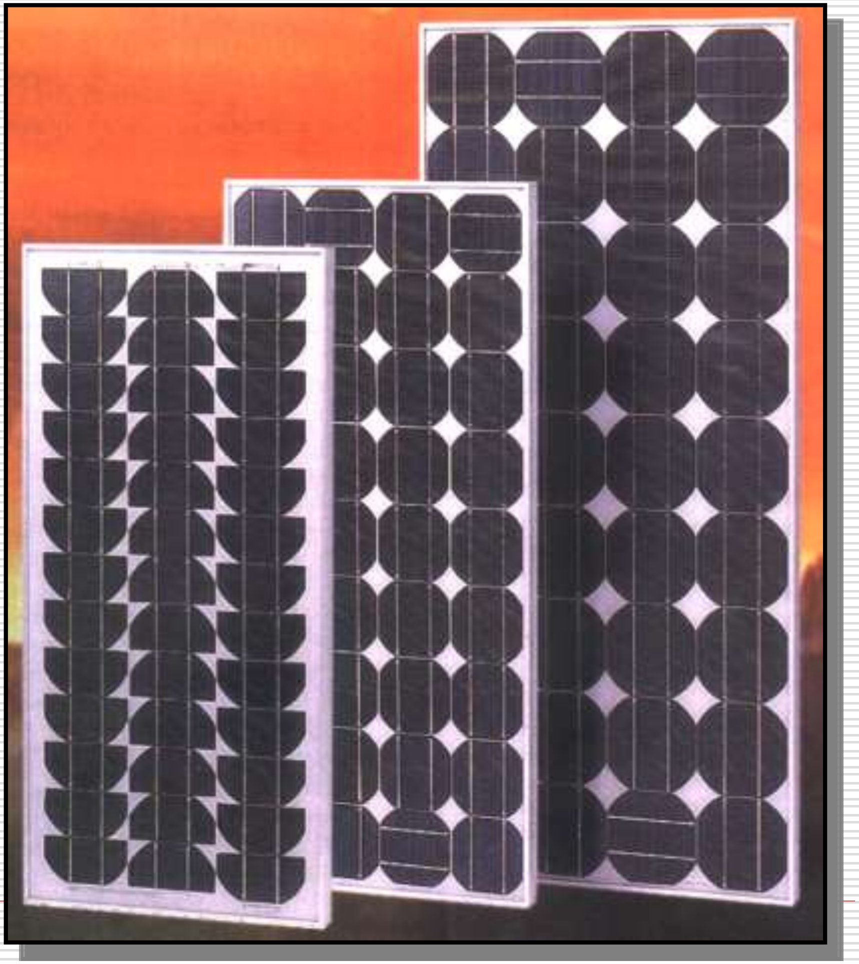
30 cm



SMALL SOLAR MODULES

TYPICAL SOLAR MODULES

160 cm



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SMALL POWER PLANTS

BIG POWER PLANTS

BAWARIA

5.3 MW

PRIVATE HOUSEHOLDS

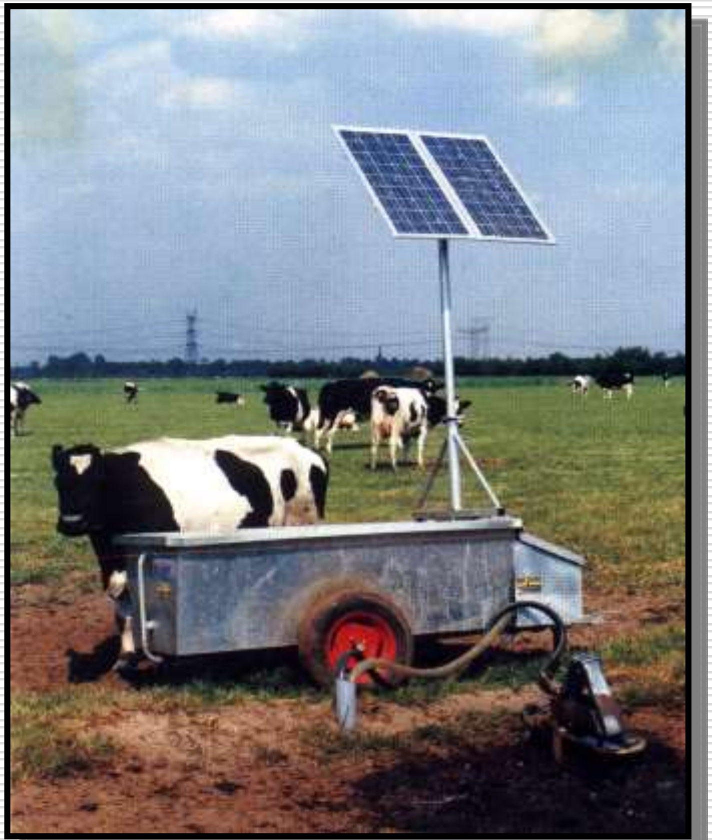
NAVIGATION

Power marine waterways

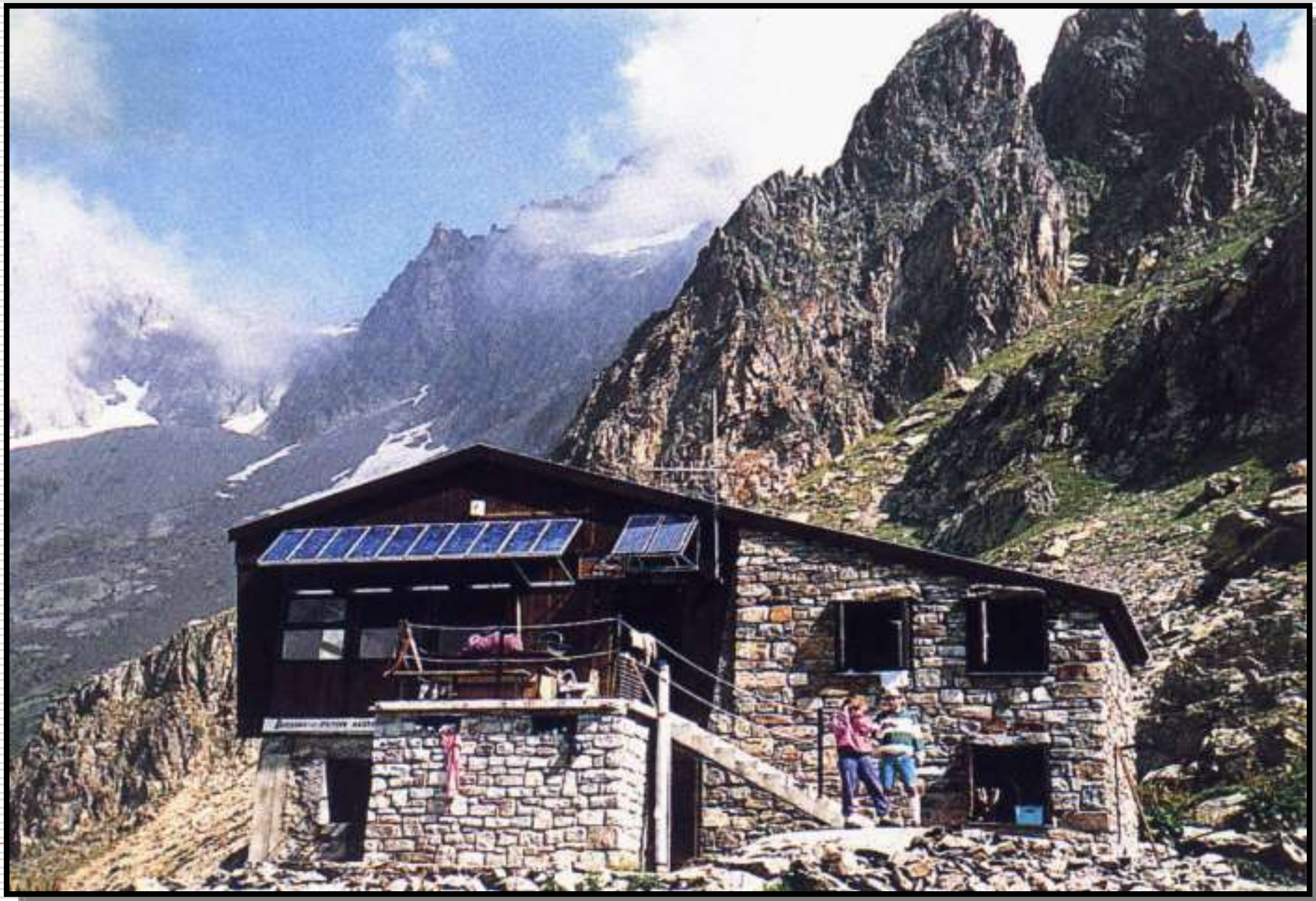
METEOROLOGY

Power for remote weather stations

FARMS



TOURISM

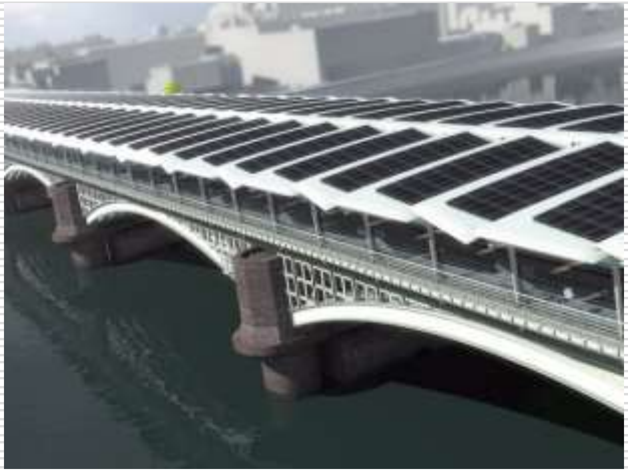


TRANSPORT

TRANSPORT

The World Solar Challenge is a biennial solar-powered car race which covers 3,021 km through the Australian Outback, from Darwin to Adelaide. „Honda Dream" **average speed 90 km/h**

One complete, the Blackfriars solar bridge will be the largest and only the second of its kind in the world. Image courtesy of Solar Century.



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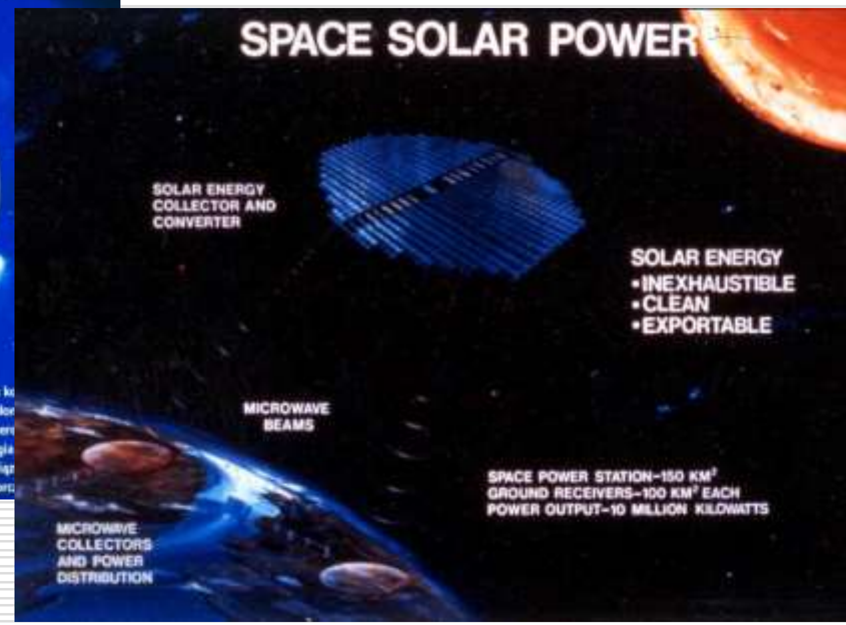
ARMY

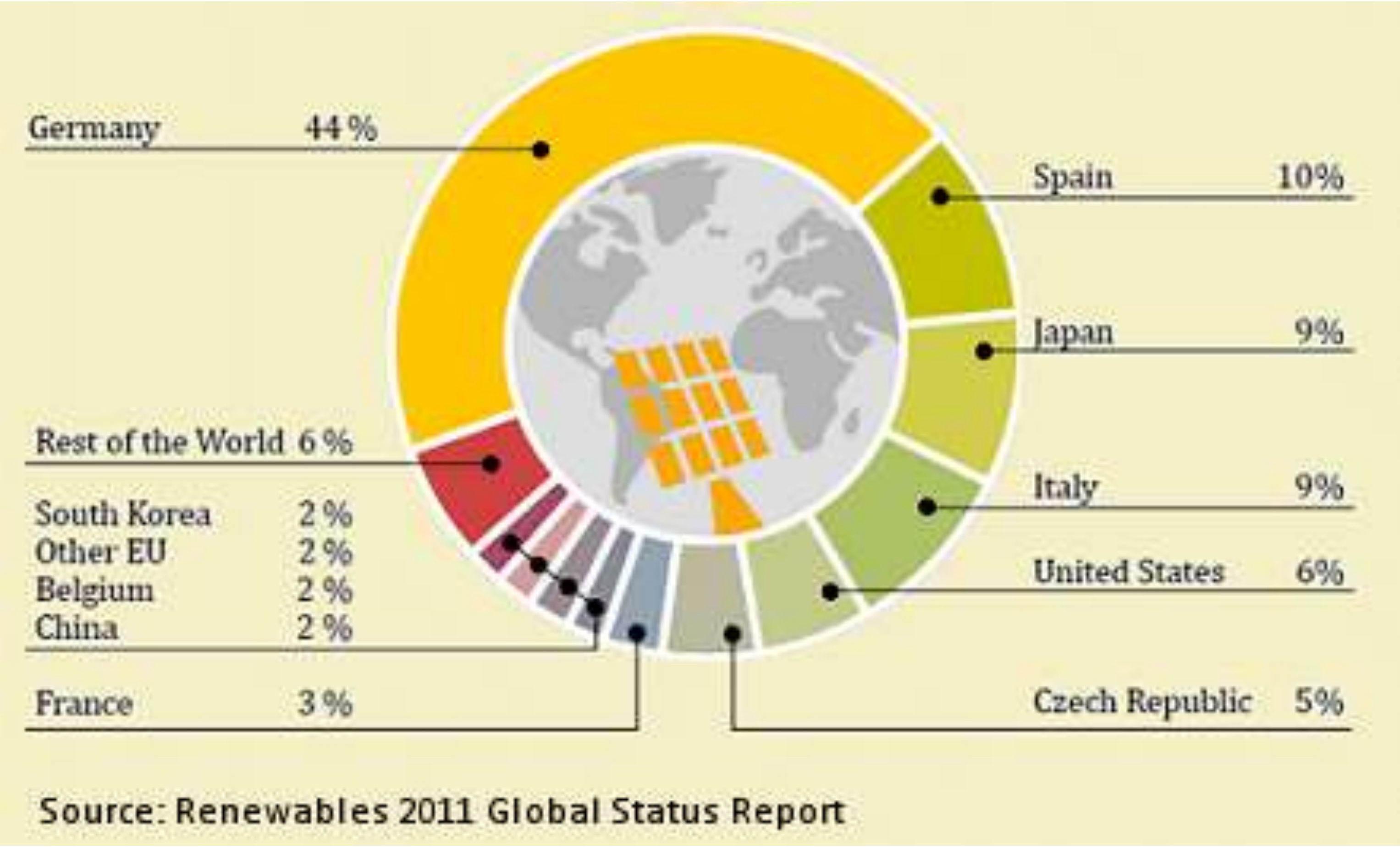
MODERN ARCHITECTURE

SATELLITE POWER PLANTS



Space-based solar power (SBSP) is the concept of collecting solar power in space (using an "SPS", that is, a "solar power satellite" or a "satellite power system") for use on Earth.

Top Ten Countires by Solar Power Capacity (Photovoltaics), 2010



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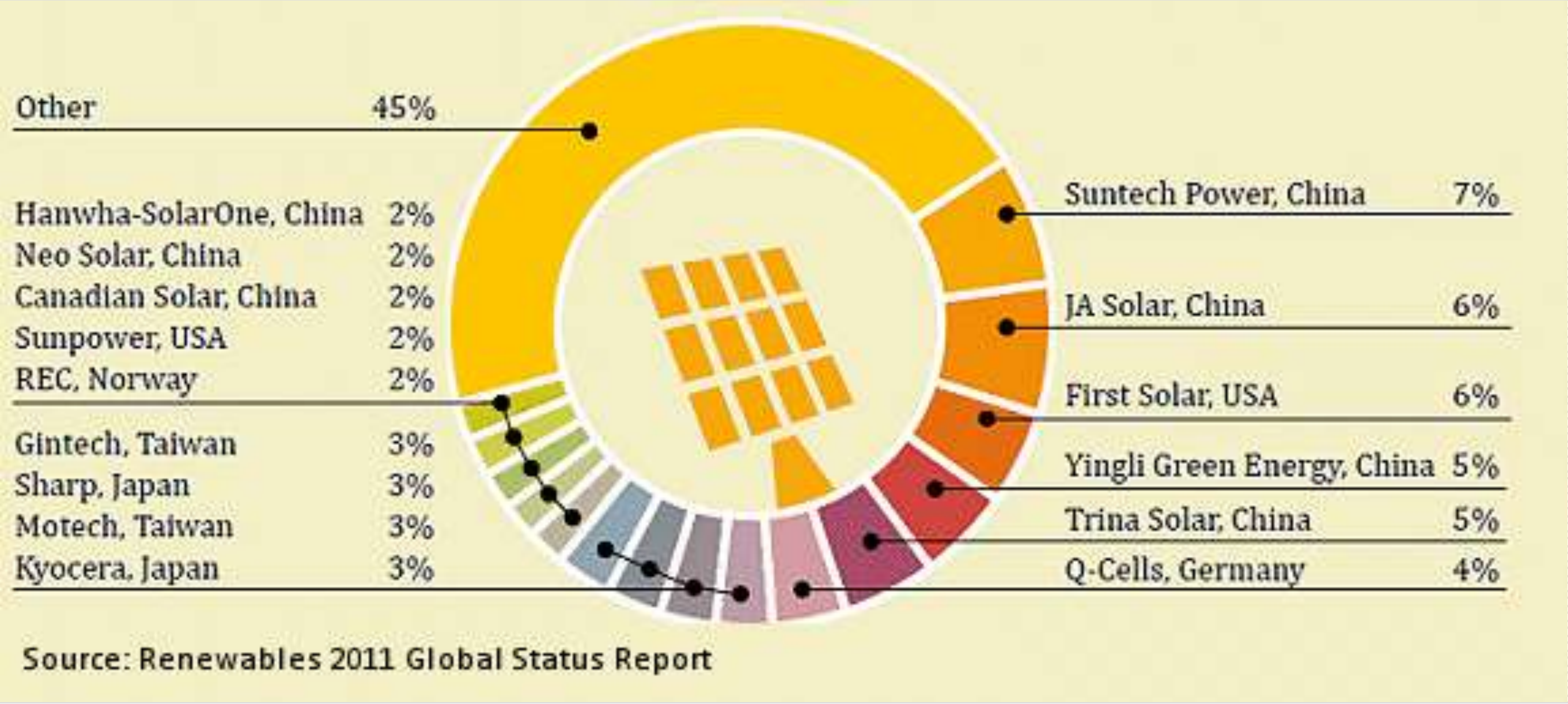
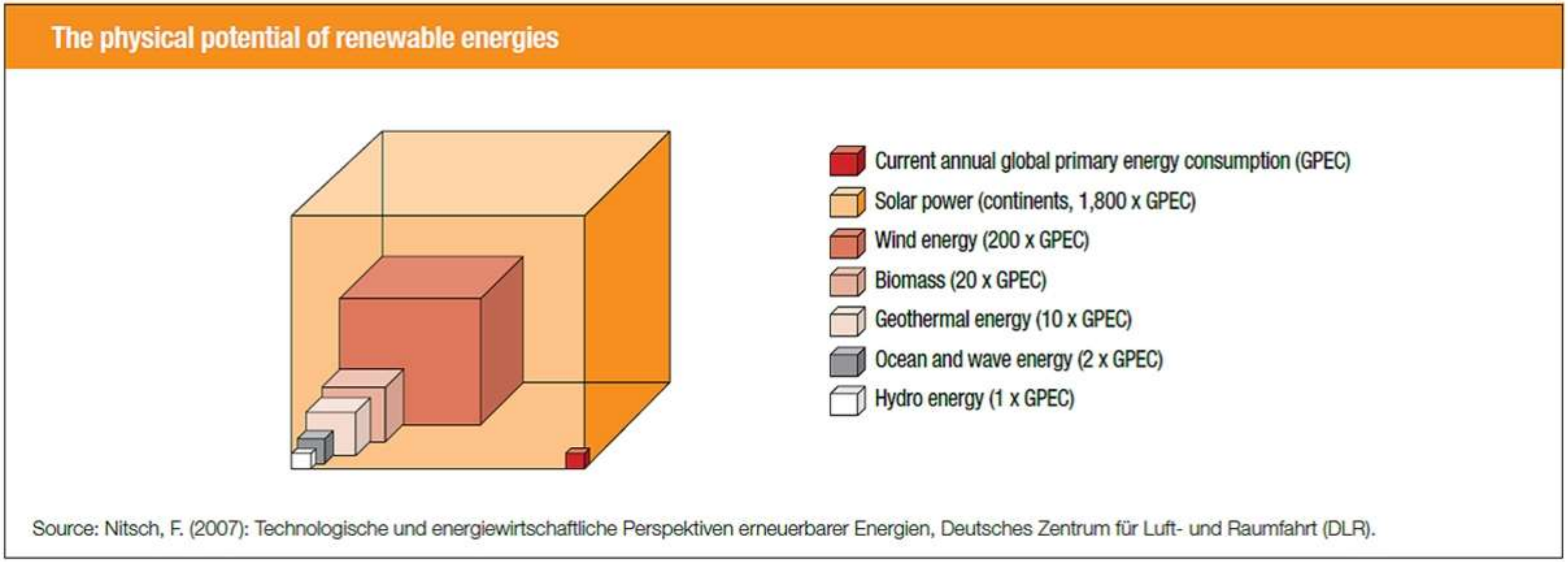
Market Shares of Top 15 Solar Photovoltaic Cell Manufactures, 2010



2. Quality and quantity of solar energy

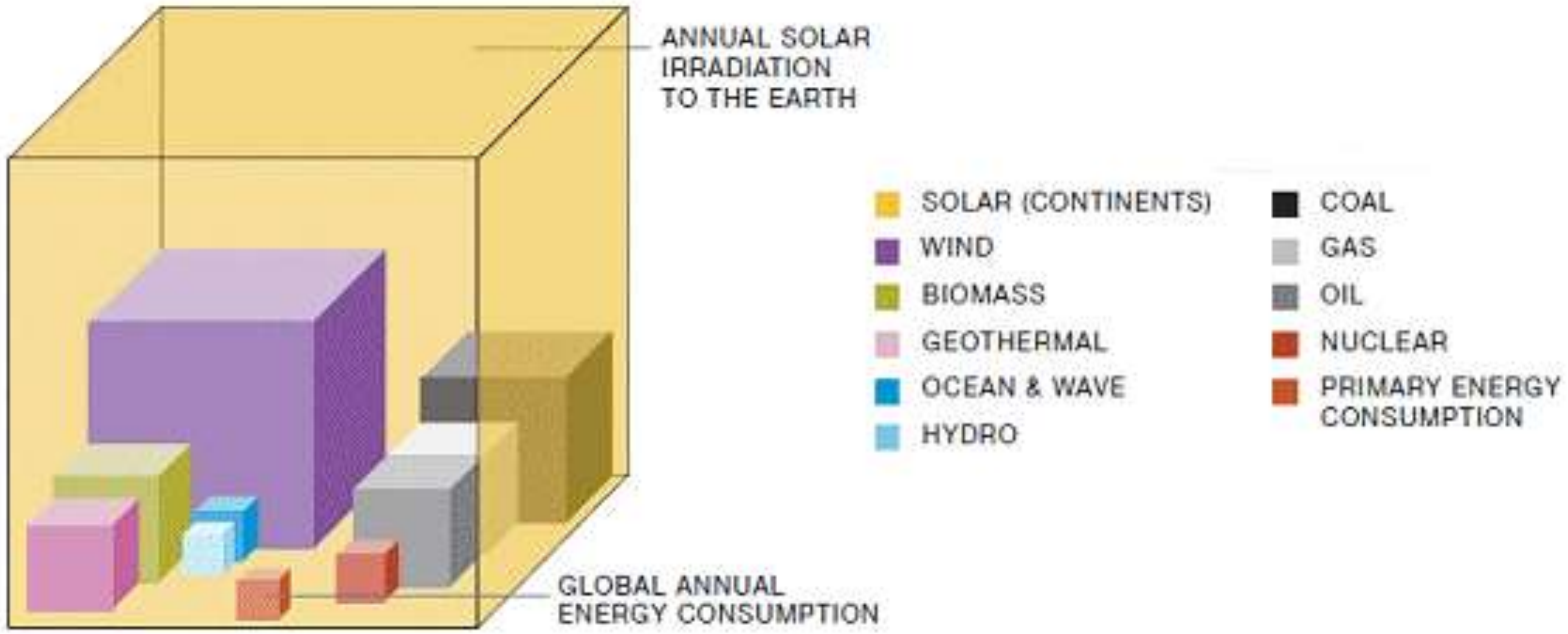
The physical potential of renewable energies



GPEC- Global Primary Energy Consumption

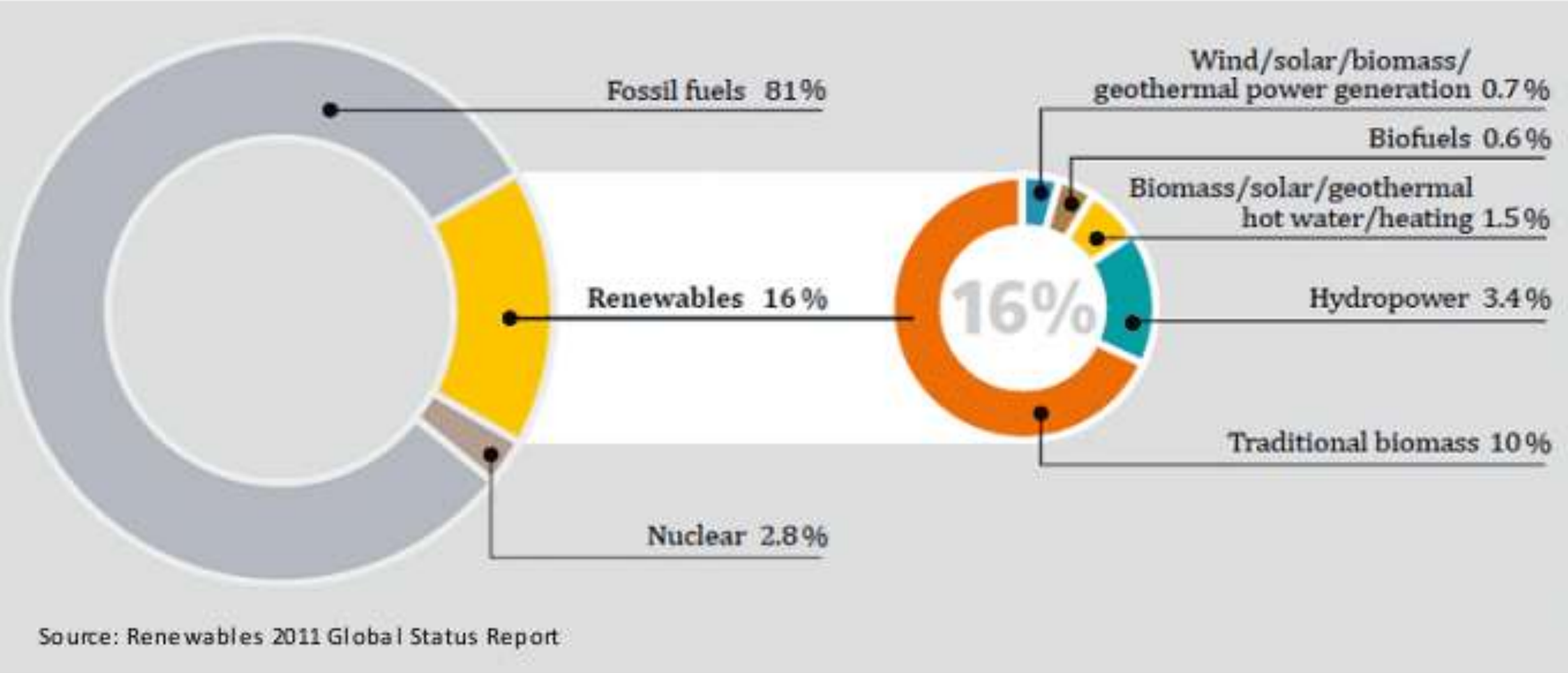
Źródło: Nitsch F. „Technologische energiewirschaftiche Perspektiven erneuerbauer Energien Deutche Zentrym fur Luft Raumfahrt (DLR) 2007.

Potential Global Energy Resources in Comparison to Annual Energy Consumption, 2011



Fossil fuels are expressed with regard to their total reserves, renewable energies to their yearly potential
Source: Greenpeace and European Photovoltaic Industry's Report Solar Generation 6

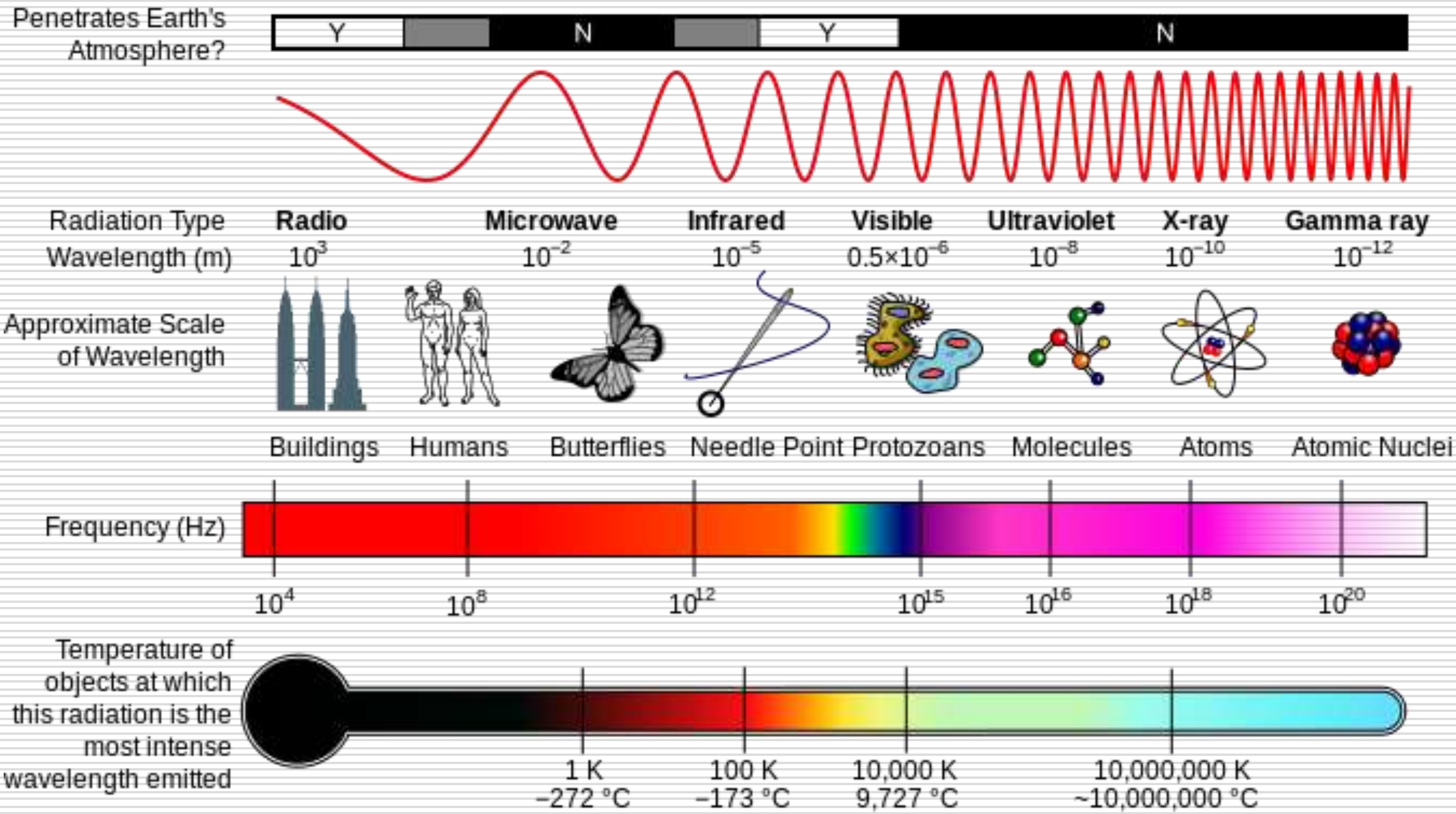
Renewable Energy Share of Global Energy Consumption, 2009



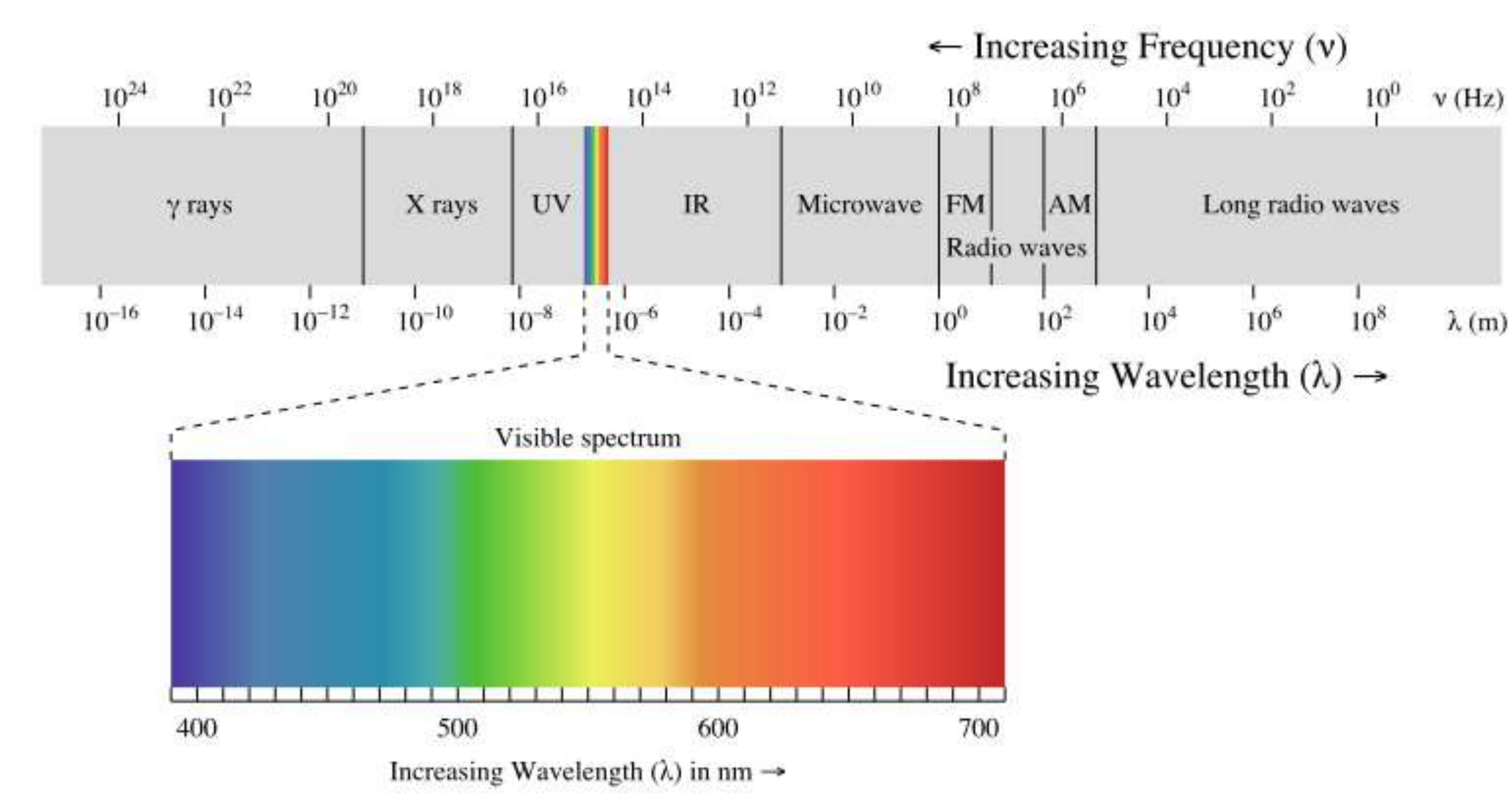
SUN

The Sun is the star at the center of the Solar System. It is almost perfectly spherical and consists of hot plasma interwoven with magnetic fields. It has a diameter of about 1,392,684 km, about 109 times that of Earth, and its mass (about 2×1030 kilograms, 330,000 times that of Earth) accounts for about 99.86% of the total mass of the Solar System. Chemically, about three quarters of the Sun's mass consists of hydrogen, while the rest is mostly helium.

The electromagnetic spectrum, showing various properties across the range of frequencies and wavelengths



The electromagnetic spectrum



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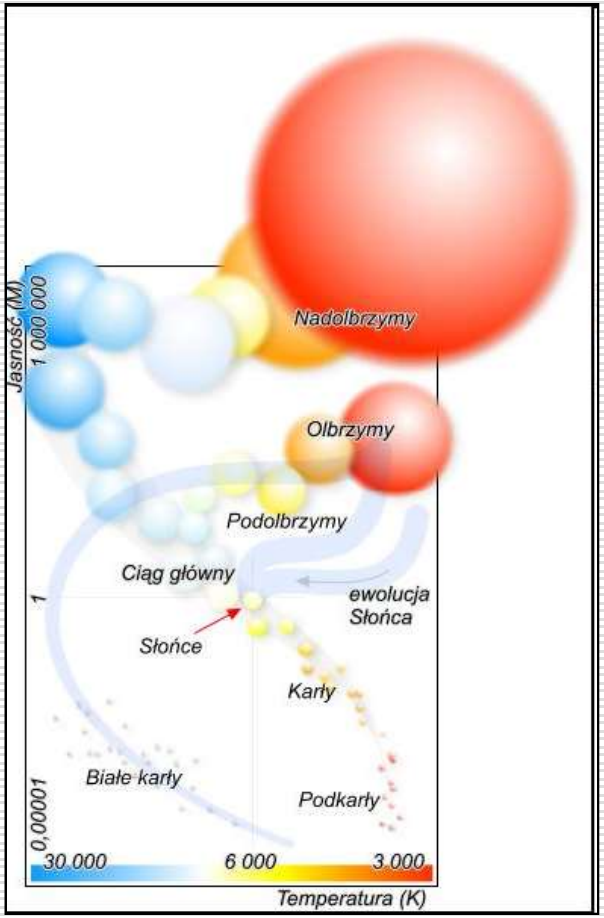
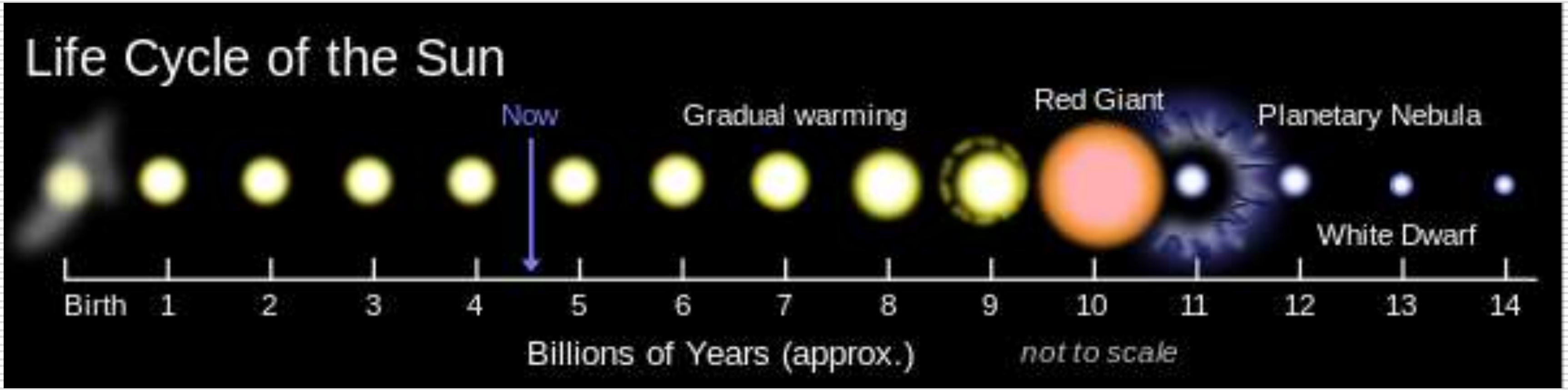
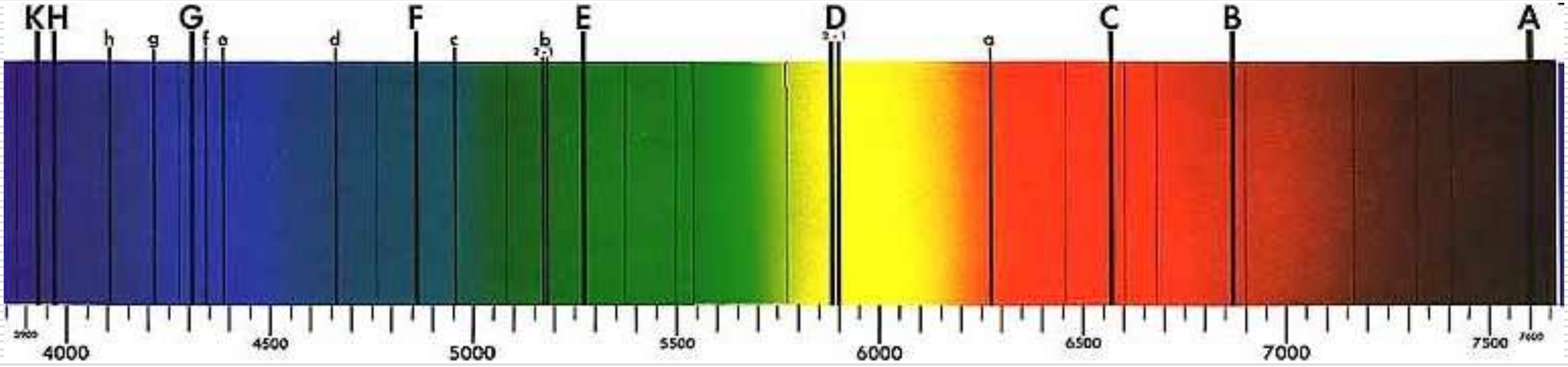
The electromagnetic spectrum of Sun



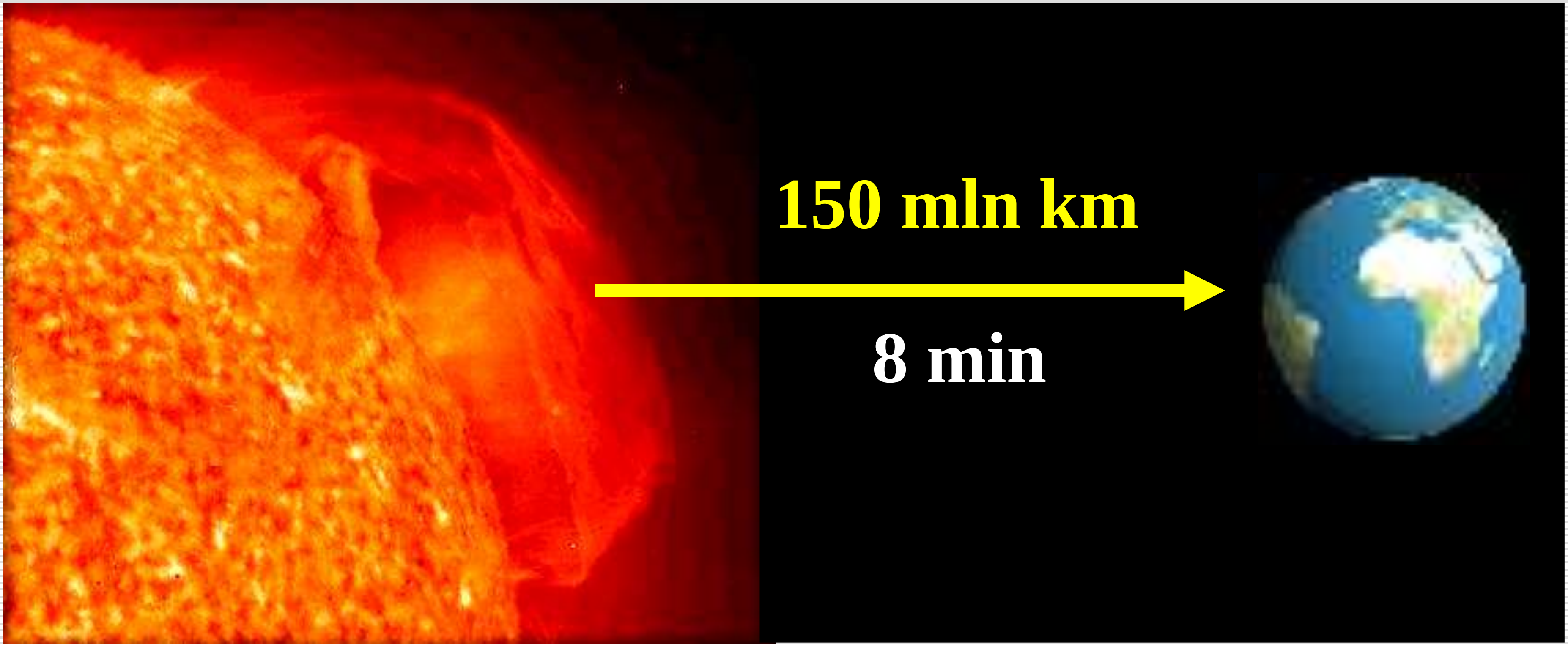
- ultraviolet 0,15 - 0,4 um (7% of power),
- Visible 0,4 - 0,75 um (45% of power),
- Infrared 0,75 - 4 um (47% of power).

Life Cycle of Sun





Sun power 3,86 10^{26} W



Solar constant 1362 W/m^2

Solar constant

The solar constant, a measure of flux density, is the amount of incoming solar electromagnetic radiation per unit area that would be incident on a plane perpendicular to the rays, at a distance of one astronomical unit (AU)

The solar constant includes all types of solar radiation, not just the visible light. It is measured by satellite to be roughly 1.361 kilowatts per square meter (kW/m^2) at solar minimum and approximately 0.1% greater (roughly **1.362 kW/m^2**) at solar maximum.[4] The actual direct solar irradiance at the top of the atmosphere fluctuates by about 6.9% during a year (from 1.412 kW/m^2 in early January to 1.321 kW/m^2 in early July) due to the Earth's varying distance from the Sun, and typically by much less than 0.1% from day to day.

Sun Power for the whole Earth

Sun about 3.86×10^{26} watts

Thus, for the whole Earth (which has a cross section of 127,400,000 km²), the power is 1.740×10^{17} W, plus or minus 3.5%.

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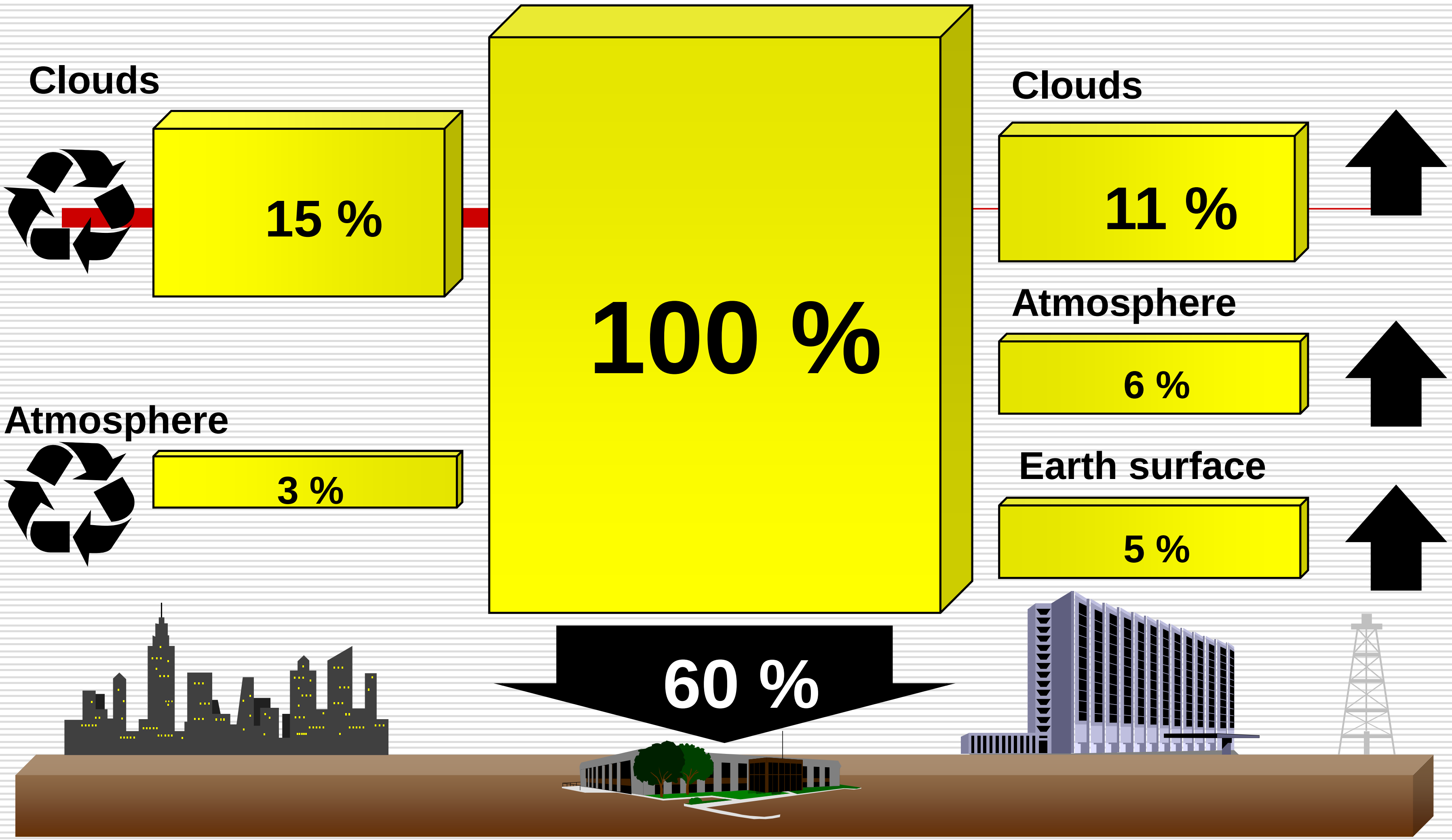
Global Irradiation for Poland

930-1160 kWh/m2* Year


Clouds
15 %
Atmosphere
3 %
100 %
Clouds
11 %
Atmosphere
6 %
Earth surface
5 %
60 %

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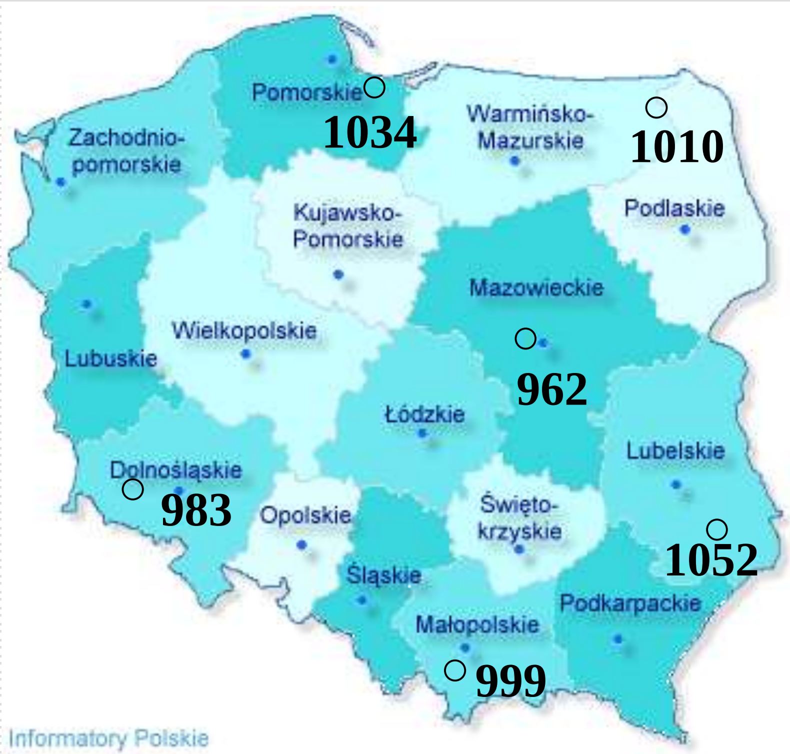
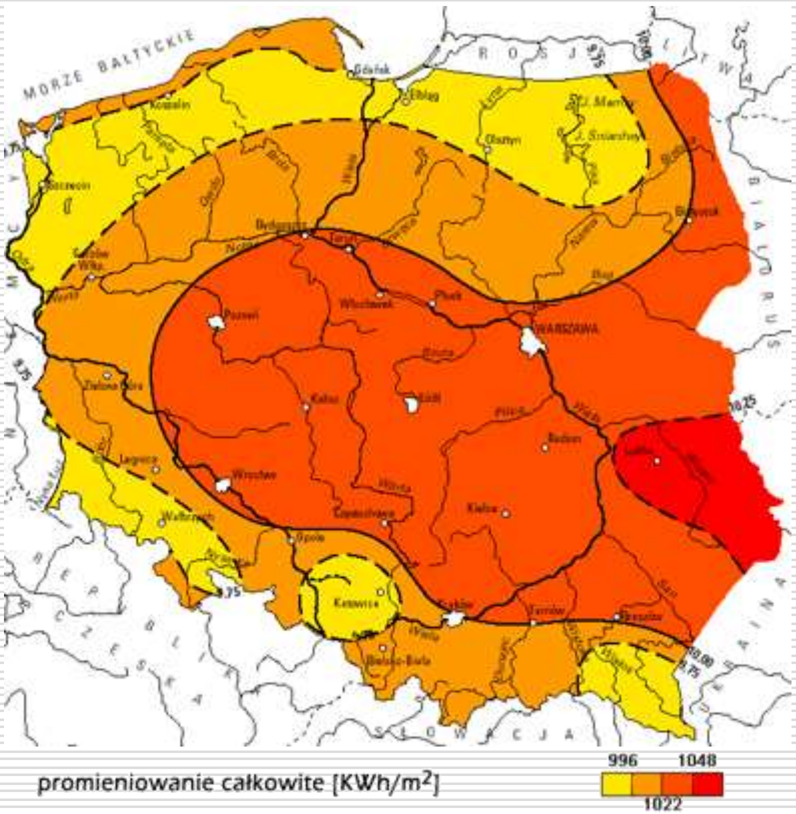
Yearly Sum of Global Irradiation

Poland - kWh/m^2



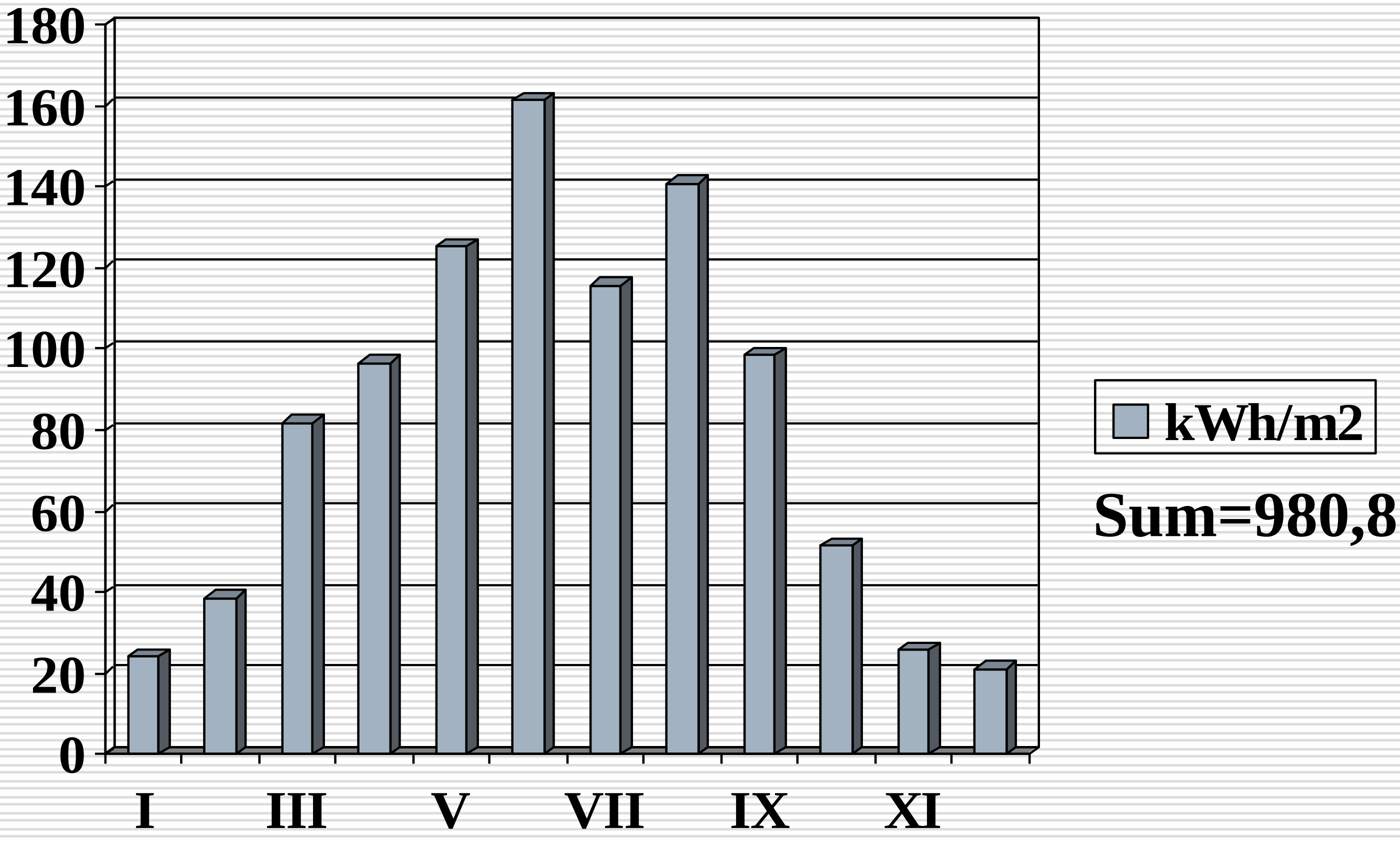


Yearly Sum of Global Irradiation - World

City	Yearly Sum of Global Irradiation kWh/m²
Sahara	2250
Marsylia	1860
Paryż	1500
Freiburg	1270
Zurich	1160
Berlin	1000
Hamburg	930
Londyn	927

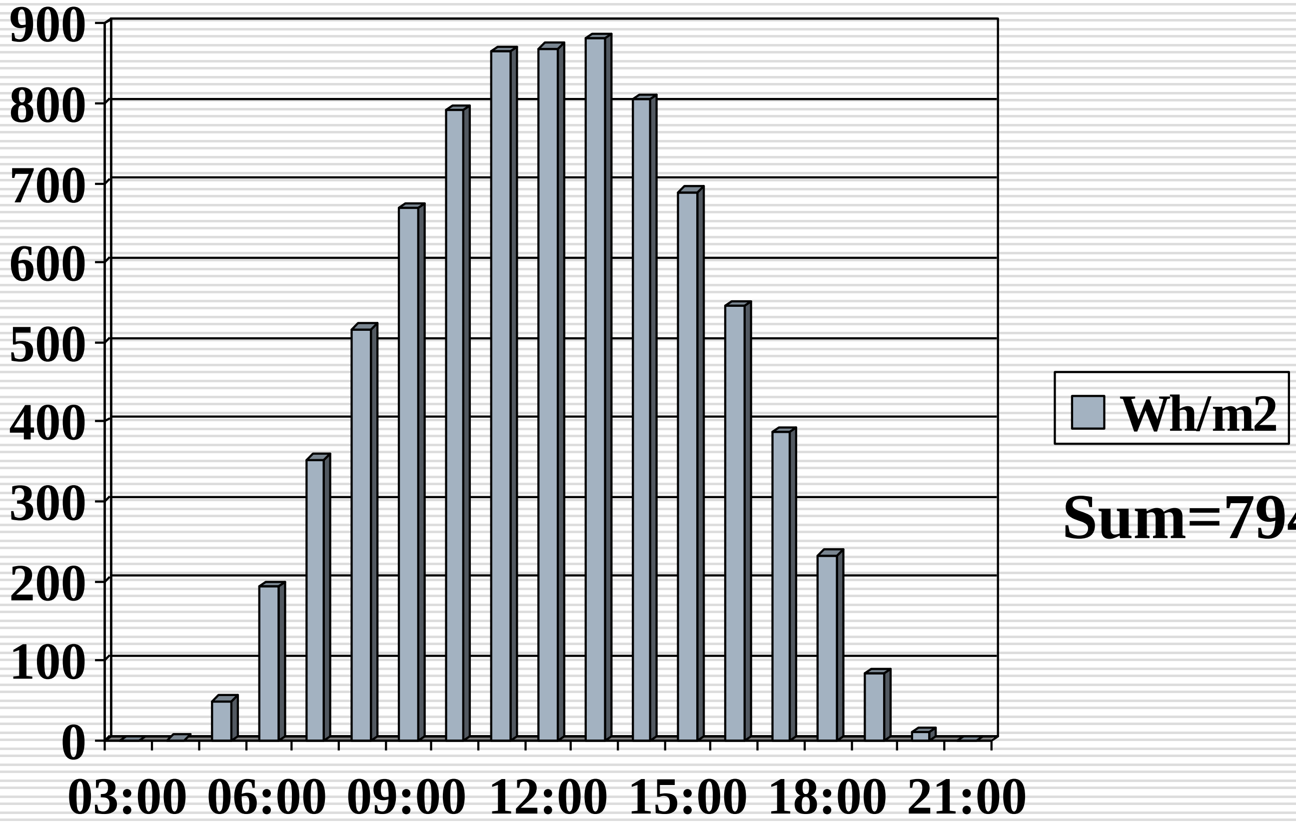
Yearly Sum of Global Irradiation

KOZY 1997



Daily Sum of Global Irradiation

KOZY of 11 June 1997r



Sum=7944

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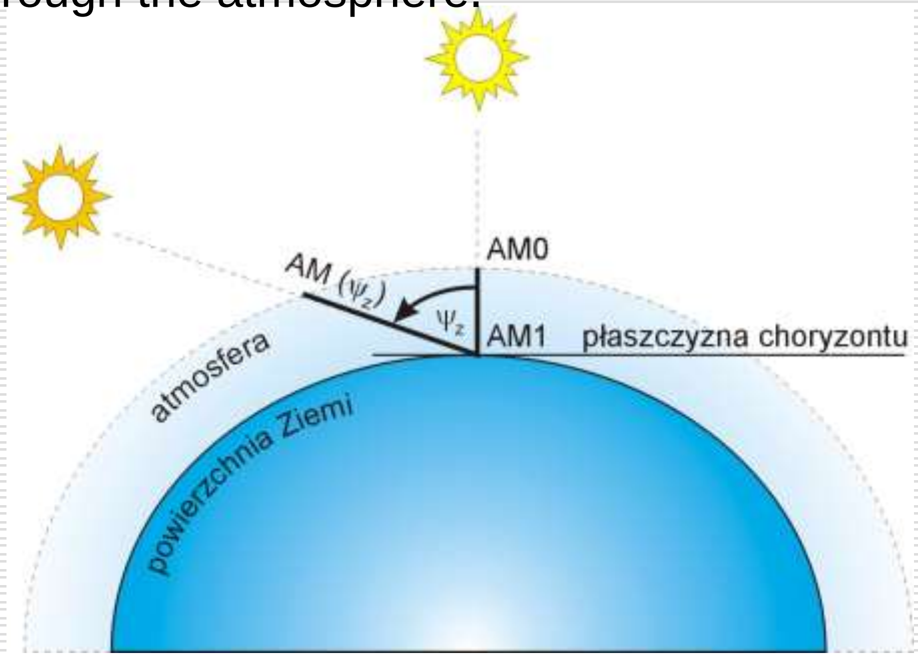
Global Irradiation

Air Mass AMm

The air mass coefficient defines the direct optical path length through the Earth's atmosphere, expressed as a ratio relative to the path length vertically upwards, i.e. at the zenith. The air mass coefficient can be used to help characterize the solar spectrum after solar radiation has traveled through the atmosphere.



The air mass coefficient

For a path length ***L*** through the atmosphere, for solar radiation incident at angle z relative to the normal to the Earth's surface, the air mass coefficient is:

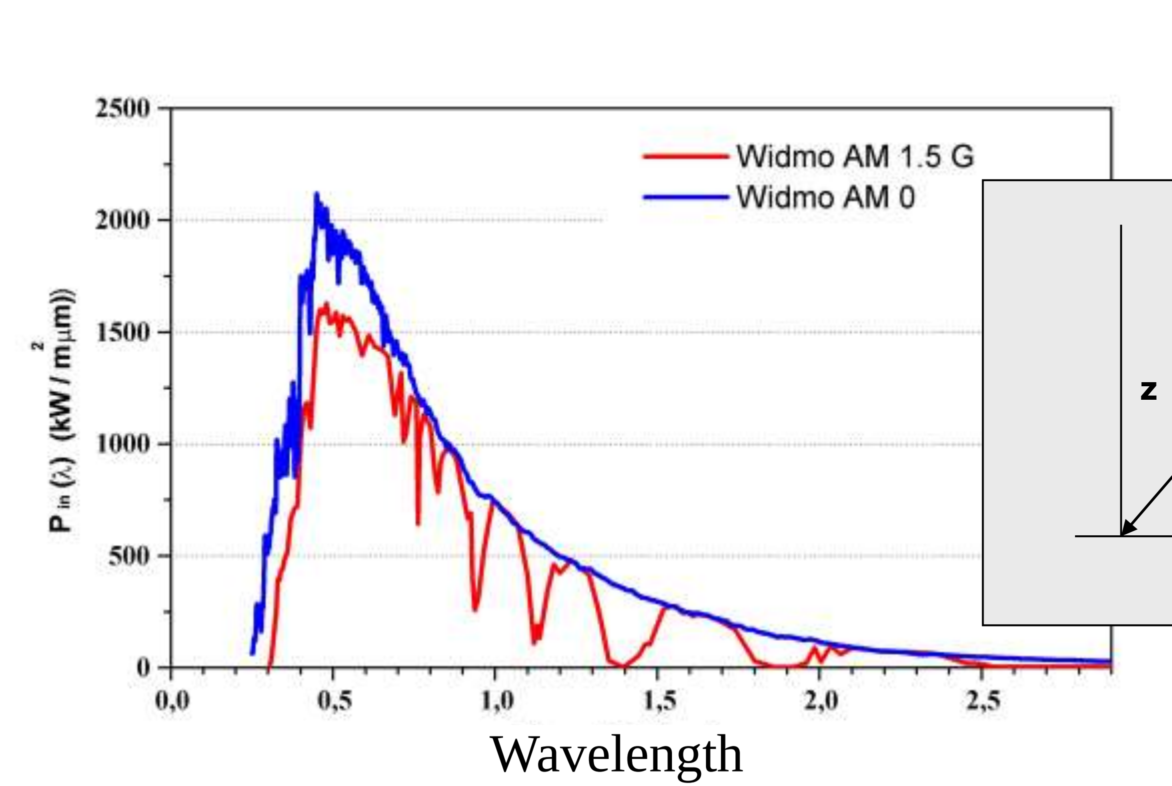
$$AM = \frac{L}{L_o} \approx \frac{1}{\cos z}$$

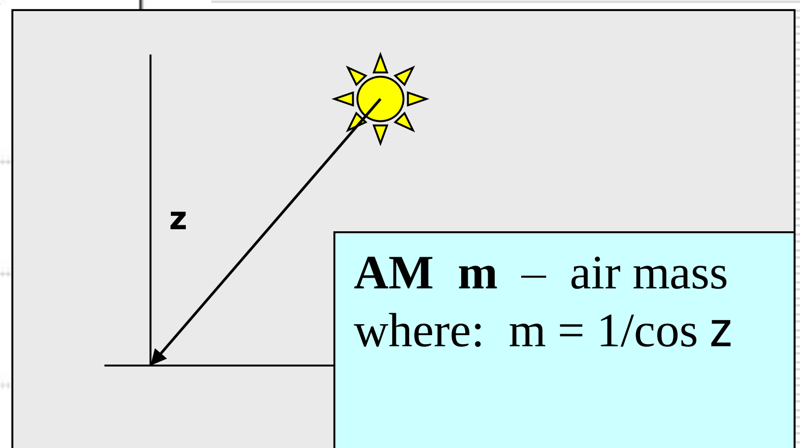
where ***Lo*** is the zenith path length (i.e. normal to the Earth's surface) at sea level and ***z*** is the zenith angle in degrees.

ψ_z	$m = \frac{1}{\cos\psi_z}$	m	ψ_z	$m = \frac{1}{\cos\psi_z}$	m
0	1,00	1,00	86	14,34	12,87
30	1,15	1,15	87	19,10	16,04
60	2,00	2,00	88	28,65	20,87
70	2,92	2,92	89	57,30	28,35
80	5,76	5,63	90	∞	29,94
85	11,47	10,69			

The air mass coefficient

Spectral distribution of radiation intensity





AM – amount of air mass the radiation passes through in individual case

3. Global Irradiation in Poland and Europe

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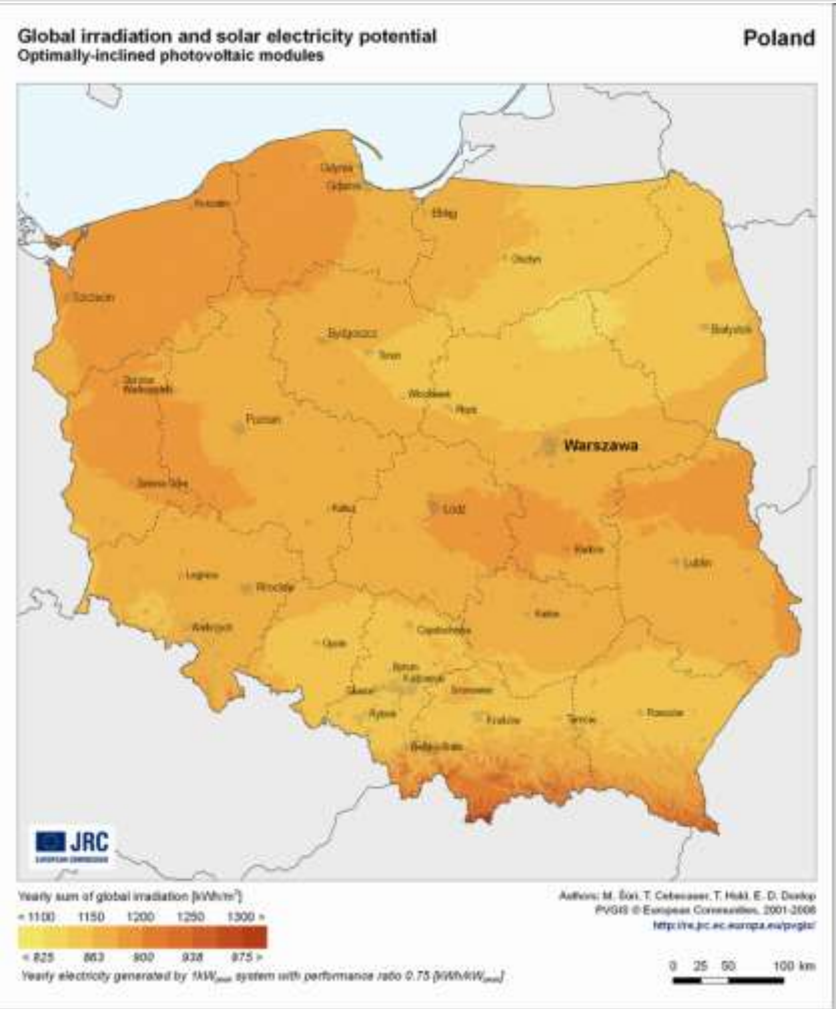
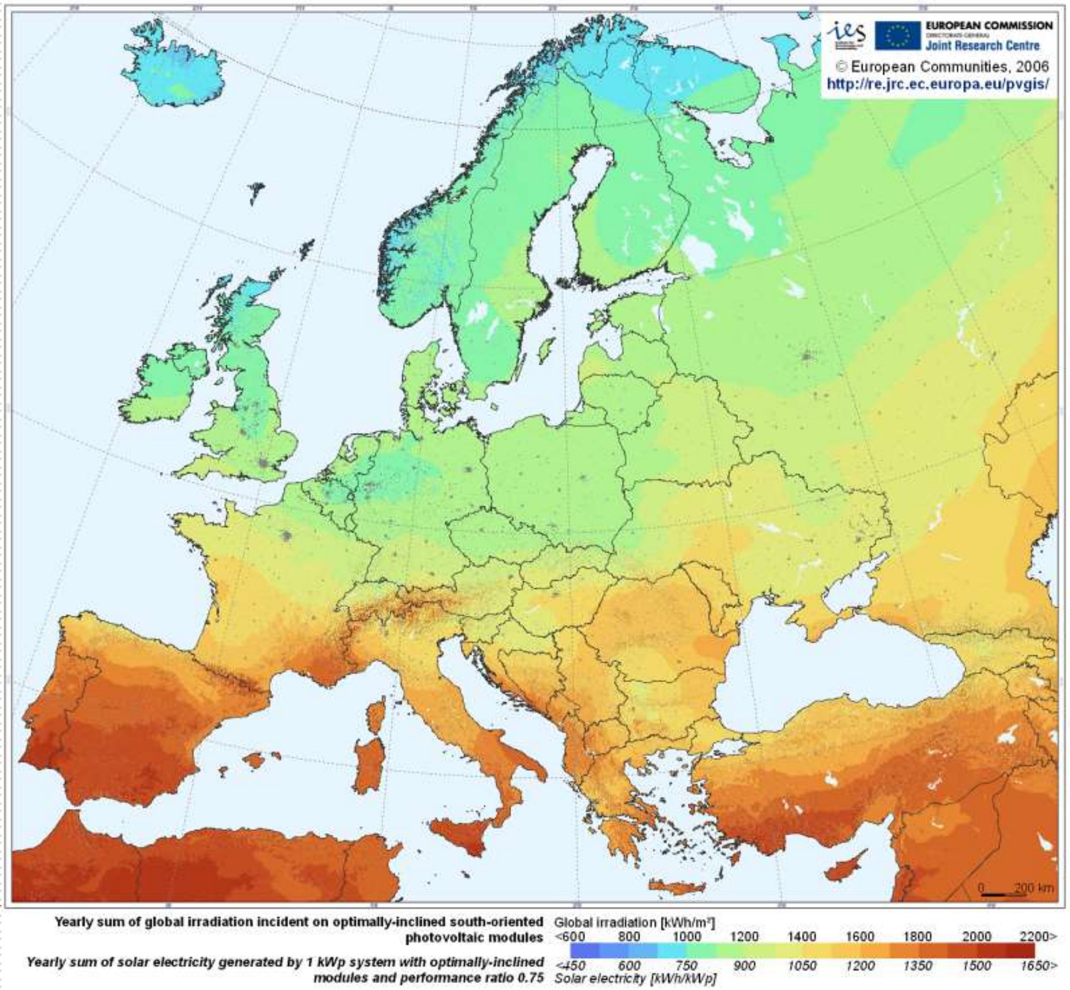
Global Irradiation

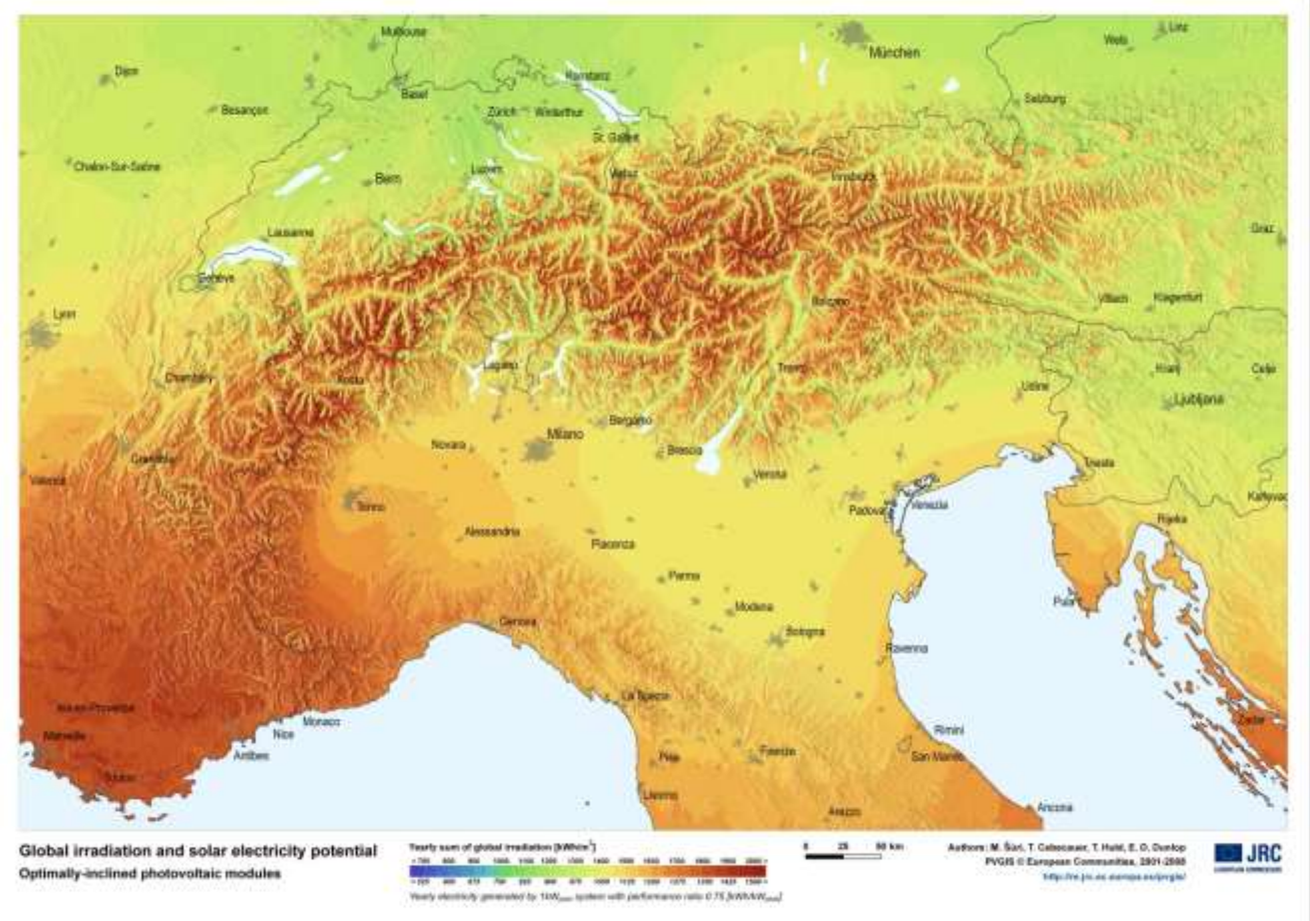


Global Irradiation in Europe

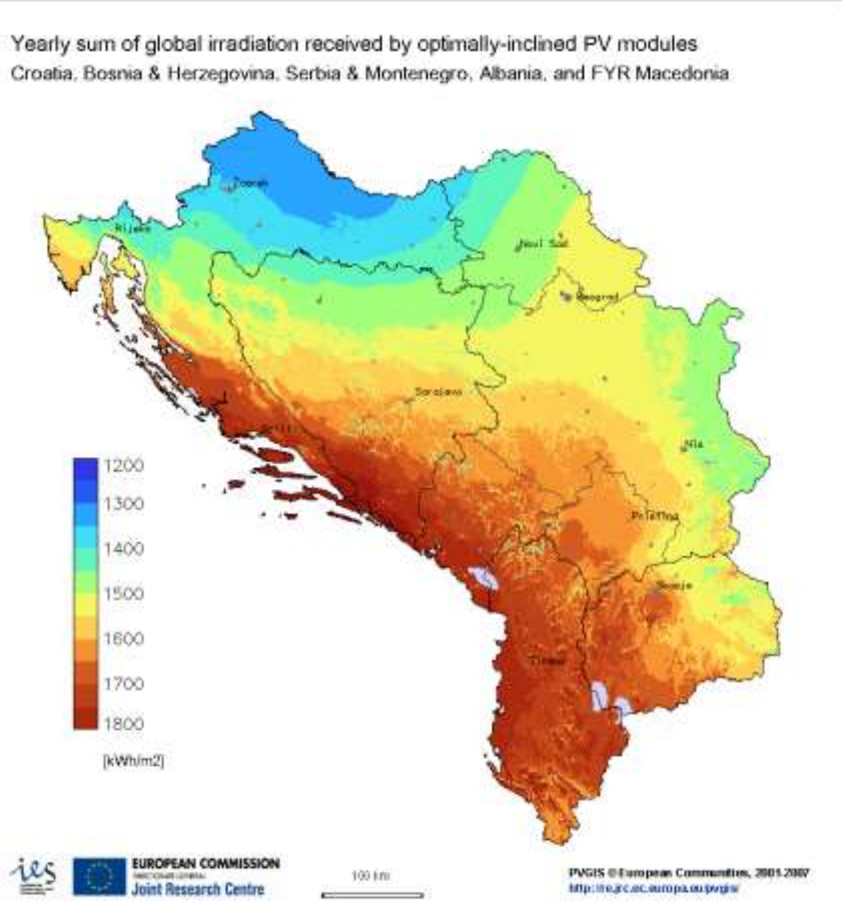
Photovoltaic Solar Electricity Potential in European Countries

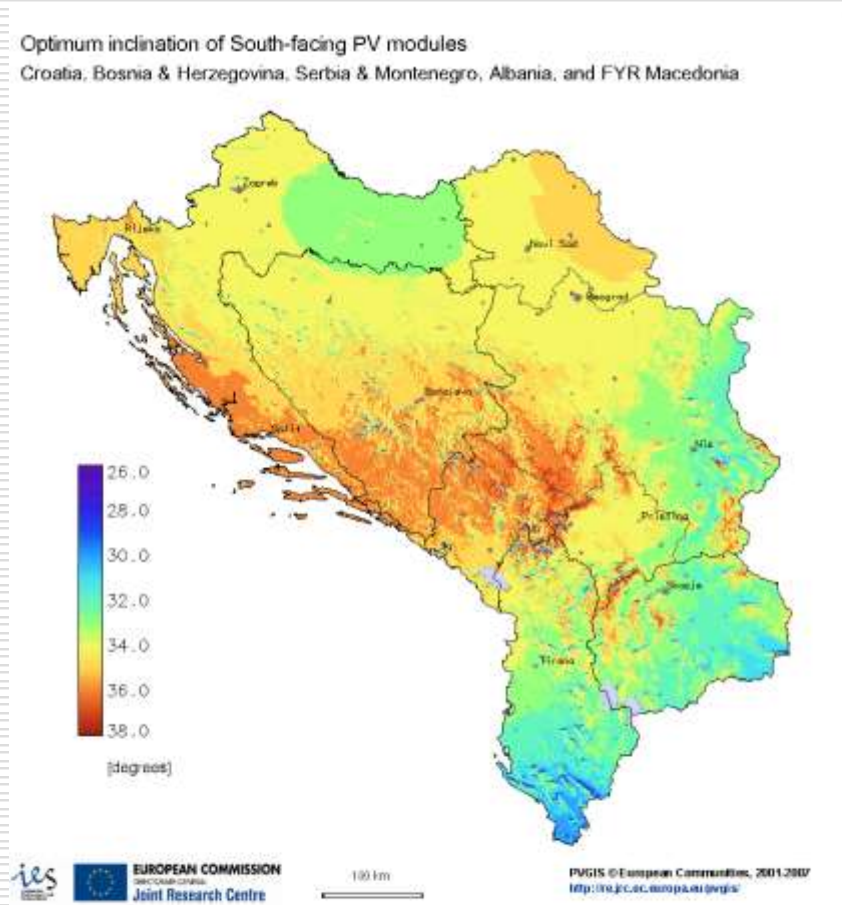


Global Irradiation in high mountains



Global Irradiation – Croatia , Bosnia and Herzegovina





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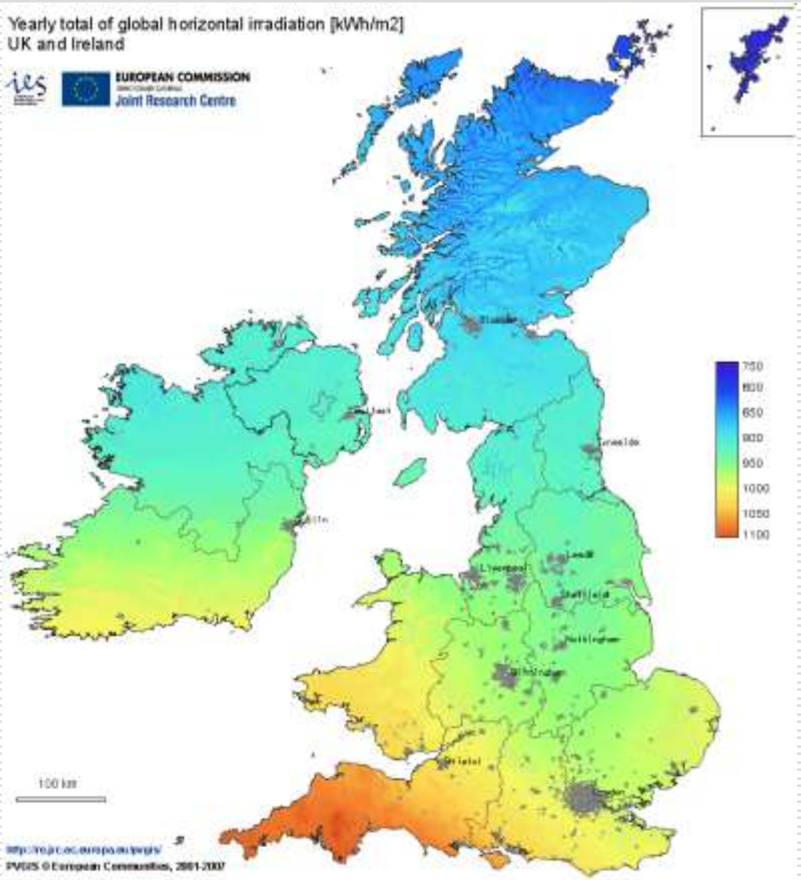
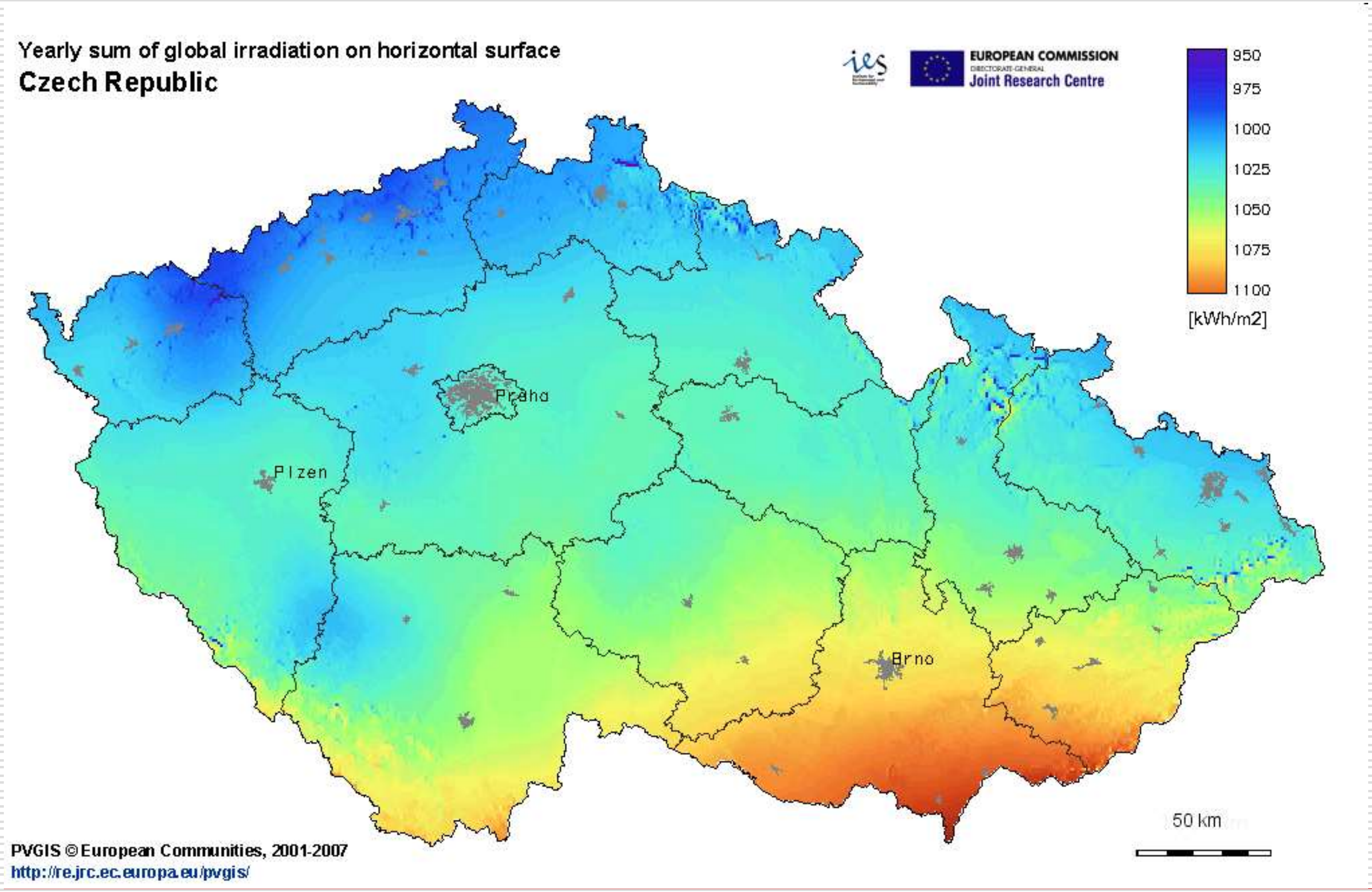
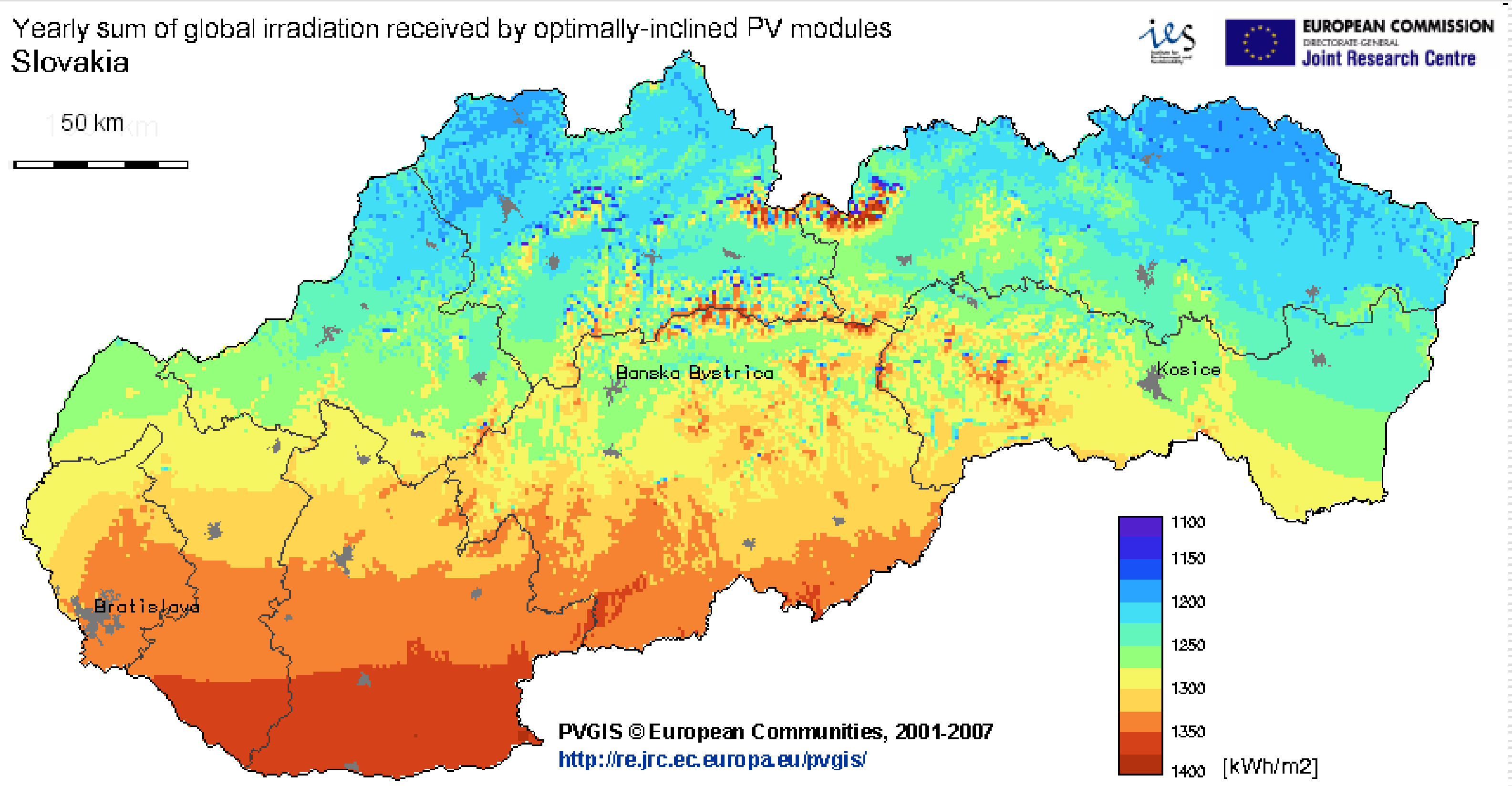
Global Irradiation - UK



Global Irradiation – Czech Republik



Global Irradiation - Slovakia



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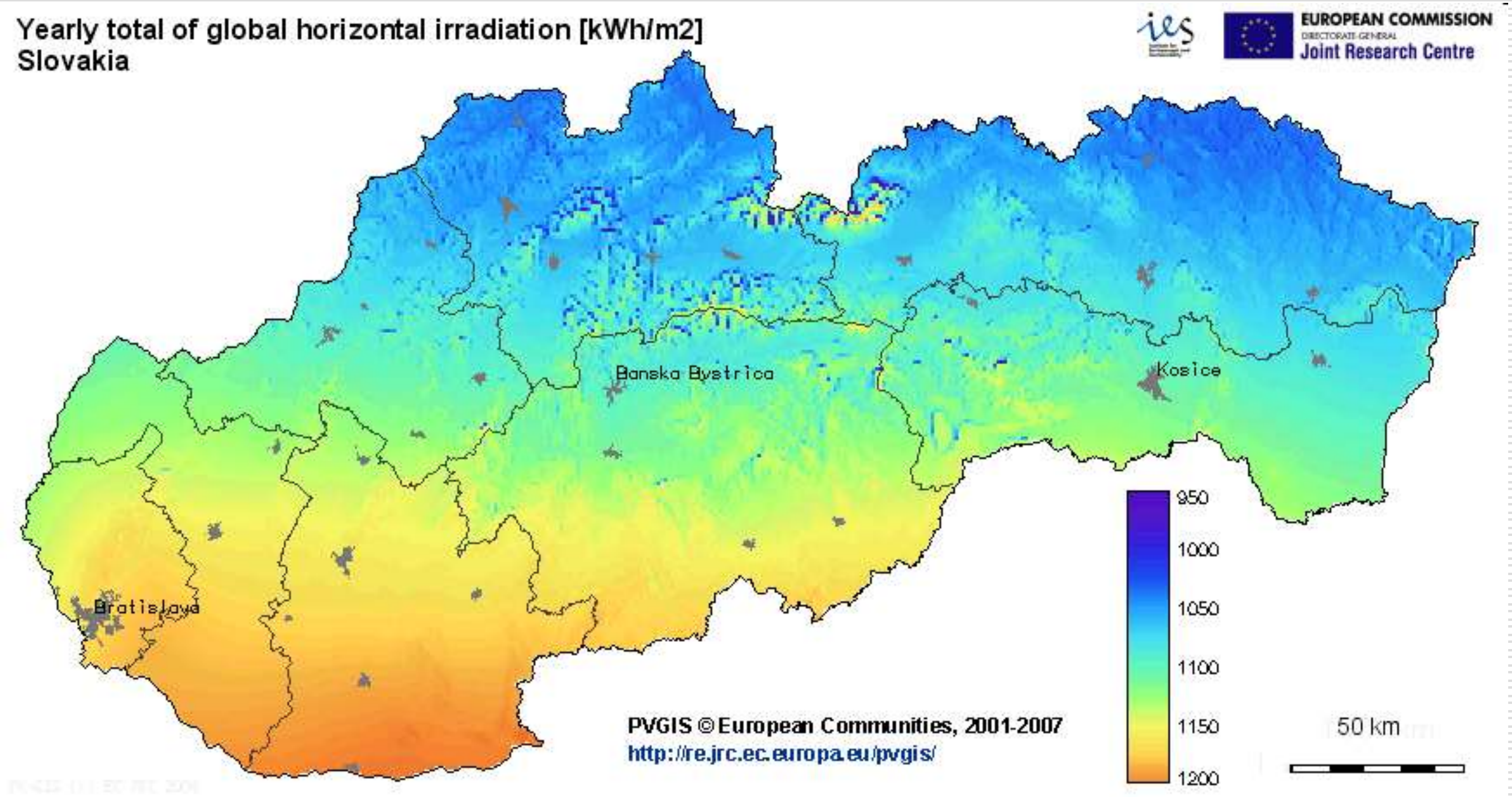
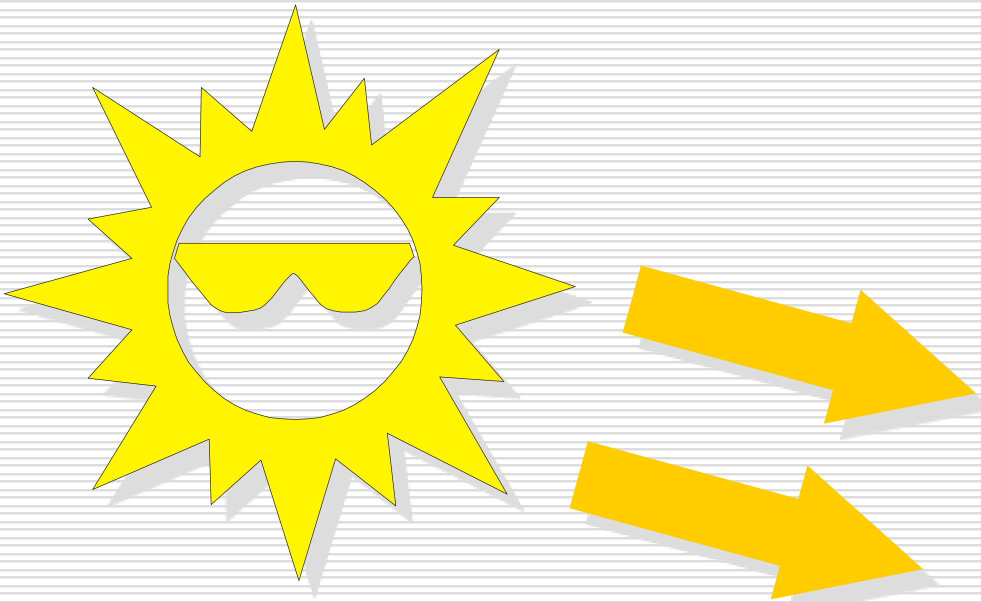
Global Irradiation - Slovakia



4. Photovoltaic Effect

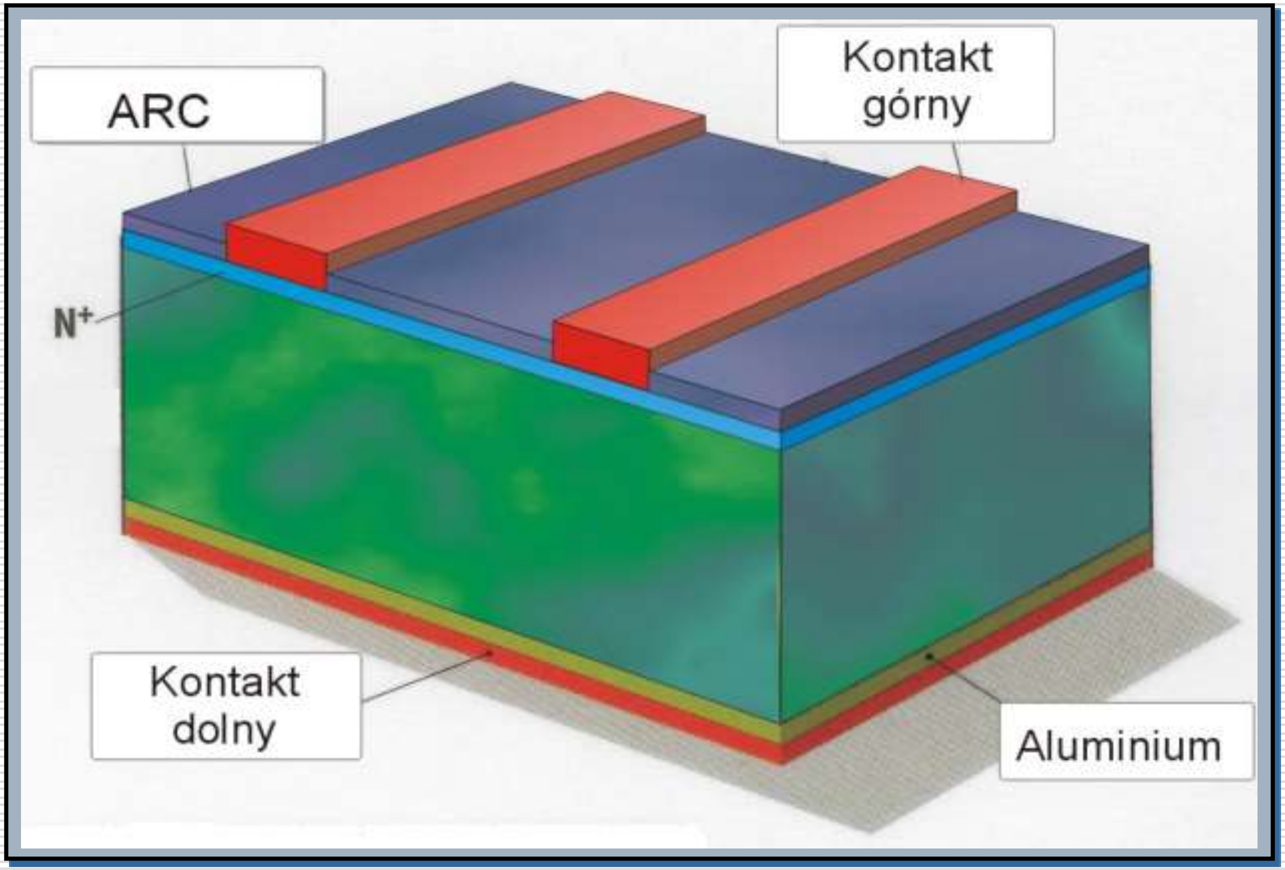
How we can transfer light into electrical current by direct way?



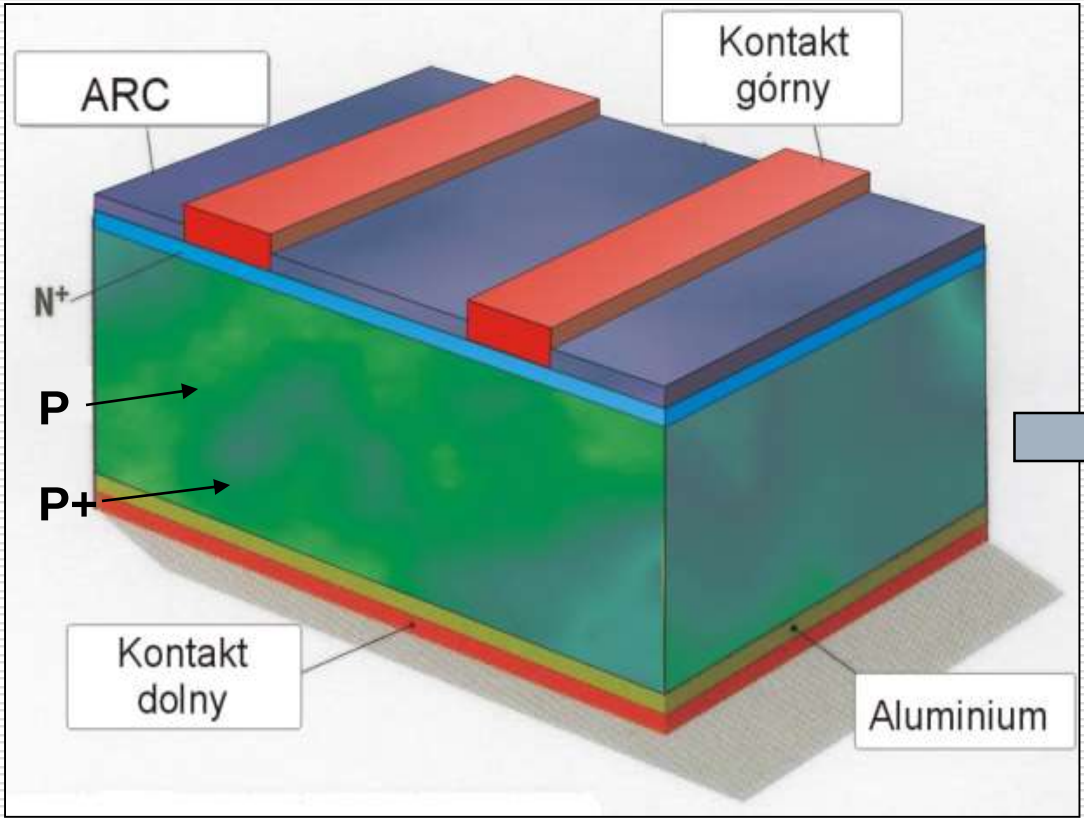
The Sun

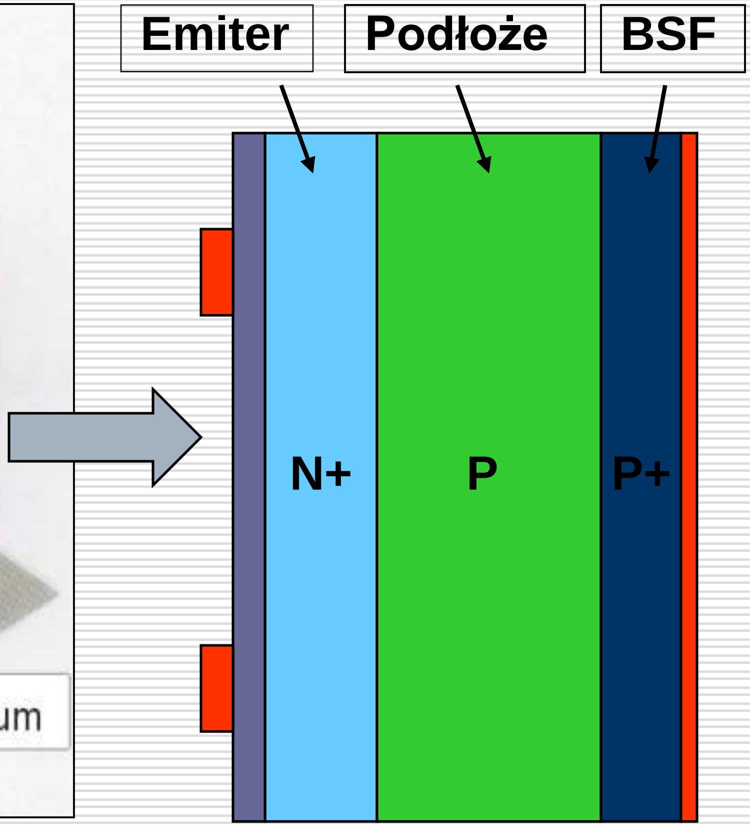
Photovoltaic cells

Crystalline Silicon Solar Cell

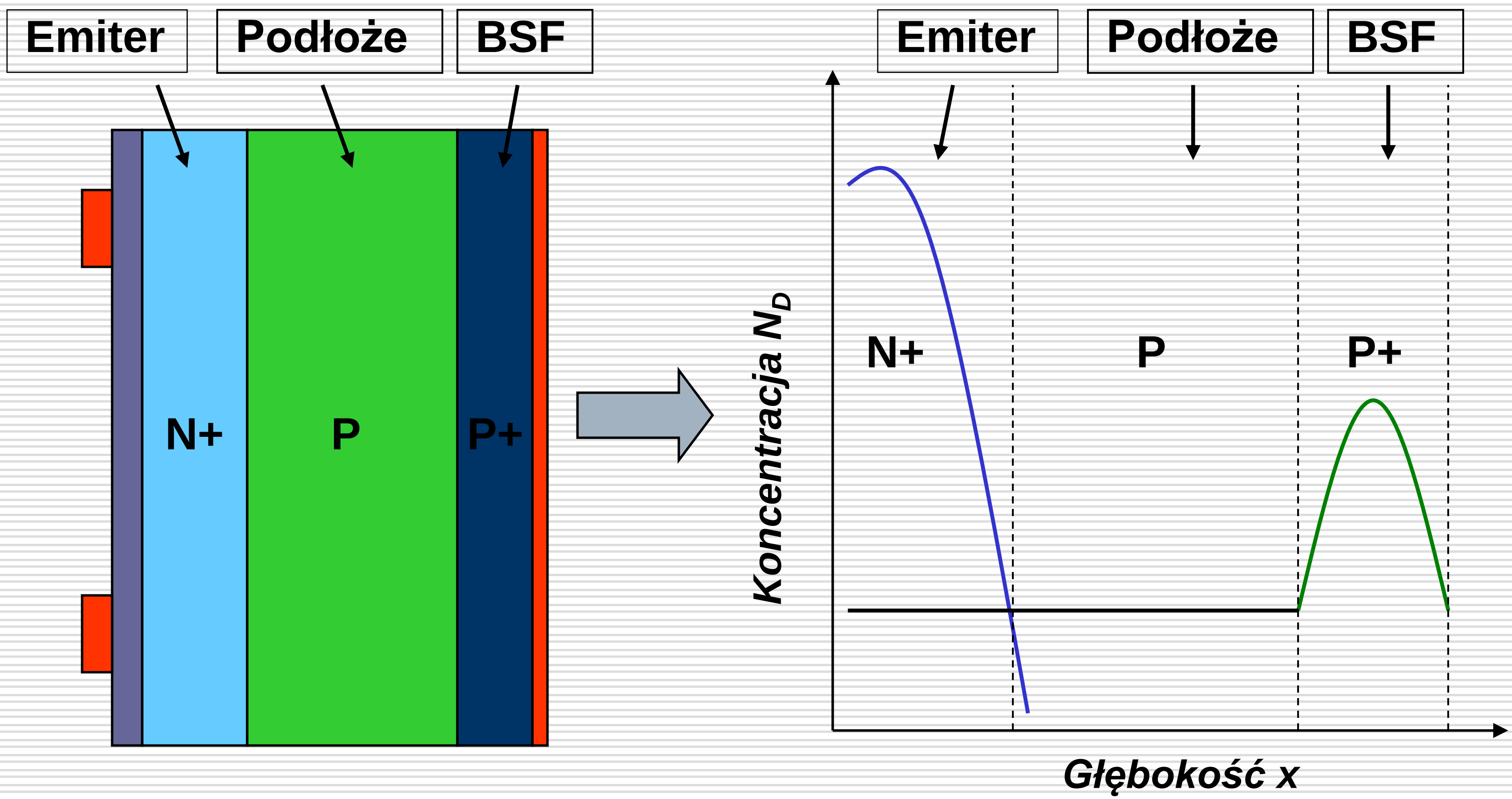


Crystalline Silicon Solar Cell





Crystalline Silicon Solar Cell



Photovoltaic Effect

When a photon hits a piece of silicon, one of three things can happen:

- the photon can pass straight through the silicon — this (generally) happens for lower energy photons,
- the photon can reflect off the surface,
- the photon can be absorbed by the silicon, if the photon energy is higher than the silicon band gap value. This generates an electron-hole pair and sometimes heat, depending on the band structure.

Band diagram of a silicon solar cell, under short circuit conditions.

When a photon is absorbed, its energy is given to an electron in the crystal lattice. Usually this electron is in the valence band, and is tightly bound in covalent bonds between neighboring atoms, and hence unable to move far. The energy given to it by the photon "excites" it into the conduction band, where it is free to move around within the semiconductor.

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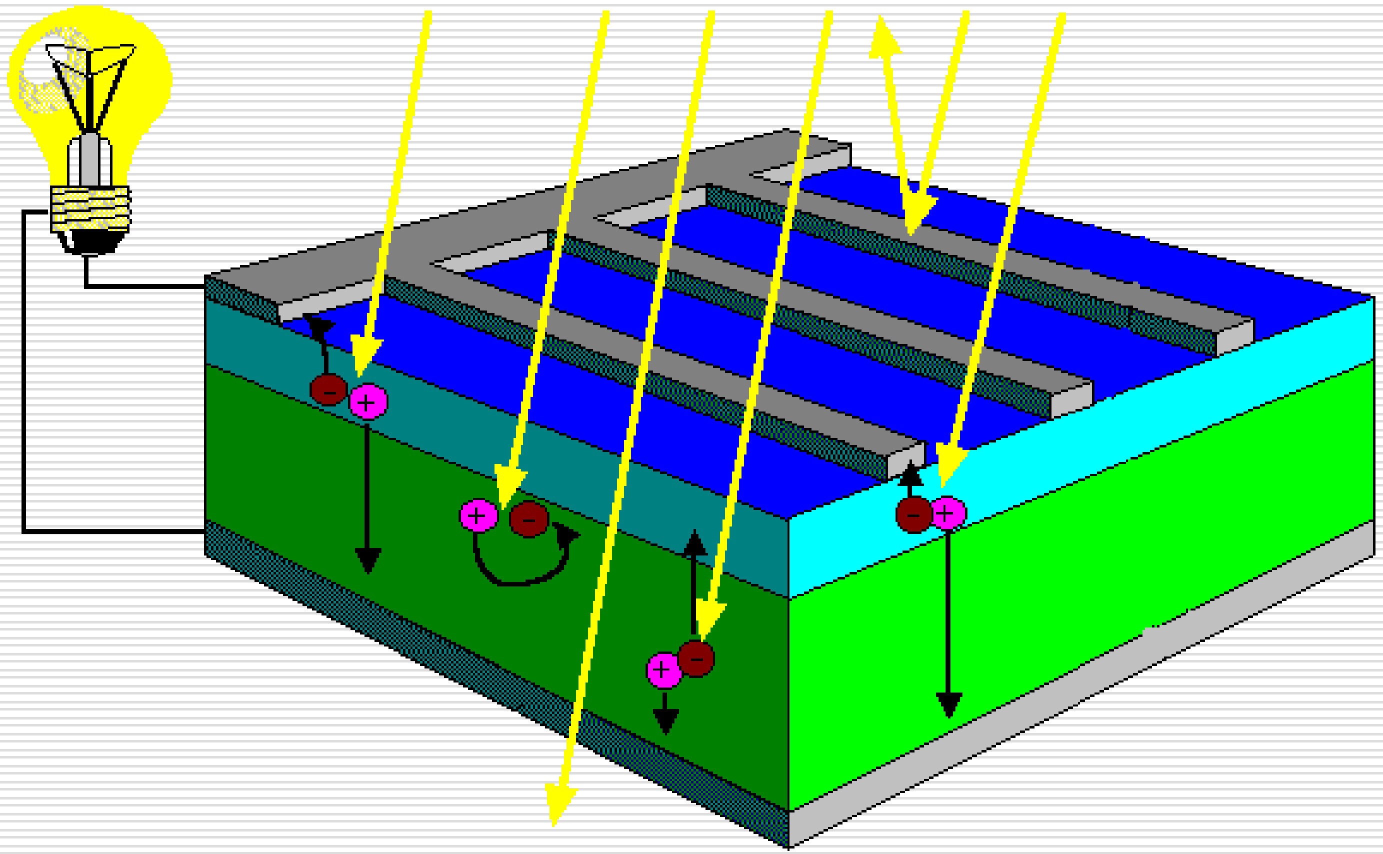
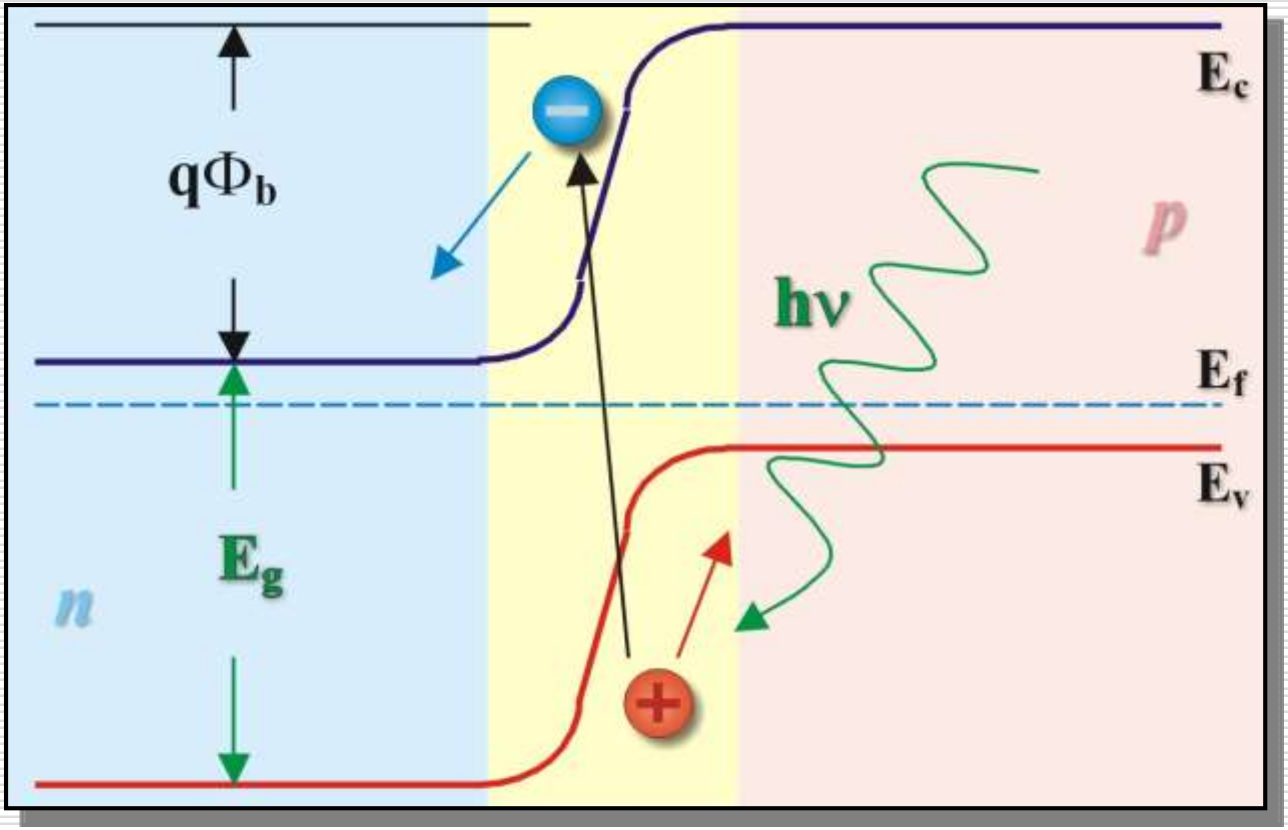
Photovoltaic Effect

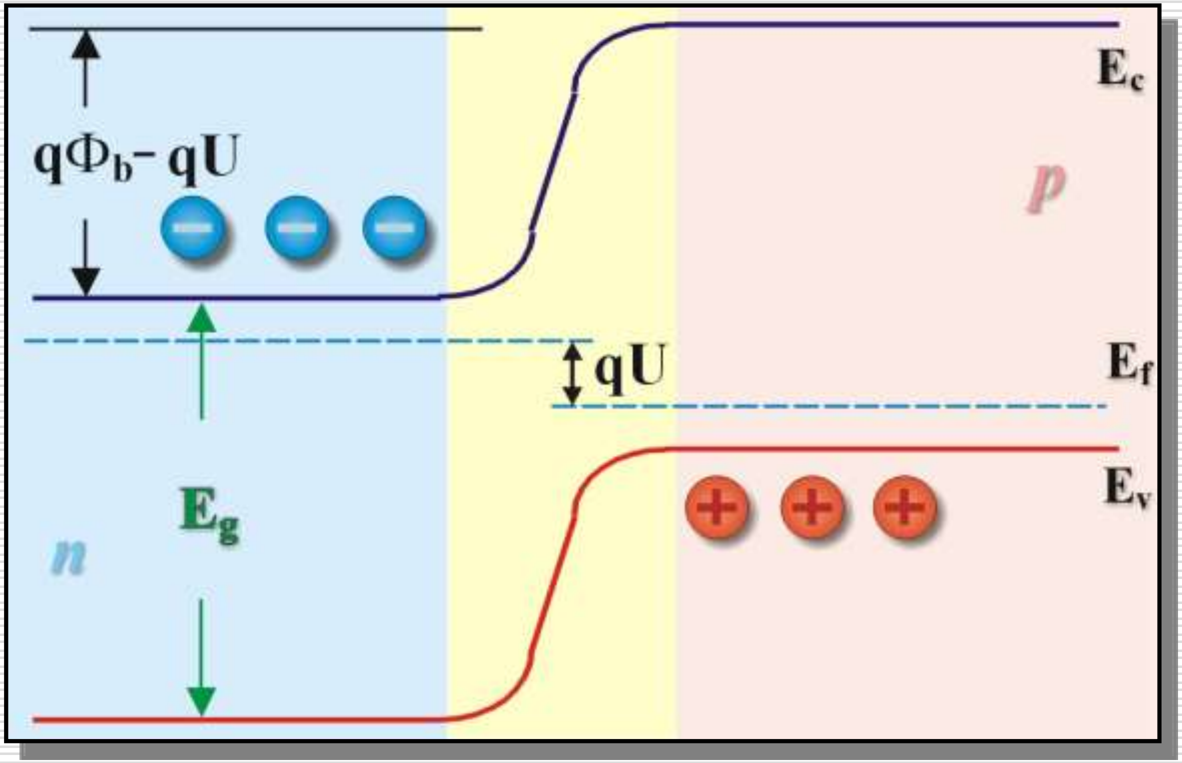


Photovoltaic Effect



Photovoltaic Effect

$$h\nu \geq E_g$$



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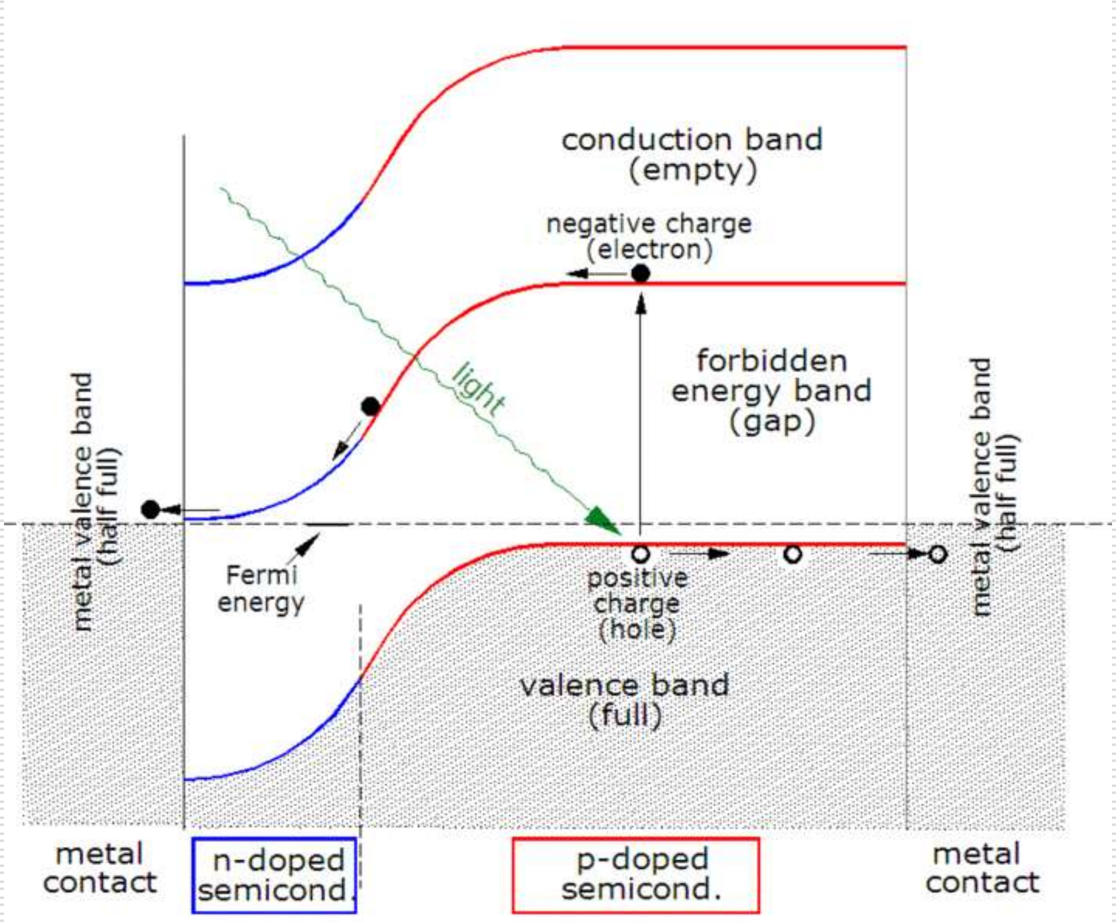

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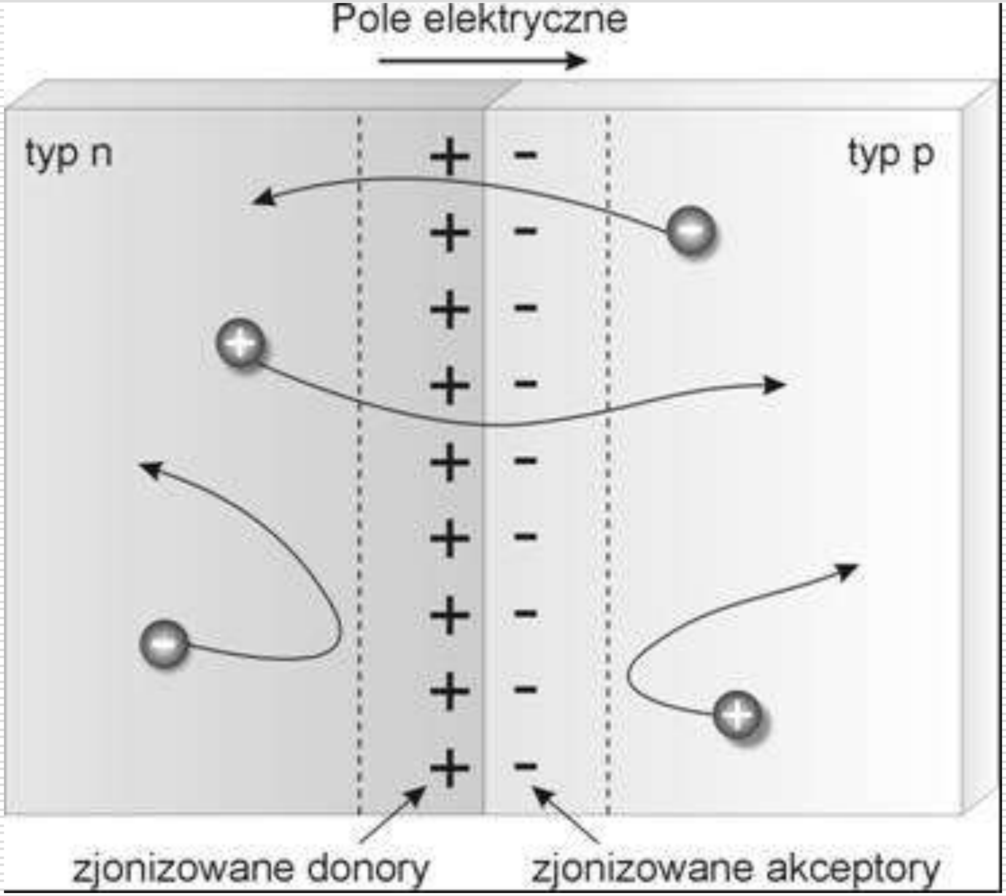

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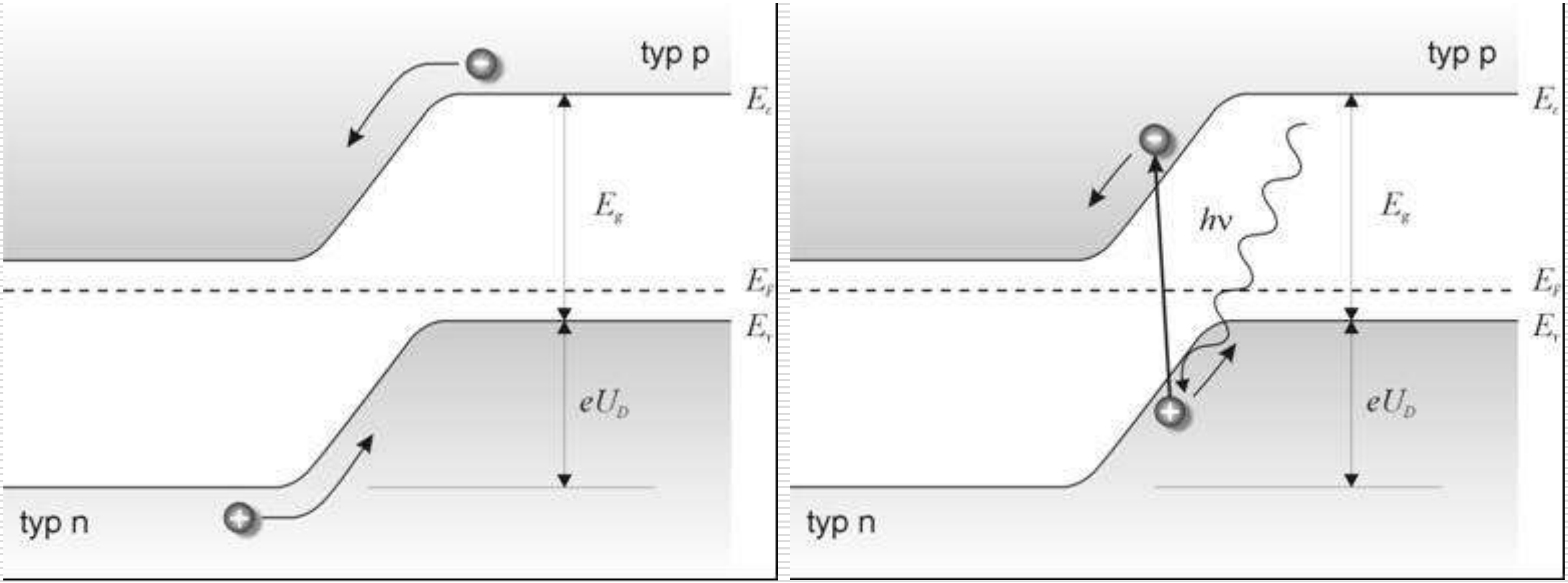

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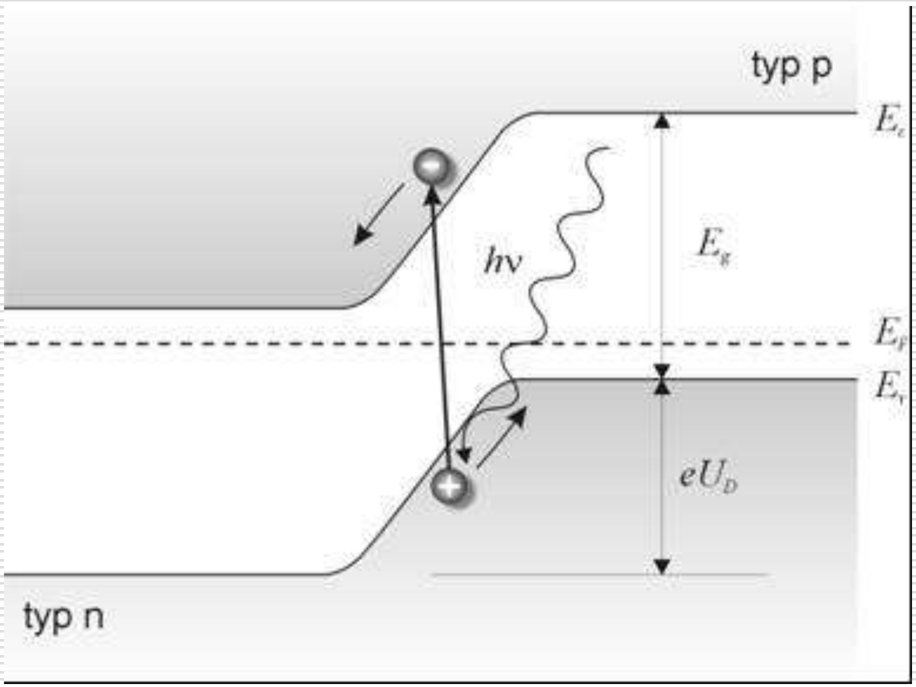
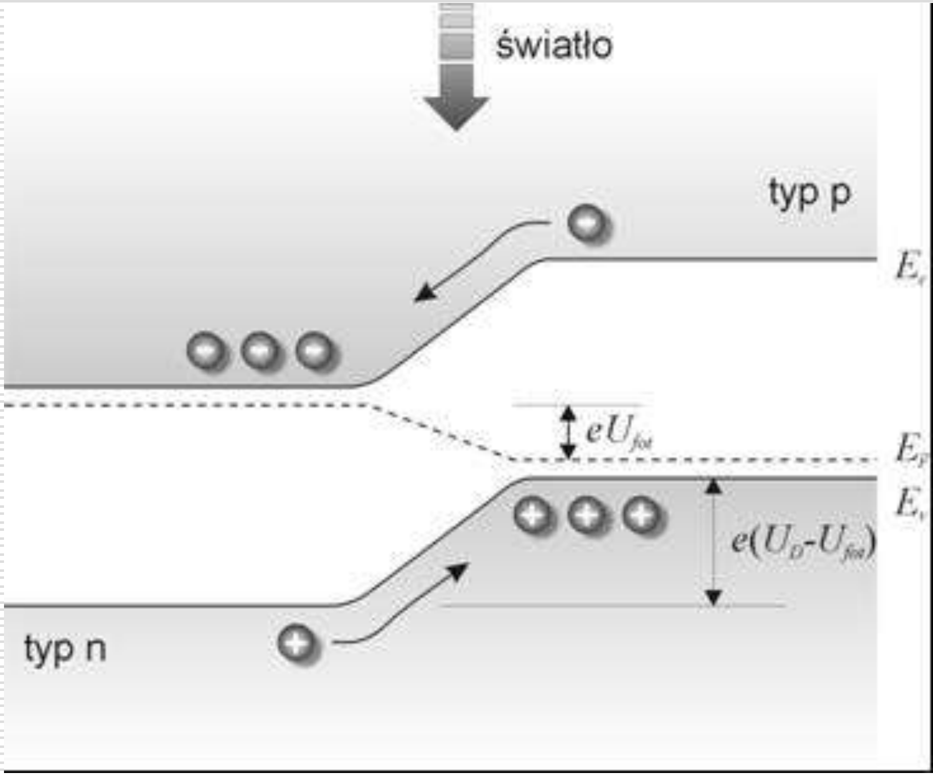
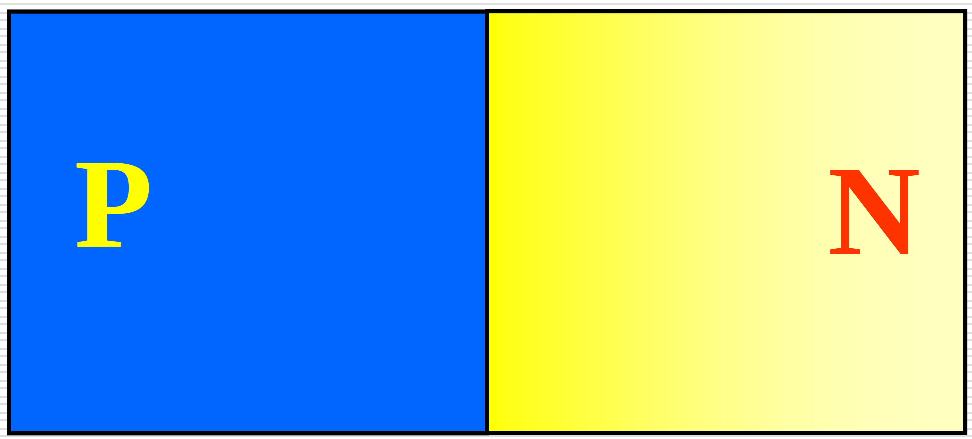
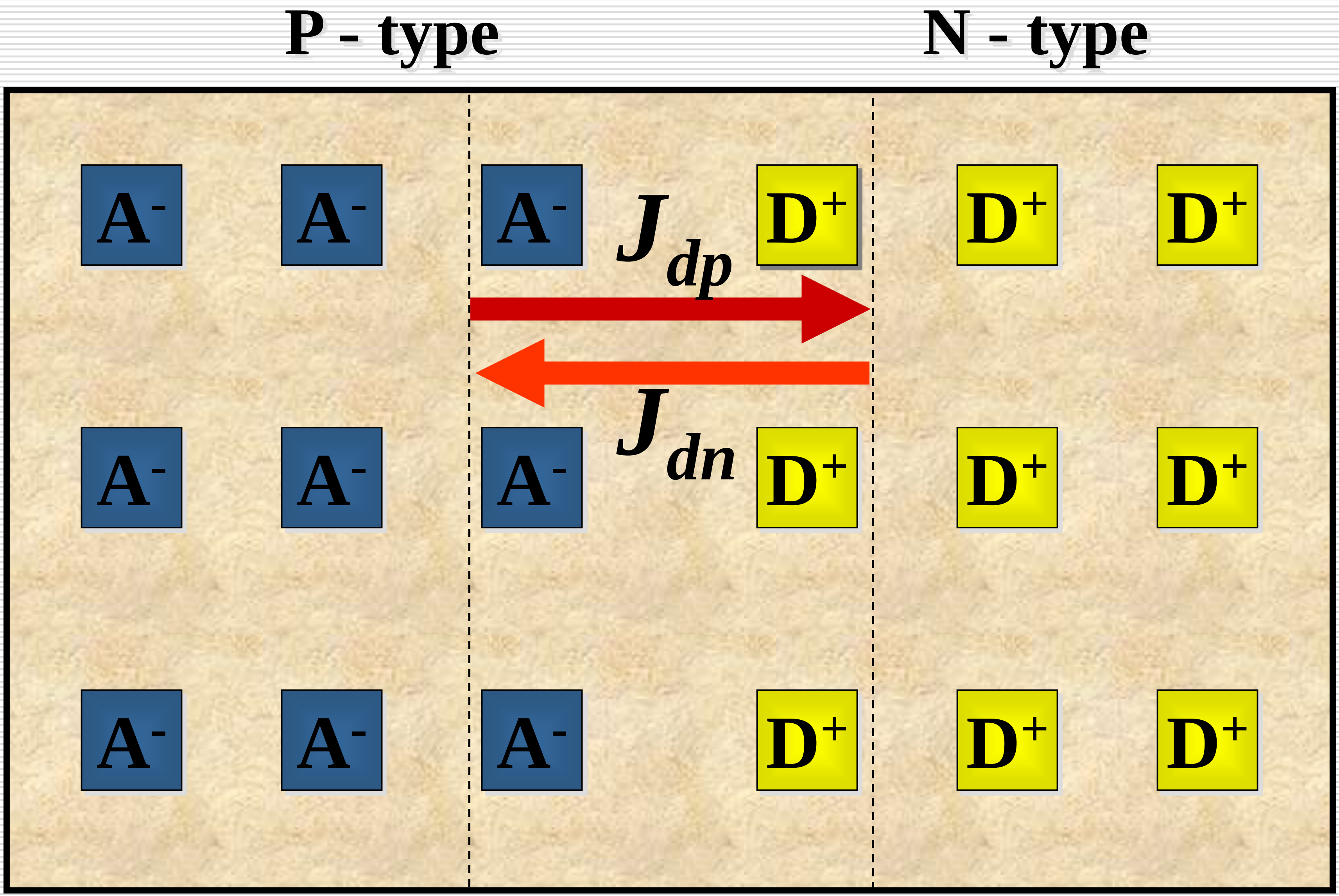


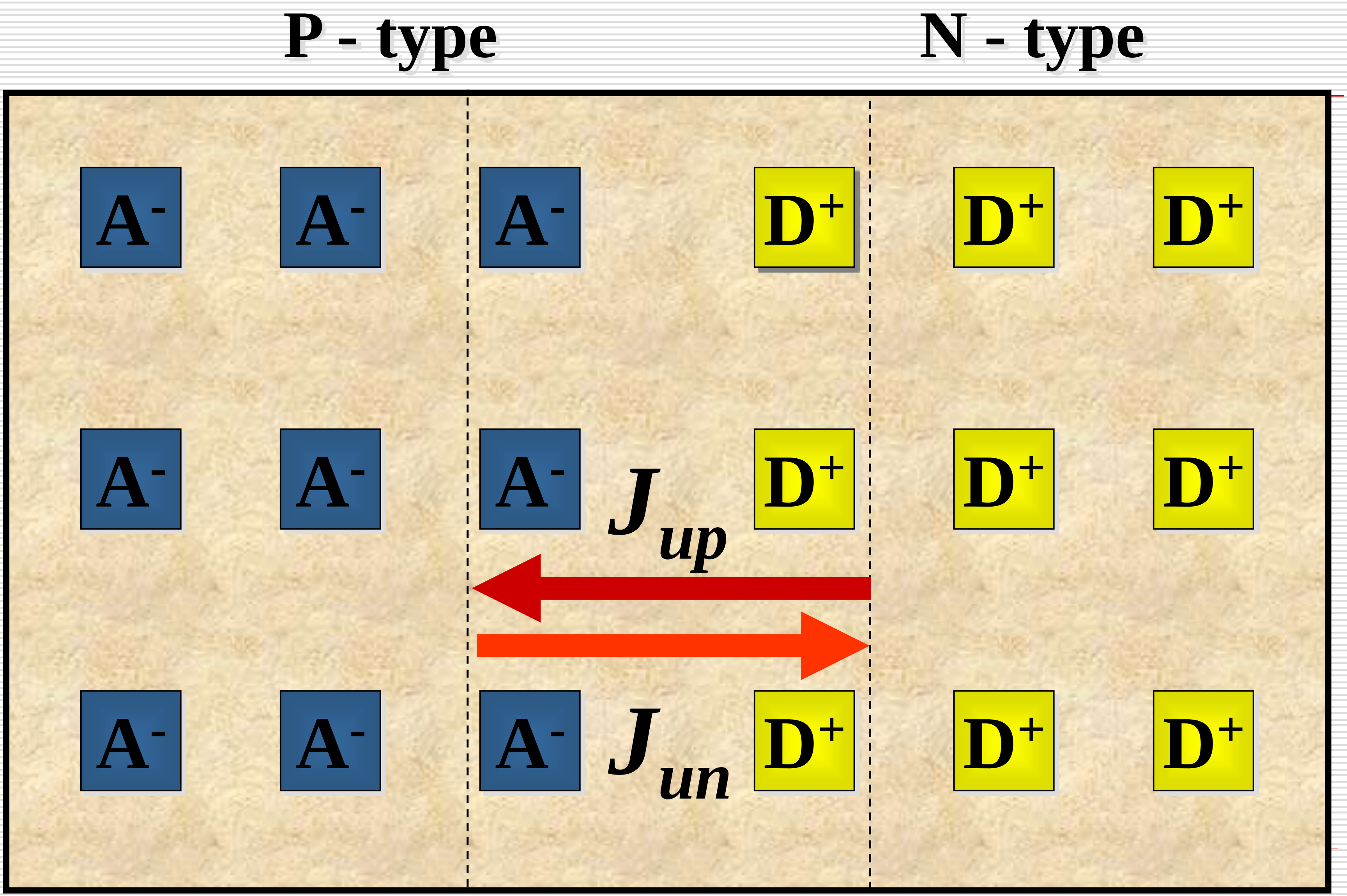


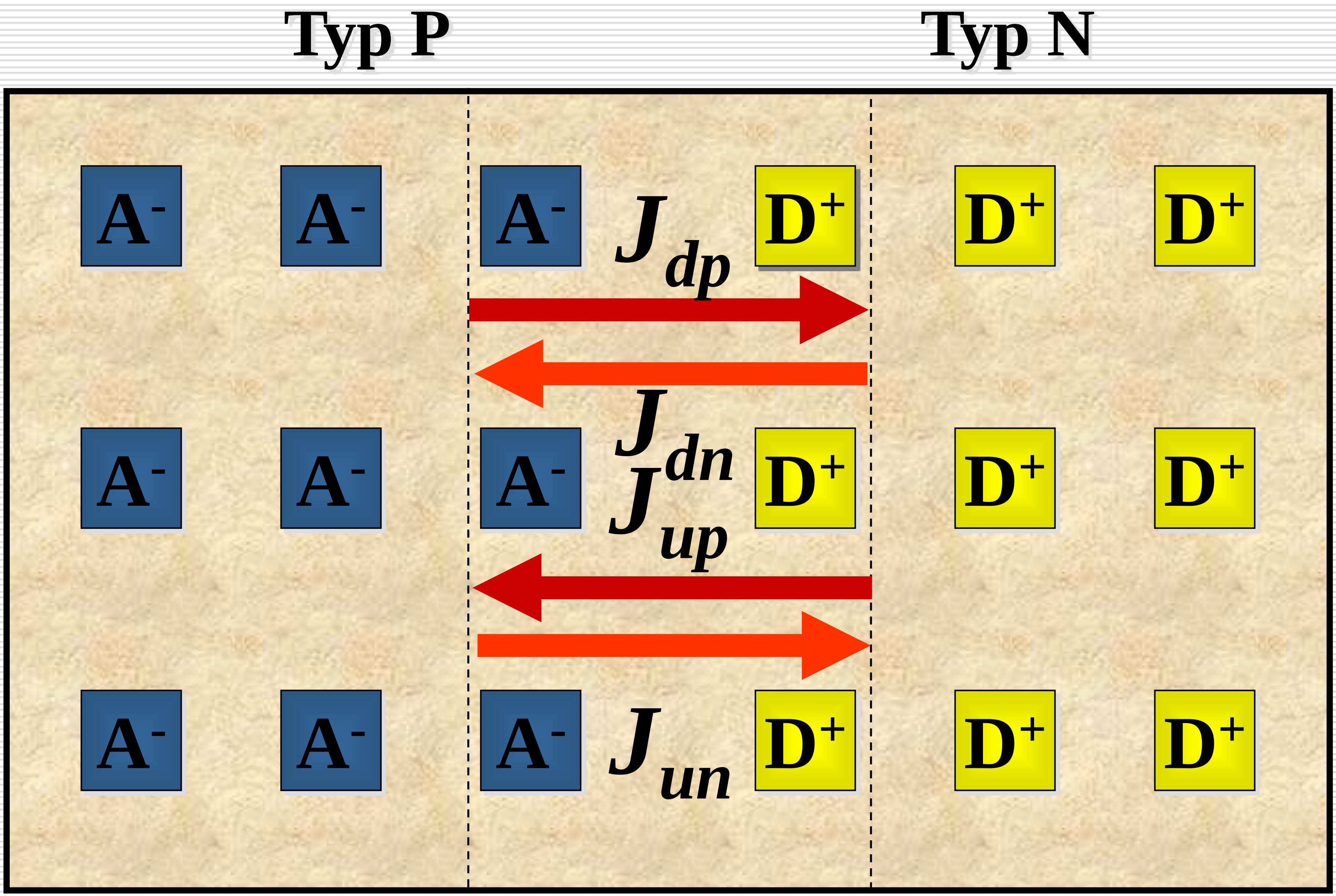
The P – N junction



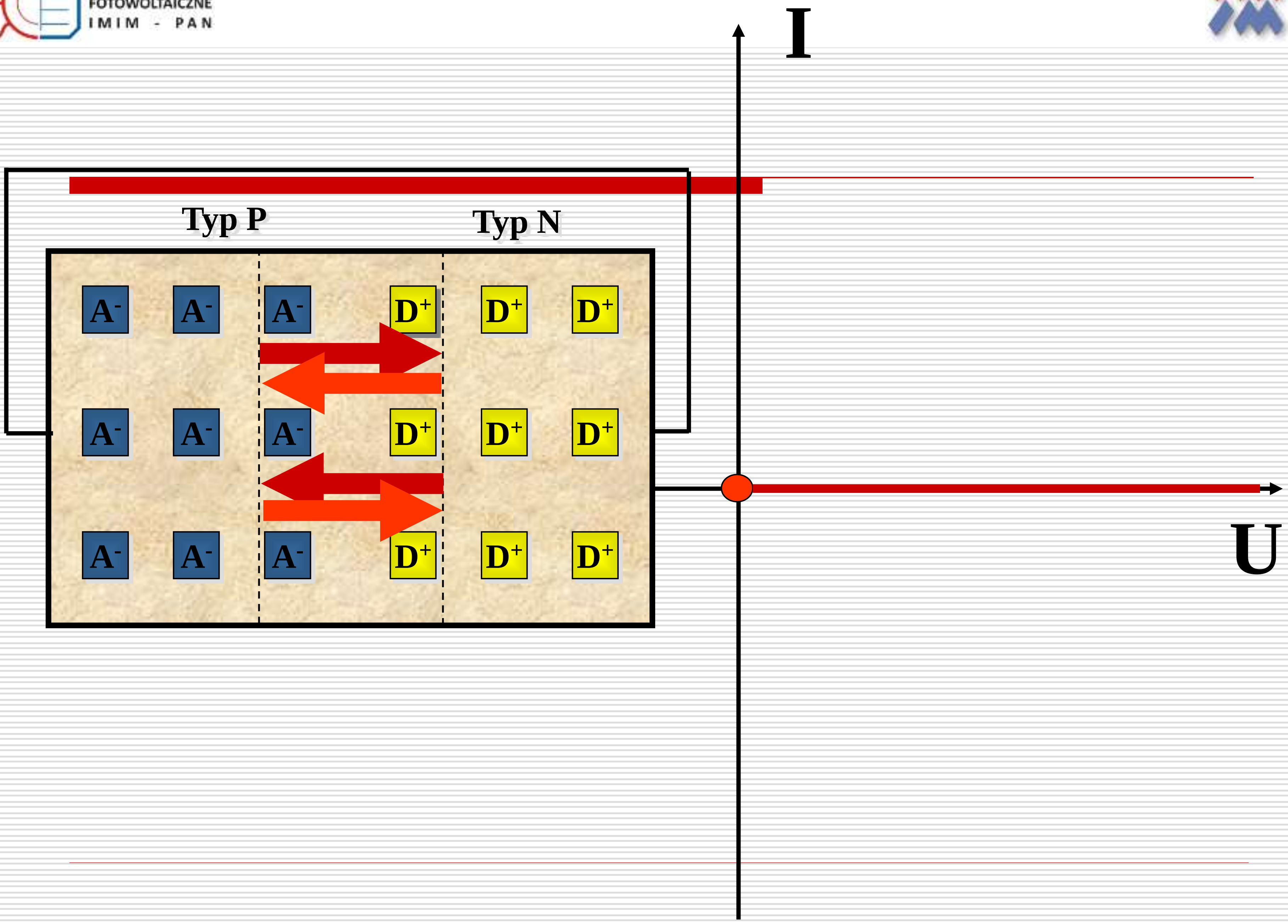
positive negative


P - type
N - type
A-
A-
A-
J dp
D+
D+
D+
A-
A-
A-
J dn
D+
D+
D+
A-
A-
A-
D+
D+
D+

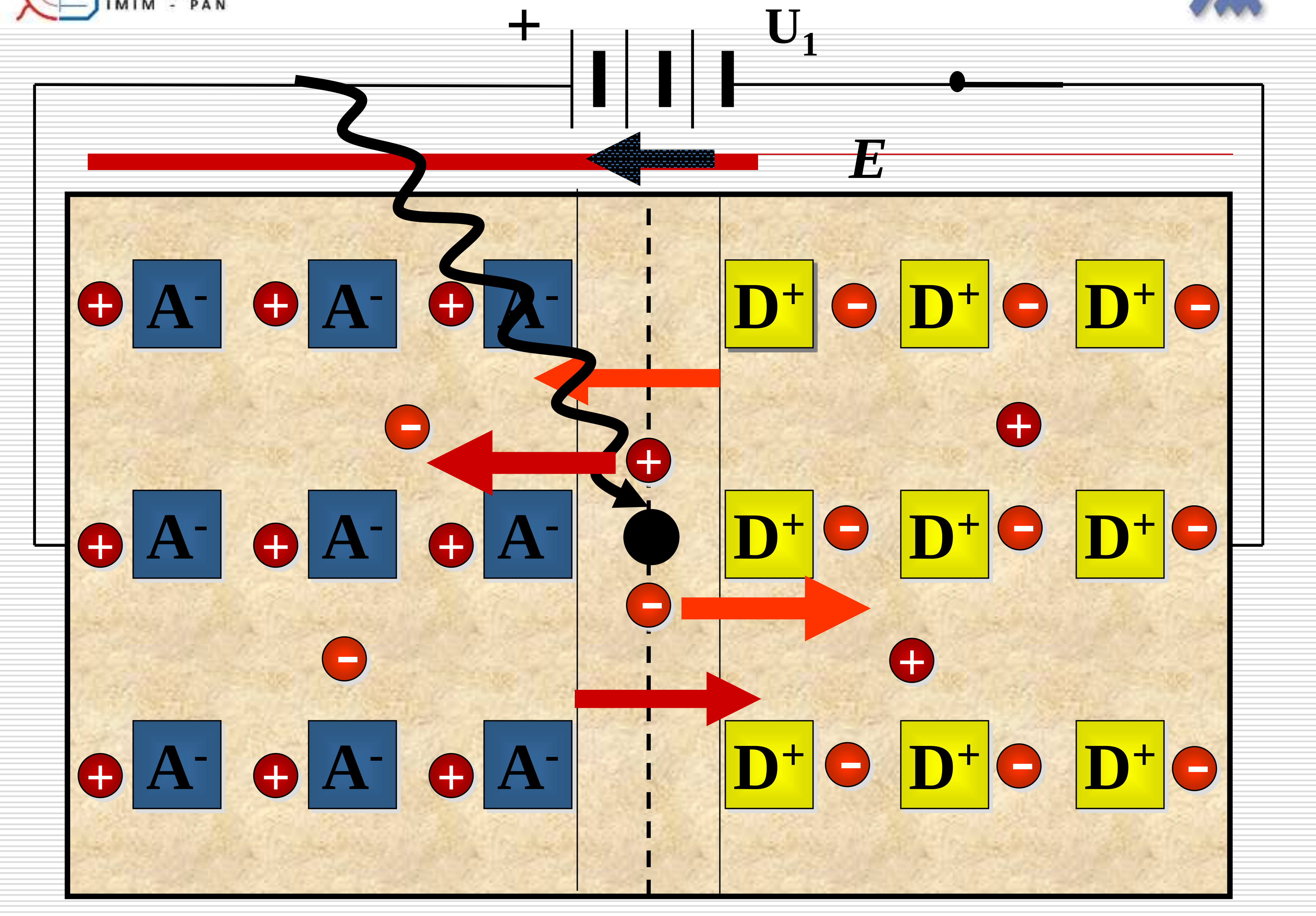

P - type
N - type
A-
D+
J_{up}
J_{un}

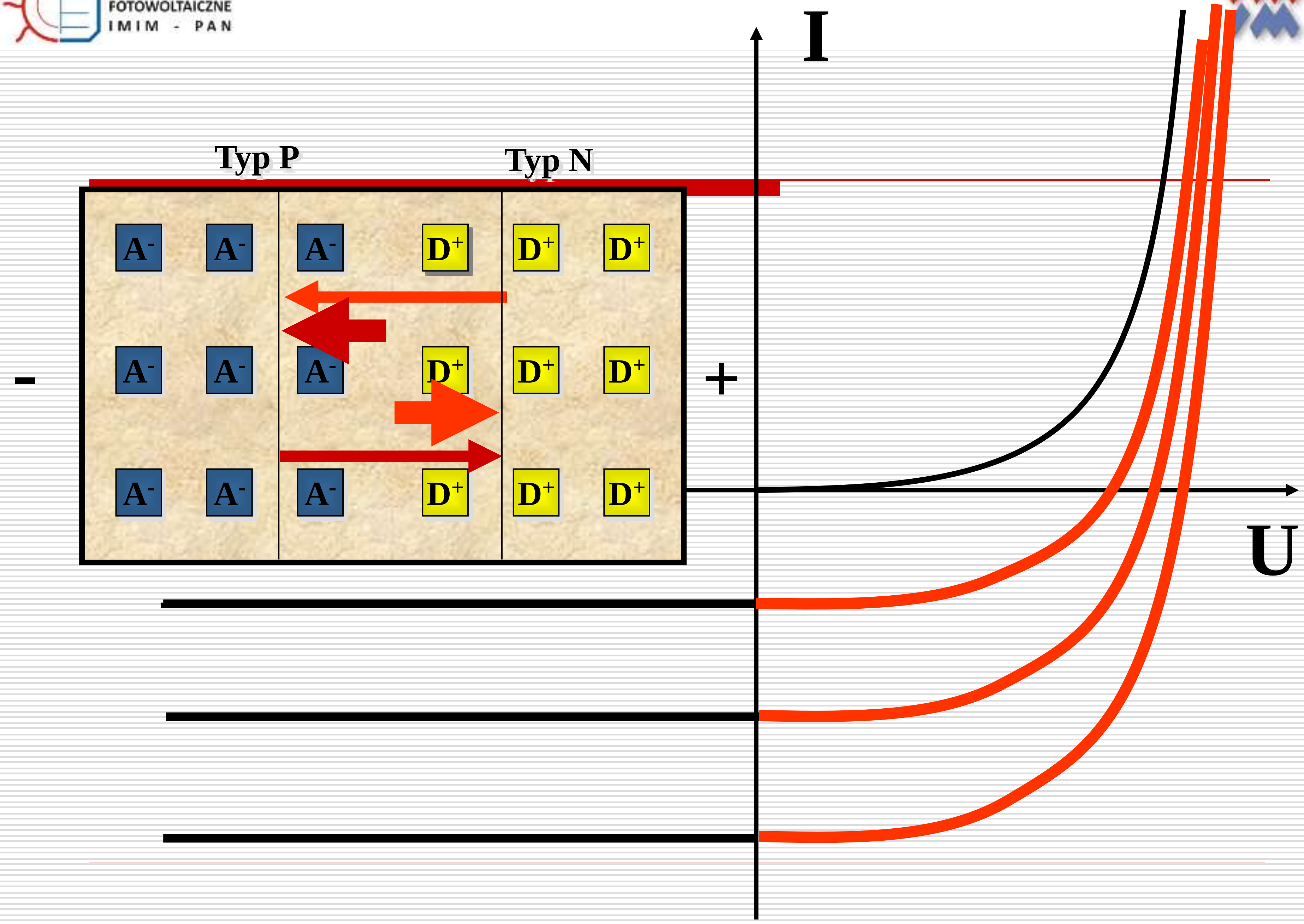


$$J_{dp} = J_{up} \quad ; \quad J_{dn} = J_{un}$$



Typ P
Typ N
A-
D+
I
U


+
U1
E
A-
A-
A-
A-
A-
A-
A-
A-
A-
D+
D+
D+
D+
D+
D+
D+
D+
D+



Typ P
Typ N
A-
D+
-
+
I
U