NTU
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وزارة التعليم العالي والبحث
العلمي/ جمهورية العراق
الجامعة التقنية الشمالية

الكلية التقنية الهندسية / الموصل
قسم هندسة تقنيات ميكانيك القوى

الطاقة المتجددة

المحاضرة الاولى: مقدمة عن انواع مصادر التقليدية والمتجددة الطاقة

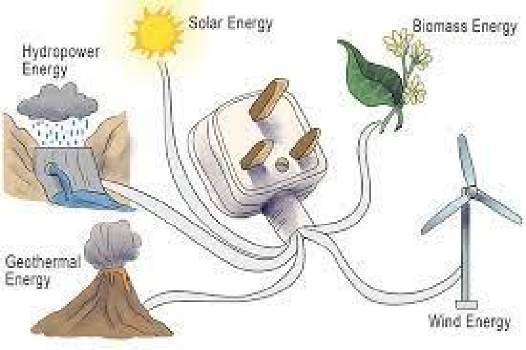
مدرس المادة: د. عمر عبد الهادي مصطفى

Traditional Energy sources

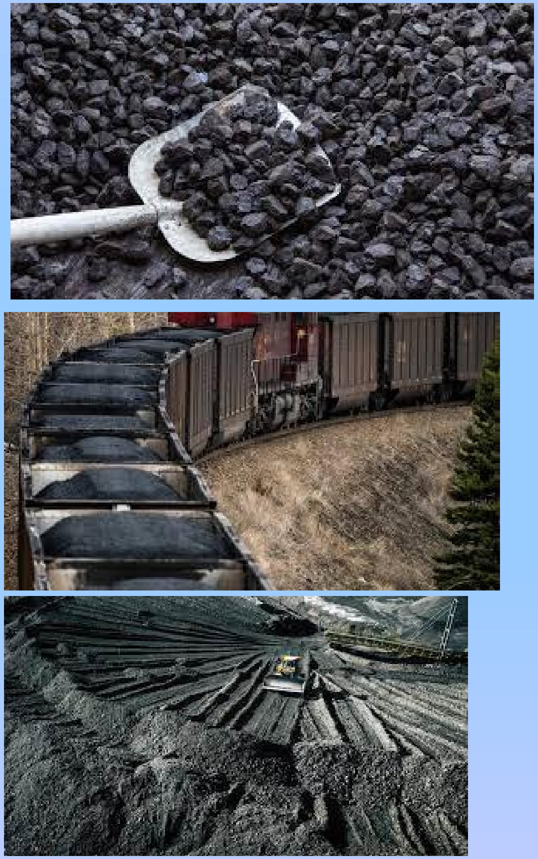
Types of common fuels

Liquid Hydrocarbons-Petroleum (oil)

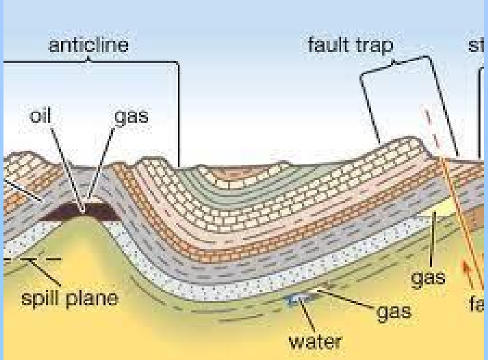
Others



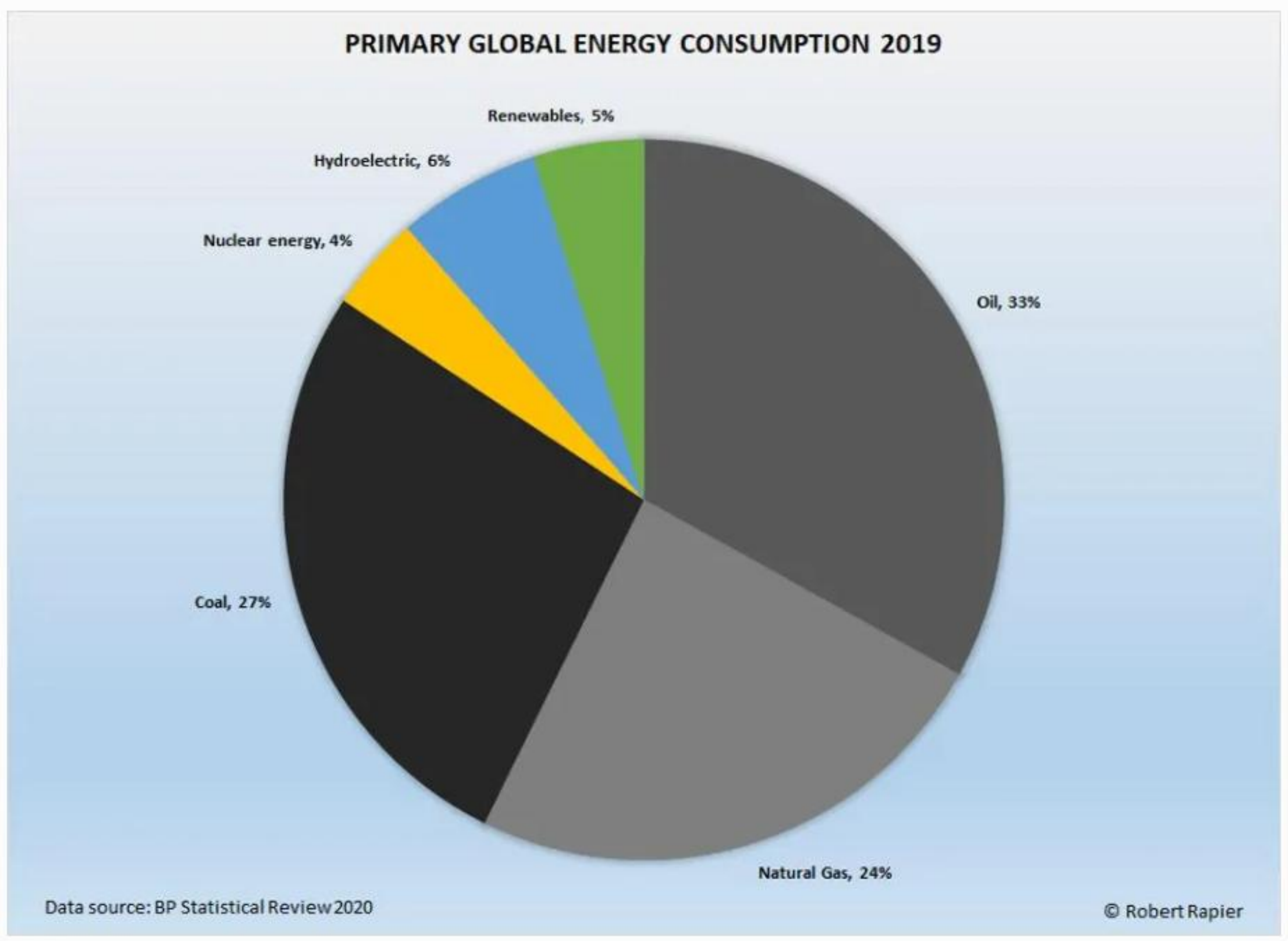
Coal



Natural Gas



Traditional Energy sources



Data source: BP Statistical Review 2020

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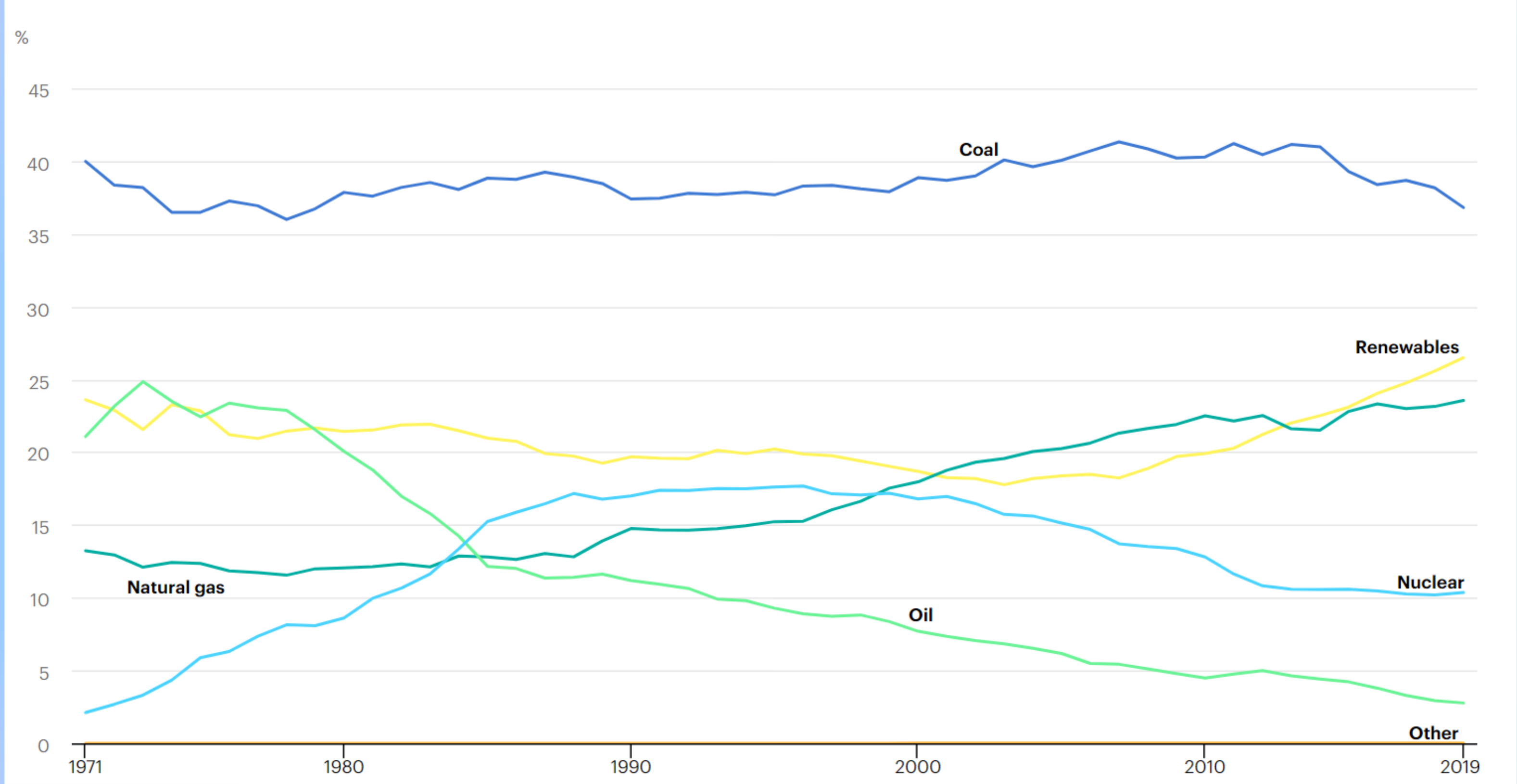
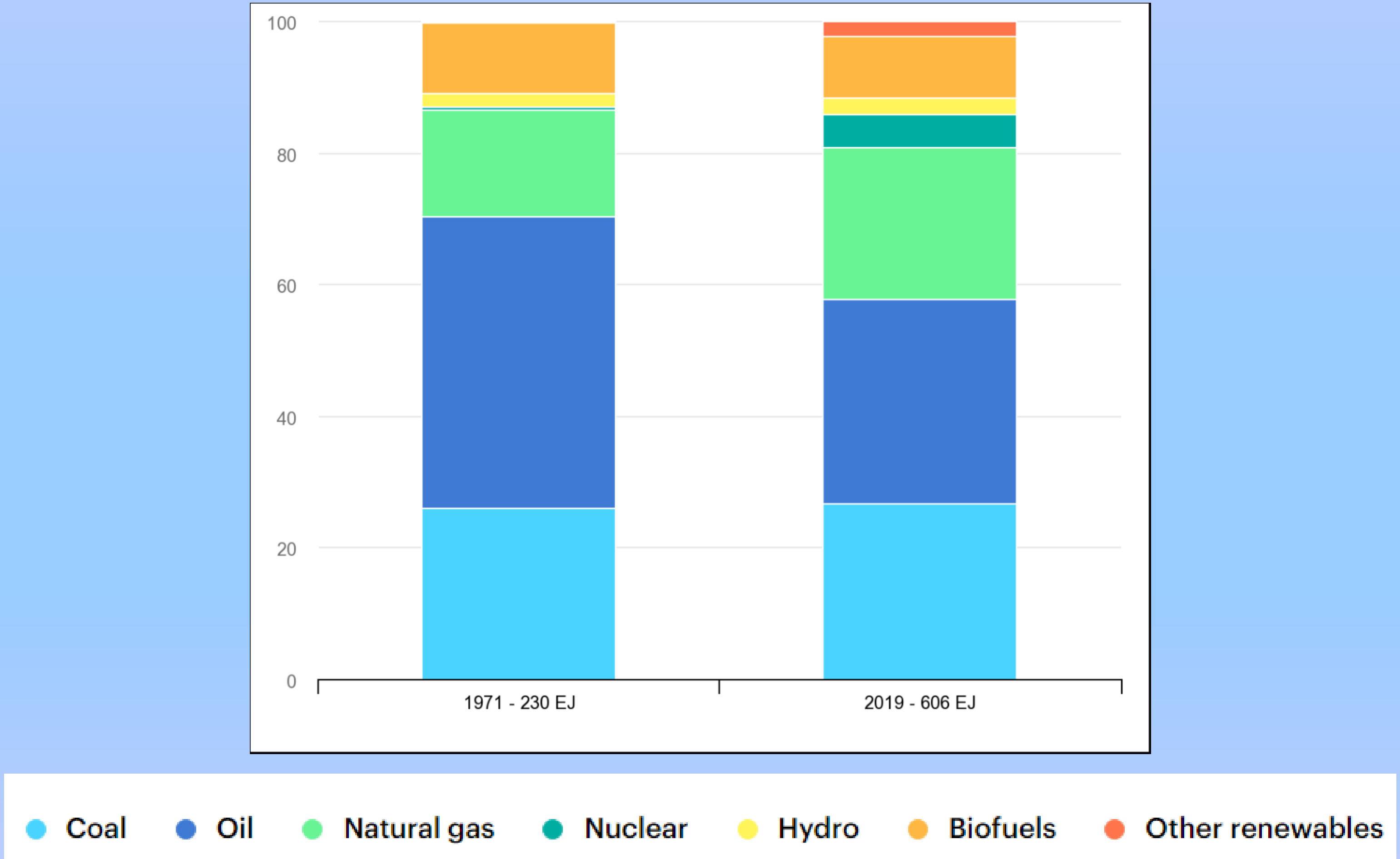
Traditional Energy sources

World electricity generation mix by fuel, 1971-2019



Traditional Energy sources

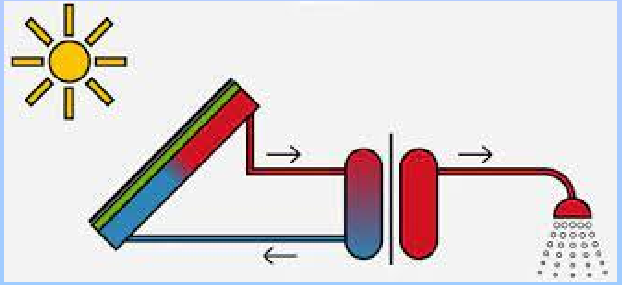
Total primary energy supply by fuel, 1971 and 2019

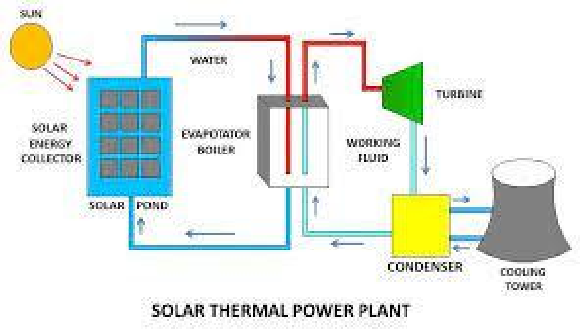


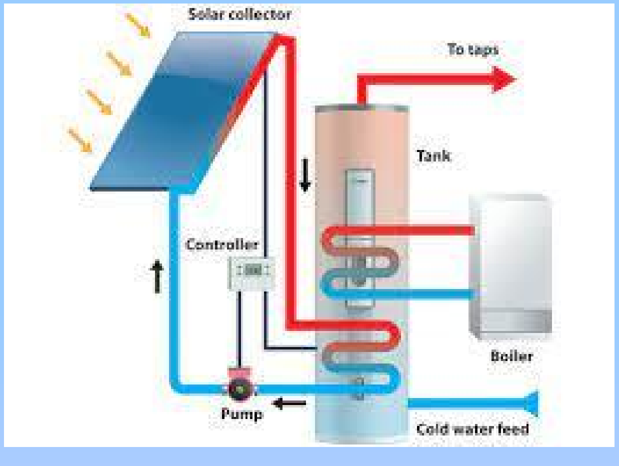
Renewable Energy Resources

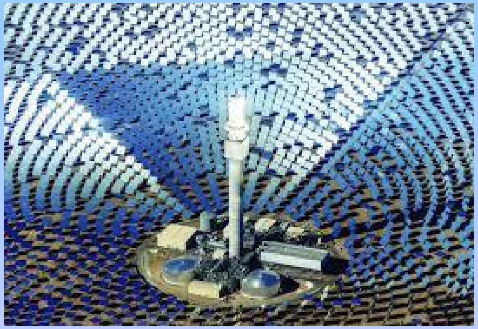
1. Solar energy
2. Wind energy
3. Biomass & Biofuels
4. Geothermal energy
5. Tidal energy
6. Fuel cell
7. Ocean energy conversion
8. Ocean waves energy
9. Hydro-power energy
10. Hydrogen energy

Solar energy

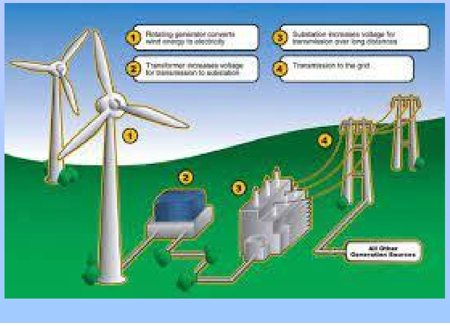


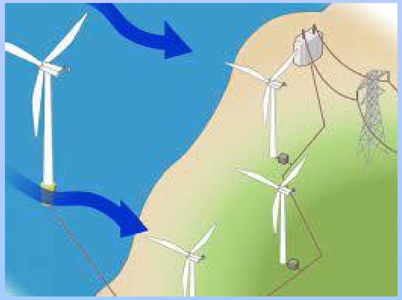


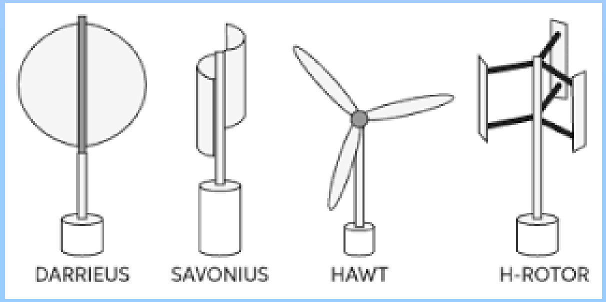


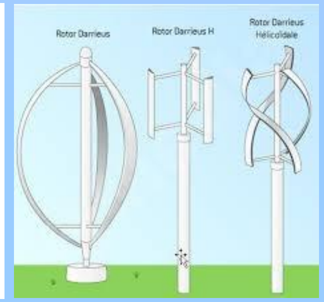


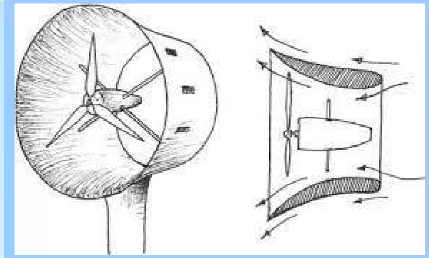
Wind energy


1 Rotating generator converts wind energy to electricity
2 Transformer increases voltage for transmission to substation
3 Substation increases voltage for transmission over long distances
4 Transmission to the grid
All Other Generation Sources

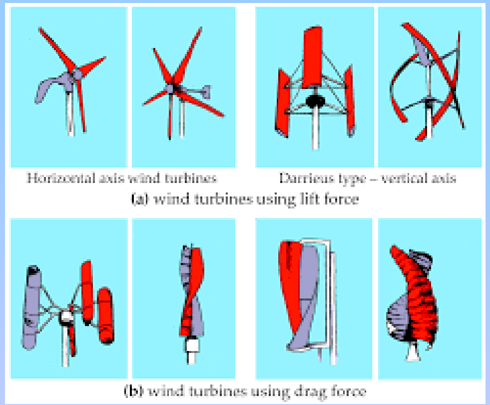



DARRIEUS
SAVONIUS
HAWT
H-ROTOR


Rotor Darrieus
Rotor Darrieus H
Rotor Darrieus Hélicoïdale

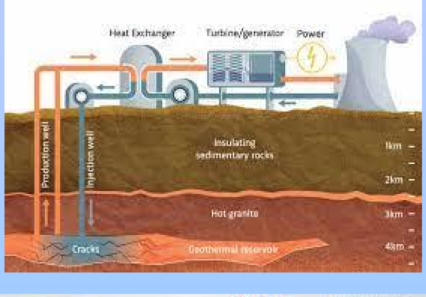


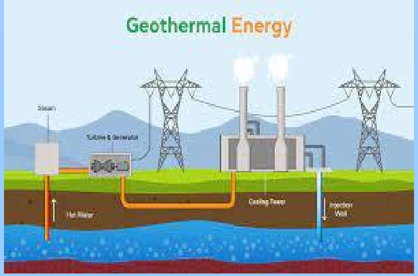

(a)
(b)

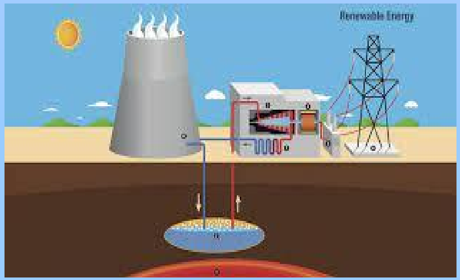

Horizontal axis wind turbines
Darrieus type – vertical axis
(a) wind turbines using lift force
(b) wind turbines using drag force

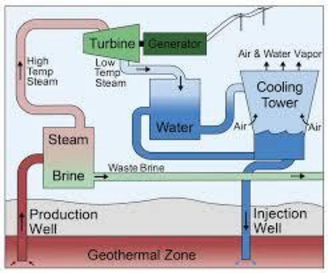
Biomass & Biofuels

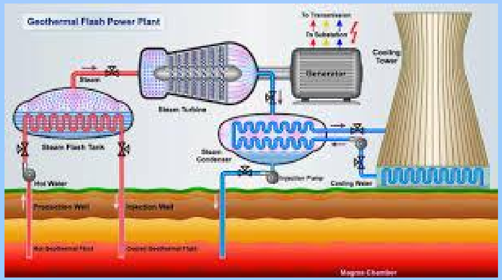
Geothermal energy

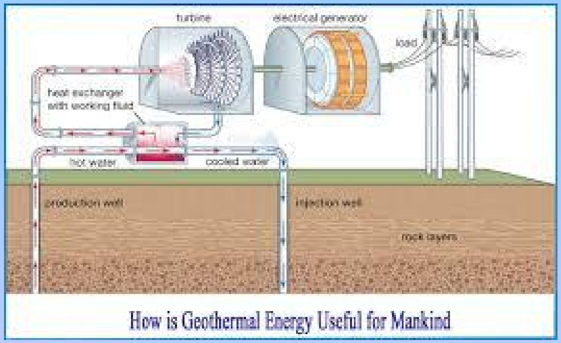




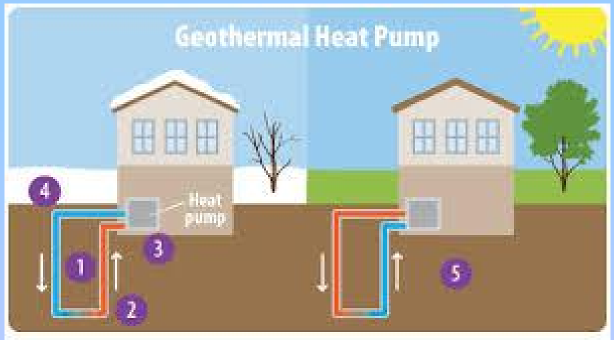




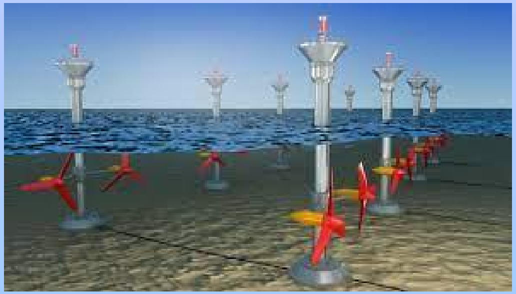


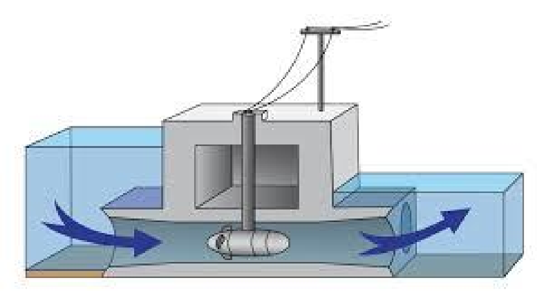


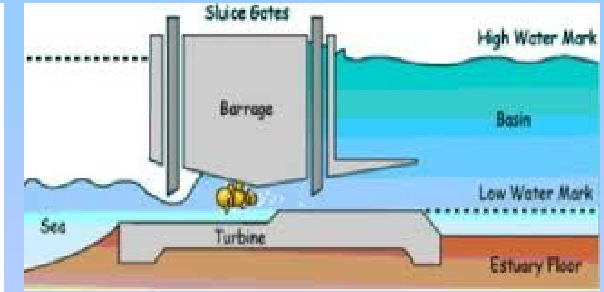
How is Geothermal Energy Useful for Mankind



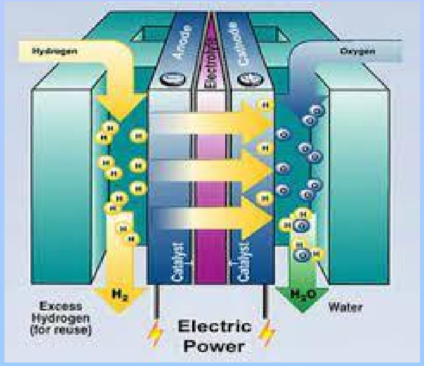
Tidal energy

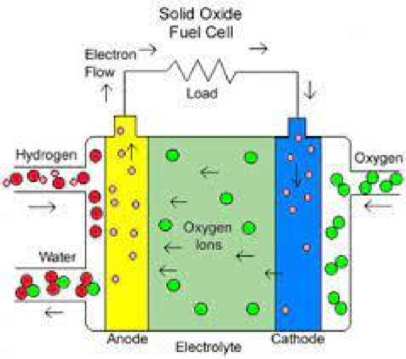


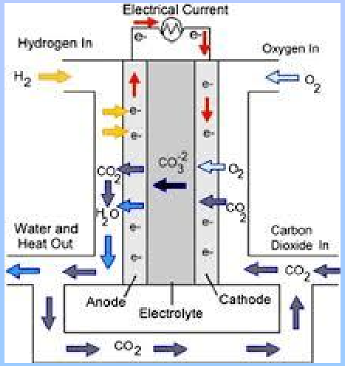




Fuel cell

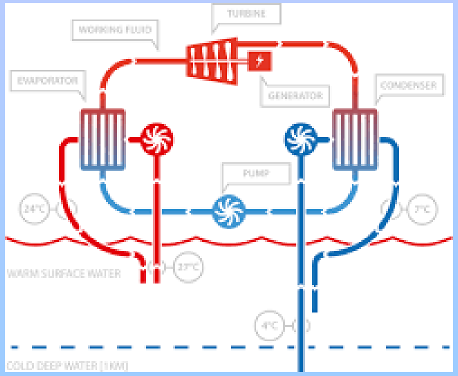

Hydrogen
Oxygen
Anode
Electrolyte
Cathode
Catalyst
Catalyst
H_2
H_2O
Excess Hydrogen (for reuse)
Electric Power
Water

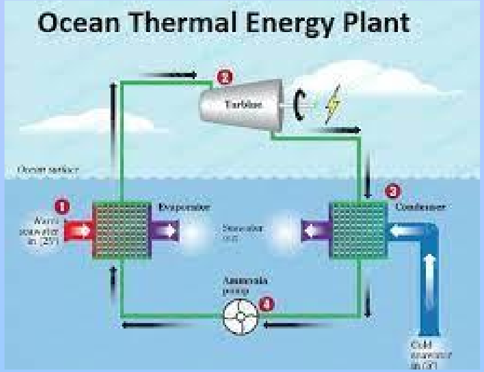

Solid Oxide Fuel Cell
Electron Flow
Load
Hydrogen
Oxygen
Water
Oxygen Ions
Anode
Electrolyte
Cathode


Electrical Current
e-
e-
Hydrogen In
Oxygen In
H_2
O_2
CO_2
CO_3^{-2}
O_2
CO_2
H_2O
Water and Heat Out
Carbon Dioxide In
CO_2
Anode
Electrolyte
Cathode
CO_2


H_2
H2
O2

Ocean energy conversion





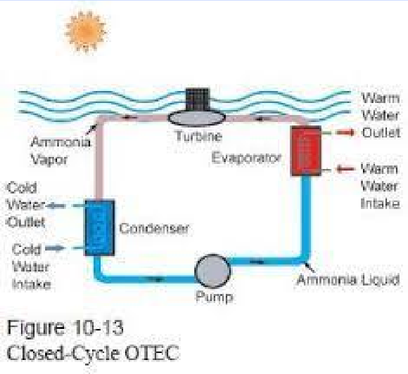
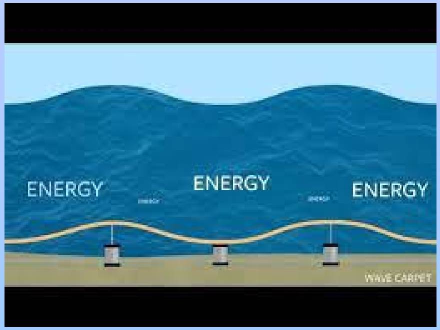
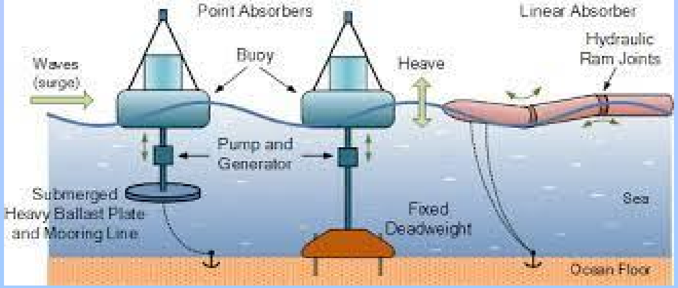
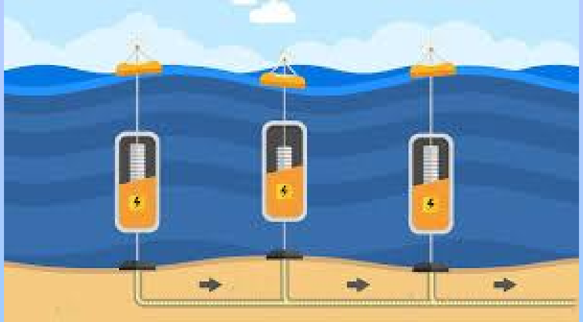


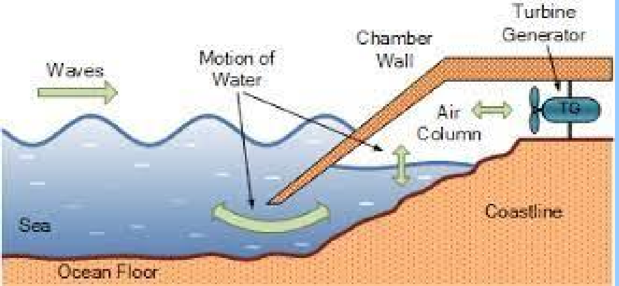
Figure 10-13
Closed-Cycle OTEC

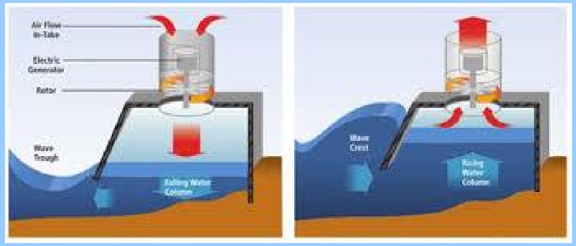
Ocean waves energy



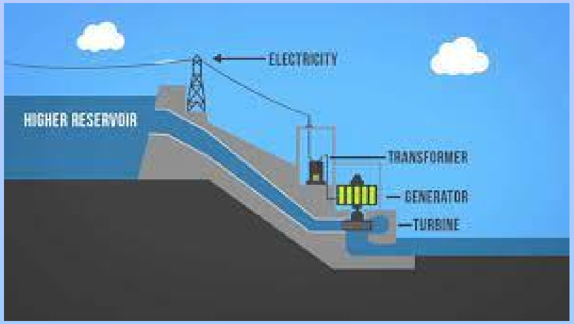


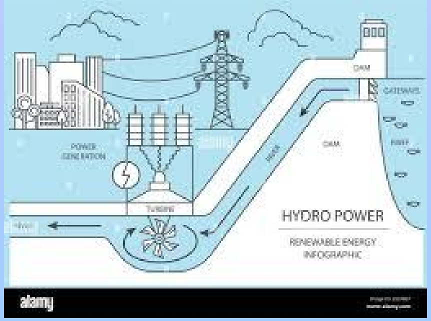


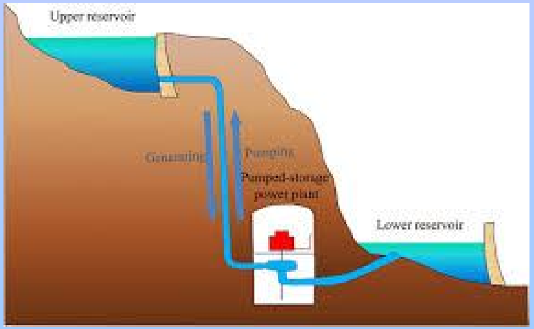


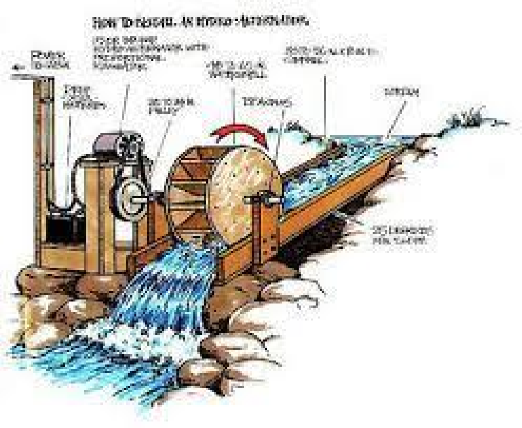


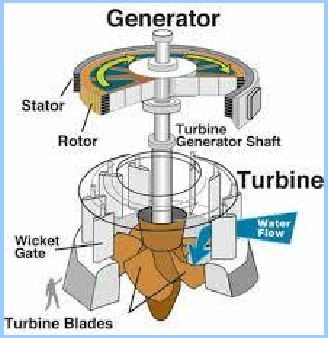
Hydro-power energy



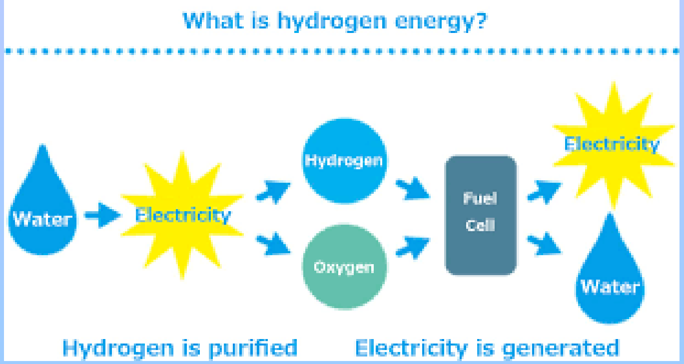


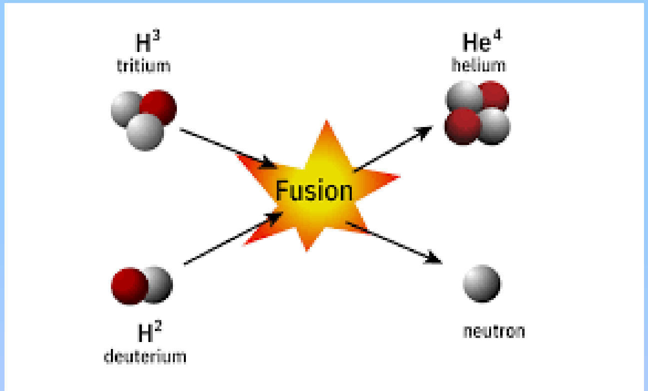


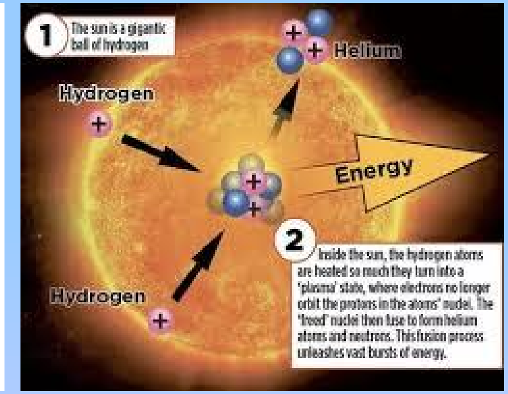




Hydrogen energy







The sun is a gigantic ball of hydrogen

Inside the sun, the hydrogen atoms are heated so much they turn into a 'plasma' state, where electrons no longer orbit the protons in the atoms' nuclei. The 'freed' nuclei then fuse to form helium atoms and neutrons. This fusion process unleashes vast bursts of energy.

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المحاضرة الثانية: الطاقة الشمسية

مدرس المادة: د. عمر عبد الهادي مصطفى

Solar Energy

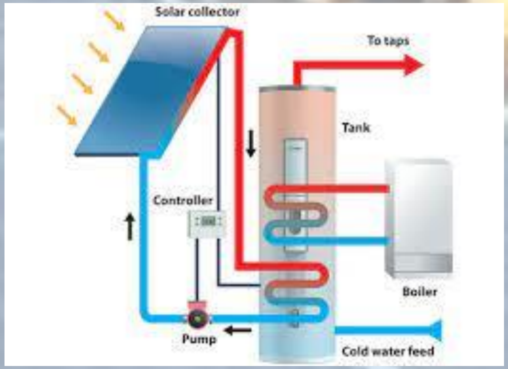
Solar Energy - Power from the Sun

Most renewable energy comes either directly or indirectly from the sun.

Solar Energy – Direct/Indirect

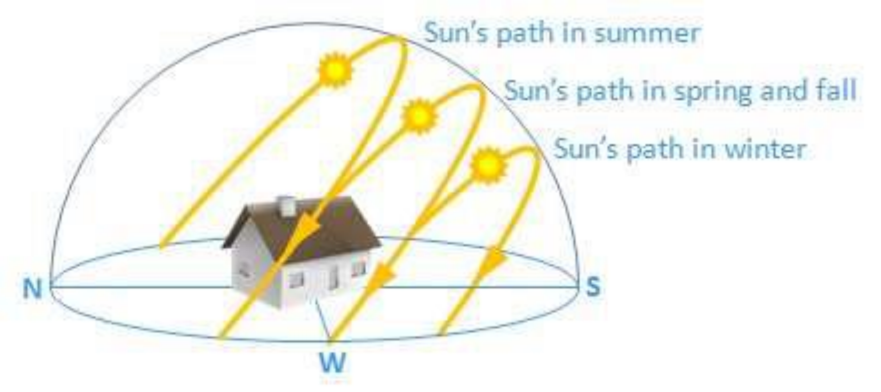
Direct solar energy is used every day, like when the sun shines on a window and heats the room.

Solar energy can also be used **indirectly** to generate electricity through solar cells or solar thermal collectors.



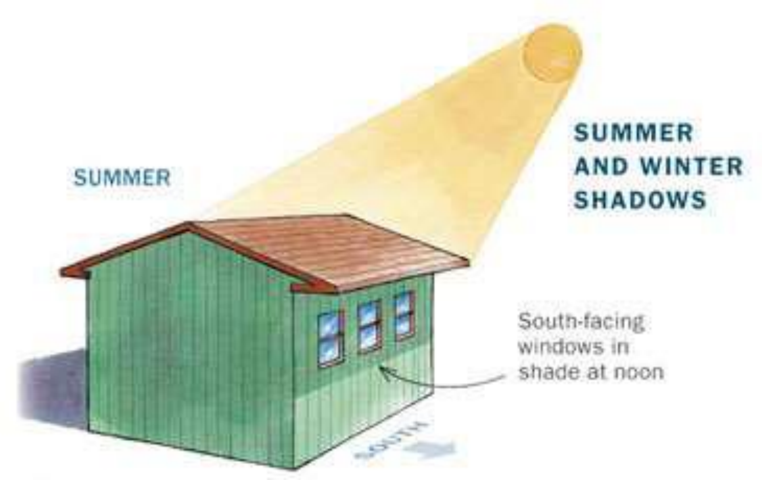
Passive solar heating/cooling

Passive solar heating is the use of sunlight to heat buildings directly. In the Northern Hemisphere, south facing windows receive the most solar energy



Passive solar heating/cooling

Therefore, passive solar buildings have large windows **that face south**



Trees – A house shaded by trees is a much **cooler** house during the summer.

Passive solar heating/cooling

Natural ventilation – requires pressure differences to move fresh air through a building.

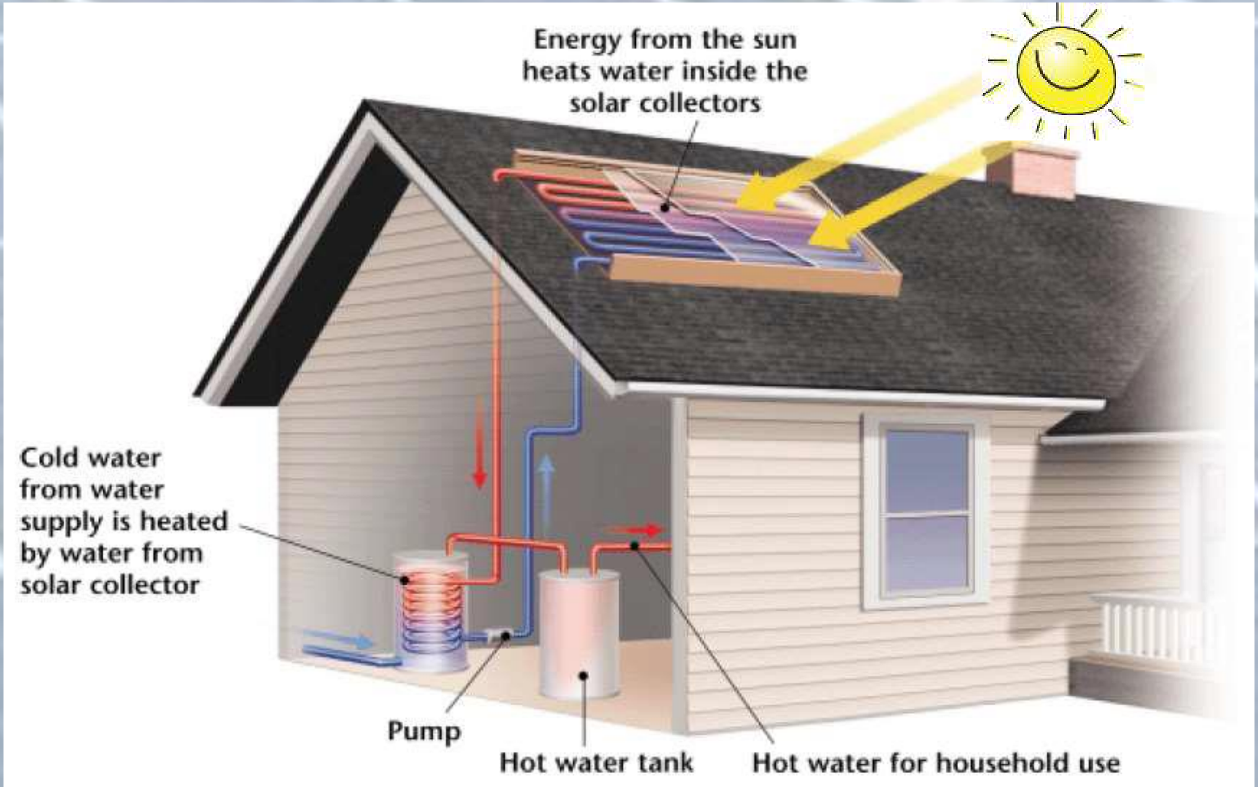
Conditioning cost can be reduced by heat removing through the natural ventilation especially in Moderate weather days.

Active solar heating – Water Heaters

Active solar heating is the gathering of solar energy by collectors that are used to heat **water** or heat a building

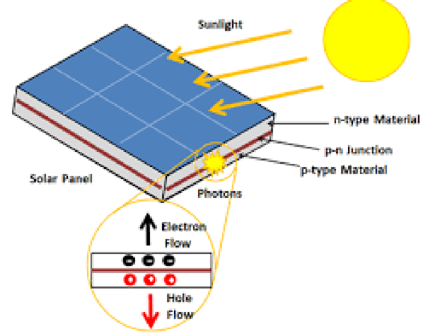
Active solar heating – Water Heaters

Solar collectors, usually mounted on a roof, capture the sun’s energy. A liquid is heated by the sun as it flows through solar collectors. The hot liquid is then pumped through heat exchangers, which heats water for the building.



Photovoltaic cells

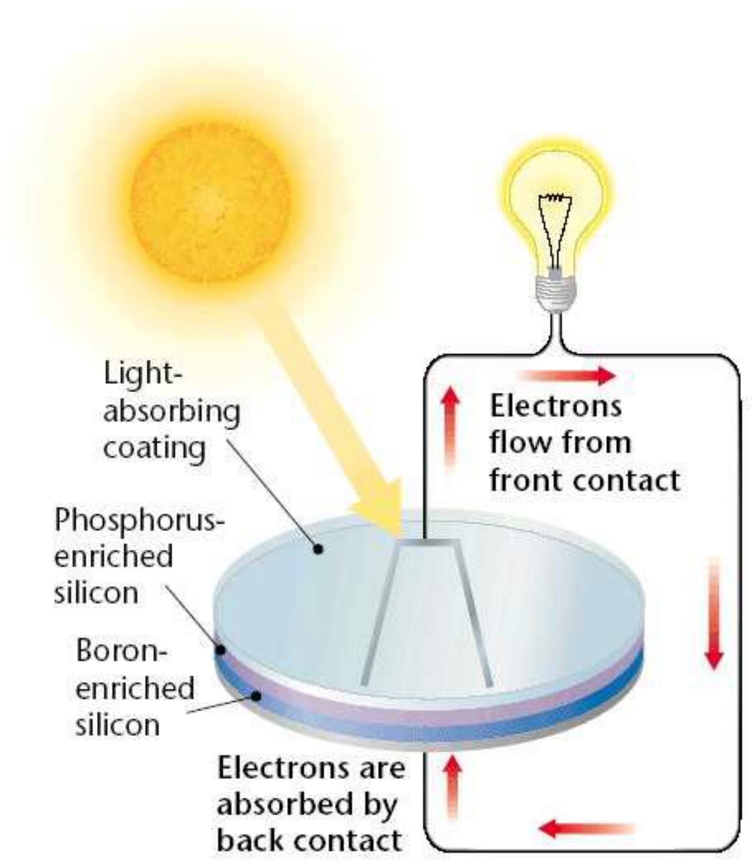
Photovoltaic (PV) cells convert the sun’s energy into electricity. PV cells have no moving parts, and they run on nonpolluting power from the sun. However, PV cells produce a small electrical DC current.



Photovoltaic cells – Land! Meeting the electricity needs of a small city would require covering hundreds of acres with solar panels.

Photovoltaic cells - Operation

Sunlight falls on a semiconductor (P-N) junction, causing it to release electrons. The electrons flow through a circuit causing the electrical current.



Photovoltaic cells

Solar cells require extended periods of sunshine to produce electricity. This energy is stored in **batteries**, which supplies electricity when the sun is not shining.

Photovoltaic cells – Usage in the World

Currently, solar cells provide energy for more than 1 million households in developing countries, where energy consumption is minimal and electricity distribution networks are limited.

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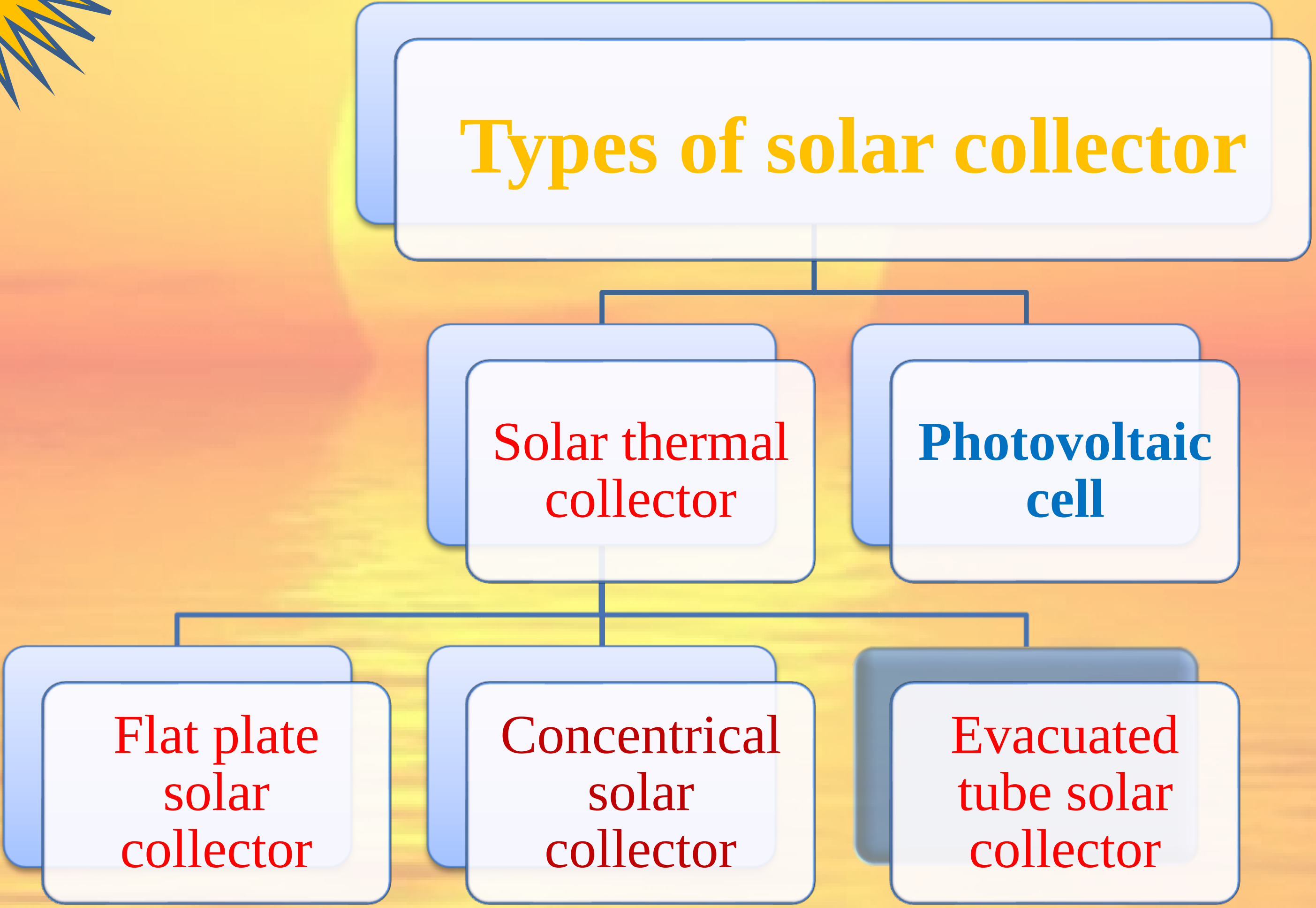
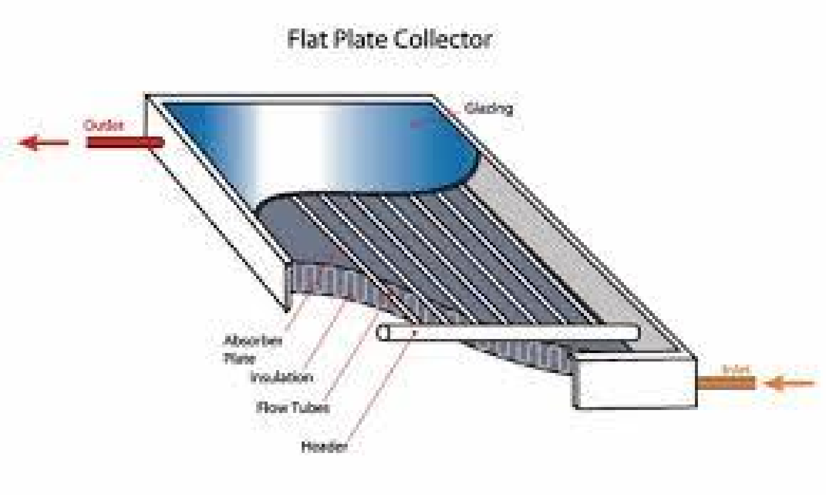


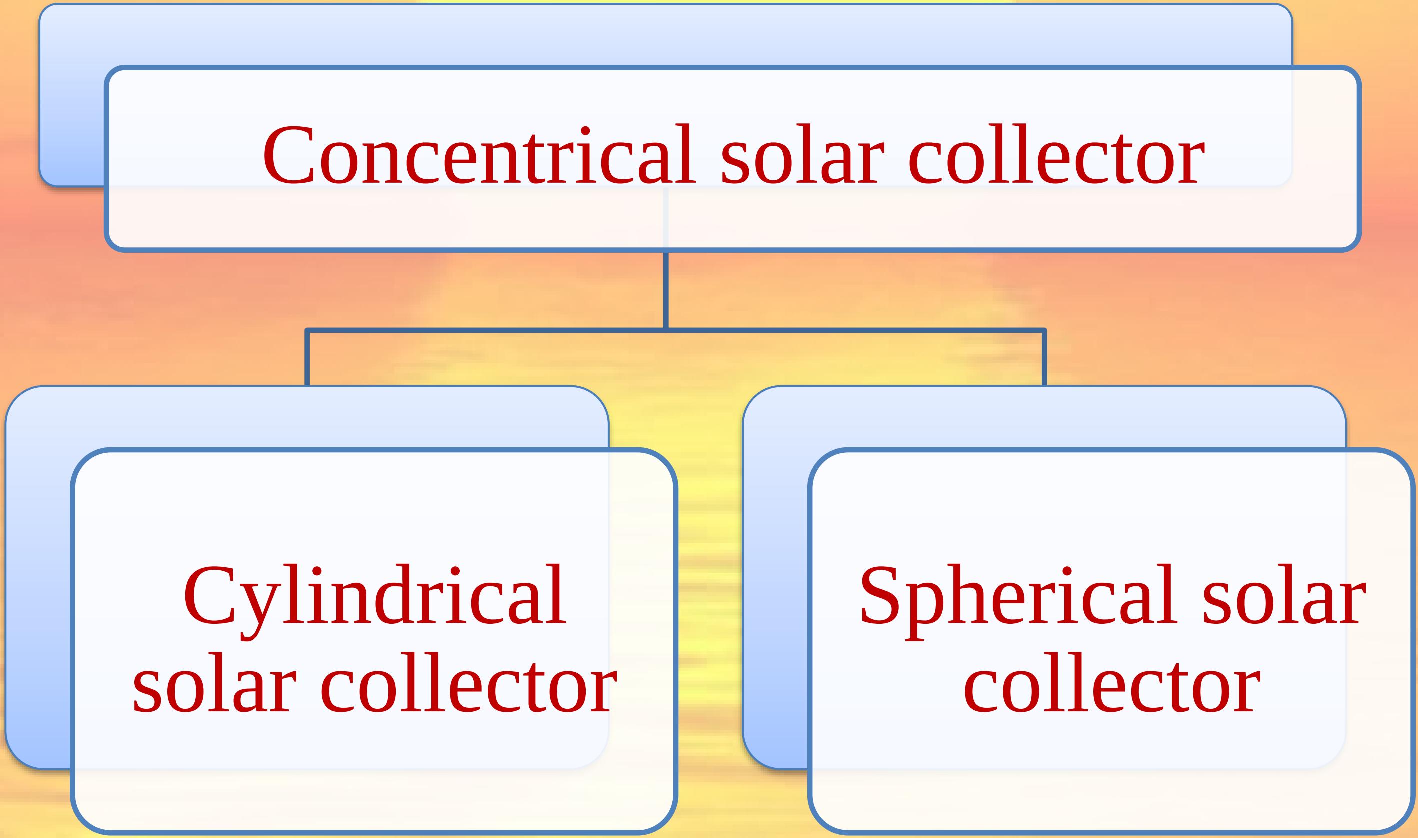
Types of solar collector

- Solar thermal collector
  - Flat plate solar collector
  - Concentrical solar collector
  - Evacuated tube solar collector
- **Photovoltaic cell**

Flat plate solar collector

This type of solar collectors is used to offer the hot water at temperature that will not **exceed 90°C**. this type is commonly used in split heating system like home individual heating system.





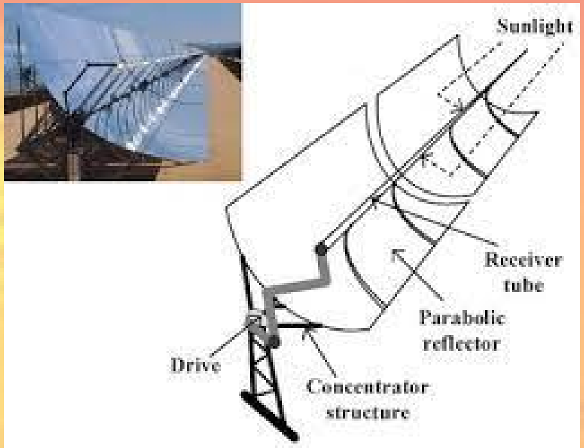
Concentrical solar collector

Cylindrical solar collector

Spherical solar collector

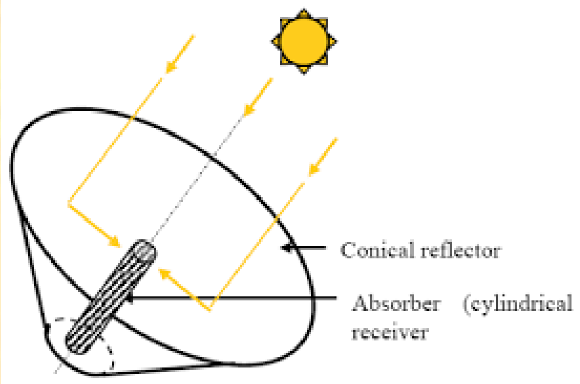
Cylindrical solar collector

This type of solar collectors is used when there is a necessity for high temperature, as in water steam generators for heating or water distillation systems.



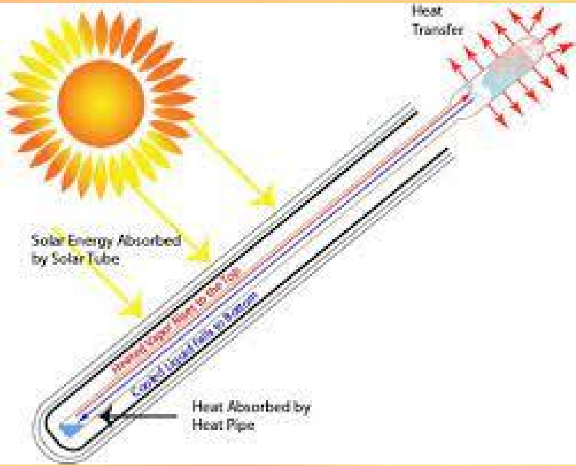
Spherical solar collector

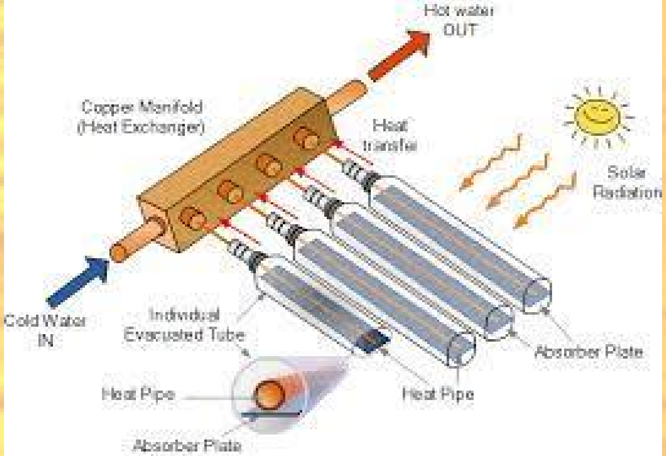
This type of solar collectors is used power plants that generate high temperature and high pressure steam to turn the steam turbine. This type may take different shapes depending on application, as well as the available area.



Evacuated tube solar collector

This type of solar collectors consist of two tubes, usually made from glass. The inner tube painted by the material that must absorb the maximum amount of the energy falling on its surface. The inner tube inserted inside the outer tube. The space between tubes evacuated to avoid heat transfer from the system to the environment by convection.

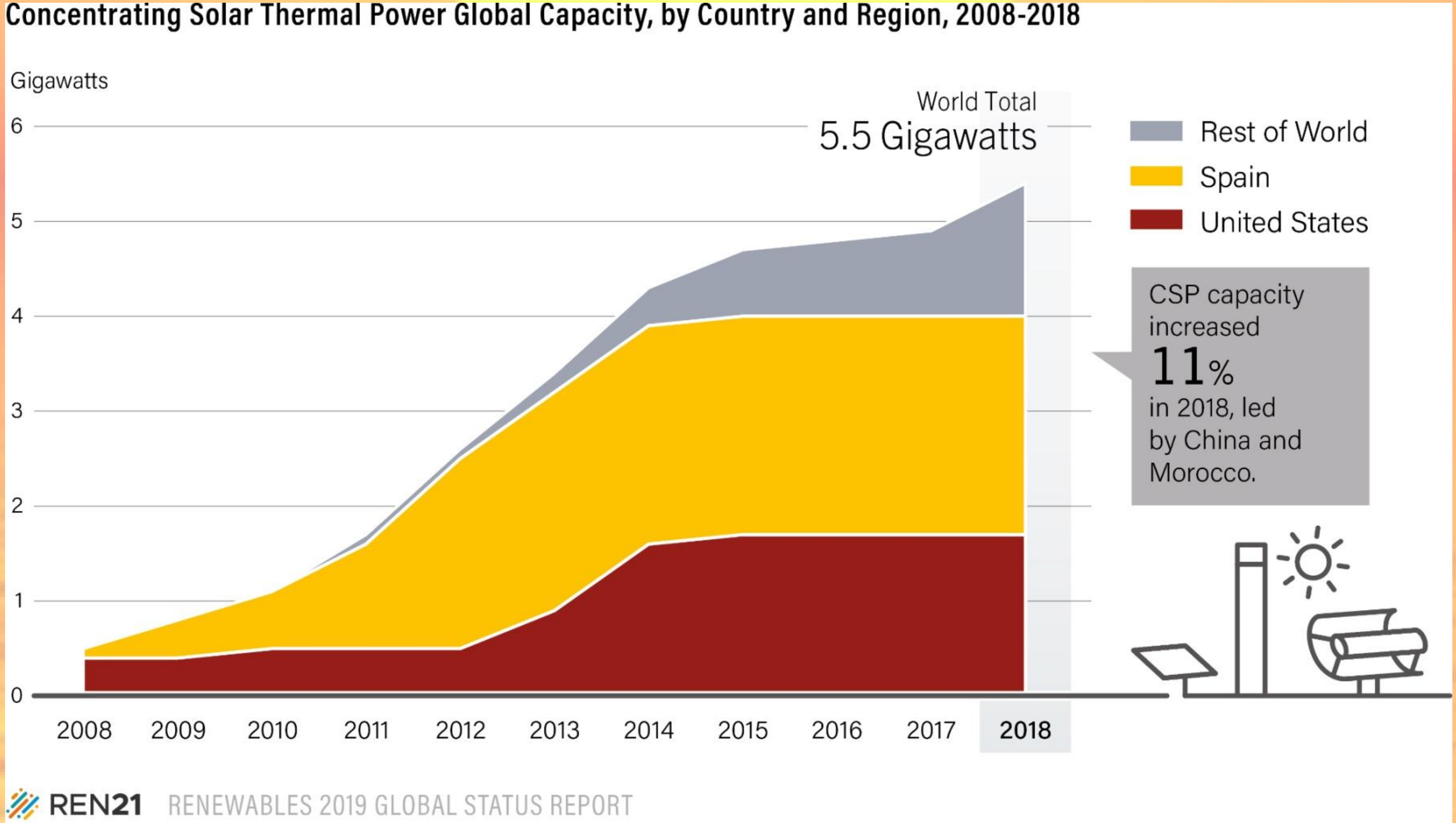




Photovoltaic cell

This type directly convert the solar energy to the electricity. The disadvantage of this collectors is the low efficiency and high initial cost. The maintenance on this type is also expensive. All above will limited the usage of this type of collectors.

Solar Concentrating Systems

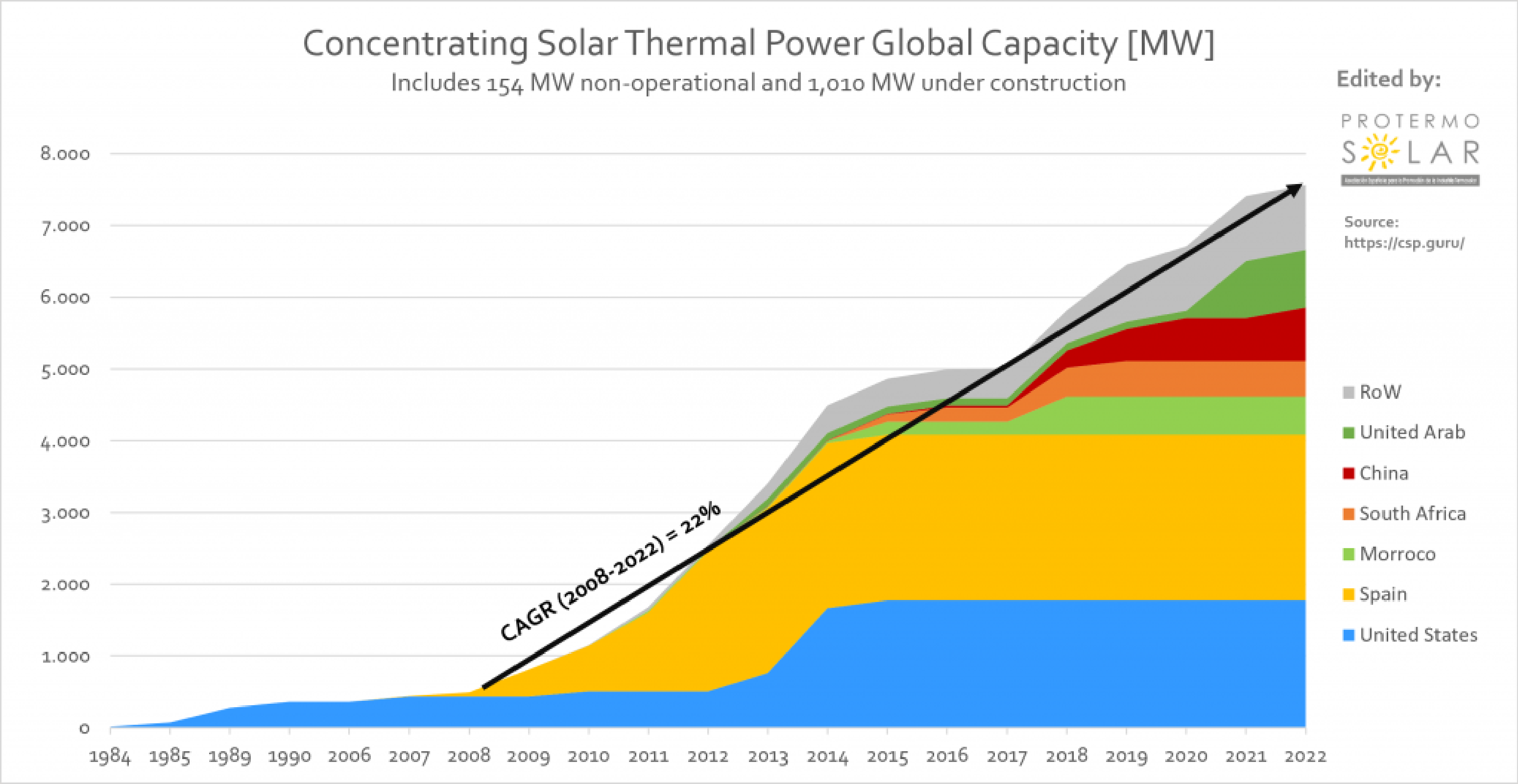


Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2008-2018

CSP capacity increased 11% in 2018, led by China and Morocco.

REN21 RENEWABLES 2019 GLOBAL STATUS REPORT

Solar Concentrating Systems



Concentrating Solar Thermal Power Global Capacity [MW]

Includes 154 MW non-operational and 1,010 MW under construction

Edited by: PROTERMO SOLAR

Source: https://csp.guru/

Advantages of Solar Concentrating Systems

- Carbon limits will close the cost gap.
- CSP can scale up fast without critical bottleneck materials. (e.g. silicon).
- Costs will come down with increase in capacity expected to fall below natural gas in the near future.

Examples of CSP Applications

1. Power Generation

Concentrated solar power project would generate up to 2,000 MW of electricity from heliostat array on the Nevada desert floor.

The plant will have an estimated capacity of 700 megawatts and a power storage system that will keep the lights of Dubai shining for up to 15 hours after sunset.

In 2018 the 150 MW Noor Ouarzazate III solar tower power plant accomplished to the Moroccan grid.

2. Thermal Needs:

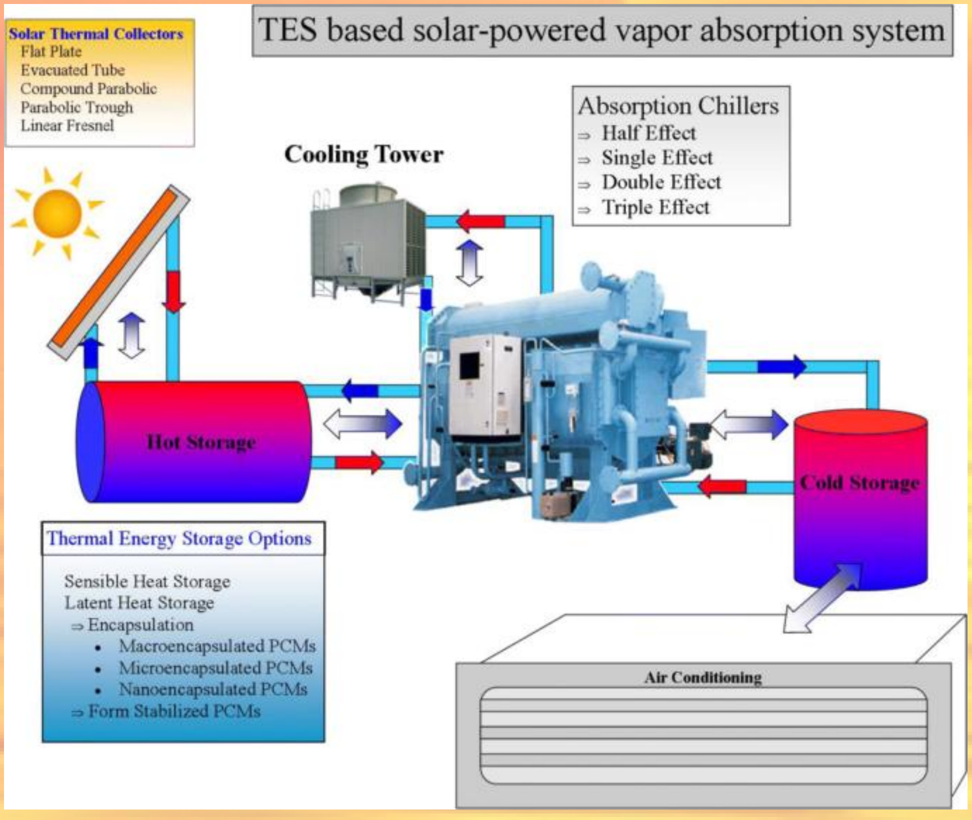
Hot Water and Steam (Industrial & Commercial Uses)

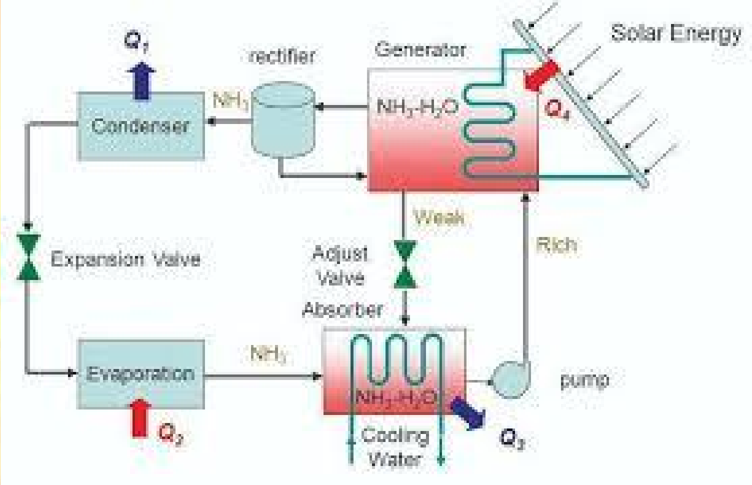




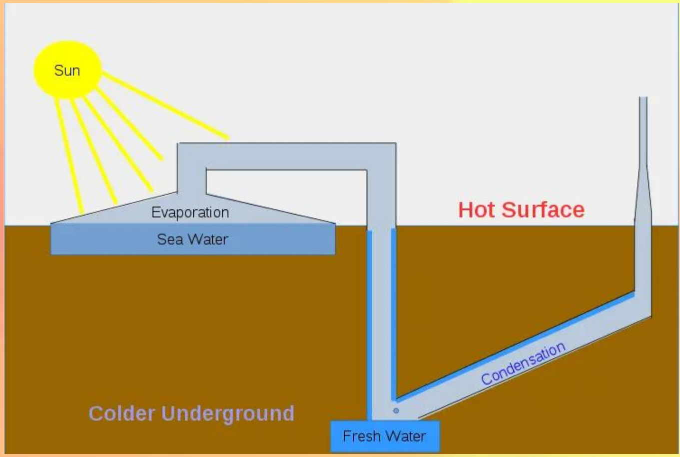
3. Air Conditioning

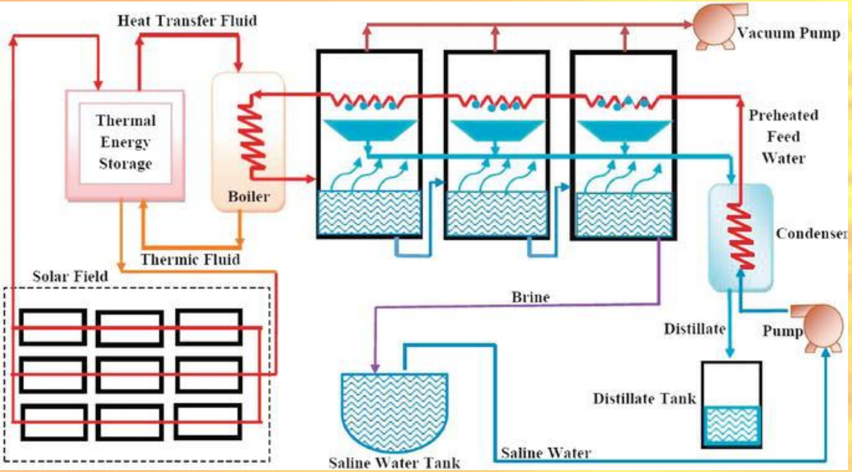
Absorption Chillers

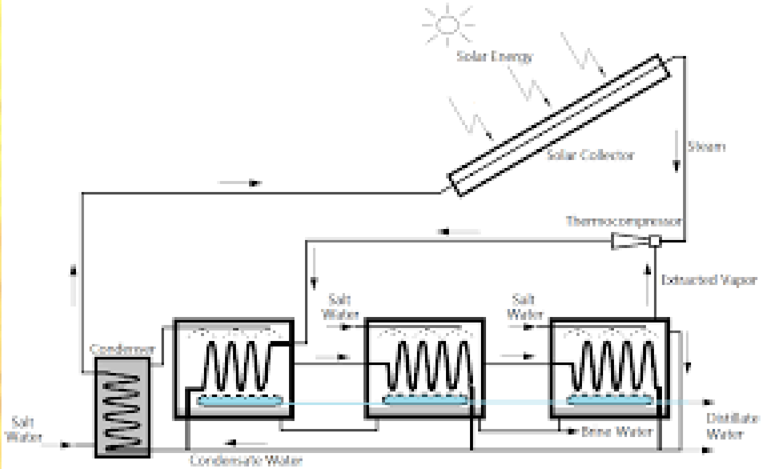




4. Desalination of seawater by solar distillatory

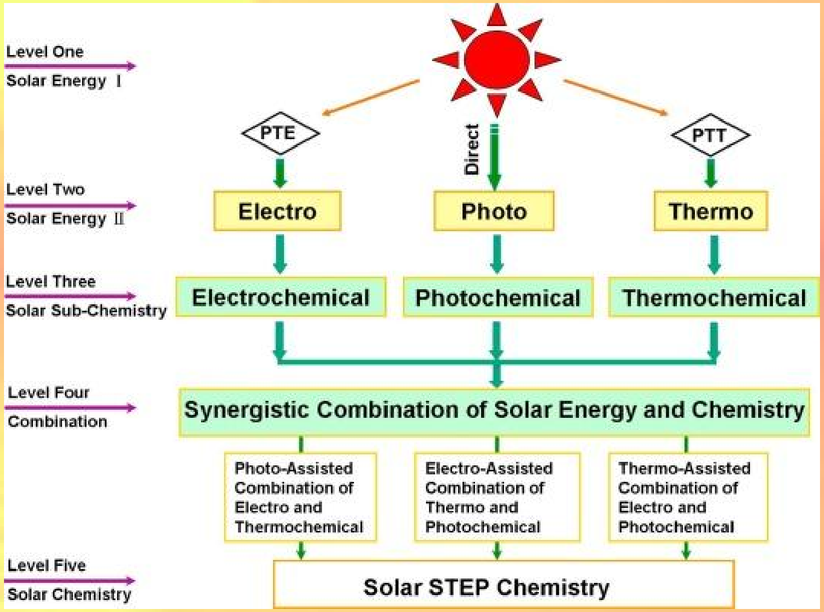


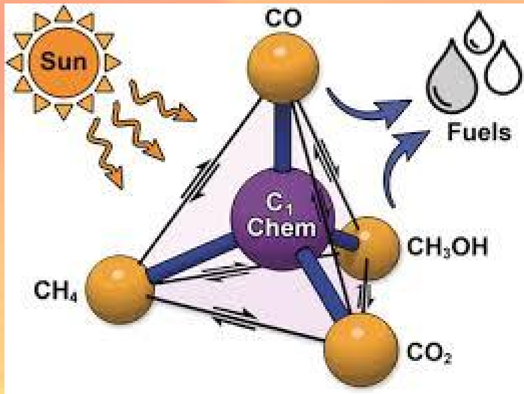




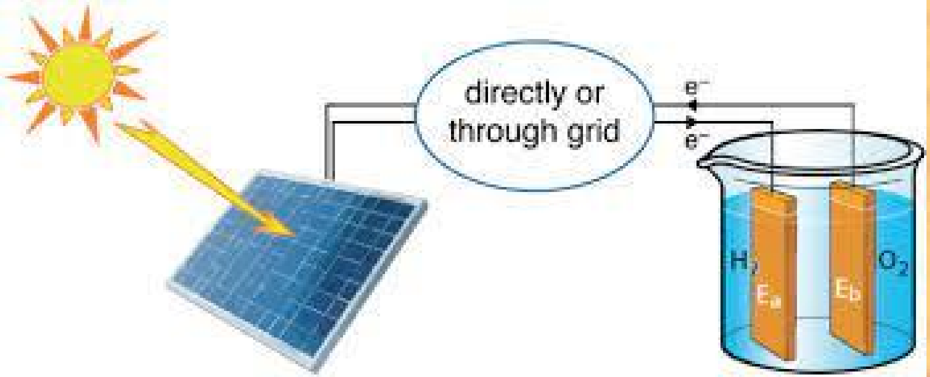
5. Solar Chemistry

Manufacture of metals and semiconductors





Hydrogen production

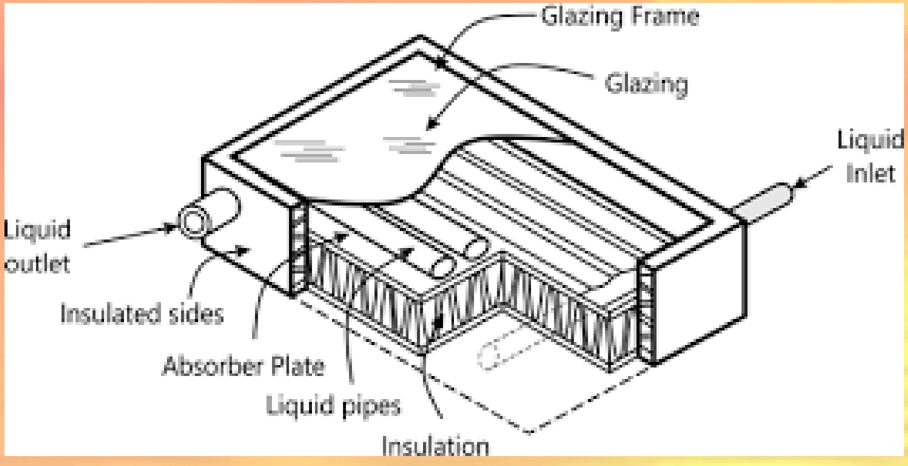


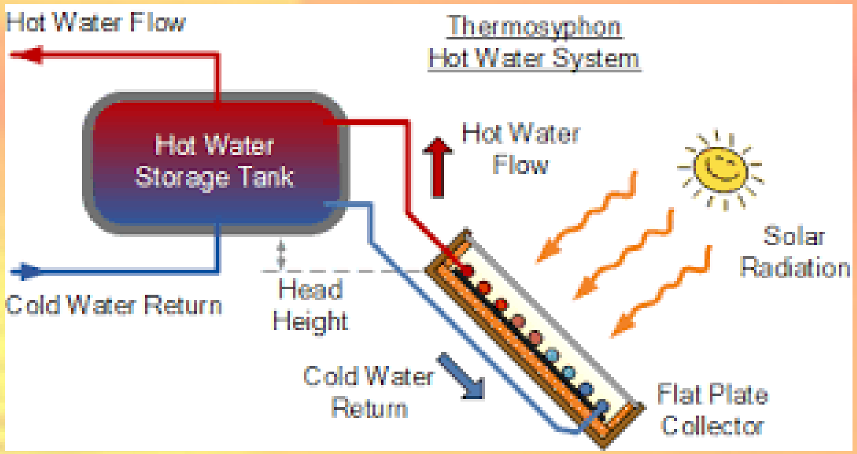
6. Materials Testing Under Extreme Conditions

Design of materials for shuttle reentry

Major Components of Solar Collectors

1. Flat plate solar collector



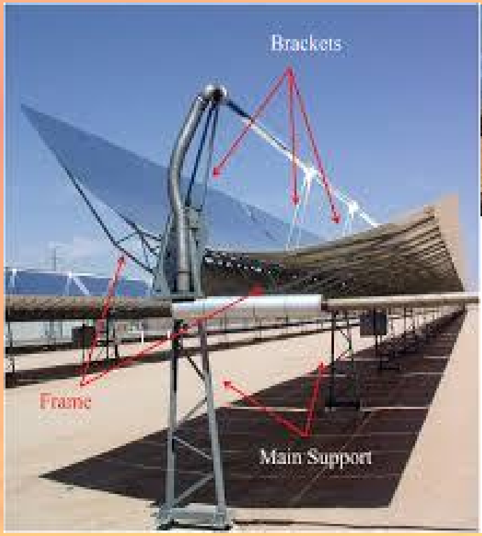


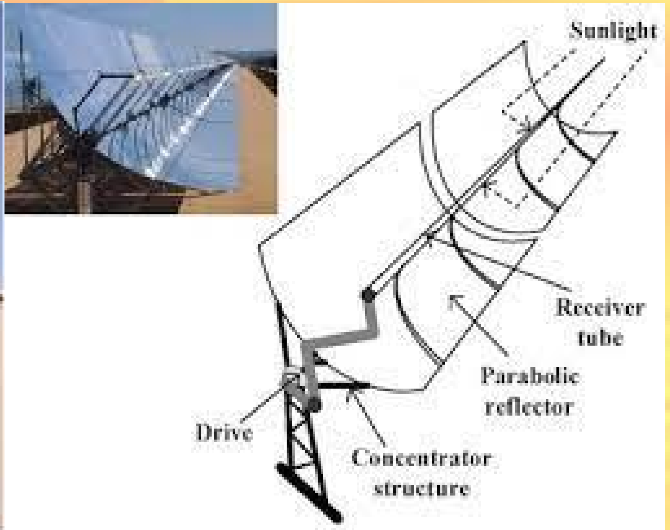
a. Glazing frame
b. Glazing
c. Liquid tubes
d. Absorption plate

e. Insulation
f. The upper portion tubes union
g. The lower portion tubes union
h. Rigged frame or frame with heliostat (tracking machine)

2. concentrated solar collector

a. Cylindrical solar collector

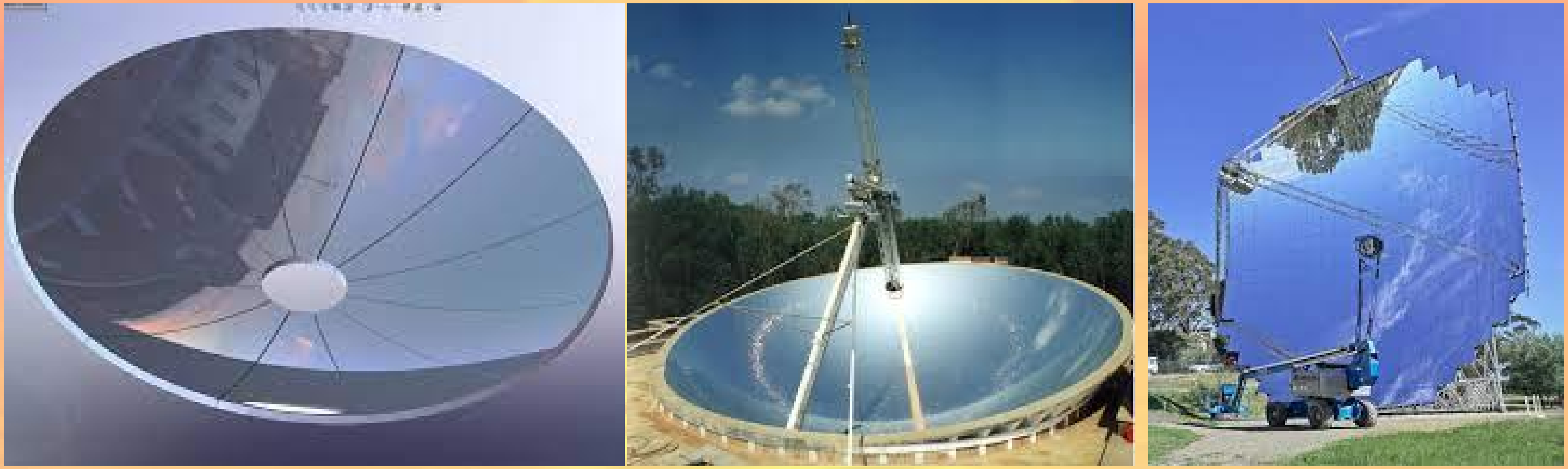




a. Reflecting mirror
b. Heat absorber (usually evacuated shield tube)
c. Metal frame
d. Tracking system or heliostat

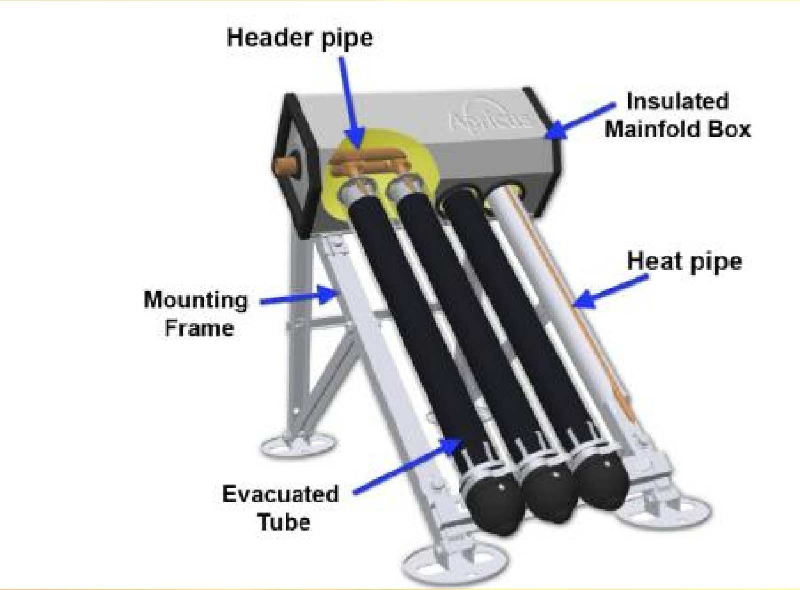
2. concentrated solar collector

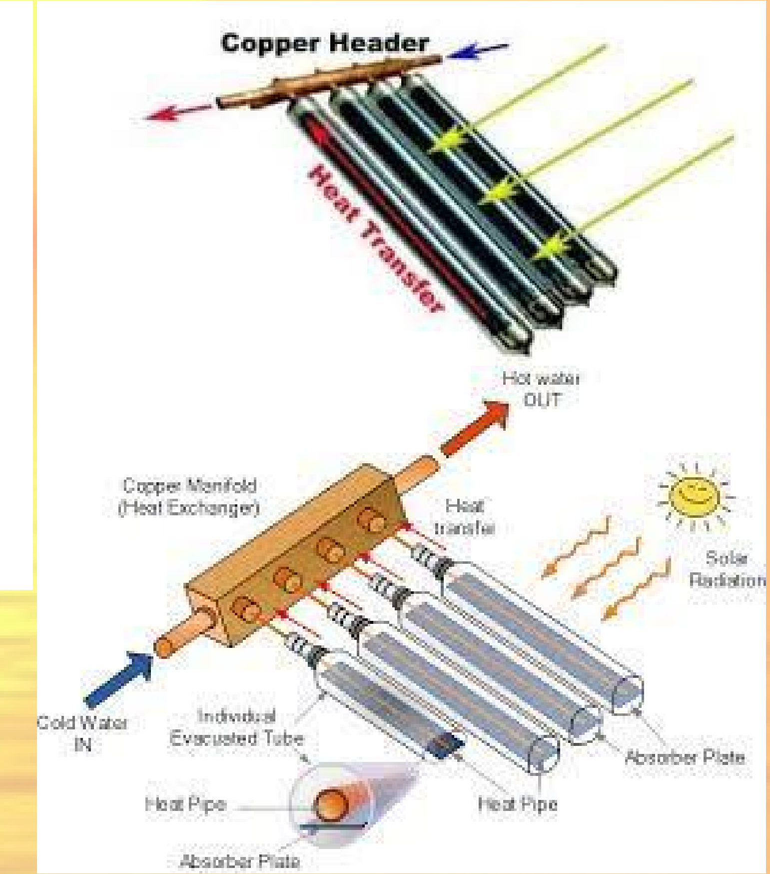
a. Spherical solar collector



a. Reflecting mirror
b. Heat absorber
c. Metal frame
d. Tracking system or heliostat

3. evacuated shield tube solar collector





a. Heat pipe
b. Evacuated glass shell
c. Cupper header
d. Rigged metal frame

Quiz

1. Enumerate 4 of the common types of fuel
2. Enumerate 6 of the renewable energy sources
3. What is the meaning of the renewable energy?
4. Can you display three of fields in which the solar energy may use?
5. Explain the physical mechanism of wind
6. Enumerate 3 of the biomass sources
7. Did the using of the geothermal energy permissible everywhere on the earth surface? Why?
8. How many methods of solar energy using? Give an example each of them

زارة التعليم العالي والبحث العلمي/ جمهورية العراق

الجامعة التقنية الشمالية

الكلية التقنية الهندسية / الموصل

قسم هندسة تقنيات ميكانيك القوى

الطاقة المتجددة

المحاضرة الرابعة: الطاقة اللازمة للاستخدام اليومي والاشعاع الشمسي

مدرس المادة: د. عمر عبد الهادي مصطفى

Thermal needs of life

- Typical showers are about 10 minutes at 6 liters per minute, or 60 liters.
- Assume four showers, and increase by 50% for other uses (dishes, laundry, etc …) and storage inefficiencies:

60 * 4 * 1.5 = 360 liters

Thermal needs of life

- To heat the 360 liters from 15 to 40 °C requires:

$$Q = \dot{m}\, c_p\, \Delta t$$

Where:

Q – is the amount of heat needed, w;

$\dot{m}$ - is the mass of the fluid, kg;

c_p - is the specific heat of the fluid at constant pressure, kj/kg. °C;

Δt – is the temperature difference, °C.

Thermal needs of life

$$\dot{m} = V * \rho$$

Where:

V – is the volume of the fluid, m^3;

ρ - is the density of the fluid, kg/ m^3.

Therefore,

$$\dot{m} = \frac{360}{1000} * 1000$$

$$\dot{m} = 360\ kg$$

Thermal needs of life

$$Q = \dot{m}\, c_p\, \Delta t$$

$$Q = 360 * 4.18 * (40 - 15)$$

$$Q = 37620\, kj$$

The average working time of the solar collector will be 6 hours, so that;

Time will be (6 * 3600) second;

$$Q = \frac{37620}{21600} = 1.7416\, kw$$

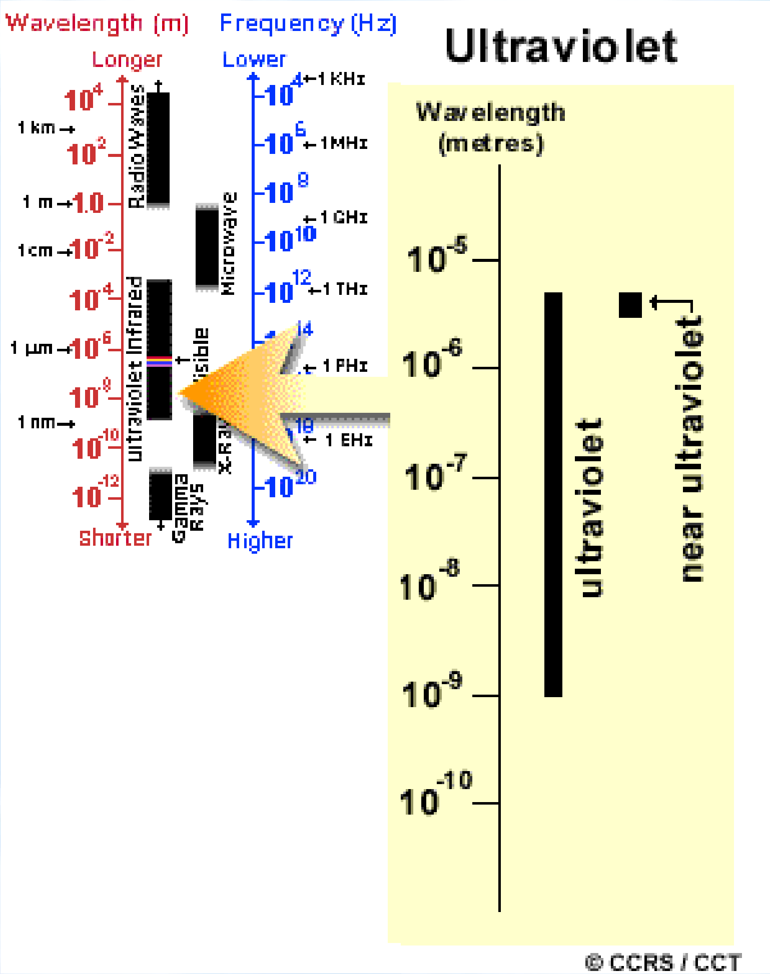
Thermal needs of life

At the worst case of the solar radiation, it can be get about 200 w/m^2 using the flat plate solar collector (if there are no heat losses from the collector), therefore, the area of the solar collector must be:

$$A = \frac{1.7416}{0.2} \sim 9\, m^2$$

Solar radiation

Types of solar radiation



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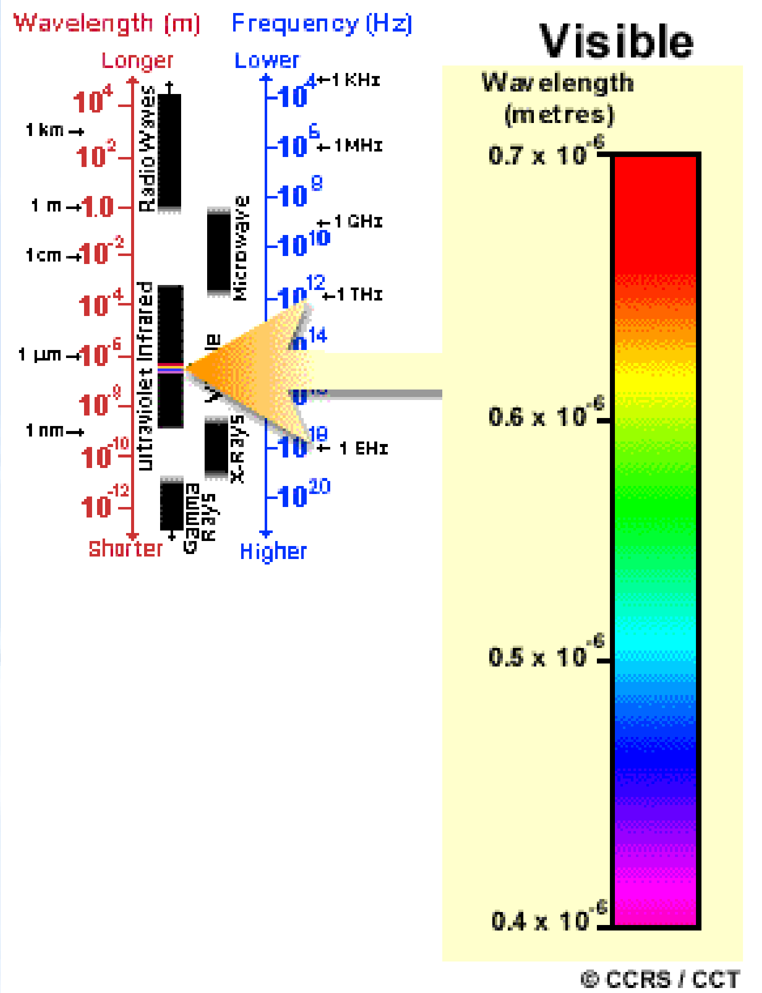

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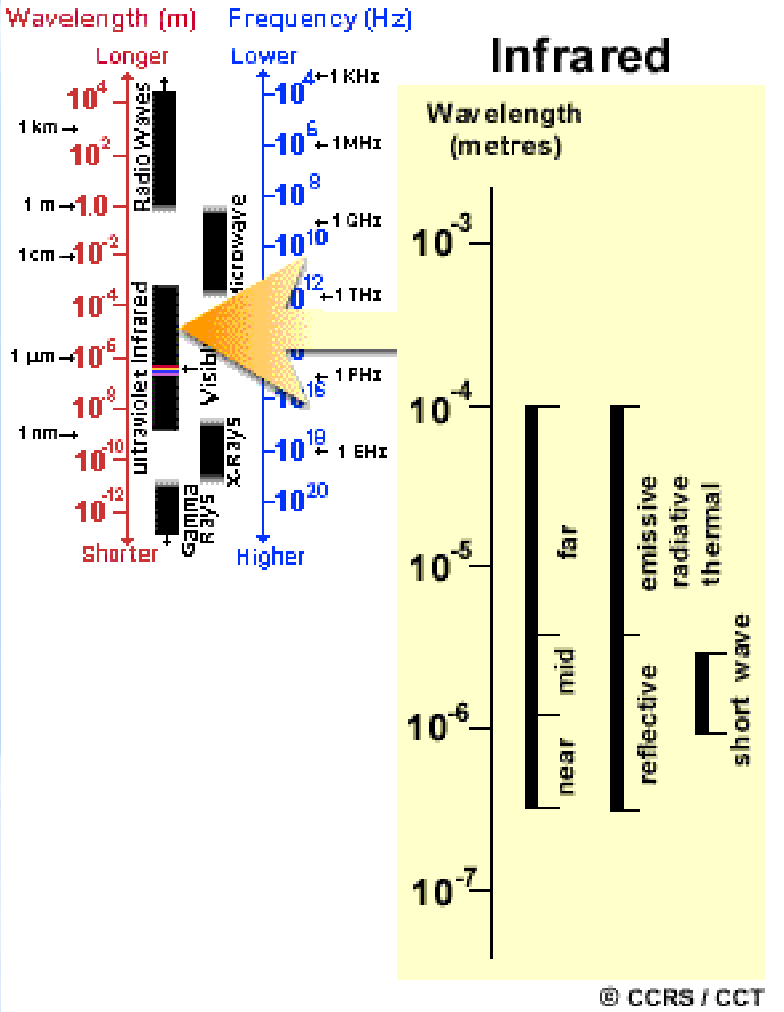
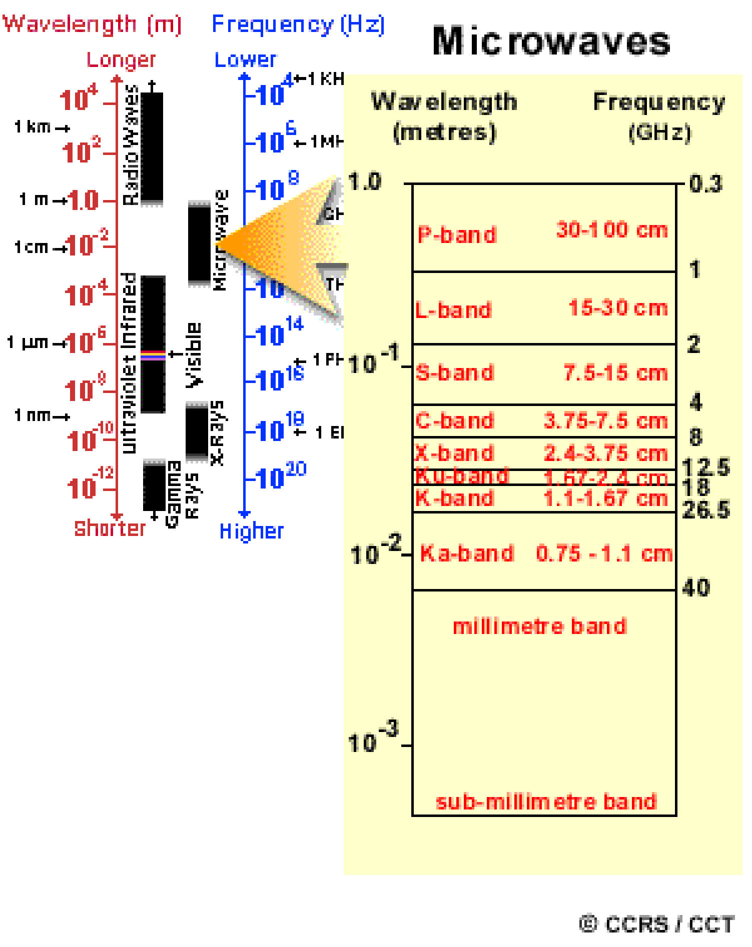
Solar radiation

Types of solar radiation

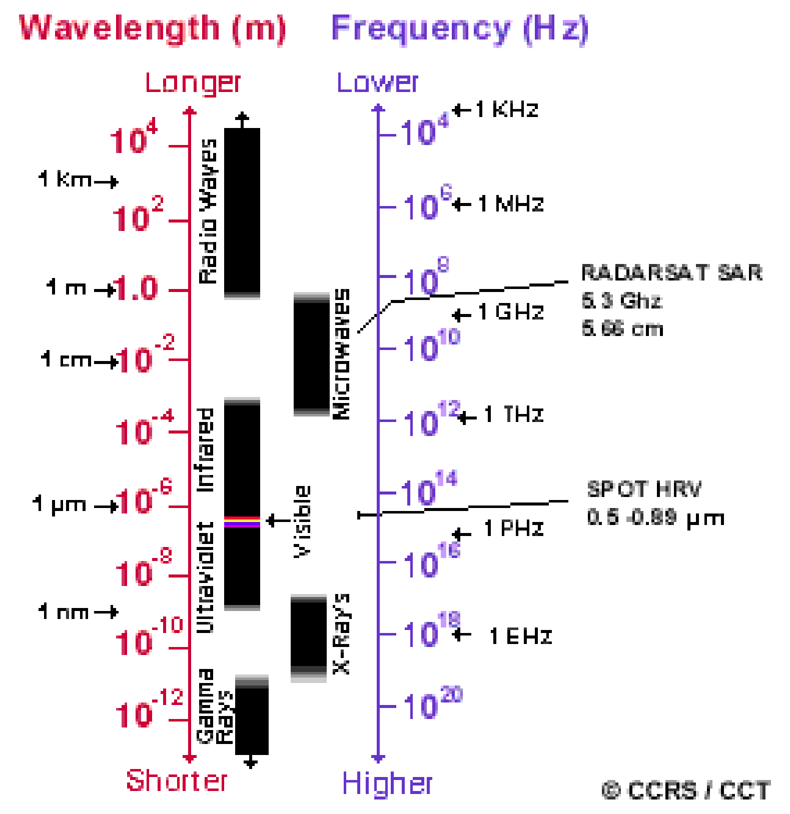




Solar radiation

Types of solar radiation

The wavelength range of 0.25 to 3.0 μm, the portion of the electromagnetic radiation that includes most of the energy radiated by the sun.



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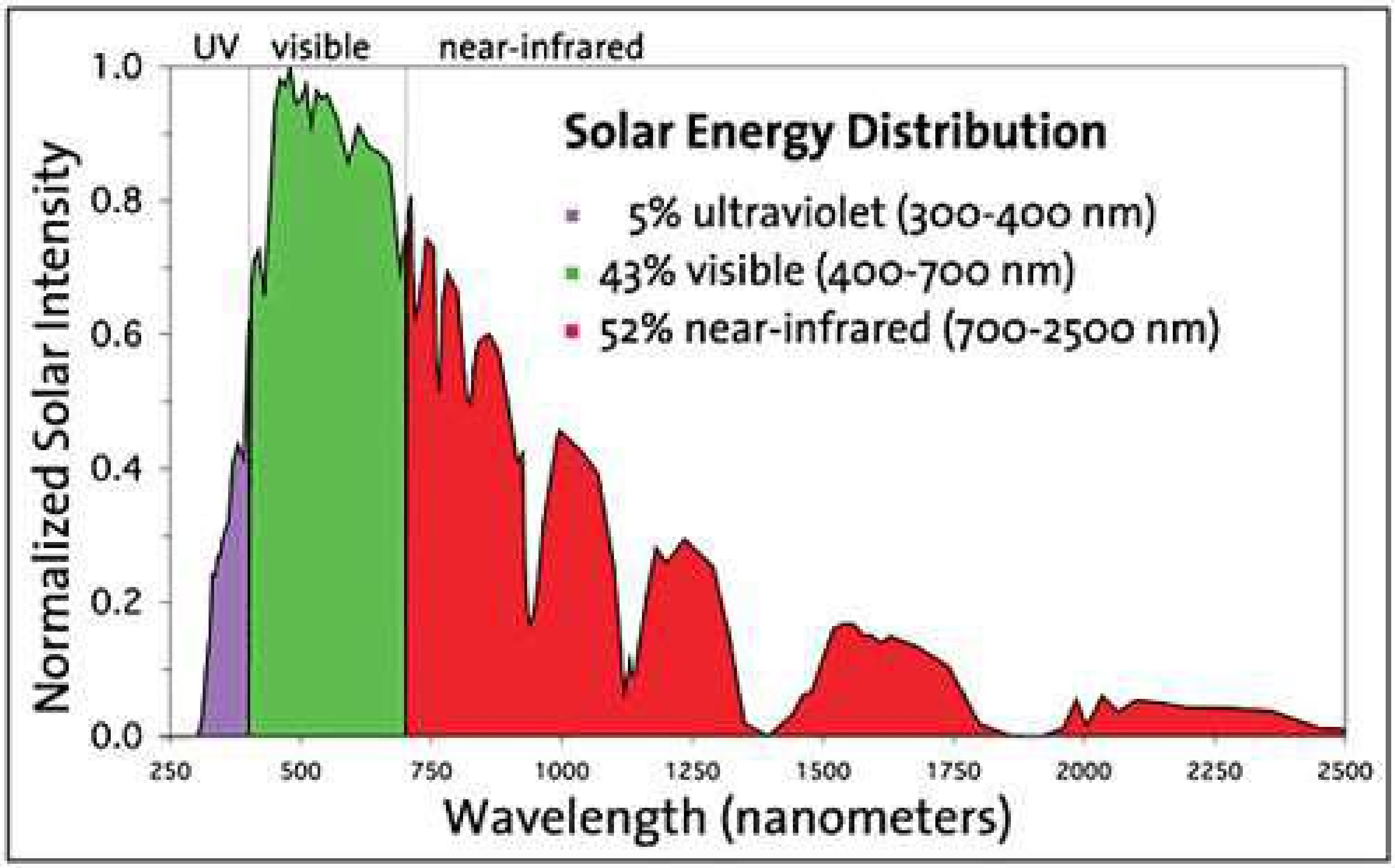
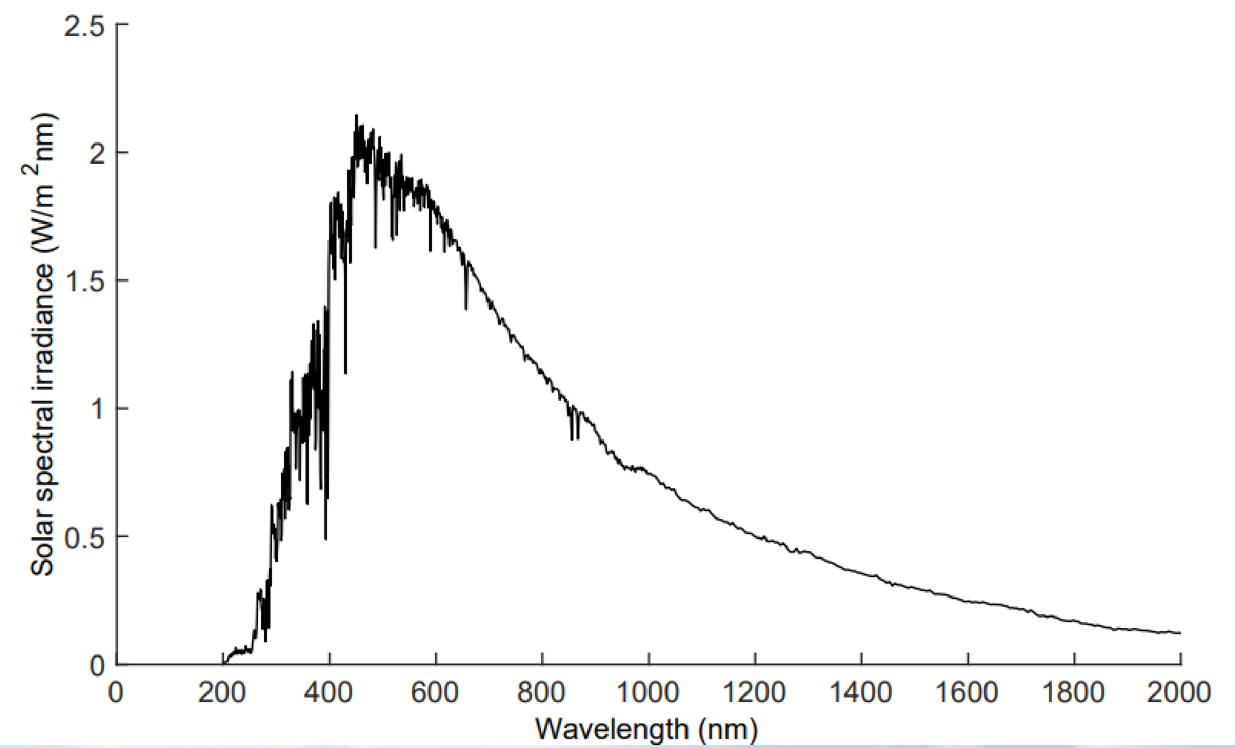
Distribution of solar radiation intensity as a function of wavelength



Spectral distribution of extraterrestrial radiation

In addition to the total energy in the solar spectrum (i.e., the solar constant), it is useful to know the spectral distribution of the extraterrestrial radiation, that is, the radiation that would be received in the absence of the atmosphere. A standard spectral irradiance curve has been compiled based on high-altitude and space measurements. The World Radiation Center (WRC) standard is shown in figure below.



Spectral distribution of extraterrestrial radiation

Table 1. provides the same information on the WRC spectrum in numerical form. The average energy $G_{sc,\lambda}$ (in W/m^2 μm) over small bandwidths centered at wavelength λ is given in the second column. The fraction $f_{0-\lambda}$ of the total energy in the spectrum that is between wavelengths zero and λ is given in the third column. The table is in two parts, the first at regular intervals of wavelength and the second at even fractions $f_{0-\lambda}$.

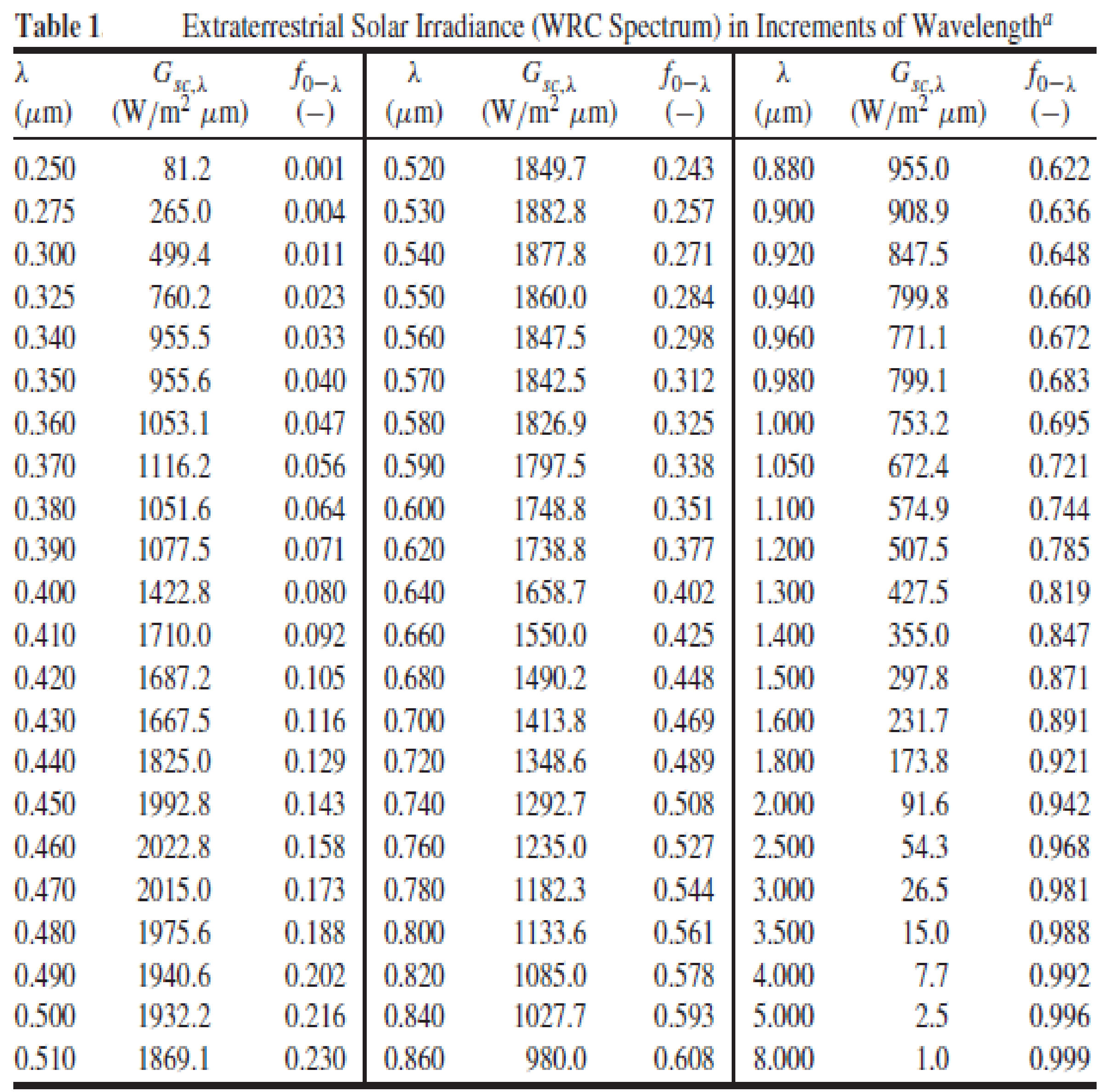
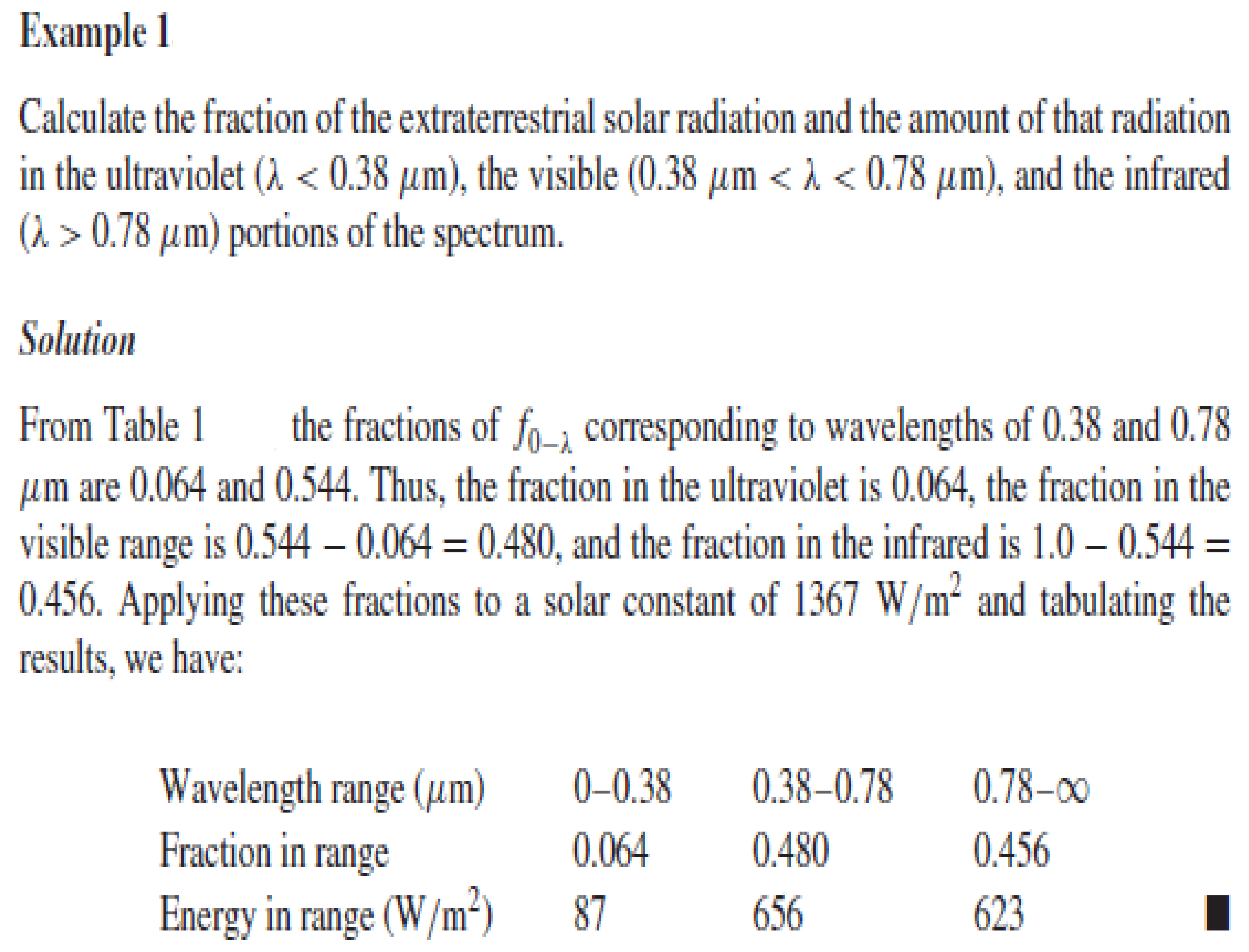


Table 1 Extraterrestrial Solar Irradiance (WRC Spectrum) in Increments of Wavelength[a]

λ (μm)	$G_{sc,\lambda}$ (W/m^2 μm)	$f_{0-\lambda}$ (–)	λ (μm)	$G_{sc,\lambda}$ (W/m^2 μm)	$f_{0-\lambda}$ (–)	λ (μm)	$G_{sc,\lambda}$ (W/m^2 μm)	$f_{0-\lambda}$ (–)
0.250	81.2	0.001	0.520	1849.7	0.243	0.880	955.0	0.622
0.275	265.0	0.004	0.530	1882.8	0.257	0.900	908.9	0.636
0.300	499.4	0.011	0.540	1877.8	0.271	0.920	847.5	0.648
0.325	760.2	0.023	0.550	1860.0	0.284	0.940	799.8	0.660
0.340	955.5	0.033	0.560	1847.5	0.298	0.960	771.1	0.672
0.350	955.6	0.040	0.570	1842.5	0.312	0.980	799.1	0.683
0.360	1053.1	0.047	0.580	1826.9	0.325	1.000	753.2	0.695
0.370	1116.2	0.056	0.590	1797.5	0.338	1.050	672.4	0.721
0.380	1051.6	0.064	0.600	1748.8	0.351	1.100	574.9	0.744
0.390	1077.5	0.071	0.620	1738.8	0.377	1.200	507.5	0.785
0.400	1422.8	0.080	0.640	1658.7	0.402	1.300	427.5	0.819
0.410	1710.0	0.092	0.660	1550.0	0.425	1.400	355.0	0.847
0.420	1687.2	0.105	0.680	1490.2	0.448	1.500	297.8	0.871
0.430	1667.5	0.116	0.700	1413.8	0.469	1.600	231.7	0.891
0.440	1825.0	0.129	0.720	1348.6	0.489	1.800	173.8	0.921
0.450	1992.8	0.143	0.740	1292.7	0.508	2.000	91.6	0.942
0.460	2022.8	0.158	0.760	1235.0	0.527	2.500	54.3	0.968
0.470	2015.0	0.173	0.780	1182.3	0.544	3.000	26.5	0.981
0.480	1975.6	0.188	0.800	1133.6	0.561	3.500	15.0	0.988
0.490	1940.6	0.202	0.820	1085.0	0.578	4.000	7.7	0.992
0.500	1932.2	0.216	0.840	1027.7	0.593	5.000	2.5	0.996
0.510	1869.1	0.230	0.860	980.0	0.608	8.000	1.0	0.999



Example 1

Calculate the fraction of the extraterrestrial solar radiation and the amount of that radiation in the ultraviolet ($\lambda < 0.38\ \mu m$), the visible ($0.38\ \mu m < \lambda < 0.78\ \mu m$), and the infrared ($\lambda > 0.78\ \mu m$) portions of the spectrum.

Solution

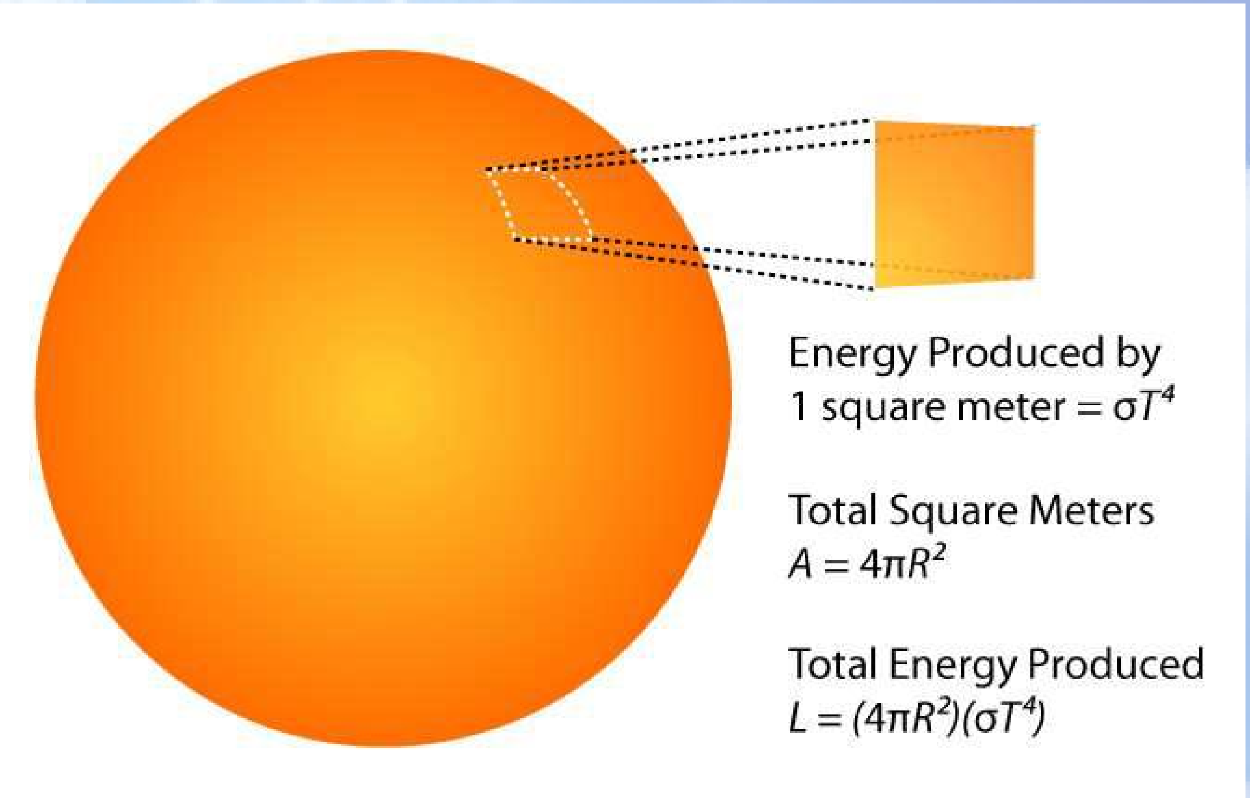
From Table 1 the fractions of $f_{0-\lambda}$ corresponding to wavelengths of 0.38 and 0.78 μm are 0.064 and 0.544. Thus, the fraction in the ultraviolet is 0.064, the fraction in the visible range is $0.544 - 0.064 = 0.480$, and the fraction in the infrared is $1.0 - 0.544 = 0.456$. Applying these fractions to a solar constant of 1367 W/m^2 and tabulating the results, we have:

Wavelength range (μm)	0–0.38	0.38–0.78	0.78–∞
Fraction in range	0.064	0.480	0.456
Energy in range (W/m^2)	87	656	623

■

The solar constant

The solar constant G_{sc} is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth-sun distance outside the atmosphere.



Energy Produced by 1 square meter = σT^4

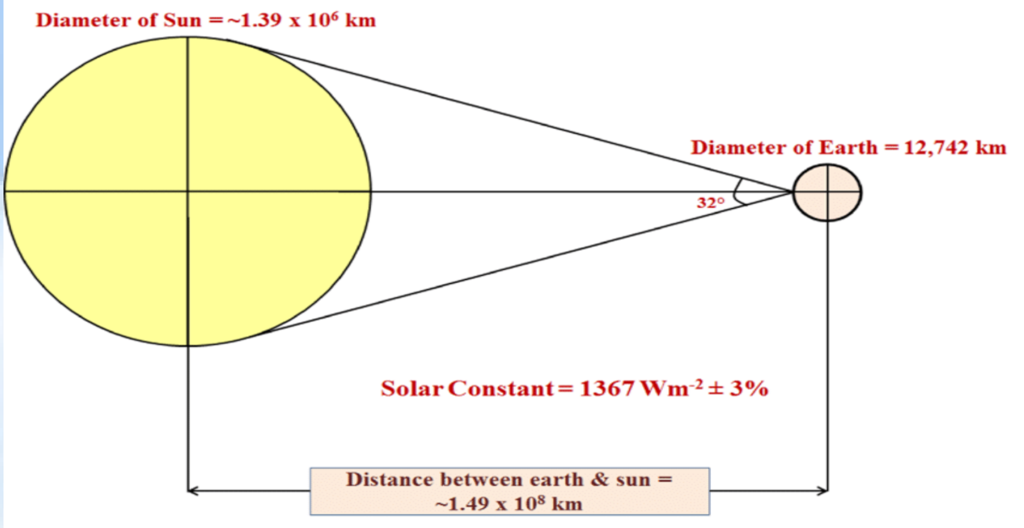
Total Square Meters $A = 4\pi R^2$

Total Energy Produced $L = (4\pi R^2)(\sigma T^4)$

The solar constant

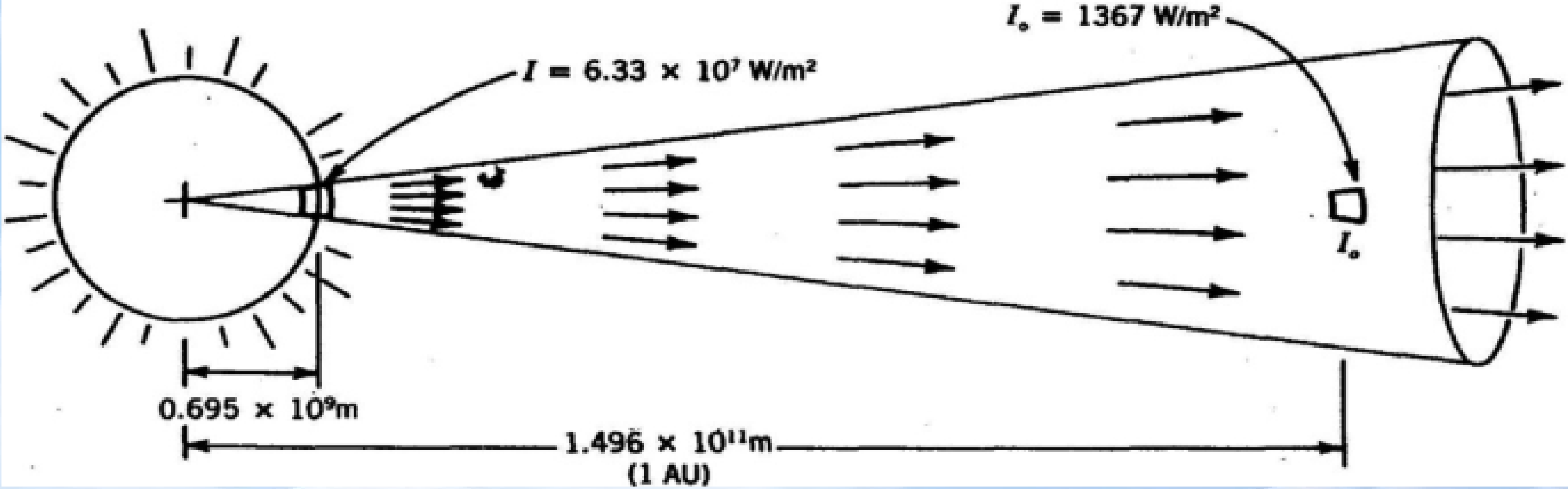
Let us now turn to the actual solar radiation that reaches Earth’s atmosphere. How much radiation is there and how is it distributed over the wavelengths? To start with, we note that solar radiation levels in the solar system drop with the square of the distance to the Sun. To realize this, assume that the Sun’s radius is r and its surface temperature T. The surface area of the Sun is then $4\pi r^2$ and the total radiative flux from the Sun is, using the Stefan-Boltzmann equation, $\sigma T^4 \times 4\pi r^2$. Now, the surface of a larger imaginary sphere with radius l with the Sun at its center will receive the same amount of radiation, but over the larger area $4\pi l^2$. Consequently, the energy flux per unit area at the distance l from the Sun is

$$G_l = \frac{\sigma T^4 \times 4\pi r^2}{4\pi l^2} = \sigma T^4 \left(\frac{r}{l}\right)^2 \ldots\ldots.(1)$$



The solar constant

If you use the black-body temperature of the Sun (5777 K), the radius of the Sun (6.957×10^8 m) and the distance between the Sun and Earth (1.495×10^{11} m), you will get the average radiative flux just outside Earth’s atmosphere, per unit area facing the Sun: 1367 W/m^2 . This will be denoted by G_{sc} and is called the solar constant, or the air mass zero (AM0) radiation.

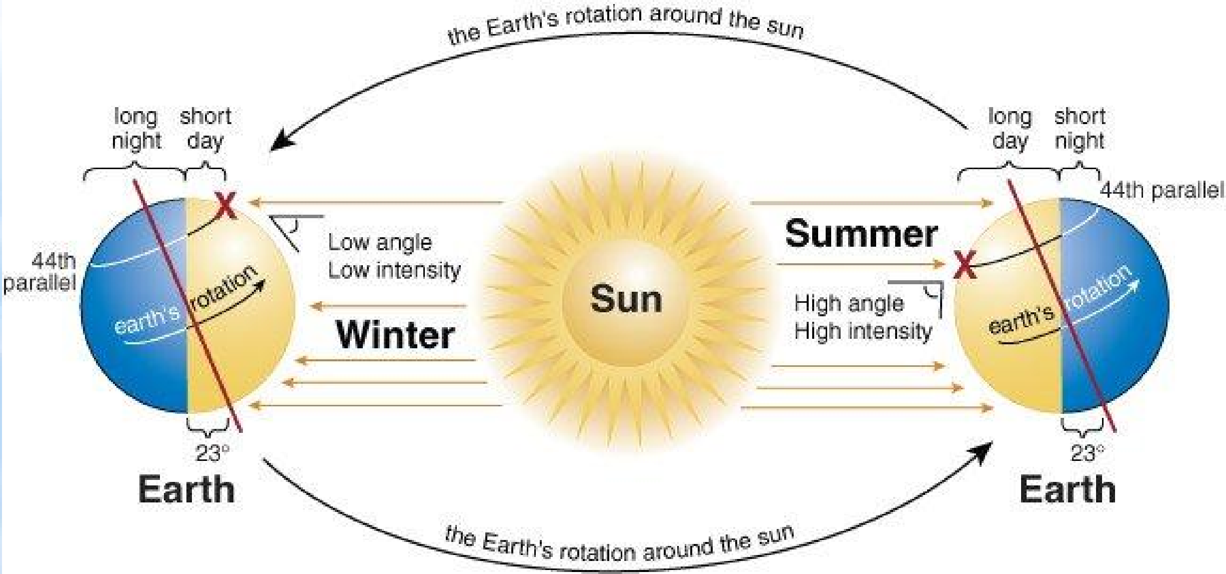


The solar constant

Due to Earth's elliptic orbit around the Sun the actual solar radiation outside the atmosphere at a given time (the extraterrestrial radiation) will differ from G_{sc}. Over the year, it varies from 1412 W/m^2 at the beginning of July to 1322 W/m^2 at the turn of the year; a 3.3% variation from the mean value. This can be expressed mathematically as

$$G_{0n} = G_{sc}\left(1 + 0.033 \times \cos\left(\frac{360d}{365}\right)\right) \quad \text{……………..(2)}$$

Where: d is the day of the year. The subscript 0 denotes zero air mass (AM0) and the subscript n indicates that the radiation is on a plane normal to the Sun-Earth axis.



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الطاقة المتجددة

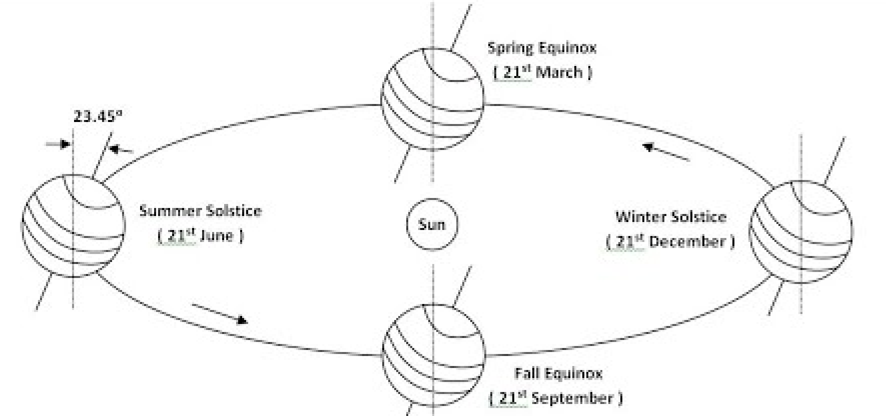
المحاضرة الخامسة: تنوع الإشعاع خارج الأرض

مدرس المادة: د. عمر عبد الهادي مصطفى

VARIATION OF EXTRATERRESTRIAL RADIATION

Two sources of variation in extraterrestrial radiation must be considered. The first is the variation in the radiation emitted by the sun. There are conflicting reports in the literature on periodic variations of intrinsic solar radiation. It has been suggested that there are small variations (less than ±1.5%) with different periodicities and variation related to sunspot activities.

The second factor is the variation of extraterrestrial Solar radiation with time of year because of the variation in distance between the earth and the sun, however, does lead to variation of extraterrestrial radiation flux in the range of 3.3%.

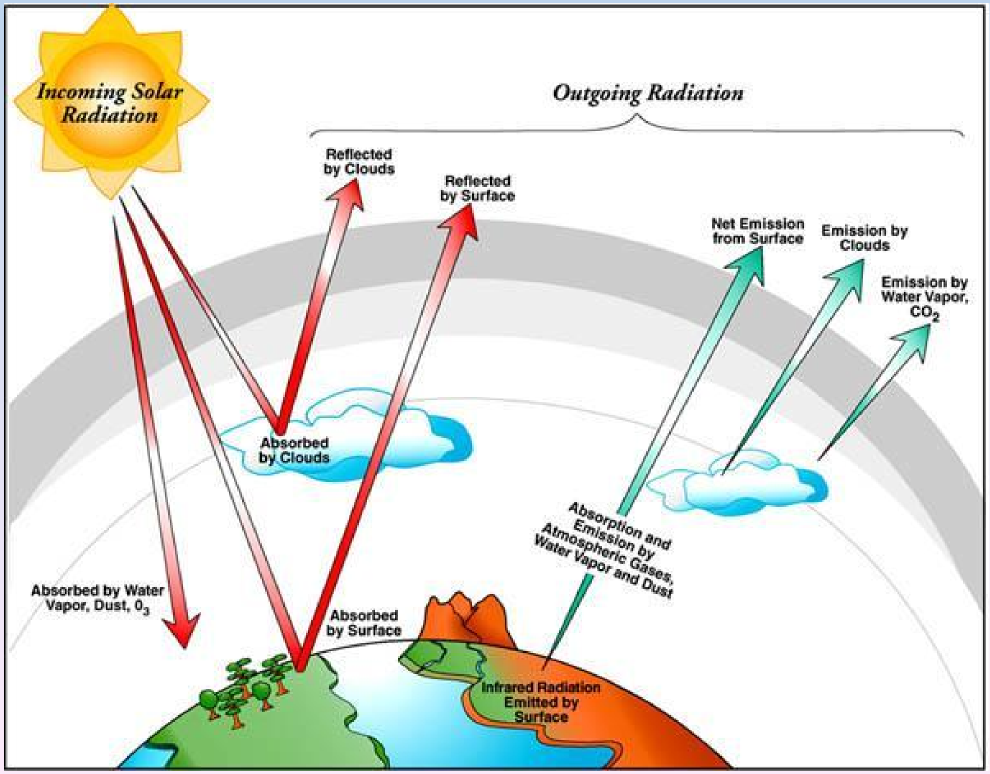


VARIATION OF EXTRATERRESTRIAL RADIATION

Available solar radiation on Earth

1. Atmospheric attenuation

Extraterrestrial radiation is affected in various ways during passage through the atmosphere. This section reviews these mechanisms and describes the properties of the solar radiation available at Earth's surface.



VARIATION OF EXTRATERRESTRIAL RADIATION

When passing through the atmosphere, solar radiation with normal incidence is subject to two sources of attenuation: scattering and absorption.

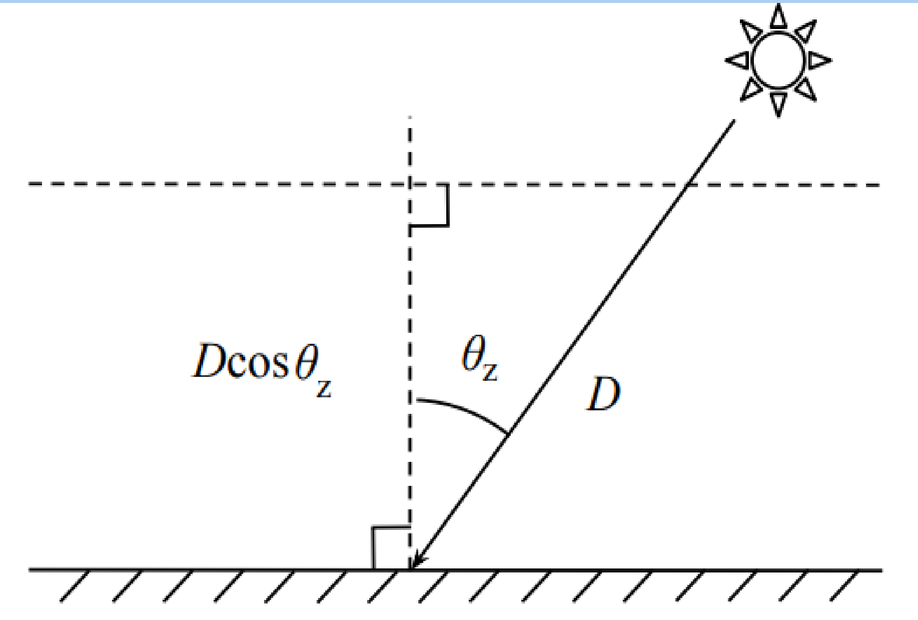
Scattering occurs when the radiation interacts with air molecules, water and dust in the atmosphere. The degree of scattering is determined by the wavelength of the radiation in relation to particle size, the concentration of particles in the atmosphere and the total mass of air that the radiation has to travel through. The most important process is Rayleigh scattering, in which light is scattered off air molecules. This type of scattering is most effective for shorter wavelengths in the blue end of the spectrum, mainly those shorter than 0.6 µm.

Absorption of solar radiation occurs in the UV range due to ozone and in the IR range due to water and carbon dioxide. In the process of absorption, the solar radiation is converted to heat, which is emitted by the particles as long-wave radiation.

VARIATION OF EXTRATERRESTRIAL RADIATION

Air mass

Attenuation of solar radiation depends on how far the radiation has to travel through the atmosphere. The longer the path length, the more particles the light has to interact with. This varies over the year and over individual days, with the longest path in the evenings, when the Sun is close to the horizon. The path length is described by the air mass.



VARIATION OF EXTRATERRESTRIAL RADIATION

Air mass

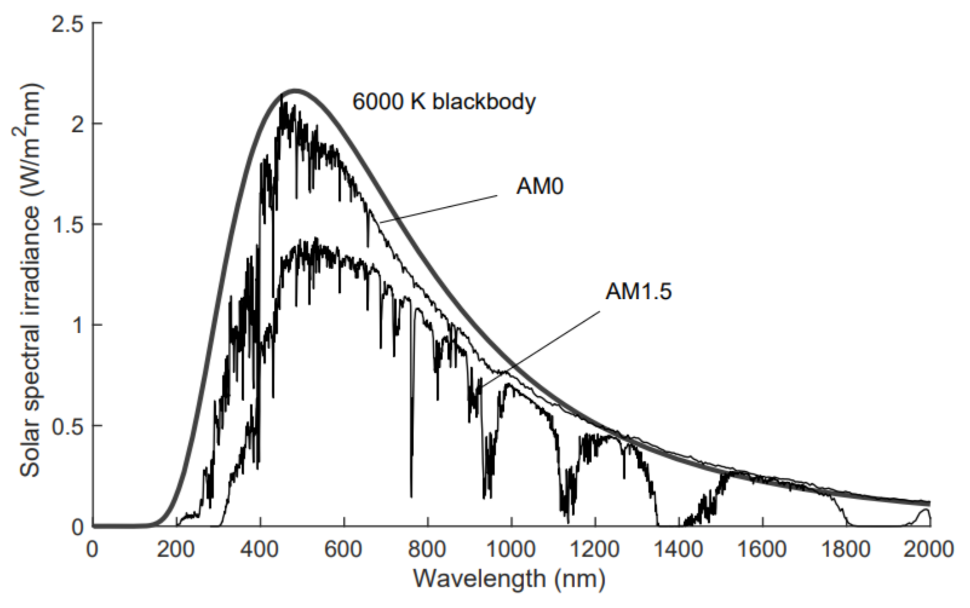
Formally, air mass is the ratio of the atmospheric mass through which the radiation passes from the Sun’s current position in the sky, to the mass that it would pass through if the Sun were at the zenith (directly overhead). For example, at air mass 2, the path length through the atmosphere is two times longer than if the Sun were directly overhead. $\theta z < 70^{\circ}$ as shown in the figure shown above. For higher angles the curvature of Earth becomes influential. For $\theta z = 85^{\circ}$ the error is 10%.

$$Am = \frac{1}{\cos\theta_z}$$

VARIATION OF EXTRATERRESTRIAL RADIATION

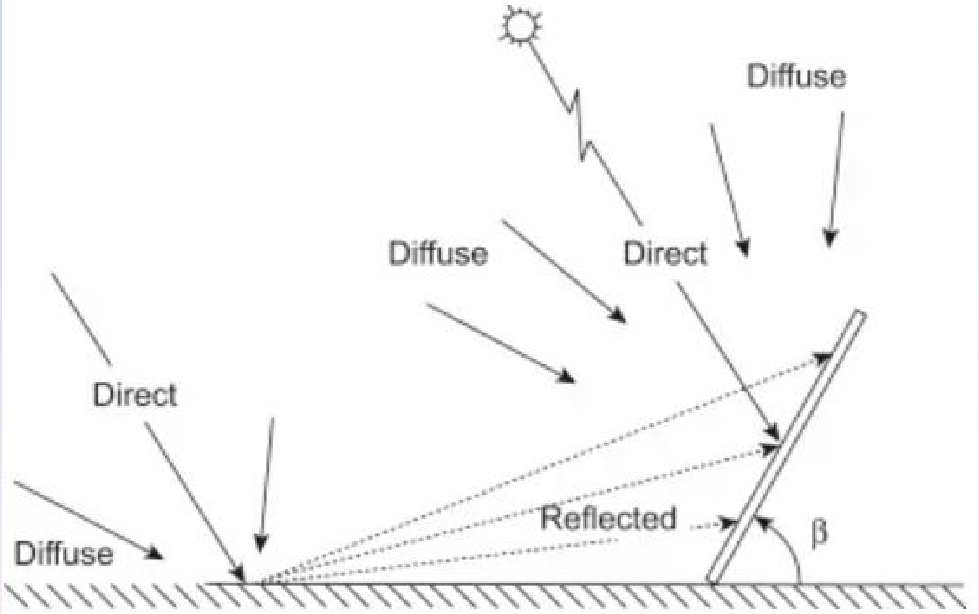
Air mass

Because the atmospheric conditions vary over time, a standard spectrum for radiation at ground level is needed for development and testing of solar devices. The accepted standard is the distribution for m = 1.5, the AM1.5 spectrum, which corresponds to a zenith angle of 48.2 ◦ . The figure below shows the so-called AM1.5 spectrum and compares it to the extraterrestrial WRC spectrum and a 6000 K black-body distribution.



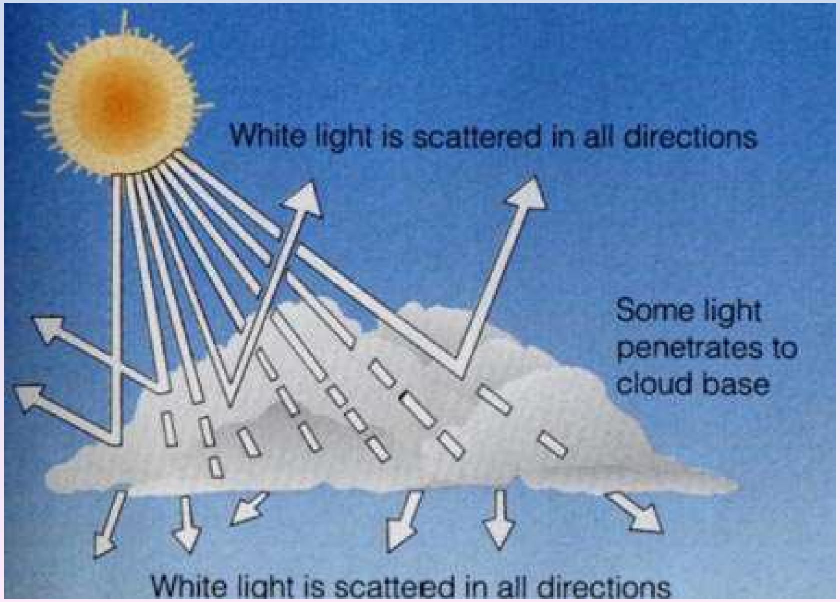
VARIATION OF EXTRATERRESTRIAL RADIATION

Beam Radiation The solar radiation received from the sun without having been scattered by the atmosphere. (Beam radiation is often referred to as direct solar radiation; to avoid confusion between subscripts for direct and diffuse, we use the term beam radiation.)



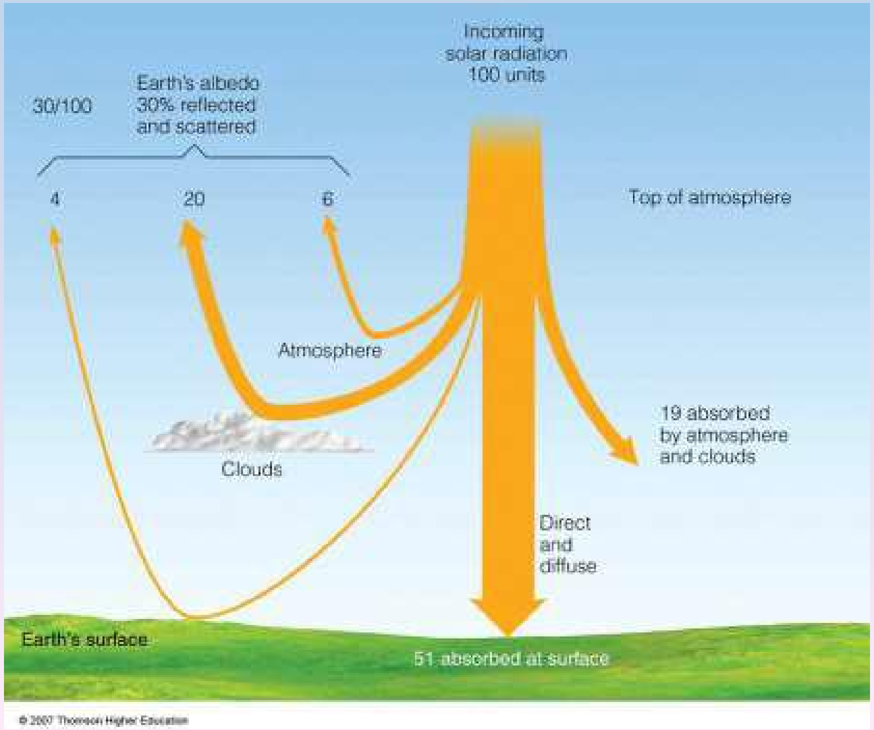
VARIATION OF EXTRATERRESTRIAL RADIATION

Diffuse Radiation The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere. (Diffuse radiation is referred to in some meteorological literature as sky radiation or solar sky radiation; the definition used here will distinguish the diffuse solar radiation from infrared radiation emitted by the atmosphere.)



VARIATION OF EXTRATERRESTRIAL RADIATION

Total Solar Radiation The sum of the beam and the diffuse solar radiation on a surface. (The most common measurements of solar radiation are total radiation on a horizontal surface, often referred to as **global radiation** on the surface.)



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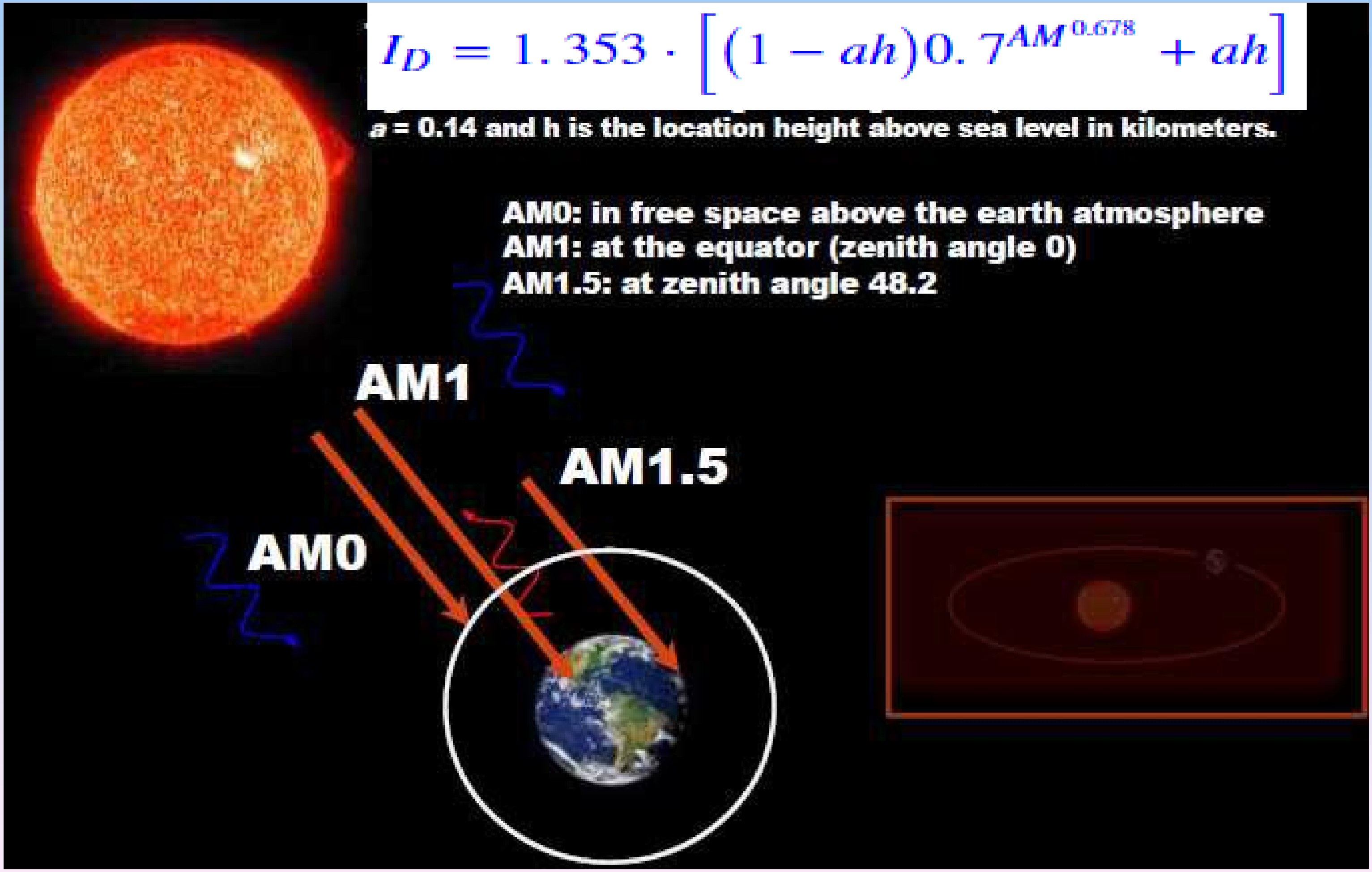
VARIATION OF EXTRATERRESTRIAL RADIATION

Solar Time: Time based on the apparent angular motion of the sun across the sky with solar noon the time the sun crosses the meridian of the observer.

Solar time is the time used in all of the sun-angle relationships; it does not coincide with local clock time. It is necessary to convert standard time to solar time by applying two corrections. First, there is a constant correction for the difference in longitude between the observer’s meridian (longitude) and the meridian on which the local standard time is based. The sun takes 4 min to transverse 1° of longitude. The second correction is from the equation of time, which takes into account the perturbations in the earth’s rate of rotation which affect the time the sun crosses the observer’s meridian.

VARIATION OF EXTRATERRESTRIAL RADIATION

Intensity of Sunlight on Ground



$$I_D = 1.353 \cdot \left[(1 - ah)0.7^{AM^{0.678}} + ah\right]$$

a = 0.14 and h is the location height above sea level in kilometers.

AM0: in free space above the earth atmosphere
AM1: at the equator (zenith angle 0)
AM1.5: at zenith angle 48.2

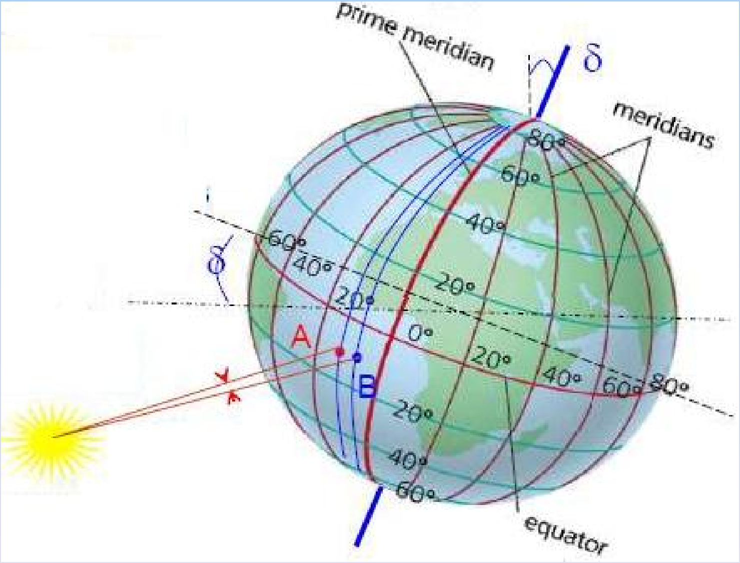
VARIATION OF EXTRATERRESTRIAL RADIATION

Longitude and Inclination

- The earth is divided into 360º longitudinal lines passing through poles.

- Zero longitudinal line passes through Greenwich

- 1 day has 24 hours, and the earth spins 360° in this time, so the earth rotates 15° every hour.



(1 hour = 15° of longitude)

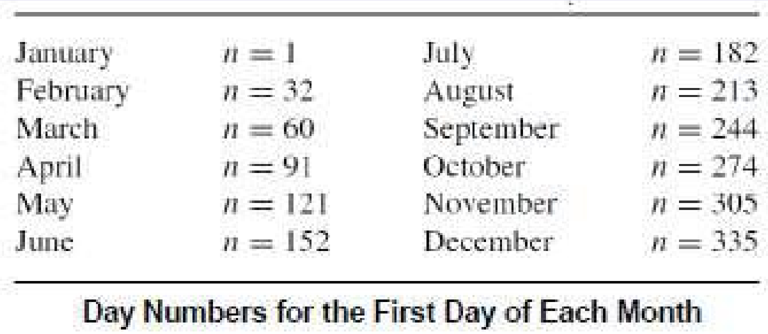
VARIATION OF EXTRATERRESTRIAL RADIATION

Longitude and Inclination

The declination angle, δ varies seasonally

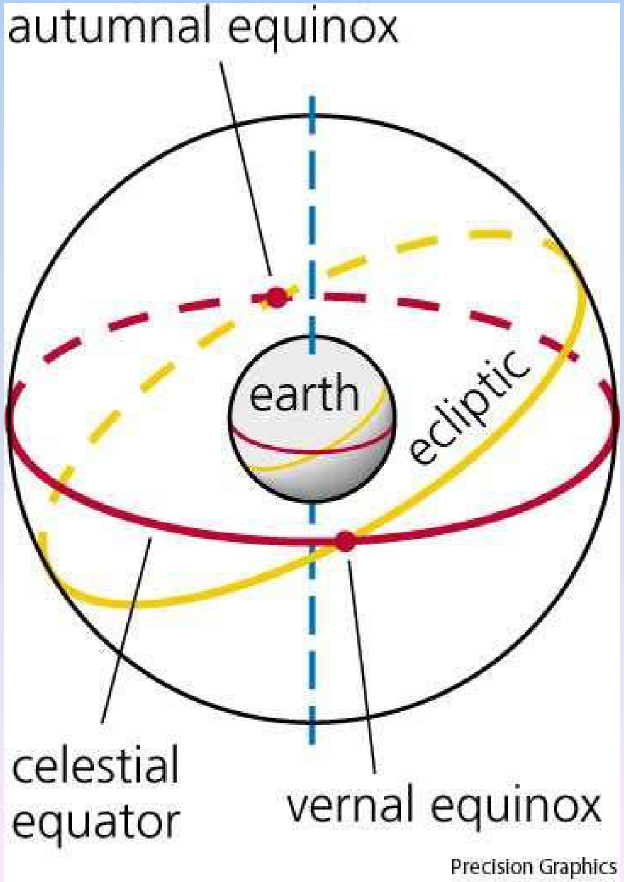
δ = 23.27 at summer and winter solstice
δ = 0 at equinoxes
δ takes all intermediate values

$$\delta = 23.45 \sin\left[\frac{360}{365}(n-81)\right]$$



January	$n = 1$	July	$n = 182$
February	$n = 32$	August	$n = 213$
March	$n = 60$	September	$n = 244$
April	$n = 91$	October	$n = 274$
May	$n = 121$	November	$n = 305$
June	$n = 152$	December	$n = 335$

Day Numbers for the First Day of Each Month



Precision Graphics

VARIATION OF EXTRATERRESTRIAL RADIATION

The incident solar radiation on a slope plane with an inclination angle β ($I_{\beta G}$) can be evaluated as the sum of direct-beam, sky-diffuse, and ground reflected components. It can be given as:

$$I_{\beta G} = I_{\beta B} + I_{\beta D} + I_{\beta R}$$

Where: $I_{\beta B}$ - is the beam radiation, w/m^2, $I_{\beta D}$ - is the sky-diffuse radiation, w/m^2, $I_{\beta R}$ - is the ground reflected radiation, w/m^2.

VARIATION OF EXTRATERRESTRIAL RADIATION

- Types of Solar Radiation measuring devices
  - Pyranometer
  - Pyrheliometer
  - Sunshine recorders

VARIATION OF EXTRATERRESTRIAL RADIATION

Pyranometer

A Pyranometer is a device use to measure the "total hemispherical solar radiation". The total solar radiation arriving at the outer edge of the atmosphere is called the "Solar constant".

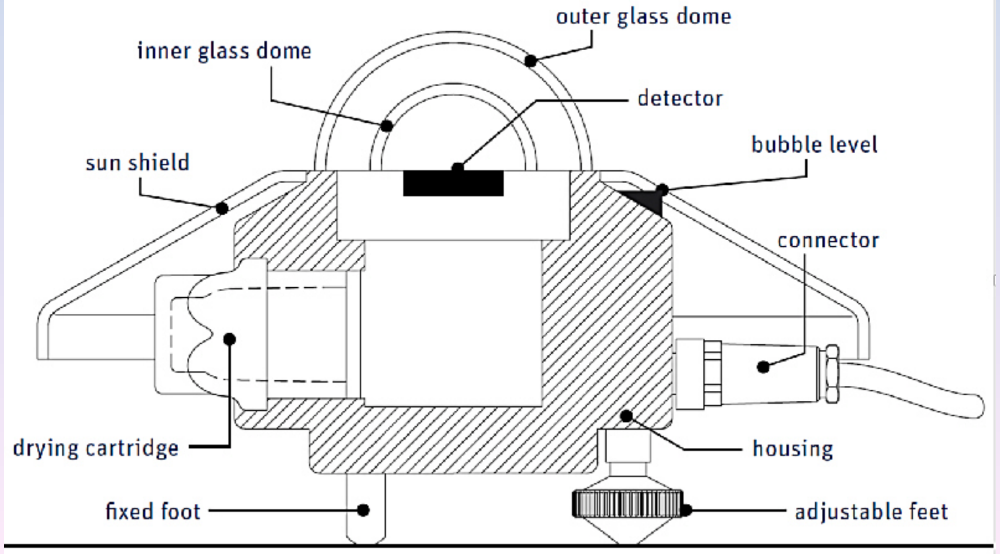
The working principle of this instrument is that sensitive surface is exposed to total (beam, diffuse and reflected from the earth and surrounding) radiations.

VARIATION OF EXTRATERRESTRIAL RADIATION

Construction of the Pyranometer

It consists of black surface which receives the beam as well diffuse radiations which rises het. A Glass some prevents the loss of radiation received by the black surface.

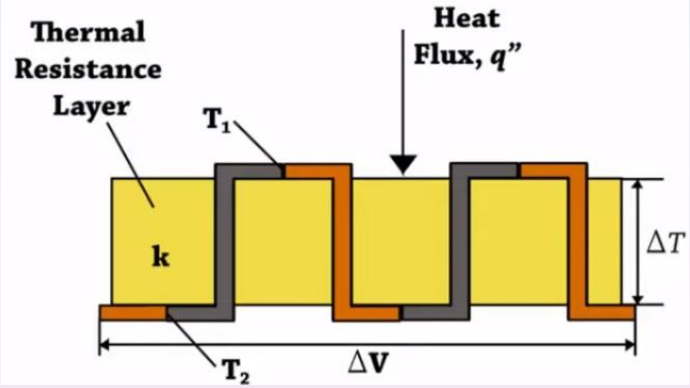
A thermocouple is a temperature sensor, and consists of a number of thermocouples connected in series to increase the sensitivity. The supporting stand keeps the black surface in a proper position.

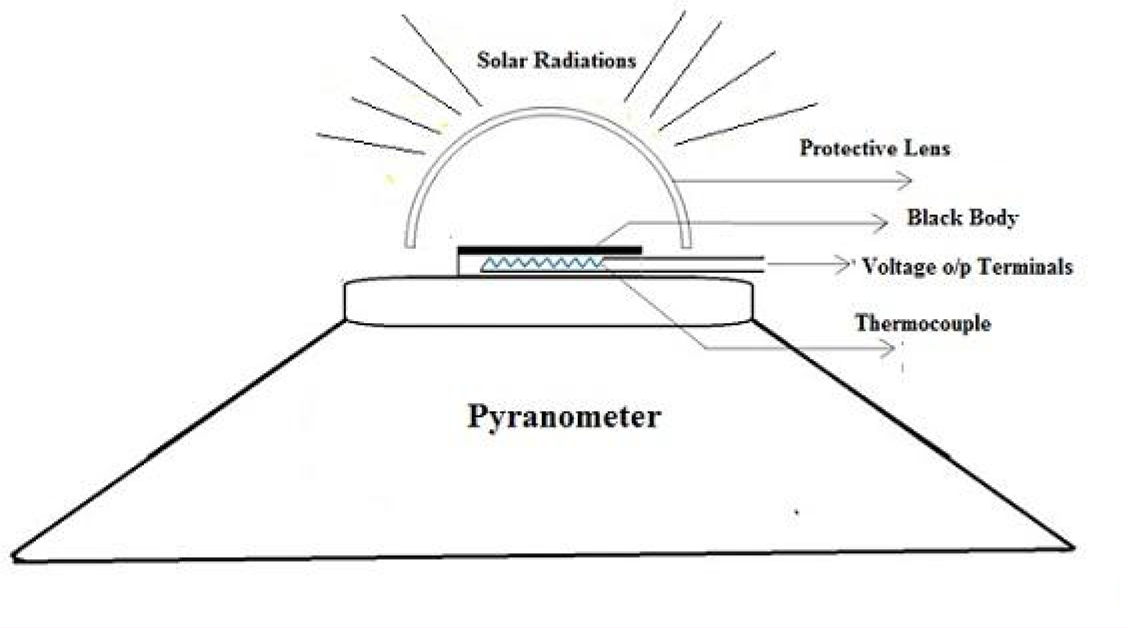


VARIATION OF EXTRATERRESTRIAL RADIATION

Working of the Pyranometer

When the Pyranometer is exposed to sun, it starts receiving the radiations. As a result, the surface temperature starts rising due to absorption of the radiation. The increase in the temperature of the absorbing surface is detected by the thermocouples. The thermocouples generates a thermo emf which is proportional to the radiations absorbed.





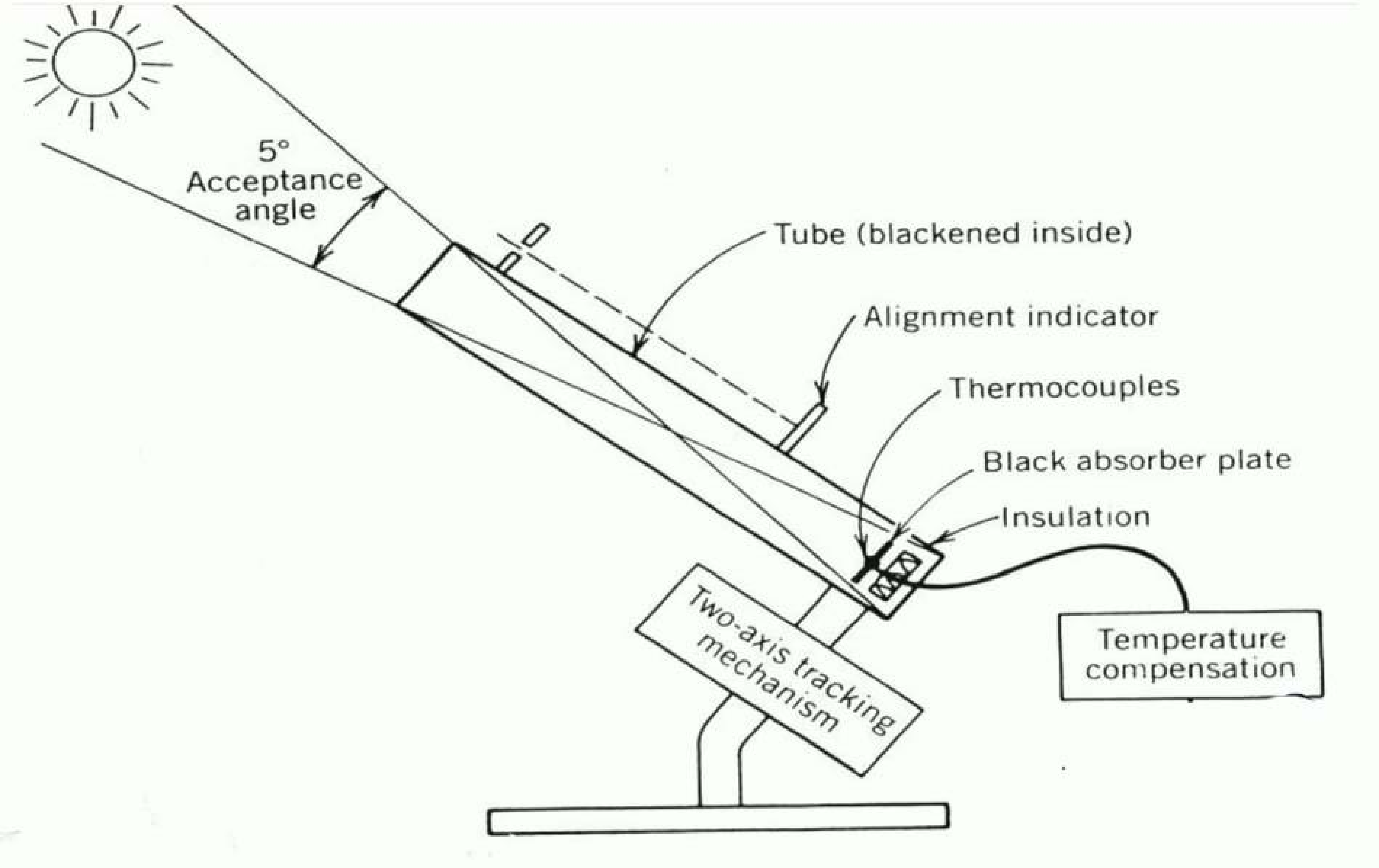
VARIATION OF EXTRATERRESTRIAL RADIATION

Pyrheliometer

A pyrheliometer is a device used to measure beam or direct radiations. It is collimates the radiation to determine the beam intensity as a function of incident angle. This instrument uses a collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun at normal incidence.

VARIATION OF EXTRATERRESTRIAL RADIATION

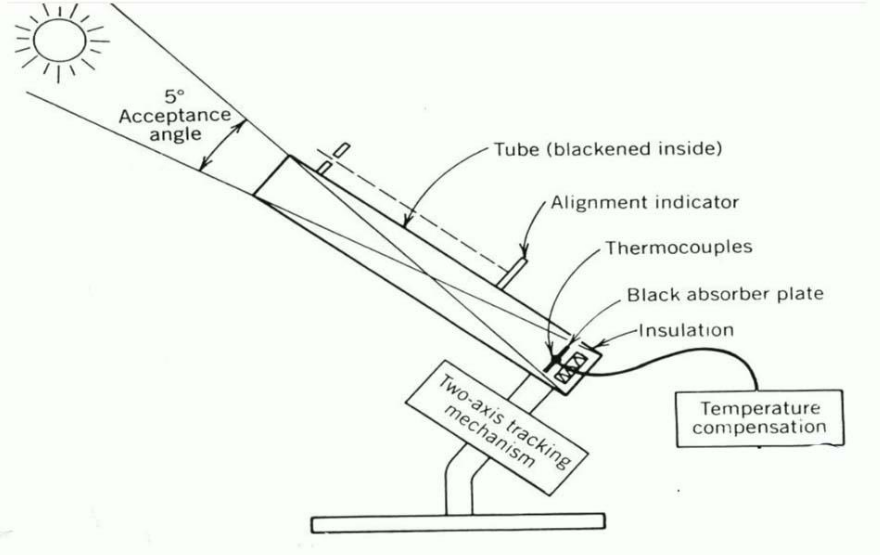
Construction of the Pyrheliometer



VARIATION OF EXTRATERRESTRIAL RADIATION

Working of Pyrheliometer

The sunlight will enter in the long collimator tube and will incident on black absorber plate. The thermopile is in contact with black absorber plate when the black plat will absorb the heat the emf will be generated between the hot and colder surface due to the temperature difference. This emf will be used to measure the value of beam radiation.



VARIATION OF EXTRATERRESTRIAL RADIATION

Sunshine recorders

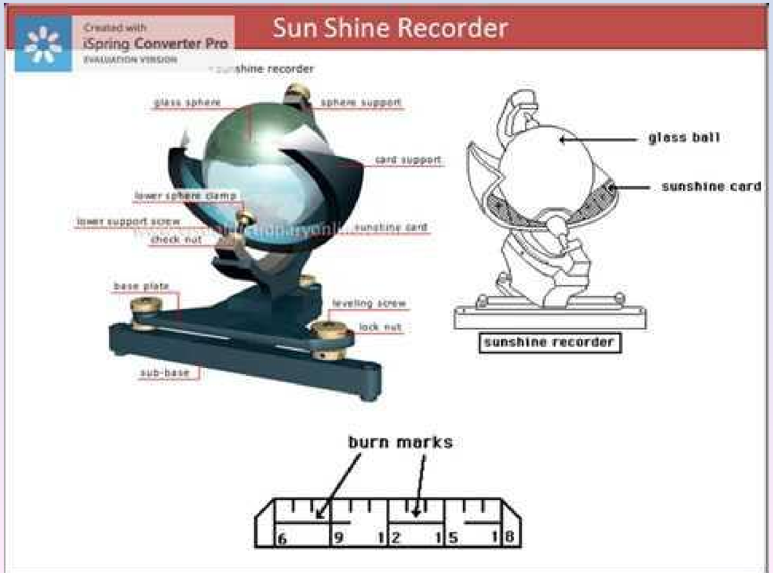
A sunshine recorder is a device used to measure the hours of bright sunshine in a day.

VARIATION OF EXTRATERRESTRIAL RADIATION

Construction and working of the Sunshine recorders

It consists of a “glass-sphere” installed in a section of “spherical metal bowl” having grooves for holding a “recorder card strip” and the glass sphere.

The glass sphere, which acts as a convex lane, focuses the sun’s rays/beams to a point on the card strip held in a groove in the spherical bowl mounted concentrically with the sphere.



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مدرس المادة: د. عمر عبد الهادي مصطفى

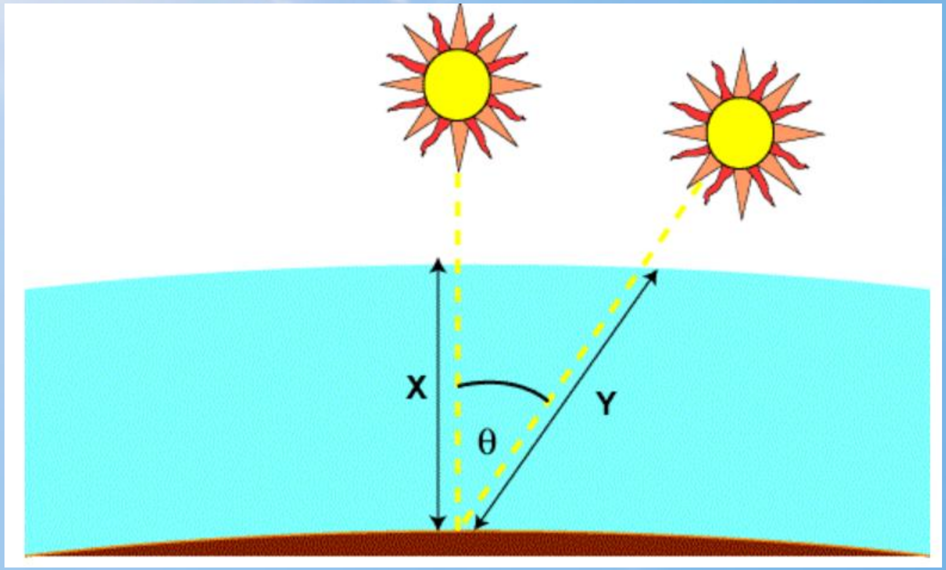
Calculations of the solar energy

Review of the air mass:

The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead).

$$AM = \frac{1}{\cos\theta}$$

The air mass represents the proportion of atmosphere that the light must pass through before striking the Earth relative to its overhead path length, and is equal to Y/X.

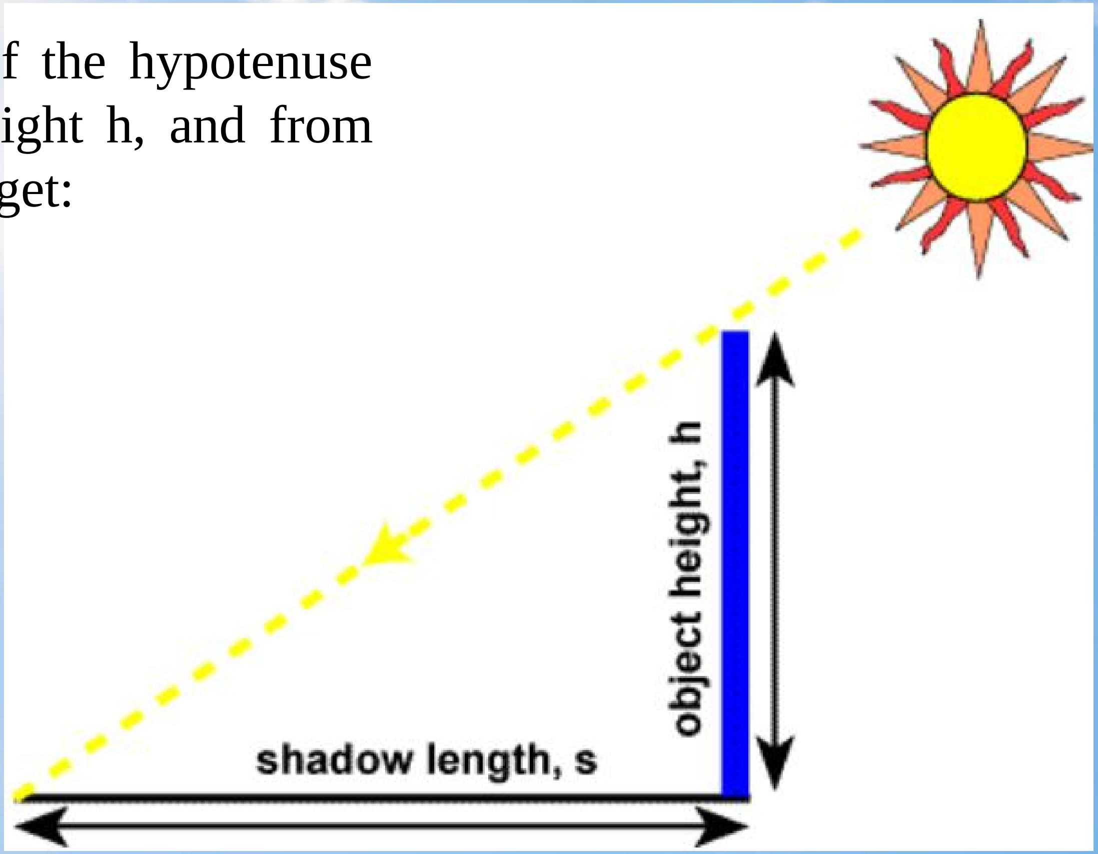


Calculations of the solar energy

An easy method to determine the air mass is from the shadow of a vertical pole.

Air mass is the length of the hypotenuse divided by the object height h, and from Pythagoras's theorem we get:

$$AM = \sqrt{1 + \left(\frac{s}{h}\right)^2}$$

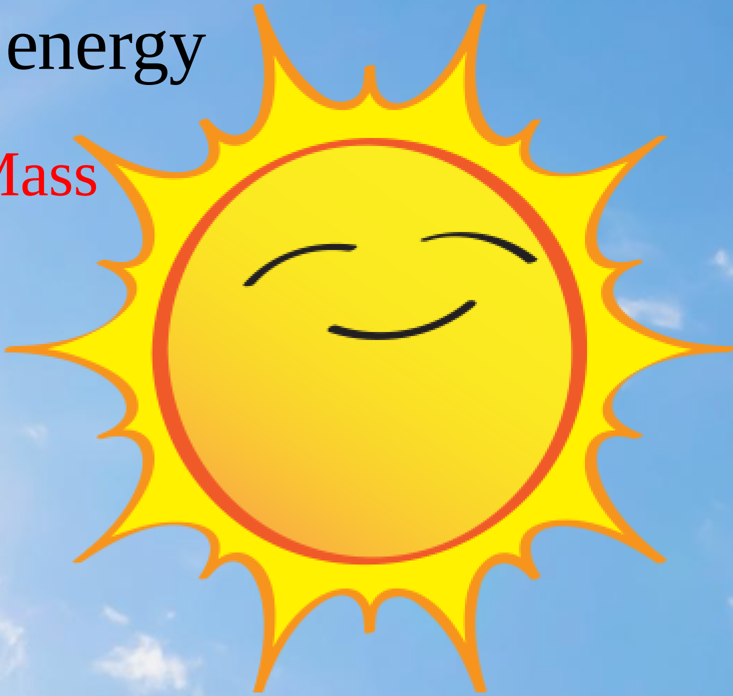


Calculations of the solar energy

The above calculation for air mass assumes that the atmosphere is a flat horizontal layer, but because of the curvature of the atmosphere, the air mass is not quite equal to the atmospheric path length when the sun is close to the horizon. At sunrise, the angle of the sun from the vertical position is 90° and the air mass is infinite, whereas the path length clearly is not. An equation which incorporates the curvature of the earth is:

$$AM = \frac{1}{\cos(\theta) + 0.50572(96.07995 - \theta)^{-1.6364}}$$

Calculations of the solar energy



Intensity Calculations Based on the Air Mass

The intensity of the direct component (beam radiation) of sunlight throughout each day can be determined as a function of air mass from the experimentally determined equation:

$$I_B = 1.353 * 0.7^{AM^{0.678}}$$

where I_B is the intensity on a plane perpendicular to the sun's rays in units of kW/m^2 and AM is the air mass. The value of 1.353 kW/m^2 is the solar constant and the number 0.7 arises from the fact that about 70% of the radiation incident on the atmosphere is transmitted to the Earth. The extra power term of 0.678 is an empirical fit to the observed data and takes into account the non-uniformities in the atmospheric layers.

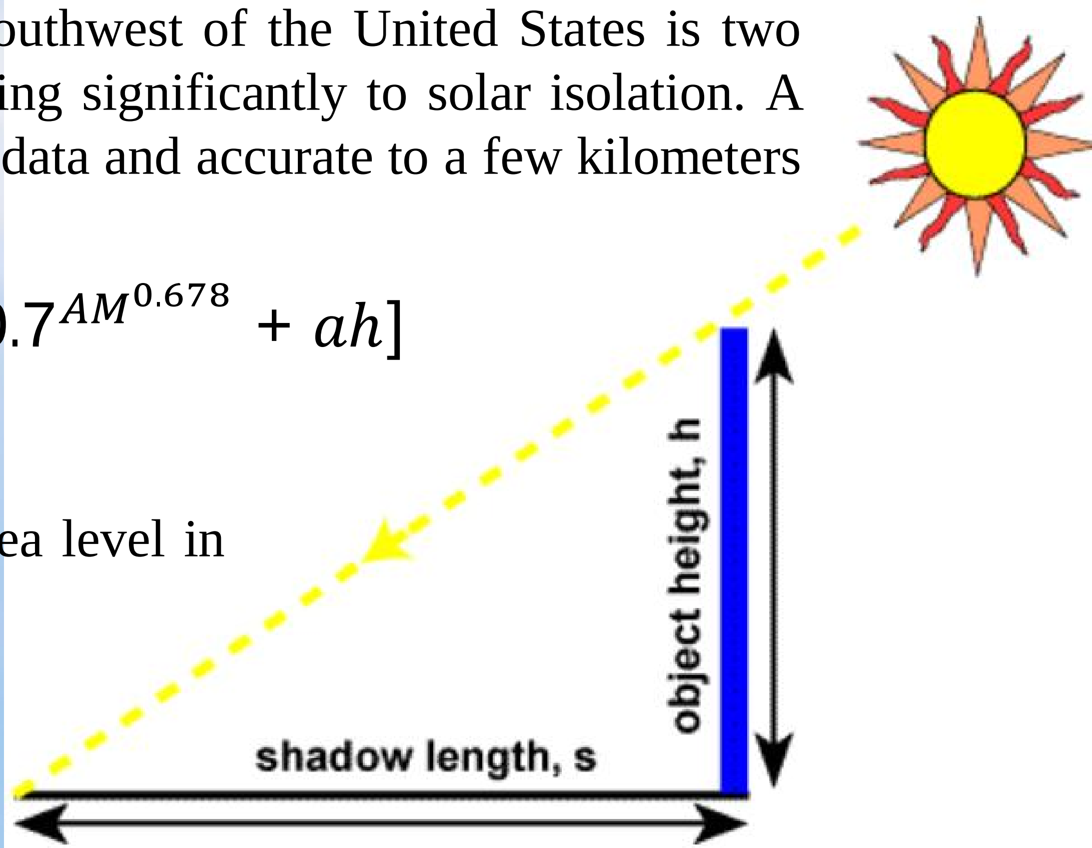
Calculations of the solar energy

Intensity Calculations Based on the Air Mass

Sunlight intensity increases with the height above sea level. The spectral content of sunlight also changes making the sky 'bluer' on high mountains. Much of the southwest of the United States is two kilometers above sea level, adding significantly to solar isolation. A simple empirical fit to observed data and accurate to a few kilometers above sea level is given by:

$$I_B = 1.353 * [(1 - ah)0.7^{AM^{0.678}} + ah]$$

where *a* = 0.14
h is the location height above sea level in kilometers.



Calculations of the solar energy

Even on a clear day, the diffuse radiation is still about 10% of the beam radiation. Thus on a clear day the global irradiance on a module perpendicular to the sun's rays is:

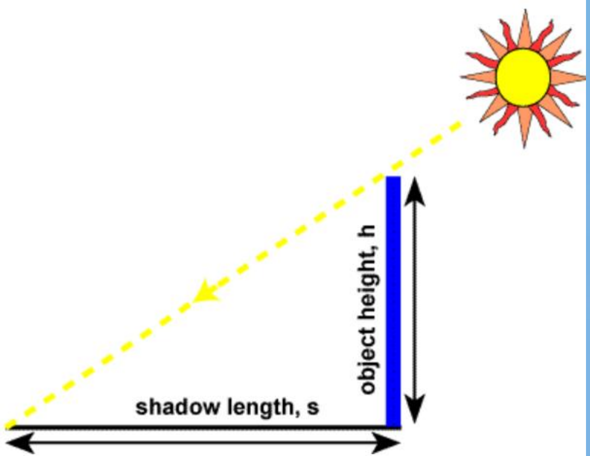
$$I_G = 1.1 * I_B$$

Calculations of the solar energy

Example 1: find out the beam, diffused and global solar radiation on the see level if the vertical object with the height of 30 cm has the shadow of 55 cm

Solution: if the atmosphere assumed as a flat horizontal layer:
h = 30 cm
s = 55 cm

$$AM = \sqrt{1 + \left(\frac{s}{h}\right)^2}$$

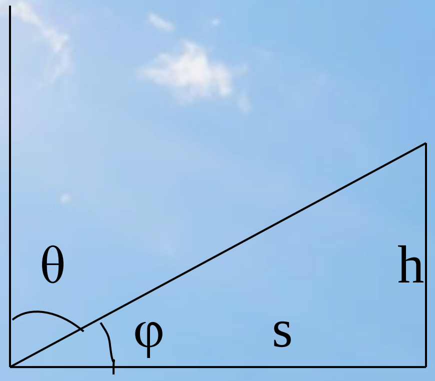


Calculations of the solar energy

So that; AM = 2.088

An other method to find the air mass is through the angle from the vertical (zenith angle) θ:

$$\varphi = tan^{-1}\left(\frac{h}{s}\right)$$



$\varphi = 28.61°$

$\theta = 90 - \varphi = 61.389$

$$AM = \frac{1}{\cos\theta} = \frac{1}{\cos 61.389} = 2.088$$

Calculations of the solar energy

Also:

$$AM = \frac{1}{sin\varphi} = 2.088$$

When the curvature shape of the atmosphere depended:

$$AM = \frac{1}{\cos(\theta) + 0.50572(96.07995 - \theta)^{-1.6364}}$$

$$AM = \frac{1}{\cos(61.389) + 0.50572(96.07995 - 61.389)^{-1.6364}} = 2.075$$

Calculations of the solar energy

Beam radiation at sea level:

$$I_B = 1.353 * 0.7^{AM^{0.678}}$$

I_B = 0.751844 kw = 751.844 w

$$I_G = 1.1 * I_B$$

I_G = 827.0284 w

$$I_G = I_B + I_D$$

Diffused radiation I_D is equal to 75.1844 w

Calculations of the solar energy

Home work: re solve the upper example find the amount of beam, diffused and global solar radiation when the object positioned at 3 km over sea level, if the height of the object and its shadow are symmetrical.

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Wind Energy Overview

Wind energy has become one of today's lower cost renewable energy technologies.



Wind turbines are becoming a more common sight in many places in the world, with a number of turbines and large wind farms in Europe and U.S.A.

Wind Energy Overview

The main questions that affect on the decision of wind energy uses

1. Are region’s winds strong enough to turn-on wind turbines practically?

2. Are wind energy costs competitive with conventional energy sources?

3. Are communities willing to have wind turbines nearby

These and similar questions face the prospective wind turbine designer and are addressed in the technology and issues sections of this course.

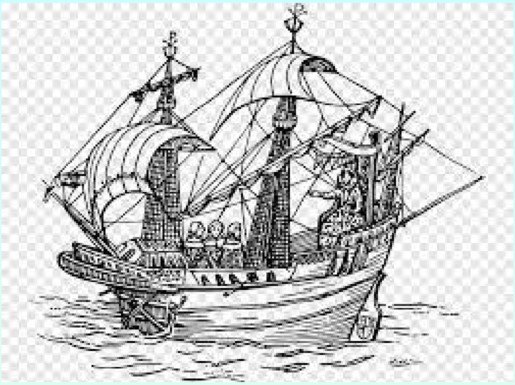
History of Wind Energy

5,000 years back in time

The wind has played a long and important role in the history of human civilization.

The first known use of wind dates back 5,000 years to Egypt, where boats used sails to travel from shore to shore .



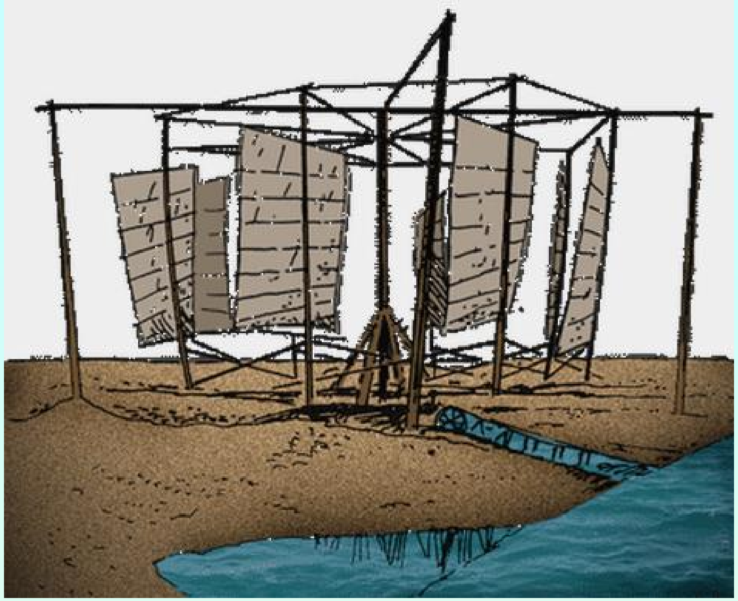


History of Wind Energy

2000 B.C.

The first true windmill , a machine with vanes attached to an axis to produce circular motion, may have been built as early as 2000 B.C. in ancient Babylon.

One of the oldest windmills is in the Ba’asheeqa region in Iraq



History of Wind Energy

10th century A.D.

By the 10th century A.D., windmills with wind-catching surfaces as long as 16 feet (~ 5m) and as high as 30 feet (~ 9m) were grinding grain in the area now known as eastern Iran and Afghanistan.

History of Wind Energy

12th century

The western world discovered the windmill much later.

The earliest written references to working wind machines date from the 12th century.

These too were used for milling grain.

History of Wind Energy

few hundred years later

It was not until a few hundred years later that windmills were modified to pump water and reclaim much of Holland from the sea.

History of Wind Energy

19th century

The familiar **multi-vane "farm windmill"** of the American Midwest and West was invented in the United States during the latter half of the l9th century.

In 1889 there were 77 windmill factories in the United States, and by the turn of the century, windmills had become a major American export.

History of Wind Energy

19th century

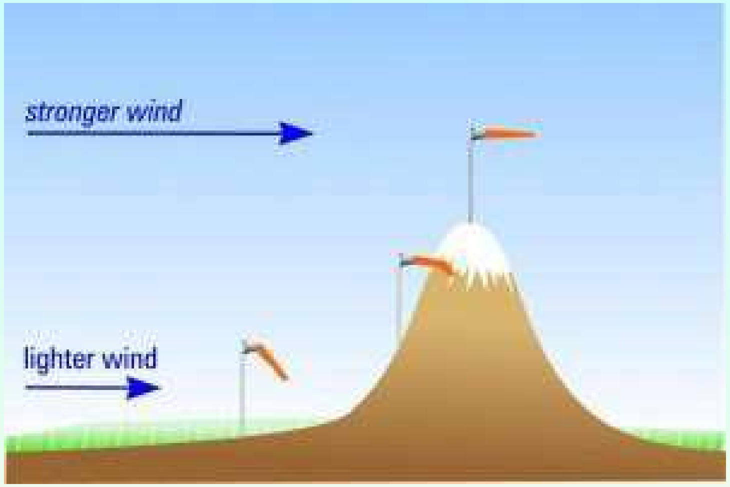
Until the diesel engine came along, many transcontinental rail routes in the U.S. depended on large multi-vane windmills to pump water for steam locomotives.

Wind Classification

Strength	Speed, km/h	Effect
Calm	0-1	Smoke rises vertically
Light air	1-5	Smoke drifts slowly
Light breeze	6-11	Wind felt on face; leaves rustle
Gentle breeze	12-19	Twigs move; light flag unfurls
Moderate breeze	20-29	Dust and paper blown about; small branches move
Fresh breeze	30-39	Wavelets on inland water; small trees move
Strong breeze	40-50	Large branches sway; umbrellas turn inside out
Near gale	51-61	Whole trees sway; difficult to walk against wind
Gale	62-74	Twigs break off trees; walking very hard
Strong gale	75-87	Chimney pots, roof tiles and branches blown down
Storm	88-101	Widespread damage to buildings
Violent Storm	102-117	Widespread damage to buildings
Hurricane	Over 119	Devastation

Wind Variation

Winds are influenced by the ground surface at altitudes up to **100 meters**. Wind is slowed by the surface roughness and obstacles. When dealing with wind energy, we are concerned with **surface winds.**



Wind Energy Natural Characteristics - Facts

- Wind energy increases proportionally with air density.
- Lower elevations have greater air density than higher elevations.
- Wind energy increases proportionally with swept area of the blades; blades are shaped like airplane wings.
- 10% increase in the swept diameter translates into 21% greater in the swept area.

Advantages of wind power

- The wind blows day and night, which allows windmills to produce electricity throughout the day.
- Energy output from a wind turbine will vary as the wind varies, although the most rapid variations will to some extent be compensated for by the inertia of the wind turbine rotor.
- Wind energy is a domestic, renewable source of energy that generates no pollution and has little environmental impact.
- Up to 95 percent of land used for wind farms can also be used for other profitable activities
- The decreasing cost of wind power and the growing interest in renewable energy sources should ensure that wind power will become a viable energy source in worldwide.

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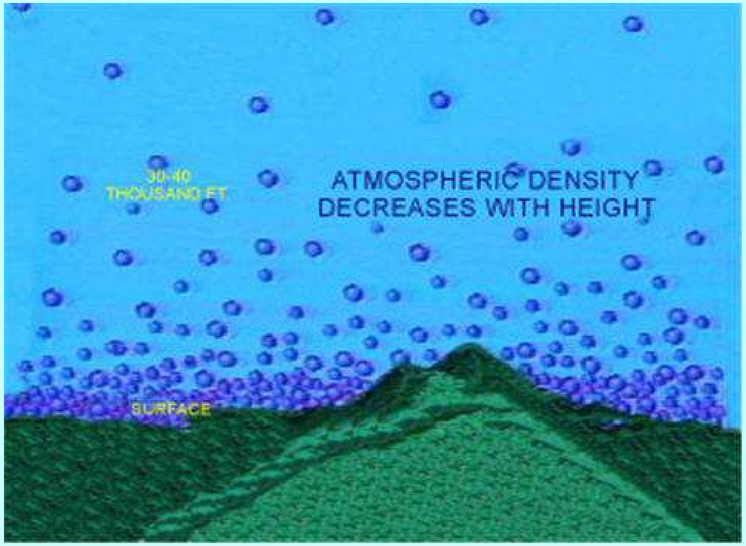
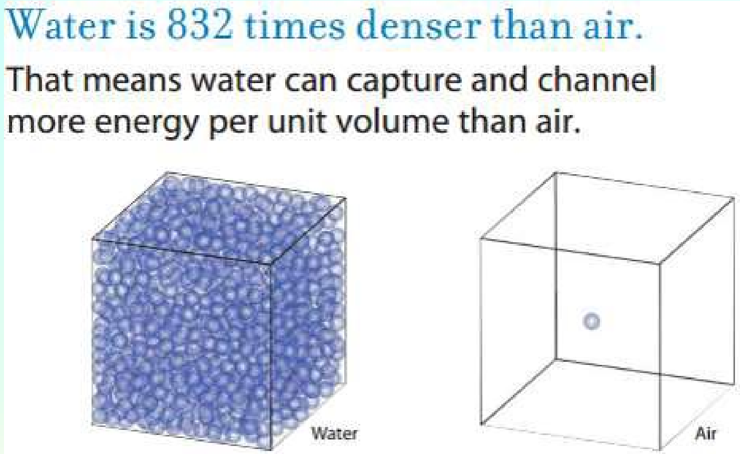
Wind Energy and air density

The kinetic energy of a moving objects (the wind here) is proportional to its mass (or weight). The kinetic energy in the wind thus **depends on** the density of the air, i.e. its mass per unit of volume. In other words, the "heavier" the air, the more energy is received by the turbine. At 15°C air weighs about 1.225 Kg/m^3, but the density decreases slightly with increasing altitude.



$$E = \frac{1}{2}\,\mathrm{m} * v^2$$

Where:
E – kinetic energy, J; m – mass, kg;
v – velocity, m/s.

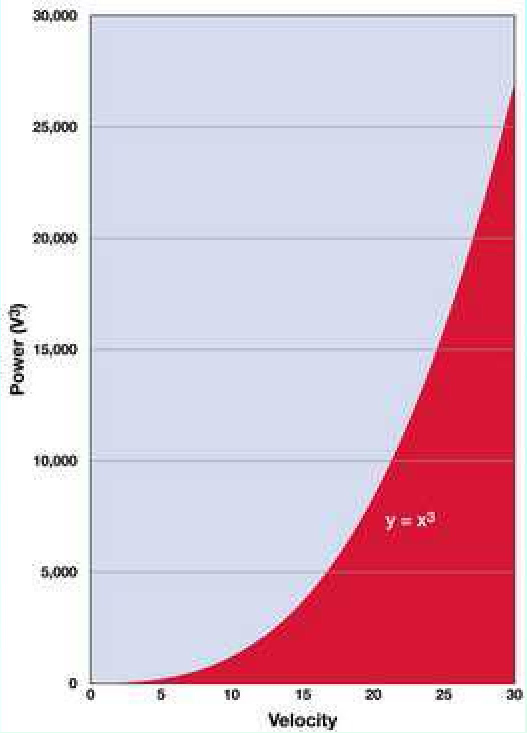

Water is 832 times denser than air.

That means water can capture and channel more energy per unit volume than air.

Wind Energy Natural Characteristics – Speed, height

Wind energy increases with the **cube** of wind speed

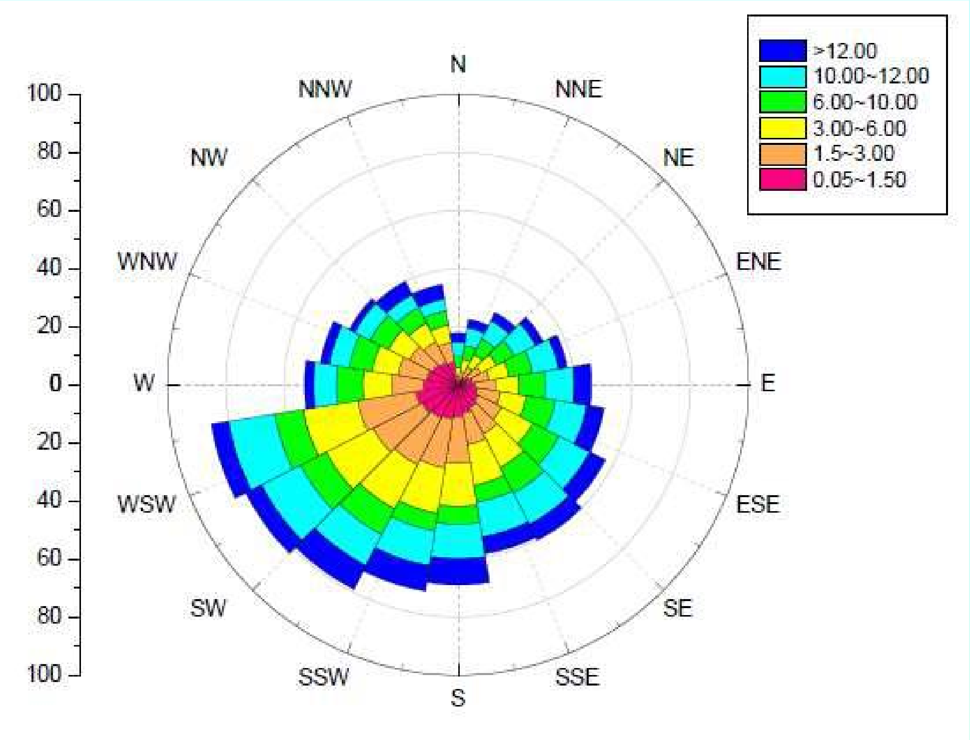
Velocity	Energy
x 1	x 1
x 3	x 27
x 5	x 125
x 7	x 343
x (....)	x (....)^3



The way that wind speed increases with height is complicated and depends on the roughness of the surrounding terrain and on the time of the day.

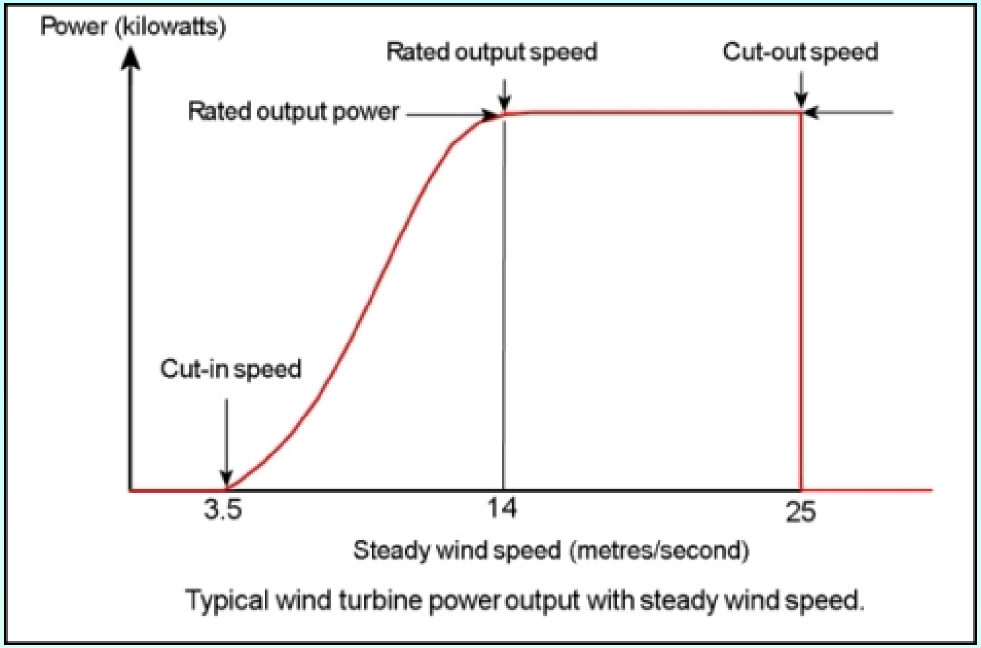
Wind Rose

A graphic tool used by meteorologists to give a view of how wind speed and direction are typically distributed at a particular location.



Operating Characteristics

All wind machines share certain operating characteristics, such as **cut-in**, **rated** and **cut-out** wind speeds

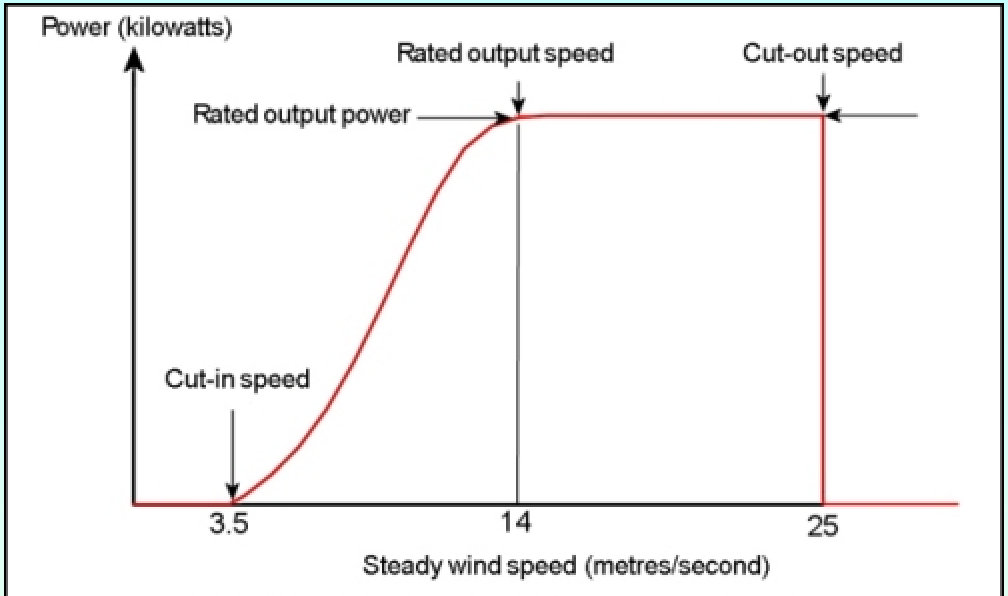


Typical wind turbine power output with steady wind speed.

Operating Characteristics

Cut-in speed

Typically between 7 and 10 mph (or 3 and 4.5 m/s).

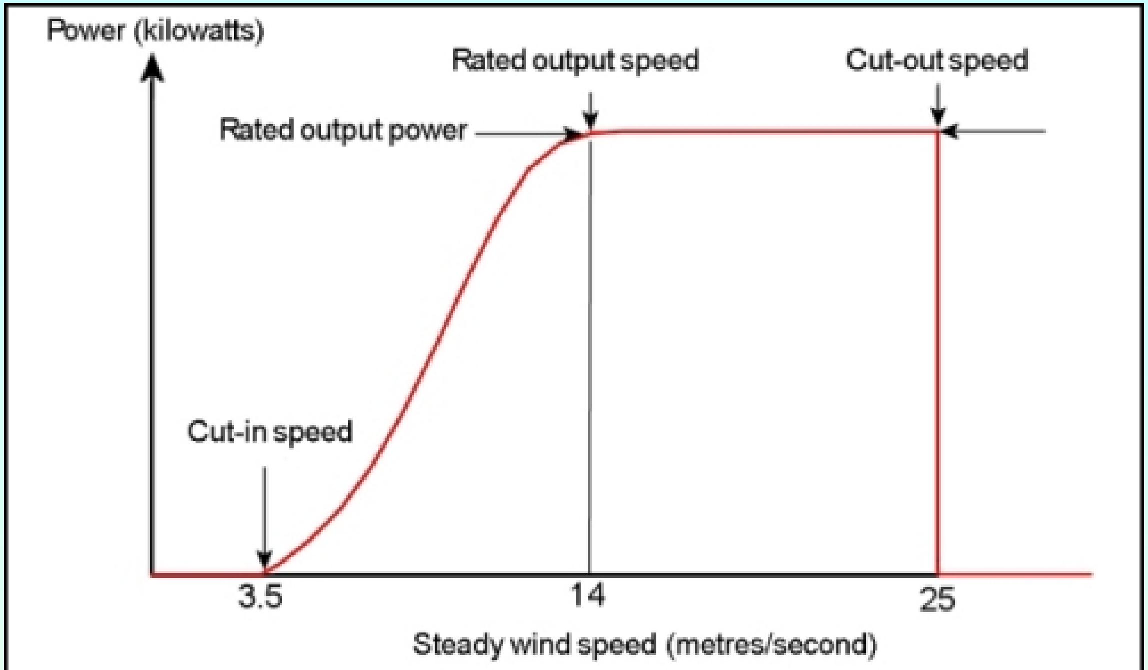


Typical wind turbine power output with steady wind speed.

Operating Characteristics

Rated speed

For most machines in the range of 25 to 35 mph (11 to 15.5 m/s).

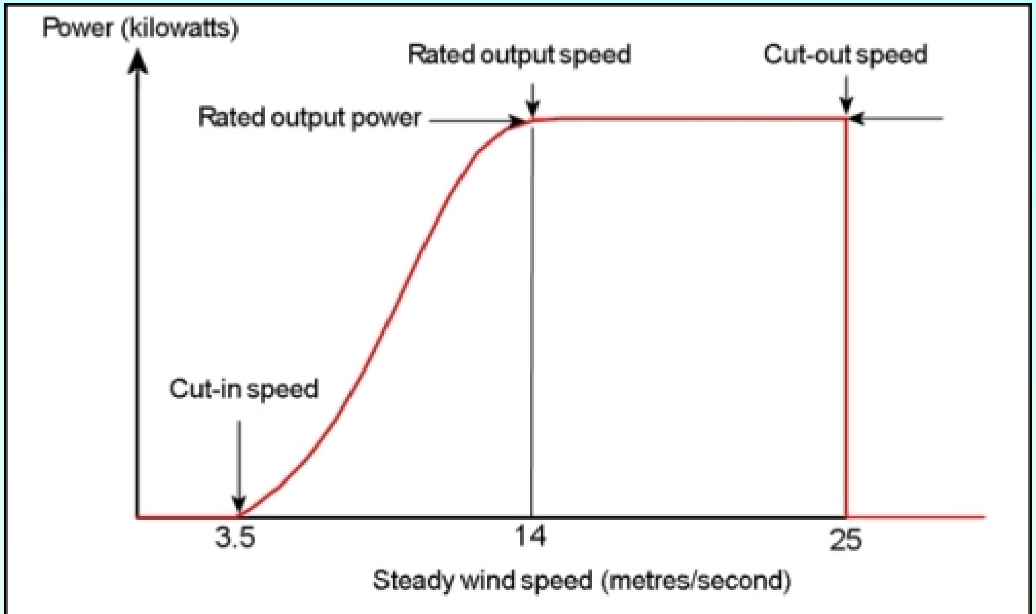


Typical wind turbine power output with steady wind speed.

Operating Characteristics

Cut-out speed

At very high wind speeds, typically between 45 and 80 mph (20 and 35.5 m/s), most wind turbines cease power generation and shut down.



Typical wind turbine power output with steady wind speed.

Operating Characteristics

Cut-out speed

Having a cut-out speed is a safety feature which protects the wind turbine from damage.

© Ross Parry Agency

Operating Characteristics

Cut-out speed

Shut down may occur in one of several ways:

1. In some machines an automatic brake is activated by a wind speed sensor;
2. Some machines twist or “pitch” the blades to spill the wind;
3. Still others use “spoilers,” drag flaps mounted on the blades or the hub which are automatically activated by high rotor rpm’s, or mechanically activated by a spring loaded device which turns the machine sideways to the wind stream.

Normal wind turbine operation usually resumes when the wind drops back to a safe level.

Power of wind

The power in wind is proportional to the cubic wind speed (v^3).

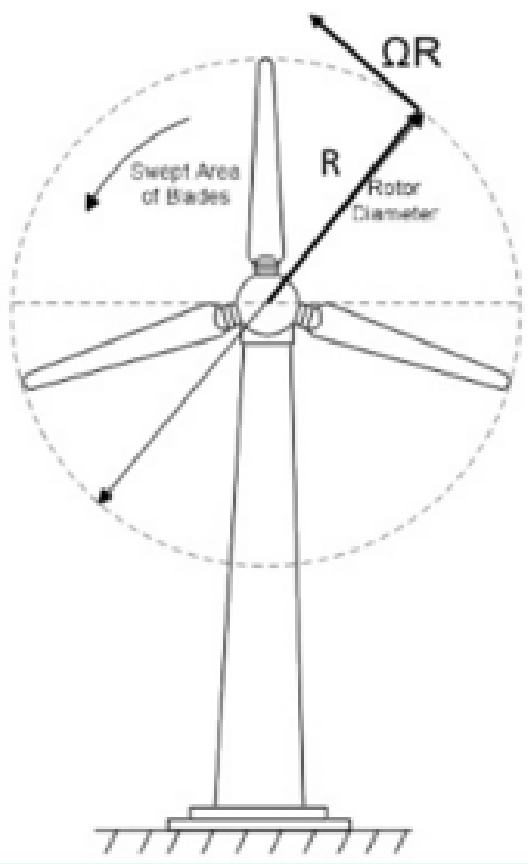
$$E = \frac{1}{2}\mathrm{m} * v^2$$

Why???

- ✓ Kinetic energy of an air mass is proportional to v^2.
- ✓ Amount of air mass moving past a given point is proportional to wind velocity (v)

Power in the Wind = $\frac{1}{2} \rho A v^3$

Calculation of Wind Power



Power in the Wind = ½ ρ A v^3

Where:
ρ – the air density, kg/m^3;
A – the swiped area by the turbine blades, m^2;
v – wind speed, m/s.

The swiped area can be find using the following:

$$A = \pi R^2$$

Where:
R – the radios of rotor, m.

The air density can be calculated by:

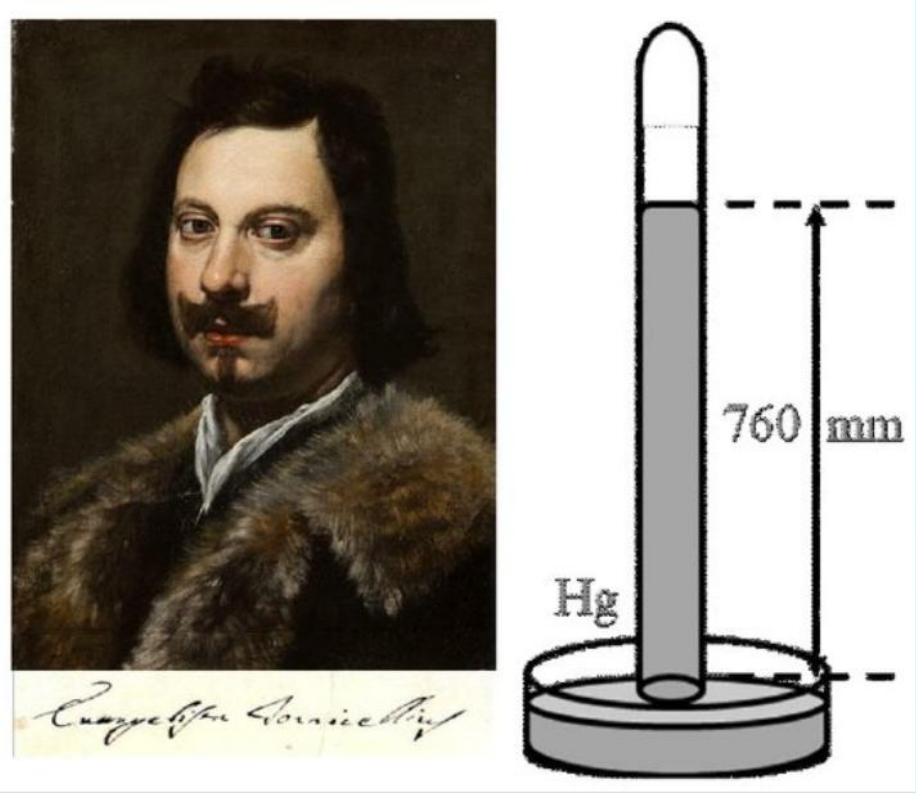
$$\rho = \frac{P}{R * T}$$

Calculation of Wind Power

The air density can be calculated by:

$$\rho = \frac{P}{R * T}$$

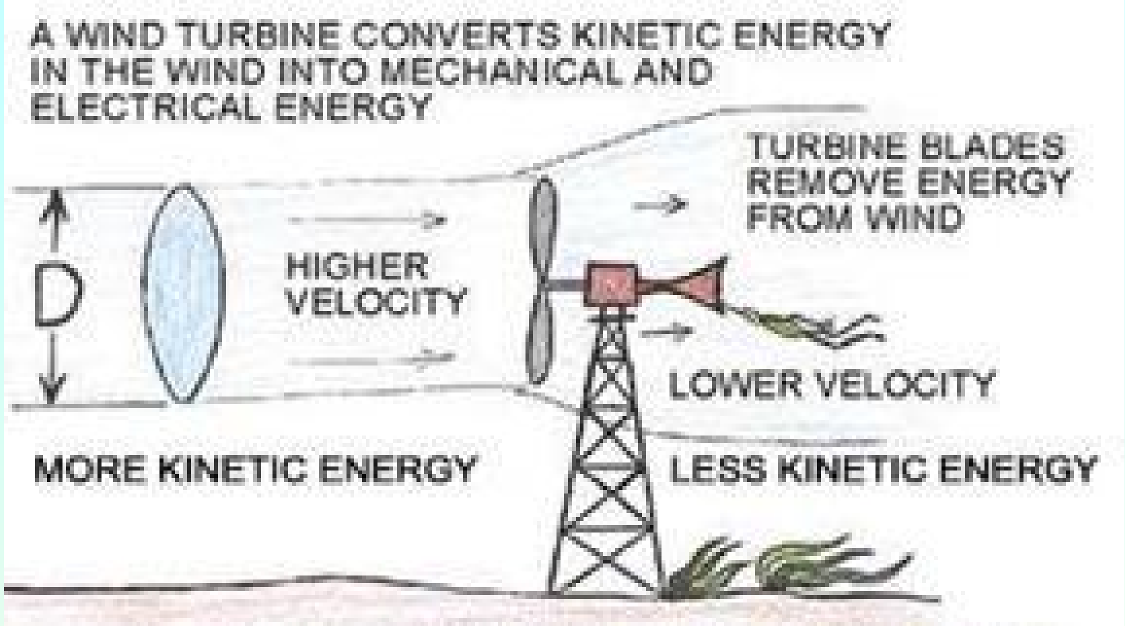
Where:
P – the atmospheric pressure, pa;
R – specific gas constant which is equal to 287 J/kg. °K
T – air temperature, K.



Calculation of Wind Power

Slowing the wind down

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down.



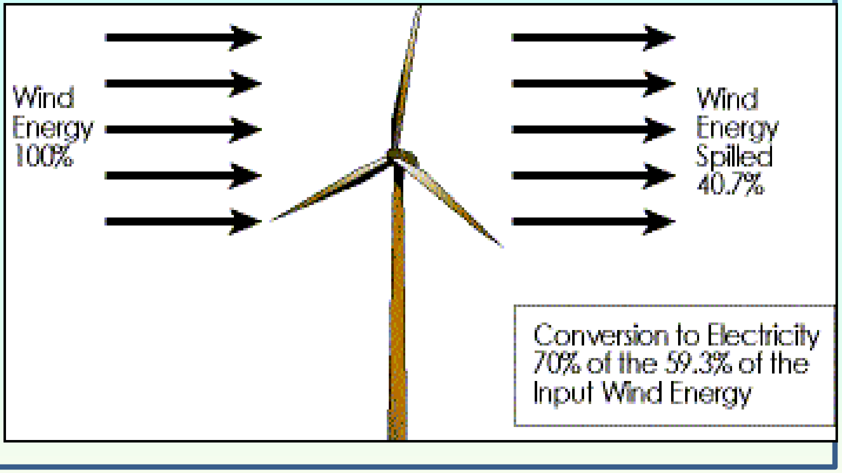
Betz Limit

The theoretical maximum amount of energy in the wind that can be collected by a wind turbine’s rotor is approximately 59%. This value is known as the Betz limit.

If the blades were 100% efficient, a wind turbine would not work because the air, having given up all its energy, would entirely stop.

In practice, the collection efficiency of a rotor is not as high as 59%. A more typical efficiency is 35% to 45%.

A complete wind energy system, including rotor, gearbox, generator, storage and other devices, which all have less than perfect efficiencies, will (depending on the model) deliver between 10% and 30% of the original energy available in the wind.



Calculation of Wind Power

Example 1:

If there is a wind turbine with the diameter of 20 m, the elevation of its tower was 60m, where the average wind speed was 5m/s. The atmospheric pressure was 70cm Hg, and the air temperature was 15°C. Find the maximum power that can be generated by the wind turbine if its efficiency considered 100%

Solution:

The density of the air can be find by:

$$\rho_{air} = \frac{P}{R * T}$$

The pressure of air at that elevation will be:

$$P = \rho_{Hg} * g * h$$

Where:

ρ_{Hg} - is the density of the mercury, which is 13600 kg/m^3

g – is the specific gravity, m/s^2

h – is the elevation of the mercury, m.

From all above, it can be find the air pressure at that elevation which will be:

P = 93391.2 pa

$$\rho_{air} = \frac{93391.2}{287 * (15 + 273)}$$

$$= 1.13 kg/m^3$$

Calculation of Wind Power

The maximum power get by the wind turbine must not exceed 59.3% of the total wind power, therefore, the maximum power can be calculate as in the following:

Power in the Wind = $\frac{1}{2} \rho A v^3$

Power of wind = 22035 w

Maximum power will be 13066.755 w

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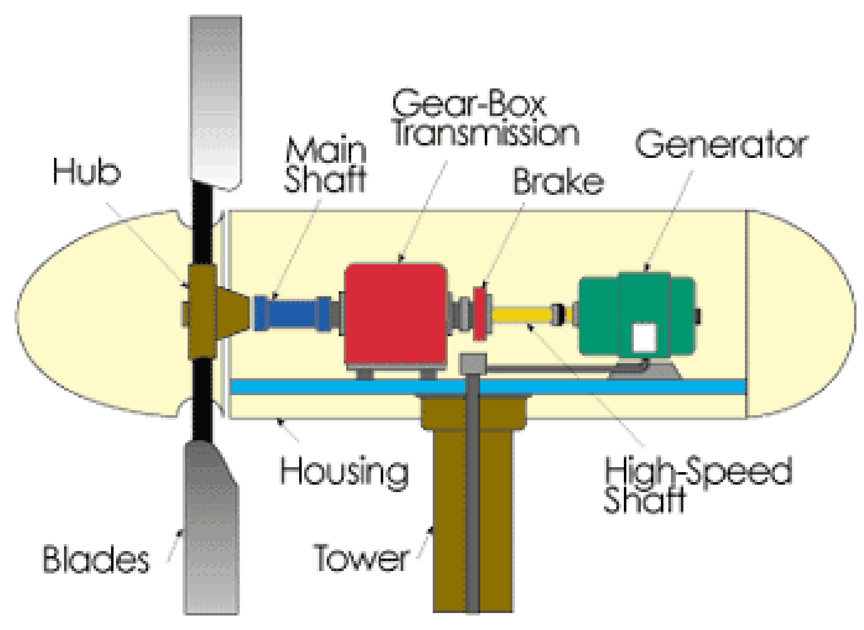
مدرس المادة: د. عمر عبد الهادي مصطفى

Main Components of a Wind Turbine

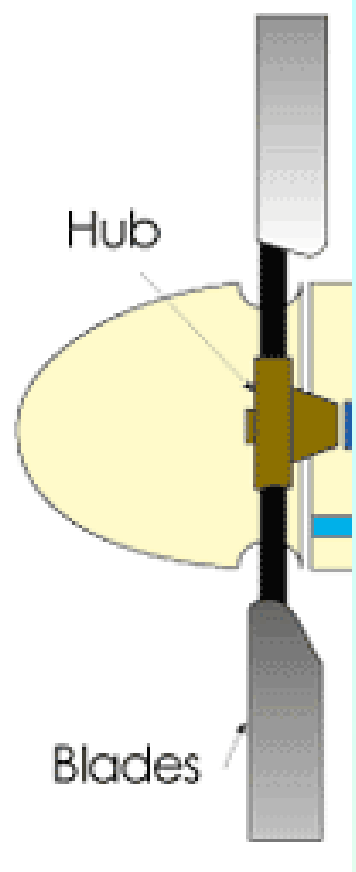
Modern wind turbines share almost the same basic components.



Main Components of a Wind Turbine

Rotor

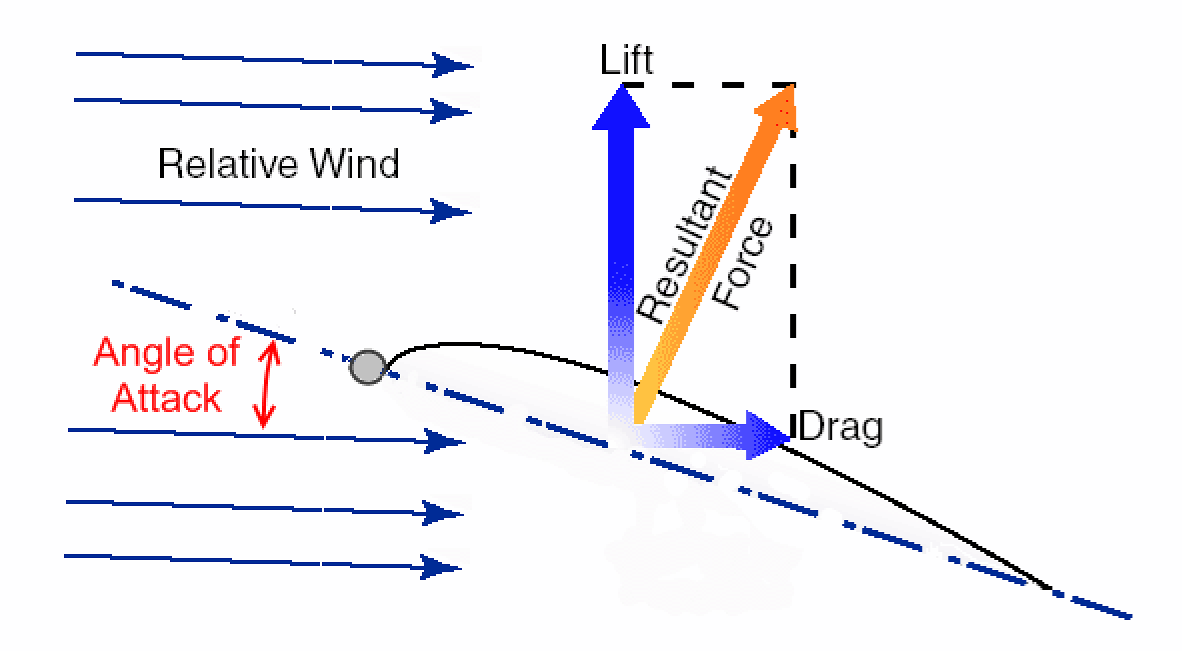
The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft.



Main Components of a Wind Turbine

Blade

Blade designs operate on either the principle of *drag* or *lift*.



Main Components of a Wind Turbine

Blade

Blades design based on the drag

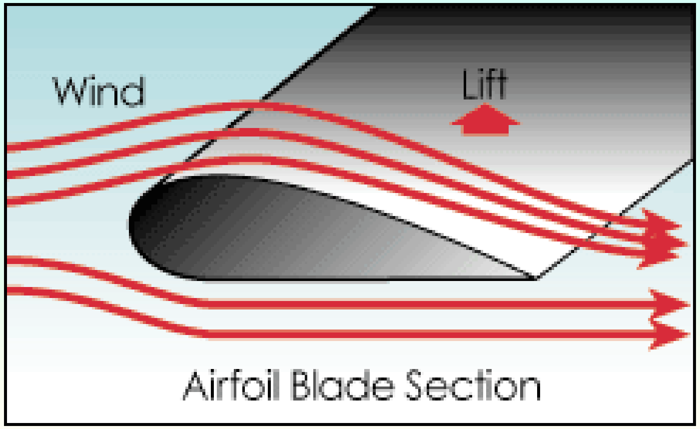
Drag designs are useful for the pumping, sawing or grinding work that windmills perform.

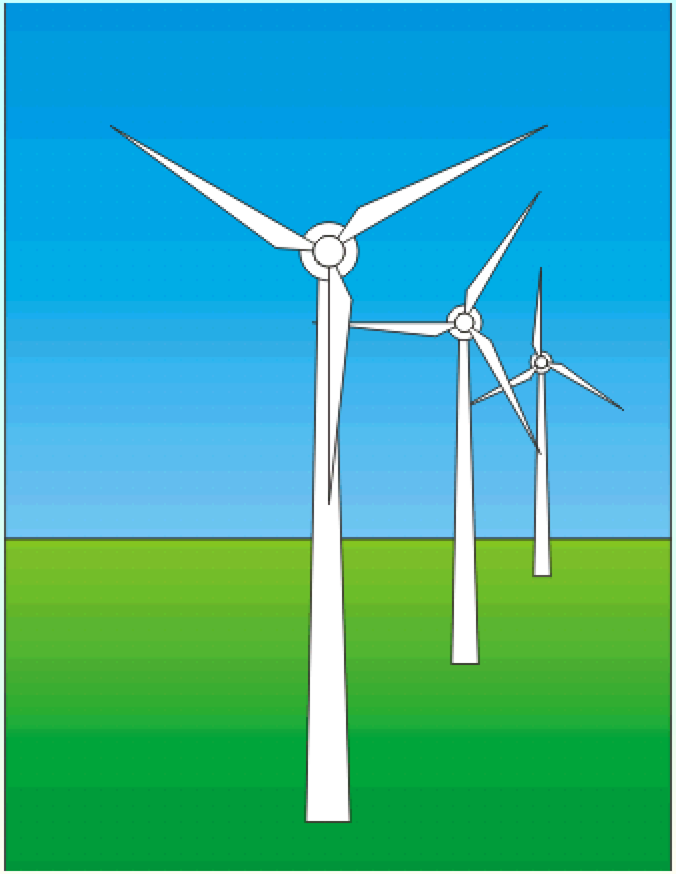
Main Components of a Wind Turbine

Blade

Blades design based on lifting

Lift-powered wind turbines have much **higher rotational speeds** than drag types and therefore well suited for **electricity** generation.

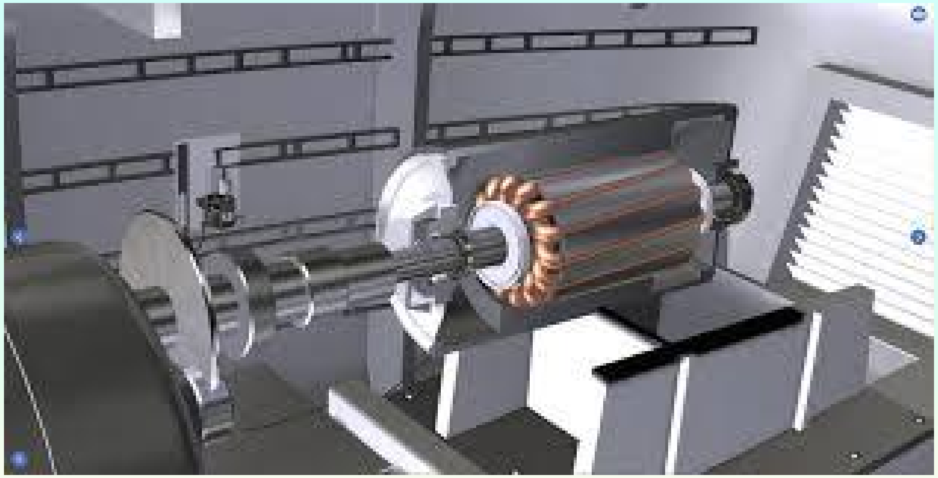


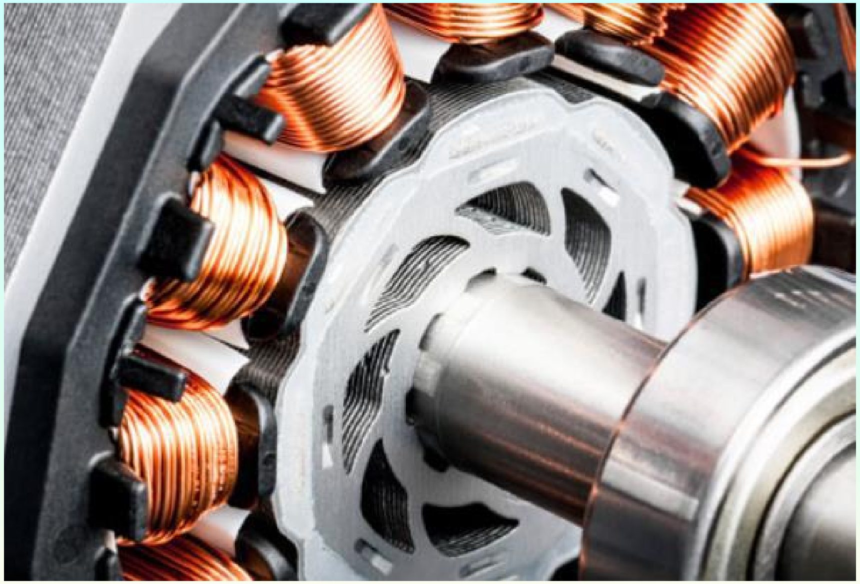


Main Components of a Wind Turbine

Generators

The generator is what converts the turning motion of a wind turbine's blades into electricity. Inside the generator, coils of wire are rotated in a magnetic field to produce electricity.





Main Components of a Wind Turbine

Generators

Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings.

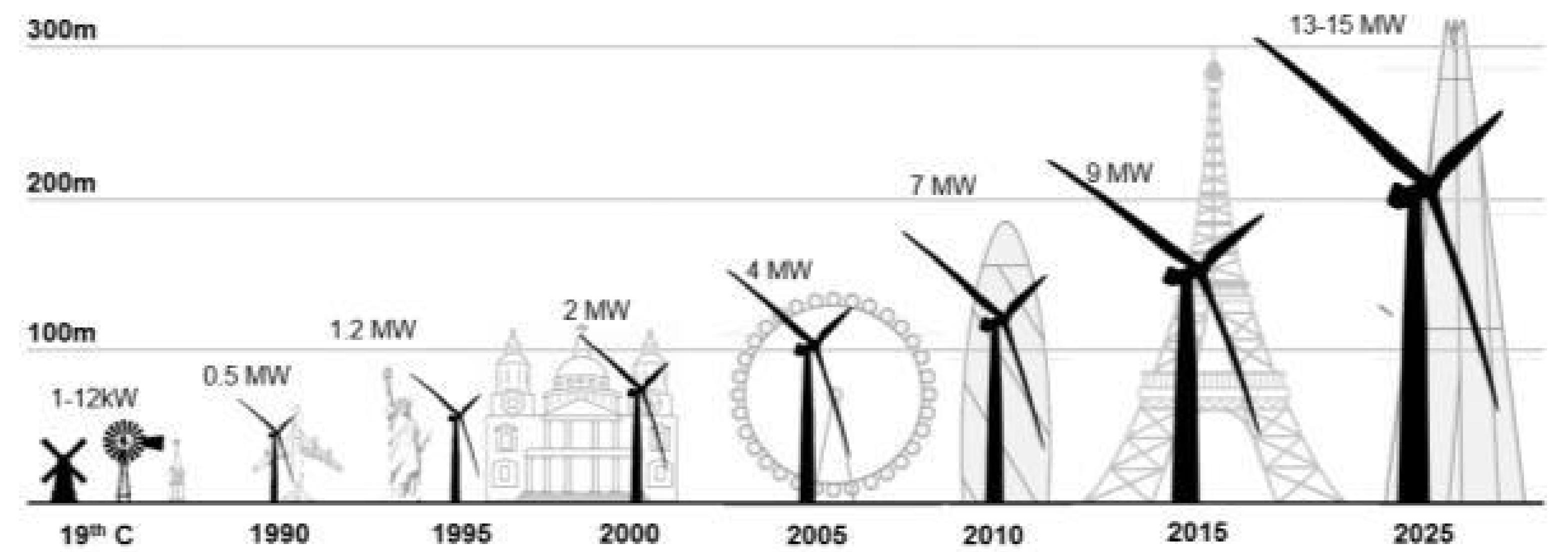
AC

DC

Main Components of a Wind Turbine

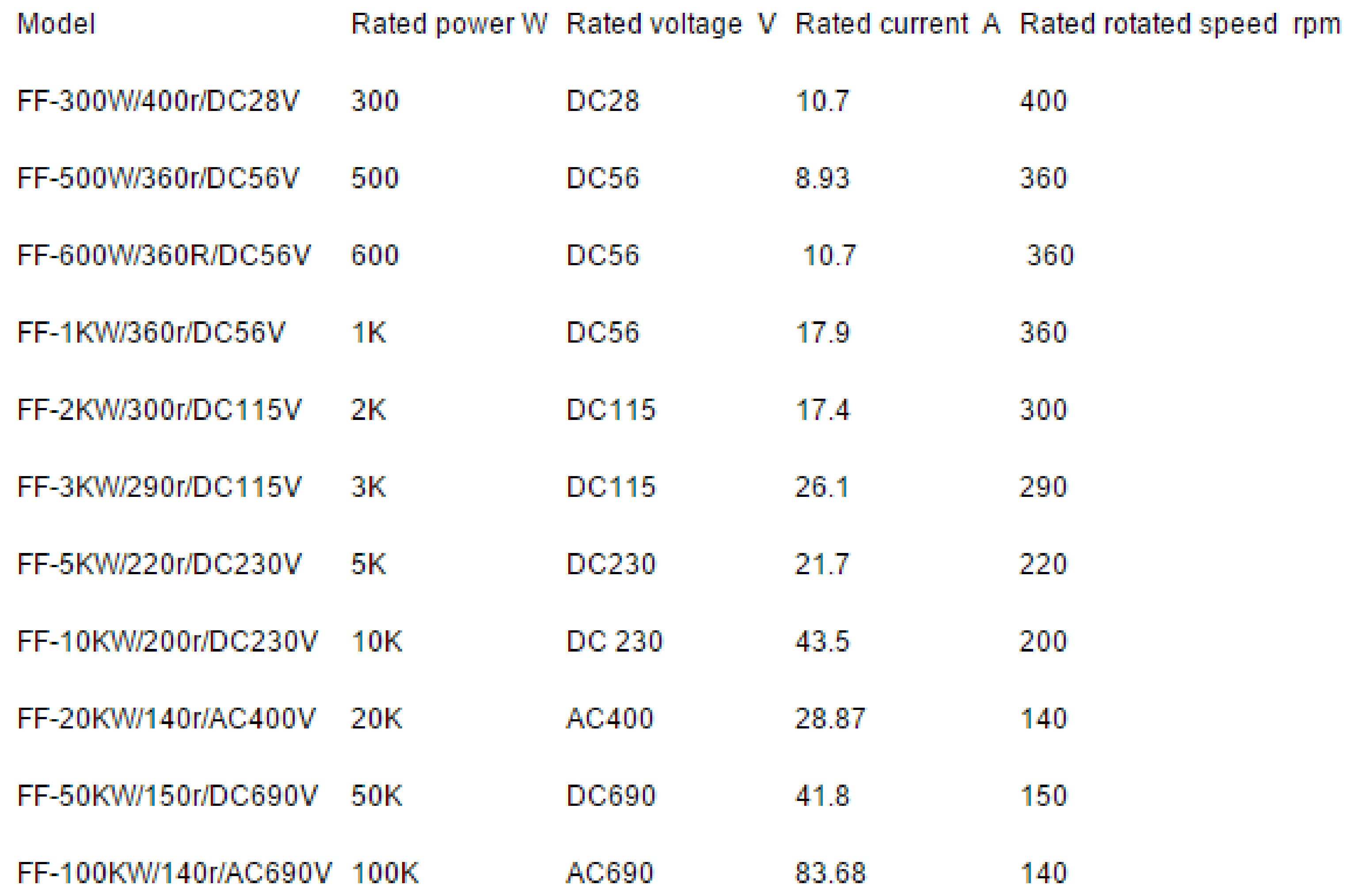
Generators

The generator’s rating, or size, is dependent on the length of the wind turbine’s blades because more energy is captured by longer blades.



Main Components of a Wind Turbine

Generators



Model	Rated power W	Rated voltage V	Rated current A	Rated rotated speed rpm
FF-300W/400r/DC28V	300	DC28	10.7	400
FF-500W/360r/DC56V	500	DC56	8.93	360
FF-600W/360R/DC56V	600	DC56	10.7	360
FF-1KW/360r/DC56V	1K	DC56	17.9	360
FF-2KW/300r/DC115V	2K	DC115	17.4	300
FF-3KW/290r/DC115V	3K	DC115	26.1	290
FF-5KW/220r/DC230V	5K	DC230	21.7	220
FF-10KW/200r/DC230V	10K	DC 230	43.5	200
FF-20KW/140r/AC400V	20K	AC400	28.87	140
FF-50KW/150r/DC690V	50K	DC690	41.8	150
FF-100KW/140r/AC690V	100K	AC690	83.68	140

Main Components of a Wind Turbine

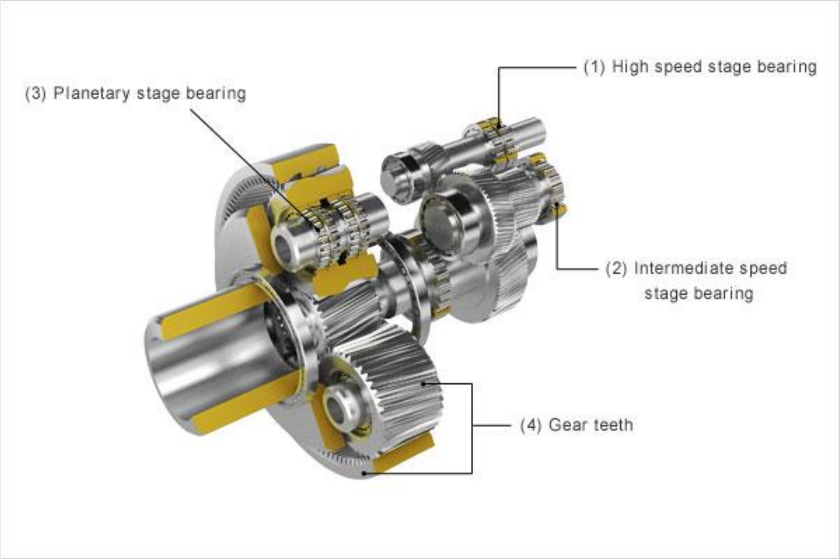
Generators

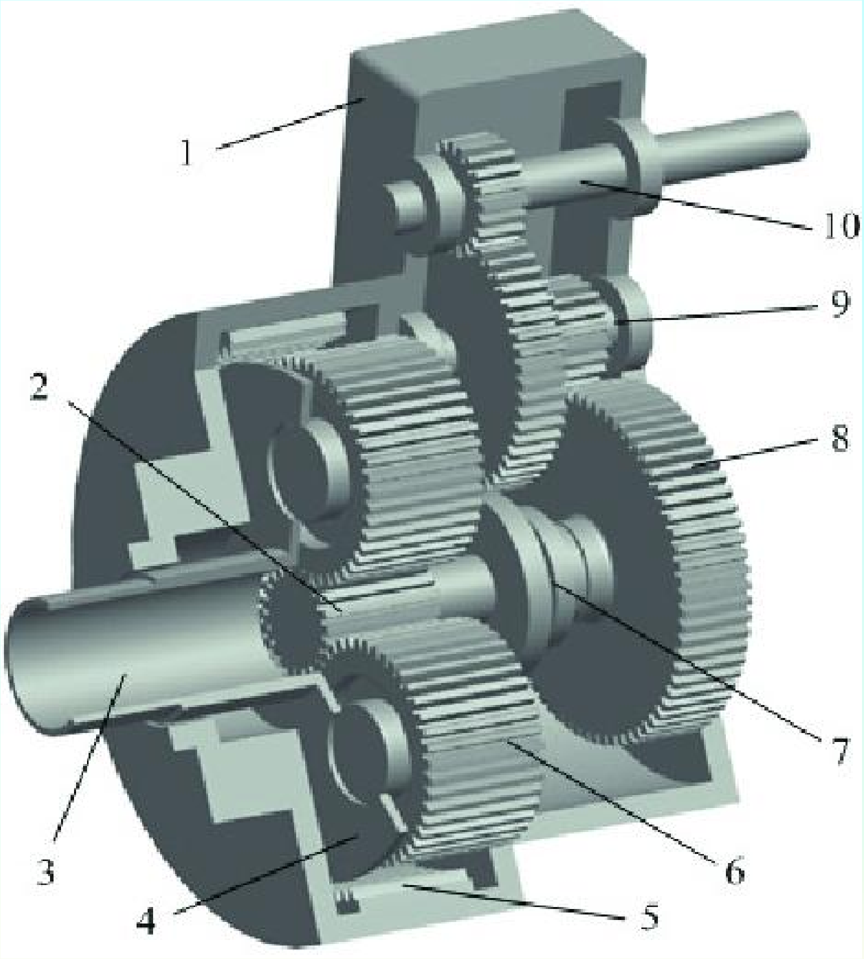
Generators that produce AC are generally equipped with features to produce the correct voltage (120 or 240 V) and constant frequency (60 or 50 cycles) of electricity, even when the wind speed is fluctuating.

DC generators are normally used in battery charging. They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC.

Main Components of a Wind Turbine

Gear Box





Main Components of a Wind Turbine

Gear Box

The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed. Generators typically require rpm’s of 1,200 to 1,800.

Most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production.

Main Components of a Wind Turbine

Gear Box

Some DC-type wind turbines do not use transmissions. Instead, they have a direct link between the rotor and generator.

These types of wind turbines are known as direct drive systems

Main Components of a Wind Turbine

Gear Box

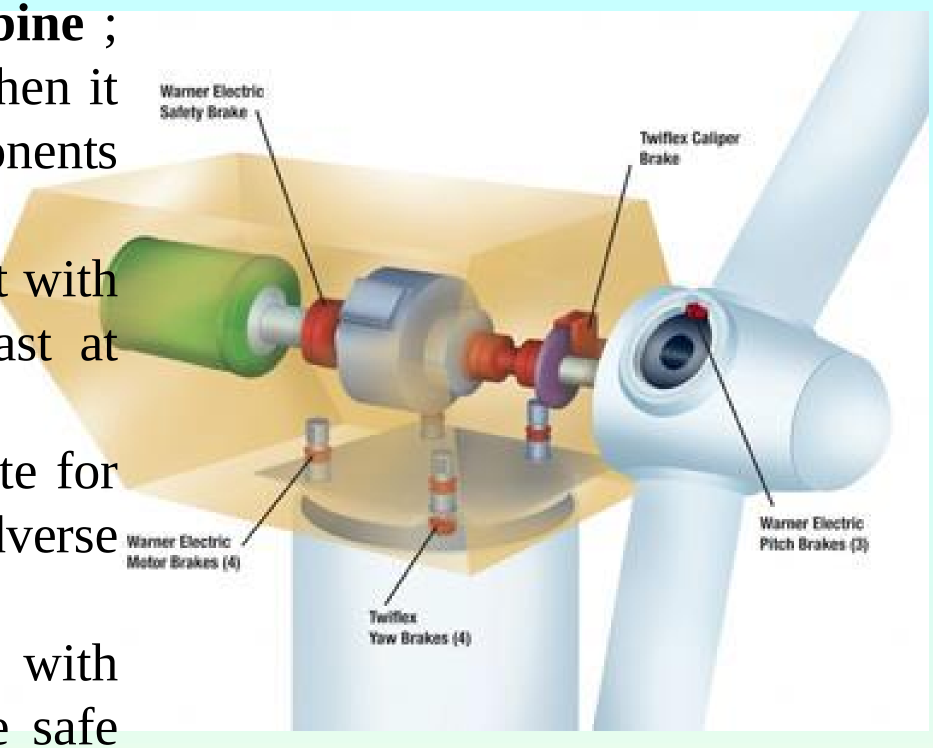
Without a transmission, wind turbine complexity and maintenance requirements are reduced, but a much larger generator is required to deliver the same power output as the AC-type wind turbines.

Braking system of wind turbine

Brakes for wind turbines call for higher cycle rates, higher loads, greater reliability and often in more compact packages than those on conventional factory equipment.

The **braking system of a wind turbine** ; ensures that it automatically stops when it detects that one of its critical components does not work properly, like:

1. wind turbine are designed so that with proper maintenance they can last at least 20 years.
2. They must be prepared to operate for about 120,000 hours in often adverse weather conditions.
3. Wind turbines are equipped with various safety devices to ensure safe operation during their lifetime.



Braking system of wind turbine

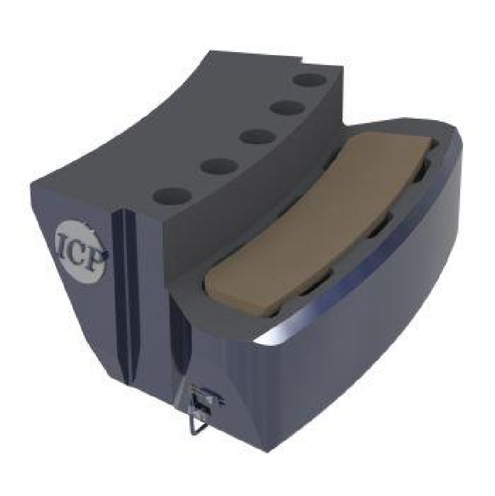
The number of emergency stops during the twenty years of service life is usually between 500 and 1 000 stops. Three general types of the braking system are used with the wind turbine which are:

1. Yaw brakes
2. Rotor brakes
3. Mechanical brakes

Braking system of wind turbine

Yaw brakes

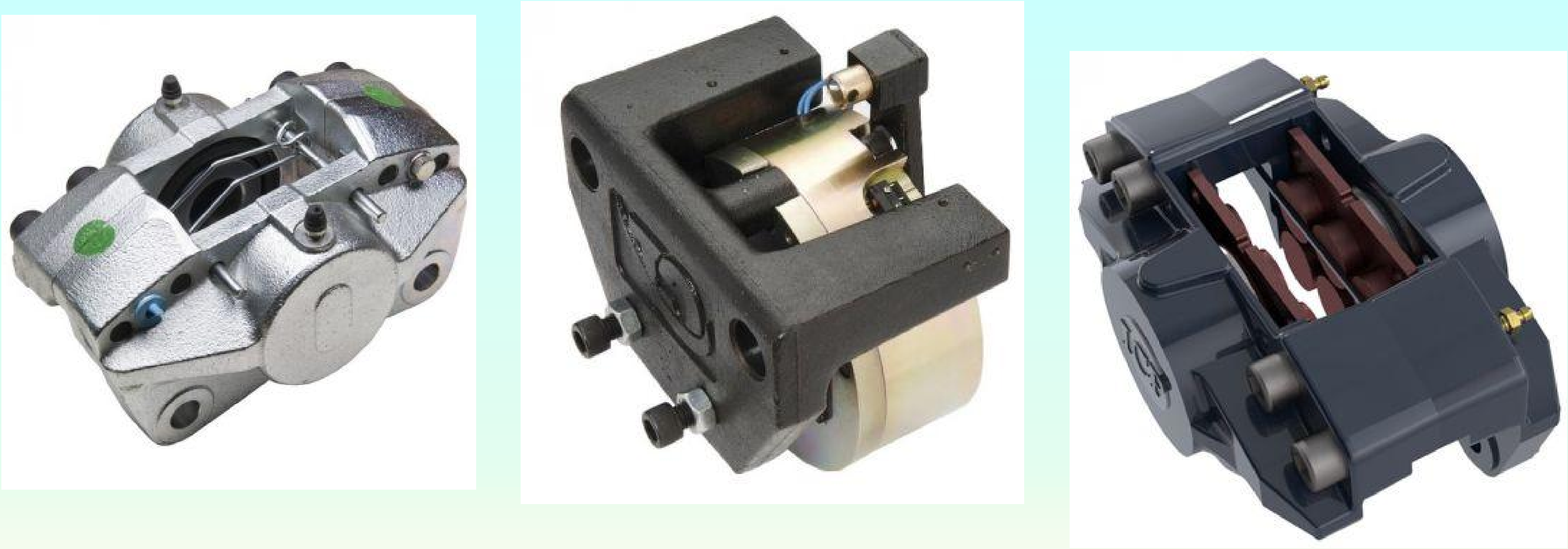
Yaw brakes for wind turbines are located on the yaw-system. Yaw brakes control the nacelle as it rotates with the wind to maximize power. The yaw brake system is an essential component of the wind turbine (generator). It helps position the nacelle in the direction of the wind. A wind turbine yaw brake system can drastically improve maintenance and decrease costs.



Braking system of wind turbine

Rotor brakes

A rotor brake for a wind turbine is often referred to as a high-speed brake. Designed to safely stop a wind turbine rotor in an emergency or parking operations. The rotor brake can be mounted on the rotor (low-speed shaft) or generator (high-speed shaft).



Braking system of wind turbine

Mechanical brakes

This type of brakes depend on different mechanism in sensing the rotational speed like the centrifugal force, therefore, they make braking on the high speed shaft as its speed pass the permissible level.

Main Components of a Wind Turbine

Towers

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations


Tubular steel tower


Tubular concrete


Lattice tower


Three-legged tower


Guy-wired pole tower

Main Components of a Wind Turbine

Towers

Maximum tower height is optional in most cases, except where zoning restrictions apply.

The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use.

Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds.

Larger wind turbines are usually mounted on towers ranging from 40 to 220 meters tall.

Main Components of a Wind Turbine

Towers

Towers for small wind systems are generally “**guyed**” designs.

This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect.

Main Components of a Wind Turbine

Towers

Guyed towers cost less than freestanding towers, but require more land area to anchor the guy wires

Some of these guyed towers are erected by tilting them up. This operation can be quickly accomplished using only a winch, with the turbine already mounted to the tower top.

Main Components of a Wind Turbine

Towers

This simplifies not only installation of guyed towers, but maintenance as well.

Guyed Towers can be constructed of a simple tube , a wooden pole or a lattice of tubes , rods , and angle iron.

Large wind turbines may be mounted on lattice towers, tube towers or guyed tilt up towers.

Main Components of a Wind Turbine

Towers

Tower must be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of the wind turbine.

Tower cost will vary widely as a function of design and height.

Some wind turbines are sold complete with tower.

More frequently, however, towers are sold separately.

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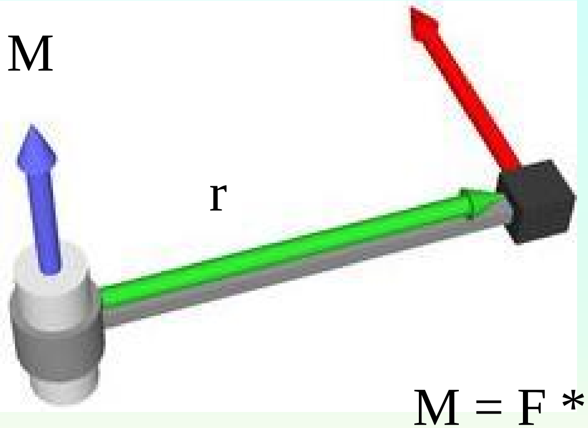
Wind Turbine design

Blade

Drag design

For the **drag** design, the wind literally pushes the blades out of the way.

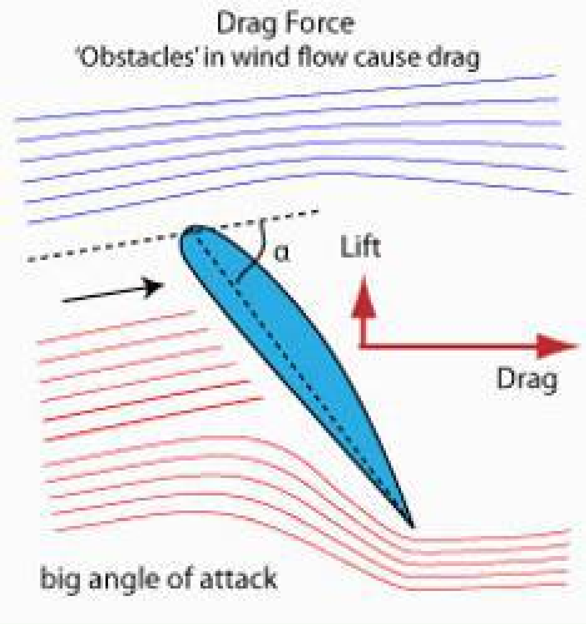


F

M

r

$M = F * r$



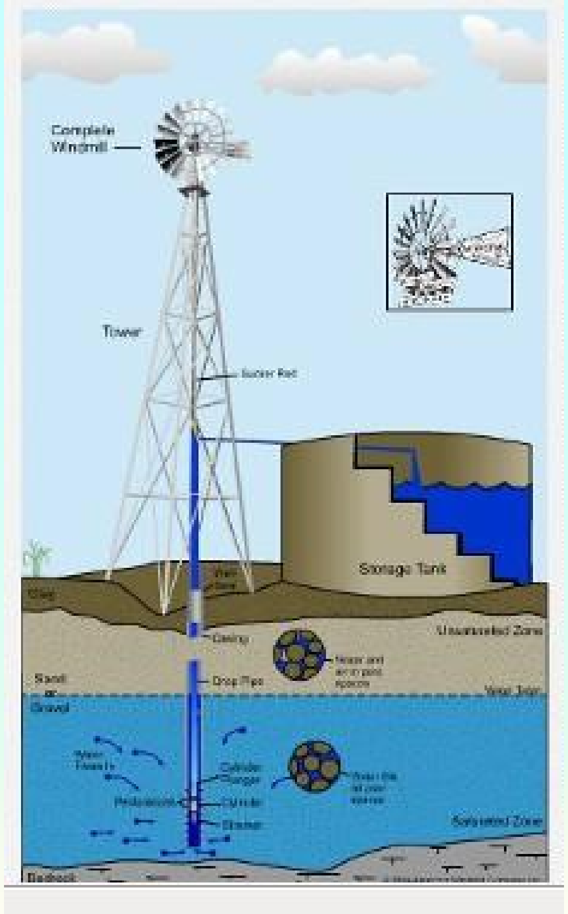
Wind Turbine design

Blade

Drag design

Drag powered wind turbines are characterized by **slower rotational speeds** and **high torque capabilities**.

For example, a farm-type windmill must develop high torque at start-up in order to pump, or lift, water from a deep well.

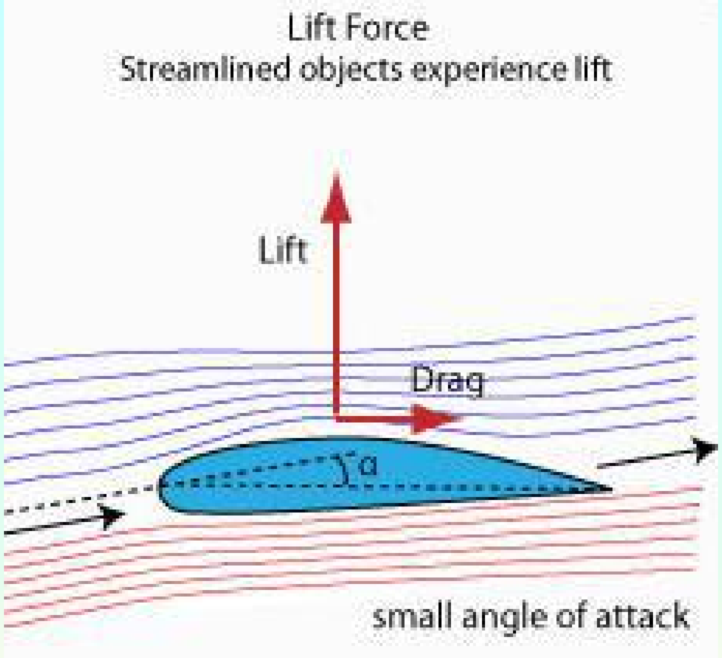


Wind Turbine design

Blade

Lift design

The **lift** blade design employs the same principle that enables airplanes, kites and birds to fly.

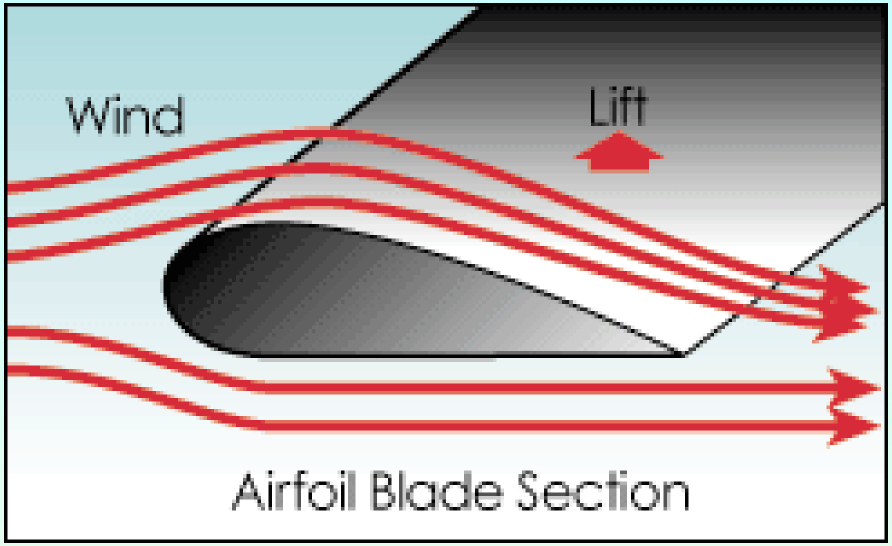


Wind Turbine design

Blade

Lift design

When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to “lift” the blade.



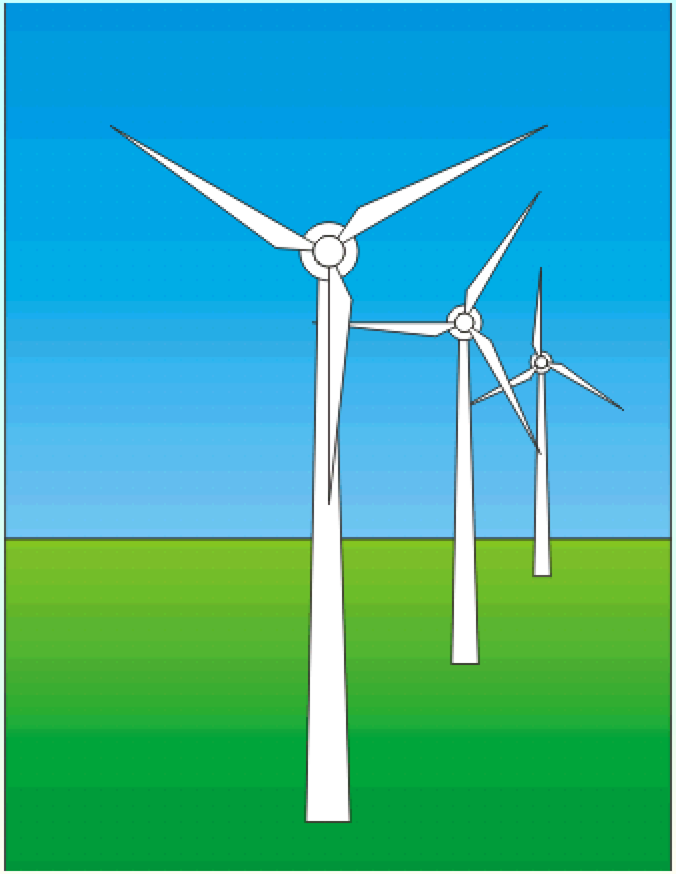
Wind Turbine design

Blade

Lift design

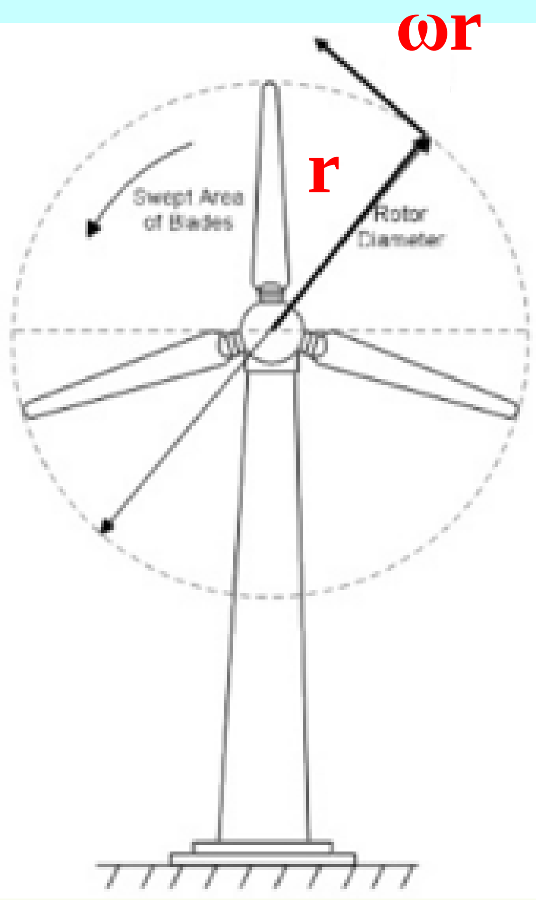
When blades are attached to a central axis, (i.e. rotor), the **lift is translated into rotational motion**.

Lift-powered wind turbines have much **higher rotational speeds** than drag types and therefore well suited for **electricity** generation.



Wind Turbine design

Tip Speed Ratio (TSR)



$$\lambda = \frac{speed\ of\ rotor\ tip}{wind\ speed}$$

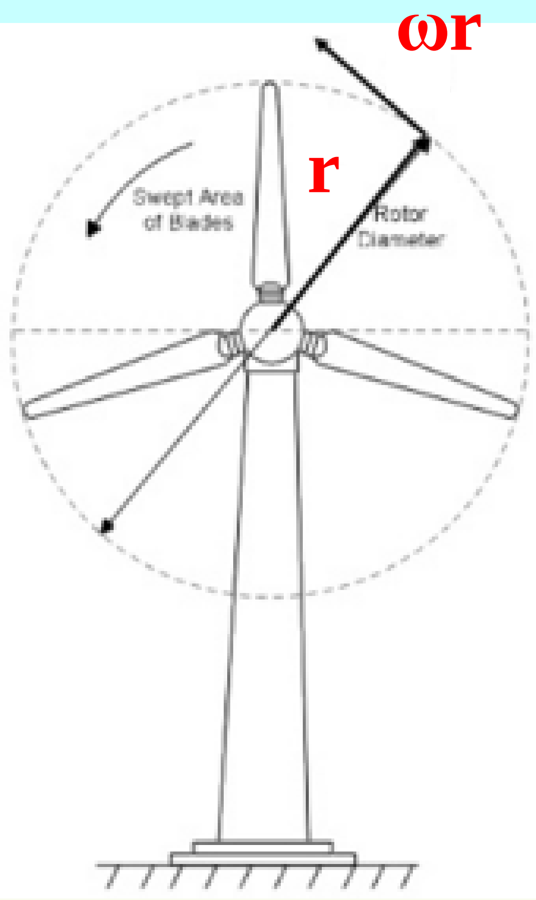
Where: λ – is the speed ratio.

The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed.

Wind Turbine design

Tip Speed Ratio (TSR)

$$\lambda = \frac{speed\ of\ rotor\ tip}{wind\ speed} = \frac{v}{V} = \frac{\omega r}{V}$$



Where:

v – is the rotor tip speed, m/s

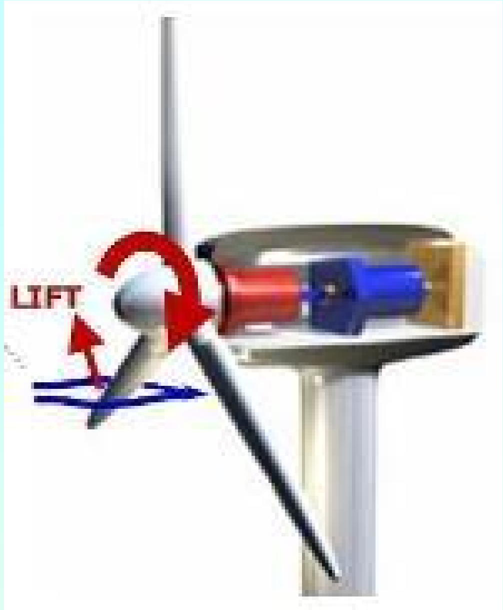
r – is the rotor radius, m

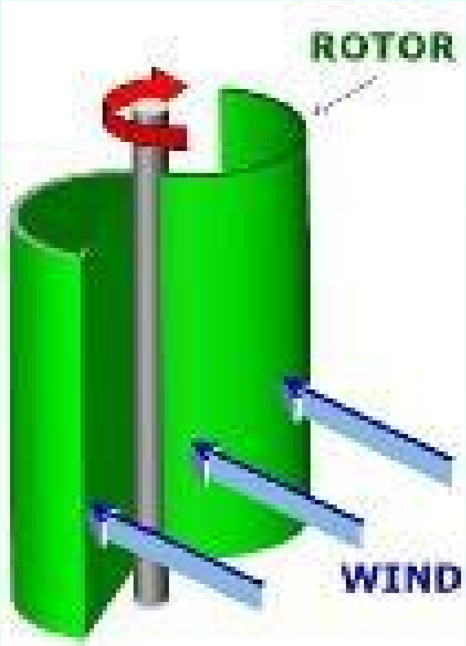
$\omega = 2\pi N$ – is the angular velocity, rad/s

N – is the rotational speed, rps.

Wind Turbine design

Tip Speed Ratio (TSR)



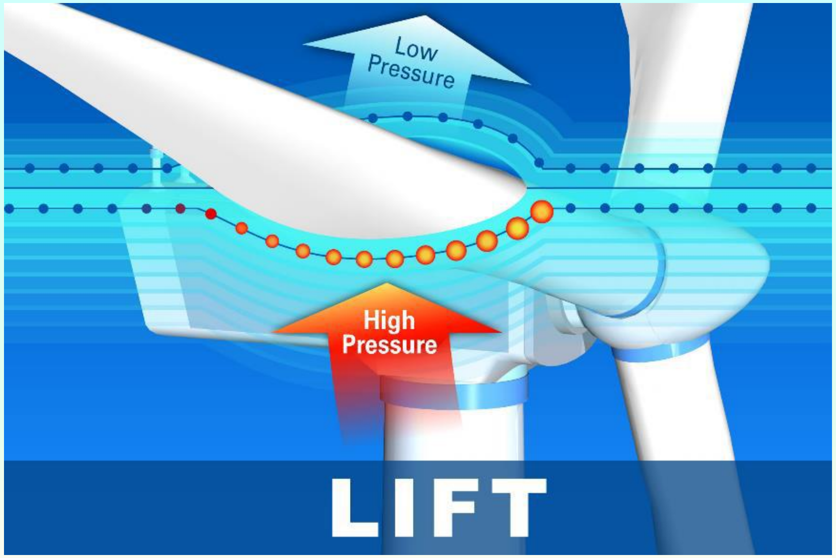


Lift-type wind turbine, $\lambda \approx 5$ Drag-type wind turbine, $\lambda \approx 1$

Wind Turbine design

The **number of blades** that make up a rotor and the **total area** they cover affect wind turbine performance.

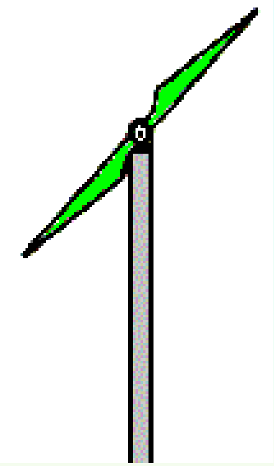
For a lift-type rotor to function effectively, the wind must flow smoothly over the blades.

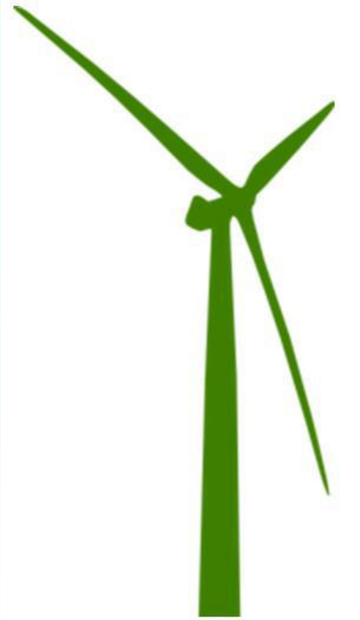


Wind Turbine design

To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it.

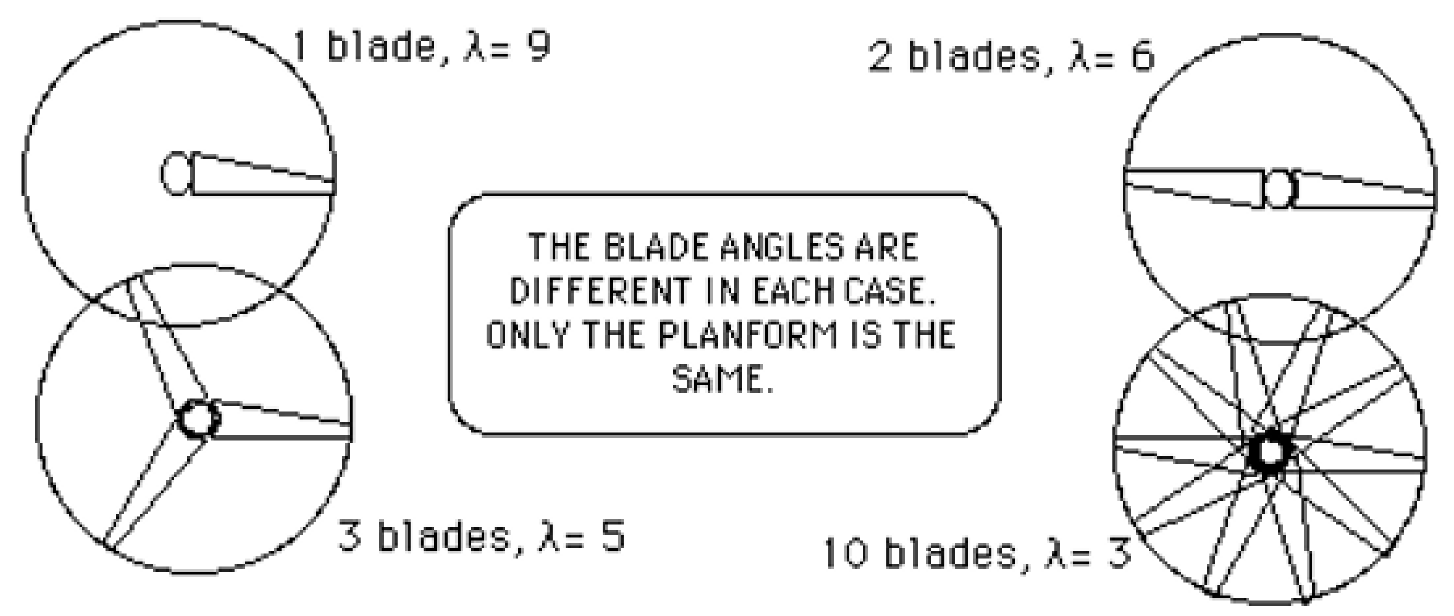
This is why most wind turbines have only two or three blades on their rotors.





Wind Turbine design

Tip Speed Ratio (TSR)



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مدرس المادة: د. عمر عبد الهادي مصطفى

Sizing Wind Turbine

Several facts must take in account before designing the wind turbine system, where:

1. The size, or generating capacity, of a wind turbine for a particular installation depends on the amount of power needed and on the wind conditions at the site.
2. It is unrealistic to assume that all your energy needs can be met economically by wind energy alone.
3. As a general rule, a wind system should be sized to supply 25% to 75% of the energy requirements.

Sizing Wind Turbine

For residential applications

Most residential applications require a machine capacity

Sizing Wind Turbine

For Farm

Farm use requires 10 to 50 kW

Sizing Wind Turbine

For Commercial/small industrial uses

Commercial/small industrial uses typically require 20 kW

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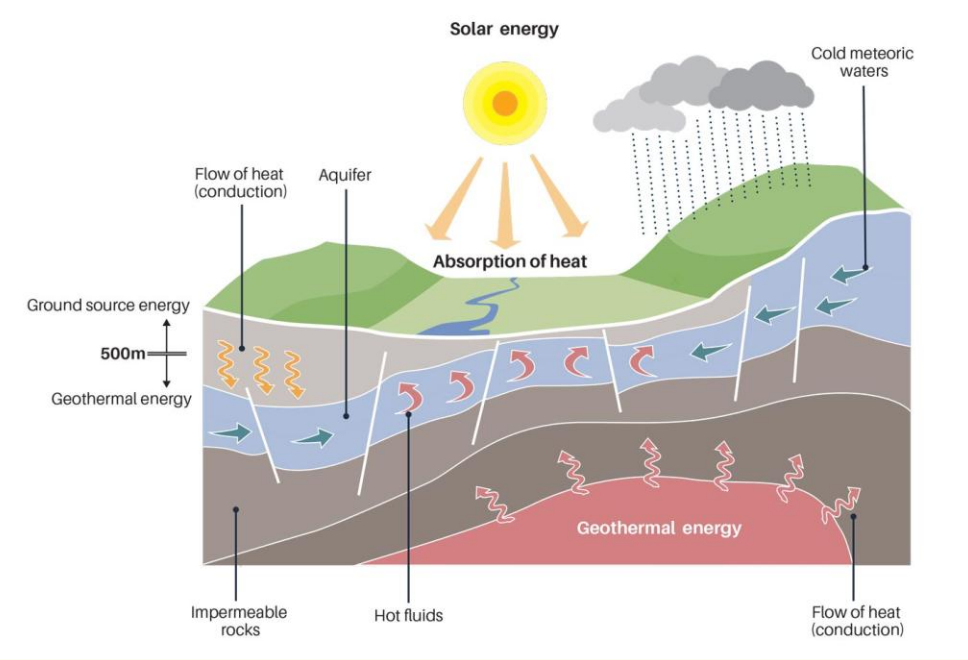
الطاقة المتجددة

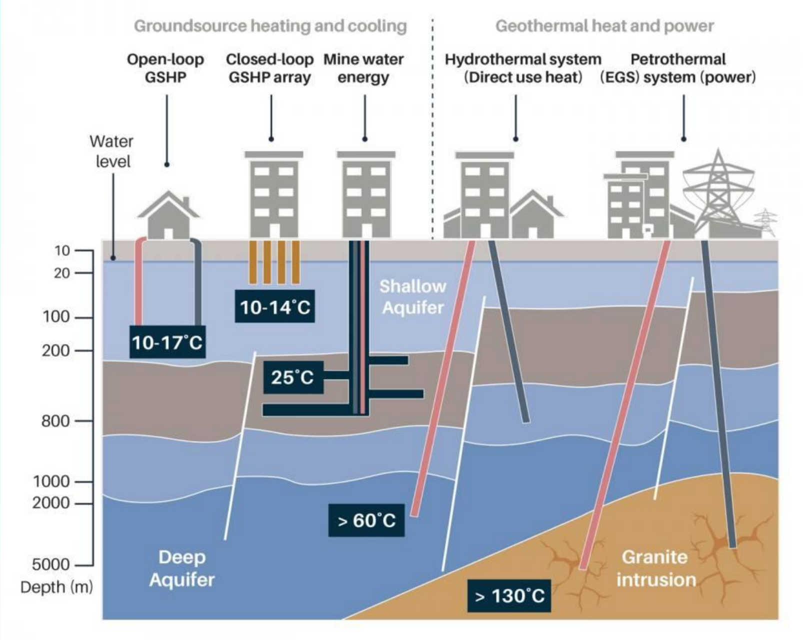
المحاضرة الثانية عشر: طاقة حرارة باطن الارض

مدرس المادة: د. عمر عبد الهادي مصطفى

Technology Basics

Geothermal energy—the heat of the Earth—is a clean, renewable resource that provides energy in the U.S. and around the world. The U.S. has been using commercial, large-scale geothermal power plants at deep resource temperatures (between 200°F and 700°F) since the 1960s. Geothermal energy development and production is a thriving international market

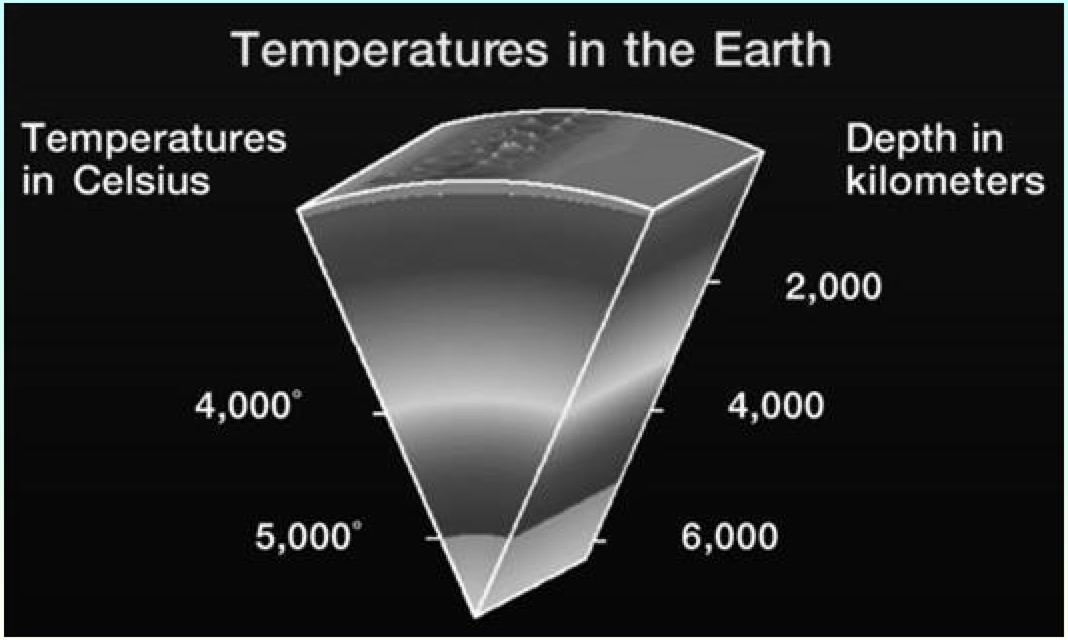




Technology Basics

What is geothermal energy?

Heat has been radiating from the center of the Earth for some 4.5 billion years. At 6437.4 km (4,000 miles) deep, the center of the Earth hovers around the same temperatures as the sun's surface, 9932°F (5,500°C). Scientists estimate that 42 million megawatts (MW) of power flow from the Earth’s interior, primarily by conduction.

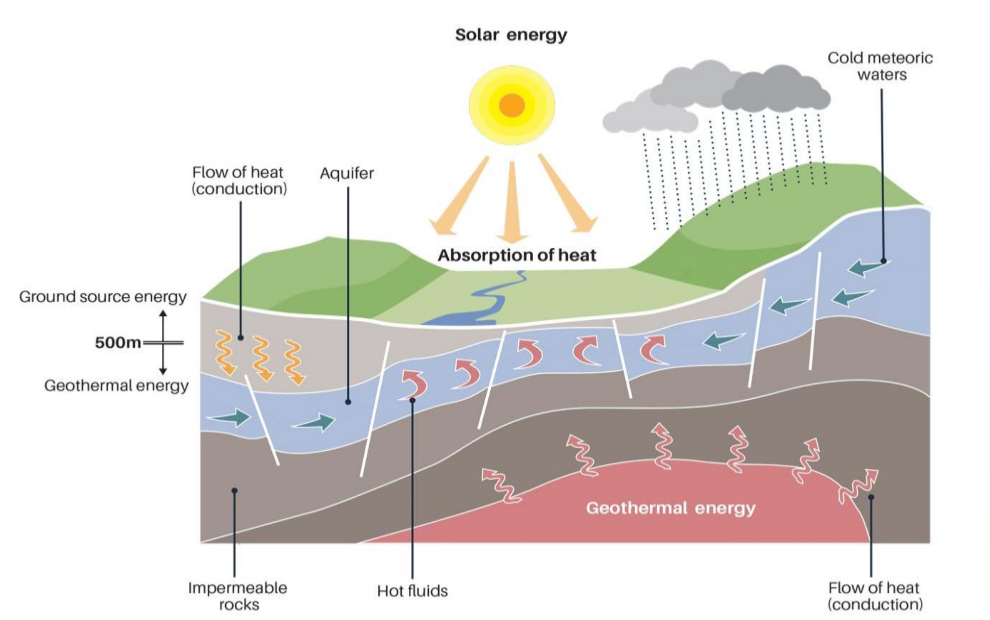


Technology Basics

Low-grade heat

Low-grade heat stored in the shallow subsurface (less than 200 m) is largely derived from solar radiation that is absorbed by the ground and distributed via natural groundwater systems and artificial structures such as flooded coal mines.

The ground acts as a solar battery and, for this heat, utilization usually requires a heat pump. This energy is widely described as ‘ground-source energy’ or ‘shallow geothermal energy’.



Technology Basics

Deep geothermal energy

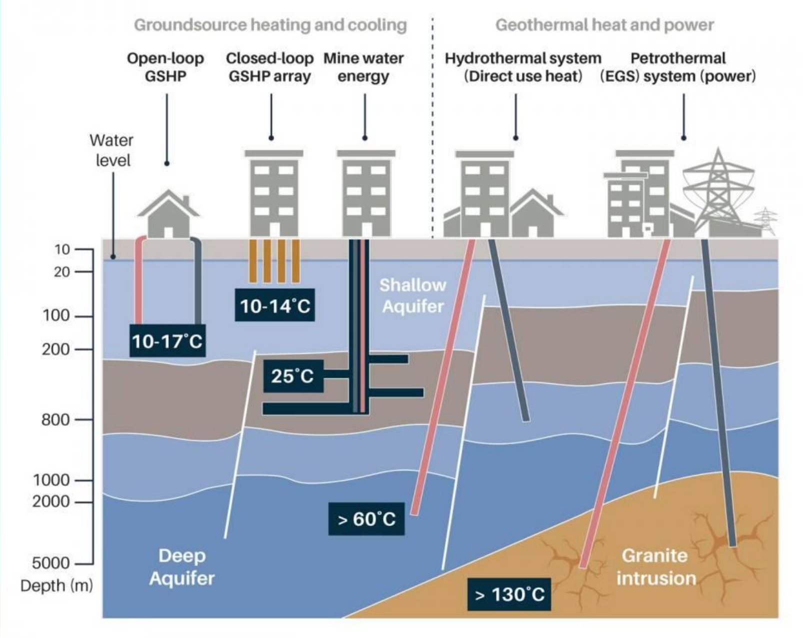
There is no strict definition for ‘deep geothermal energy’, but the UK Government has adopted the term to refer to heat resources derived from depths of >500 m. The heat of the Earth increases with depth, a phenomenon described as the geothermal gradient. This heat is partly the primordial heat from when the Earth was formed and partly heat generated from within the Earth’s crust from the decay of mildly radioactive elements. This upward heat flux varies across the globe, but in the UK is around 27°C/1000km. Assuming an average annual air temperature of 12°C, this means that subsurface temperatures at 1000 m, 3000 m and 5000 m are around 39°C, 89°C and 139°C, respectively.

Geothermal energy technologies

Ground source heating and cooling

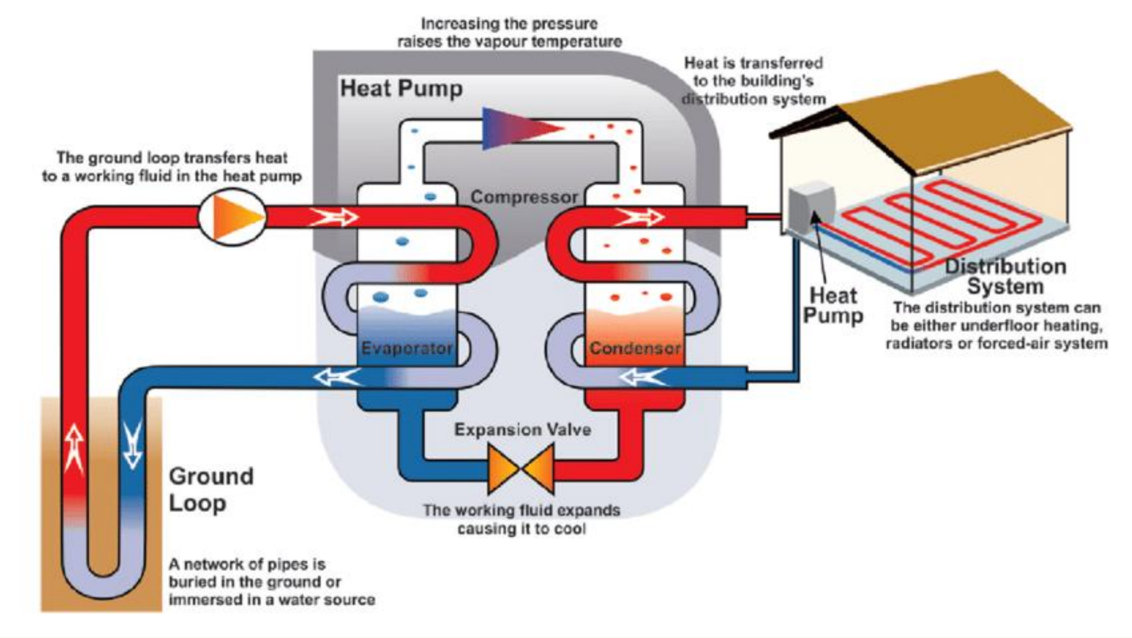
Exploitation of this low-grade, ground-source heat resource requires use of ground-source heat pump (GSHP) systems.

These extract heat from the ground either via ground heat exchangers (‘closed-loop’ systems) or from pumped groundwater stored in aquifers (‘open-loop’ systems).



Geothermal energy technologies

These systems utilize a heat pump to extract the low-grade heat from the fluid and upgrade it to more useful temperatures (>40°C) required for the heating of buildings. The cold carrier fluid/groundwater is then returned to the subsurface.



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الطاقة المتجددة

المحاضرة الثالثة عشر: انواع محطات الطاقة المستخدمة في توليد الطاقة من حرارة باطن الارض وحساباتها

مدرس المادة د. عمر عبد الهادي مصطفى

Commercial types of conventional geothermal power plants

There are three commercial types of conventional geothermal power plants:

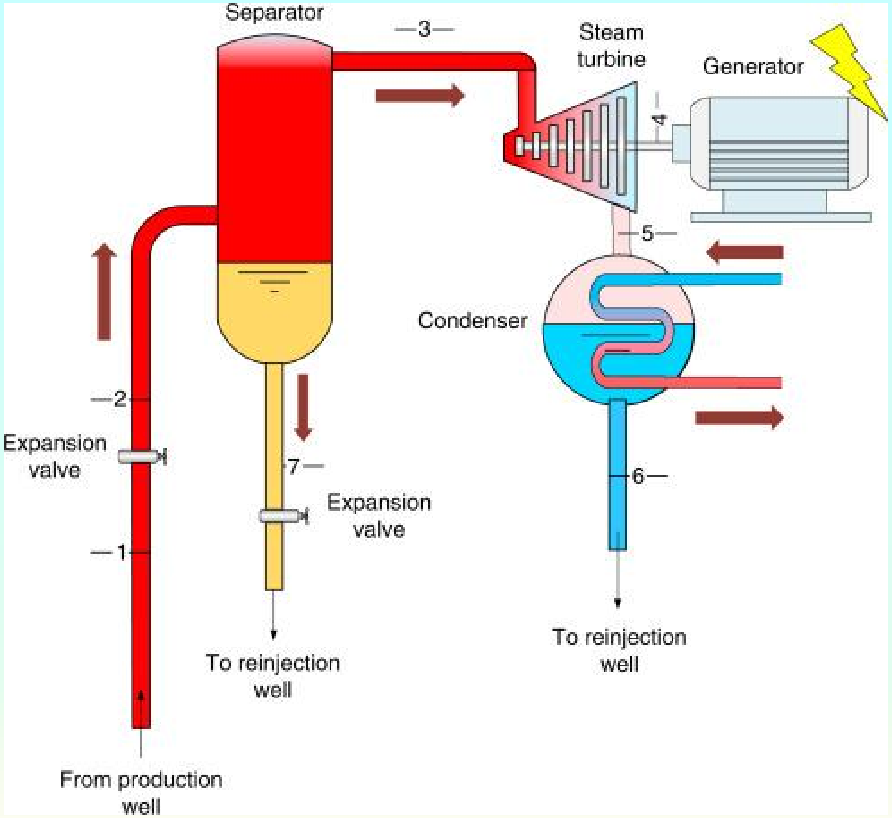
1. Flash type geothermal power plant
2. Dry steam type geothermal power plant
3. Binary type geothermal power plant

Commercial types of conventional geothermal power plants

Single-Flash System

Flash steam is a mixture of pressurized hot water and steam that converts to steam when pressure is released. This combination of liquid and vapor in an underground reservoir is called a liquid-dominated reservoir; it is produced when large volumes of water from artesian wells come into contact with extremely hot rocks deep in the earth.

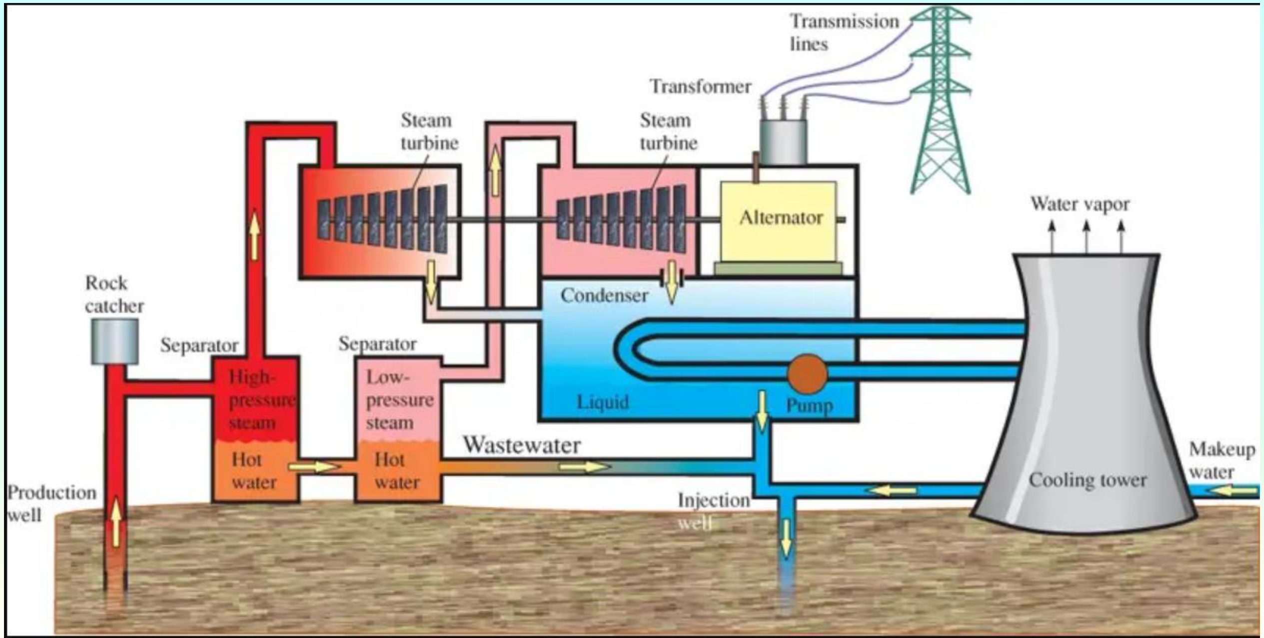
In a geothermal flash power plant, high pressure separates steam from water in a “steam separator” as the water rises and as pressure drops. The steam is delivered to the turbine, and the turbine then powers a generator. The liquid is reinjected into the reservoir.



Commercial types of conventional geothermal power plants

Double-Flash Steam Plants

When the source is very hot, the water that remains from the separator may be much hotter than the normal boiling temperature of 100° C (212° F) because it is still under pressure that is higher than atmospheric pressure. Additional steam can be created from the hot water by expanding it through a second separation system. This type of geothermal plant is called a double-flash steam plant.



Commercial types of conventional geothermal power plants

Advantages and disadvantages of double- flash steam plants

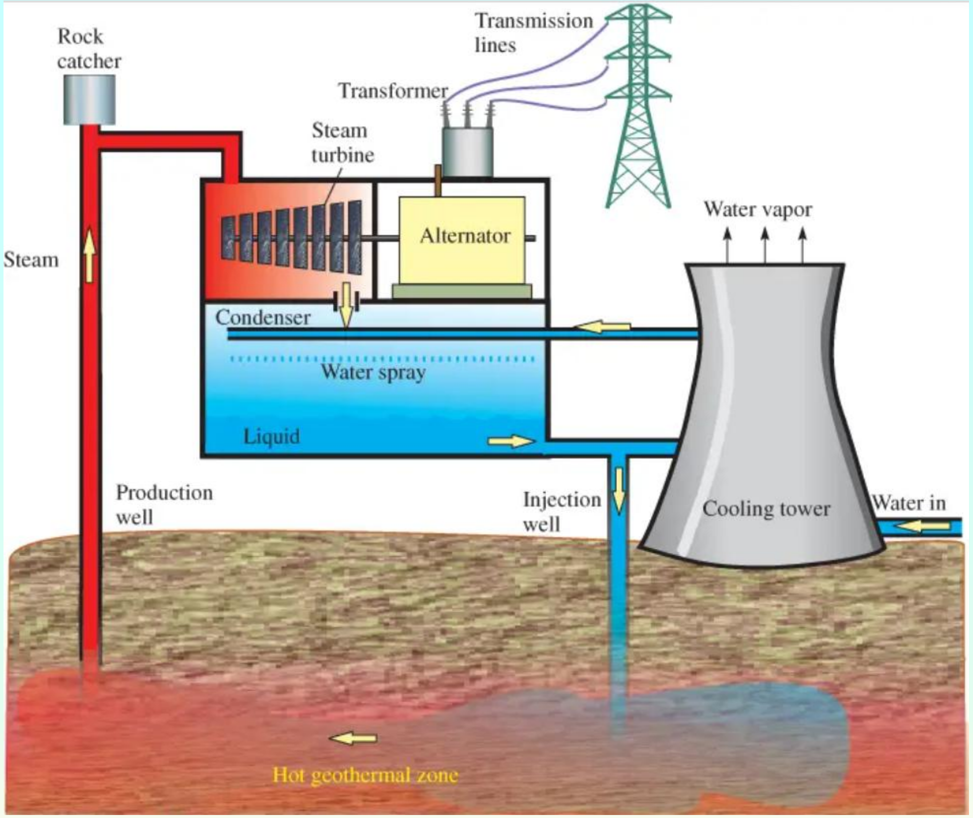
About 20% more electrical power can be produced in a double-flash system but at greater cost due to the second turbine, which is a special low-pressure turbine.

In addition, a double-flash system has extra piping and valves.

Commercial types of conventional geothermal power plants

Dry-Steam Plants

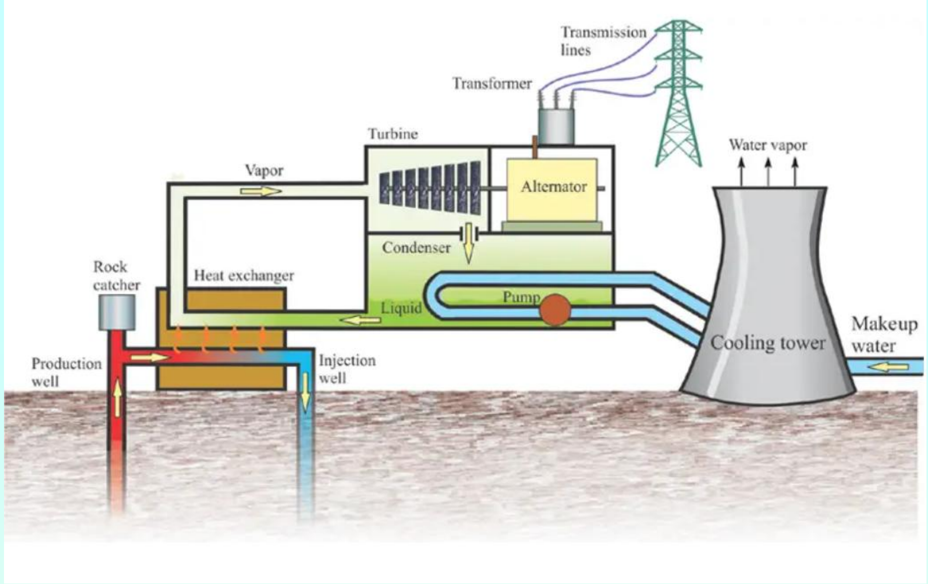
Dry steam (also called superheated steam) is steam so hot that it contains no liquid water in suspension. When a geothermal reservoir is located in a place that has steam at the surface, the steam can be piped directly to a steam turbine that drives an electric generator. This type of plant is called a dry-steam plant. At some dry-steam plants, adequate amounts of fresh water are introduced to restore the reservoir when some of the steam escapes to the atmosphere after it passes through the steam turbine.



Commercial types of conventional geothermal power plants

Binary-Cycle Plants

The geothermal binary-cycle plant is different from dry-steam and flash-steam systems because the hot brine water and steam from the geothermal reservoir go directly to a heat exchanger and never comes in contact with the turbine that drives the generator.



A secondary fluid is heated and vaporizes. It circulates through a closed loop to the turbine in the traditional Rankin cycle.

Generally, the secondary fluid is an organic fluid (contains carbon) that has a lower boiling point than water. For this reason, binary-cycle plants are also known as organic Rankin cycle (ORC) plants.

Commercial types of conventional geothermal power plants

Advantages of binary-cycle plant

1. The binary-cycle plant can produce power with lower-quality heat sources. The fluid in the secondary loop of the heat exchanger is an organic fluid such as a thermal oil or isobutene that vaporizes at a lower temperature. The fluid is selected based on the temperature of the source. Because the vaporization temperature in the secondary loop is lower than that of steam, it can produce vapor even when the temperature of the brine solution is in the moderate range (typically 110° C to 176° C) or even lower.
2. Geothermal sources frequently contain dissolved materials that may be corrosive and also may contain small debris carried up from the geothermal reservoir. Corrosive steam and debris are particularly hazardous to turbines because they spin at very high rates, so the binary-cycle plant avoids these problems by recycling the underground water and brine in a separate loop, where it gives most of its heat energy to a secondary fluid. The turbine is exposed only to this clean material, which is recycled in a separate closed loop.

Commercial types of conventional geothermal power plants

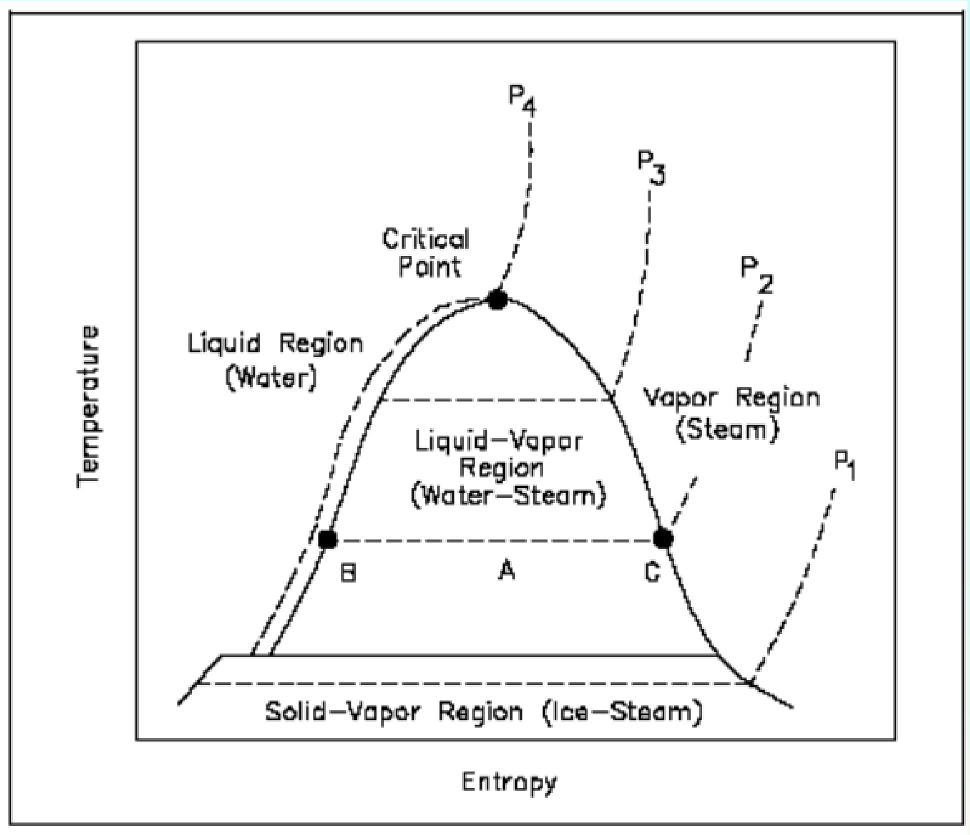
Advantages of binary-cycle plant

3. Because the two loops in a binary-cycle system are completely enclosed, there is less waste and lower water usage than in other geothermal systems.

4. By its nature, the binary-cycle plant does not release any pollutants and does not have any emissions except for a small amount of water vapor at the cooling tower.

Thermal cycles of the geothermal power plants

Temperature – entropy diagram review



Thermal cycles of the geothermal power plants

Single flash system

From heat and mass balance of flash tank, we can get:

$$m_2 = m_3 + m_7$$

$$m_2 h_2 = m_3 h_3 + (m_2 - m_3) h_7$$

$$m_2 (h_2 - h_7) = m_3 (h_3 - h_7)$$

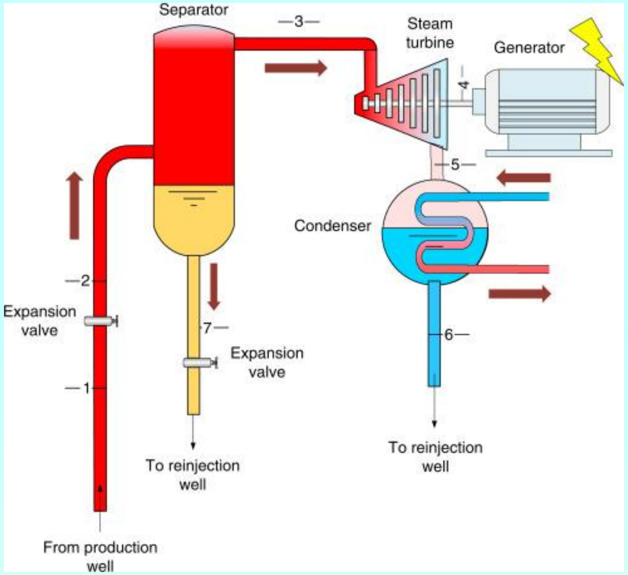
The output power from the system will be:

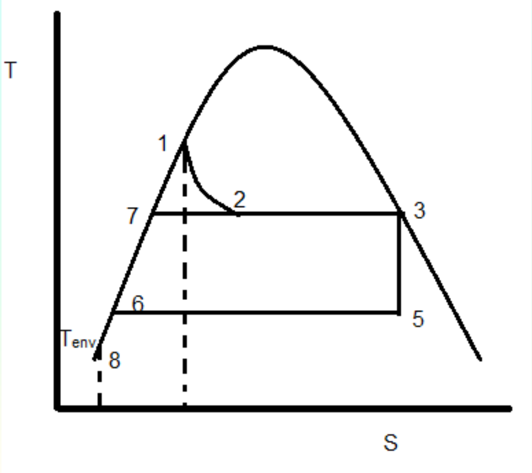
$$P_{out} = m_3 (h_3 - h_5)$$

The power ratio is the relation of the consumed power to the produced power, as in the following:

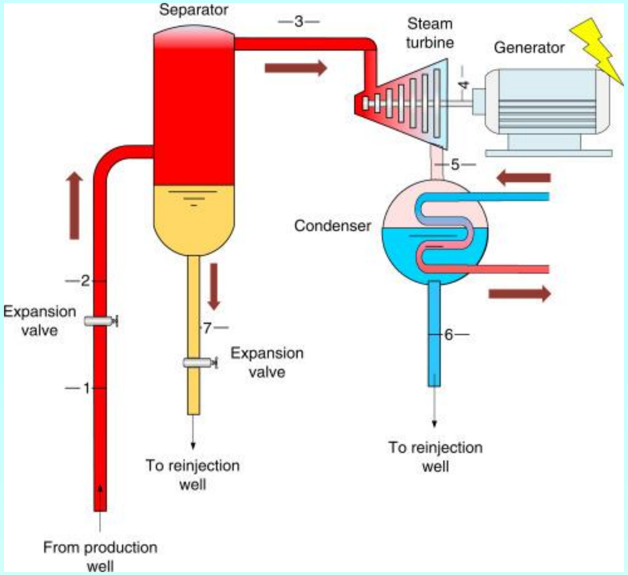
$$X = \frac{P_c}{P_{out}}$$

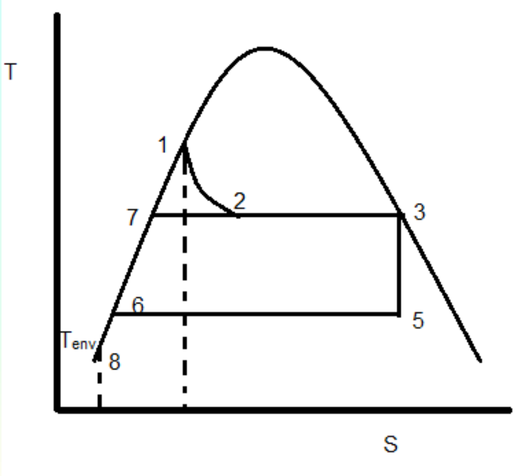
Where: P_c - is the consumed power.





Thermal cycles of the geothermal power plants





The net power out from the system will be:

$$P_{net} = P_{out} - P_c$$

The efficiencies that affect on the work of the system are:

Isentropic efficiency; which must not be less than 0.76

Mechanical efficiency; which must not be less than 0.98

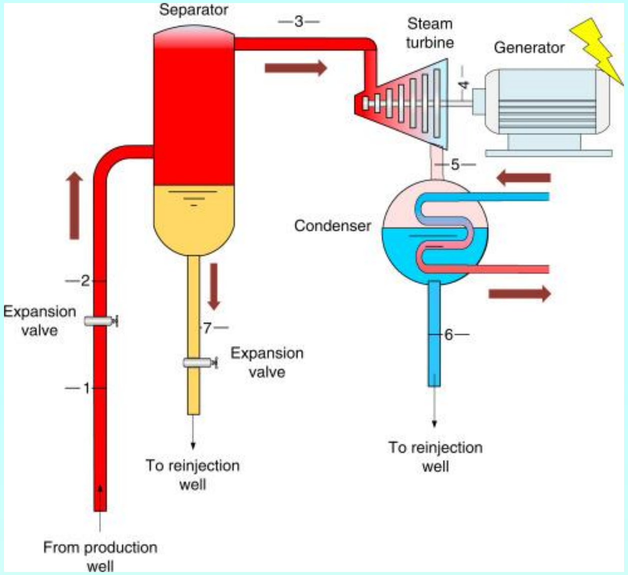
Electrical efficiency. which must not be less than 0.97

The net power outlet from the system will be:

$$P_{net} = \frac{m_3(h_3 - h_5)(1 - X)}{3.6} \eta_{isen.} \eta_{mech.} \eta_{elec.}$$

The power ratio (X) must not exceed 0.25

Thermal cycles of the geothermal power plants



The net efficiency of the cycle:

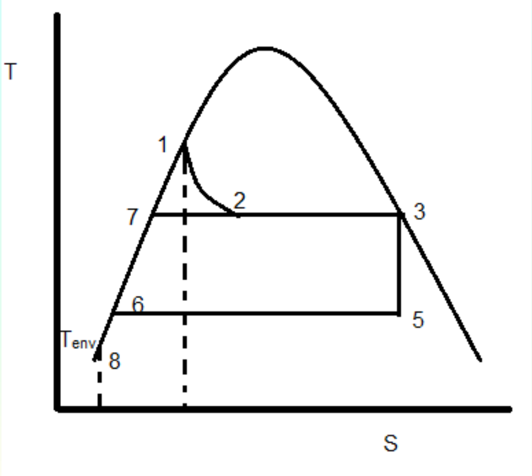
$$\eta_{net} = \frac{3.6P_{net}}{m_1(h_1 - h_6)}$$

The maximum work produced by the system will be:

$$w_{max} = h_1 - h_8 - T_{env}(s_1 - s_8)$$

The utilized efficiency of the cycle:

$$\eta_{ut} = \frac{3.6P_{net}}{m_1 w_{max}}$$



Thermal cycles of the geothermal power plants

Dry steam system

In this type of plants, the cycle will be more simple, as in the following:

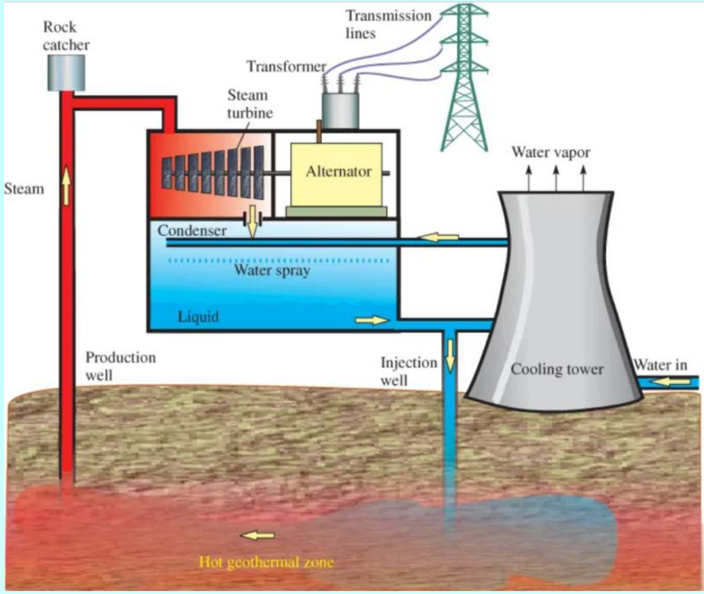
The output power from the system will be:

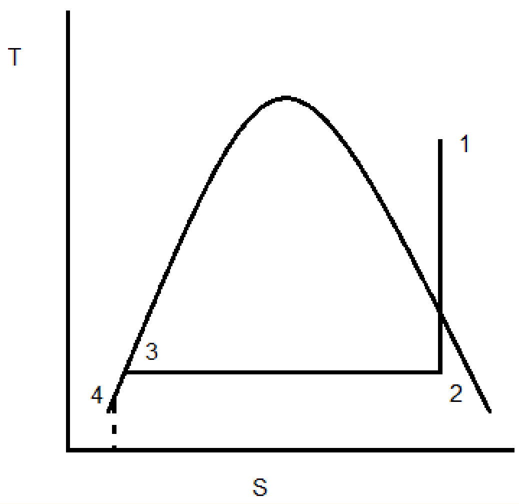
$$P_{out} = m_1(h_1 - h_2)$$

The power ratio is the relation of the consumed power to the produced power, as in the following:

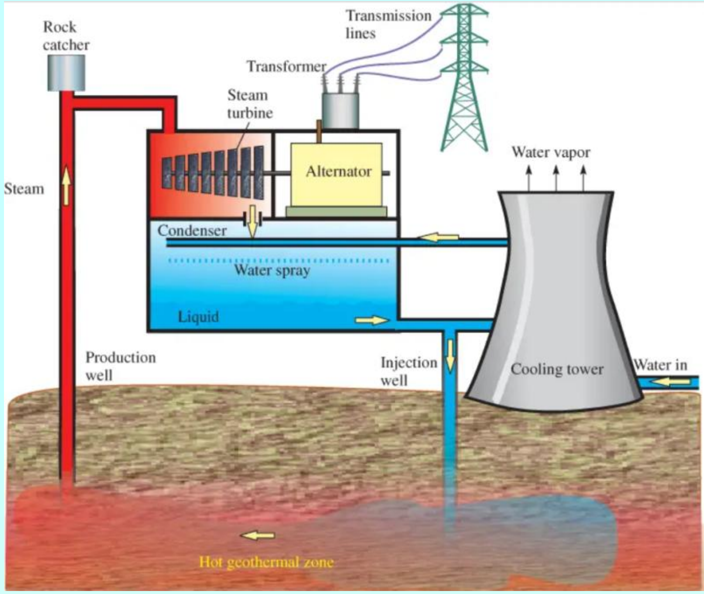
$$X = \frac{P_c}{P_{out}}$$

Where: P_c - is the consumed power.





Thermal cycles of the geothermal power plants



The net power out from the system will be:

$$P_{net} = P_{out} - P_c$$

The efficiencies that affect on the work of the system are:

Isentropic efficiency; which must not be less than 0.76

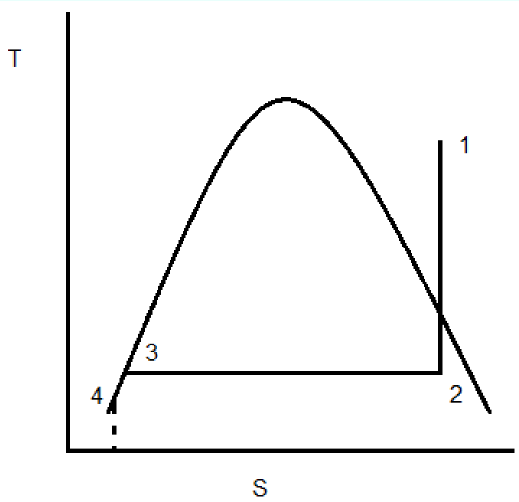
Mechanical efficiency; which must not be less than 0.98

Electrical efficiency. which must not be less than 0.97

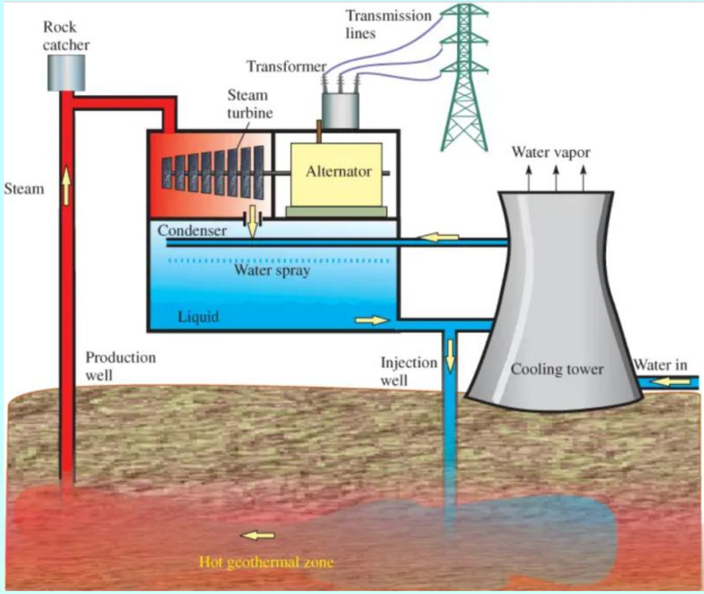
The net power outlet from the system will be:

$$P_{net} = \frac{m_1(h_1 - h_2)(1 - X)}{3.6} \eta_{isen.} \eta_{mech.} \eta_{elec.}$$

The power ratio (X) must not exceed 0.25



Thermal cycles of the geothermal power plants



The net efficiency of the cycle:

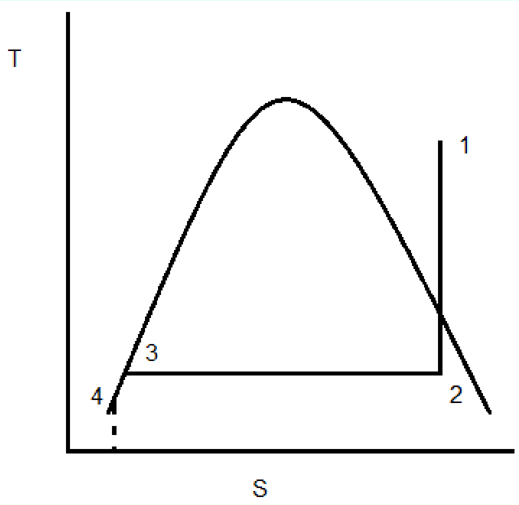
$$\eta_{net} = \frac{3.6P_{net}}{m_1(h_1 - h_3)}$$

The maximum work produced by the system will be:

$$w_{max} = h_1 - h_4 - T_{env}(s_1 - s_4)$$

The utilized efficiency of the cycle:

$$\eta_{ut} = \frac{3.6P_{net}}{m_1 w_{max}}$$



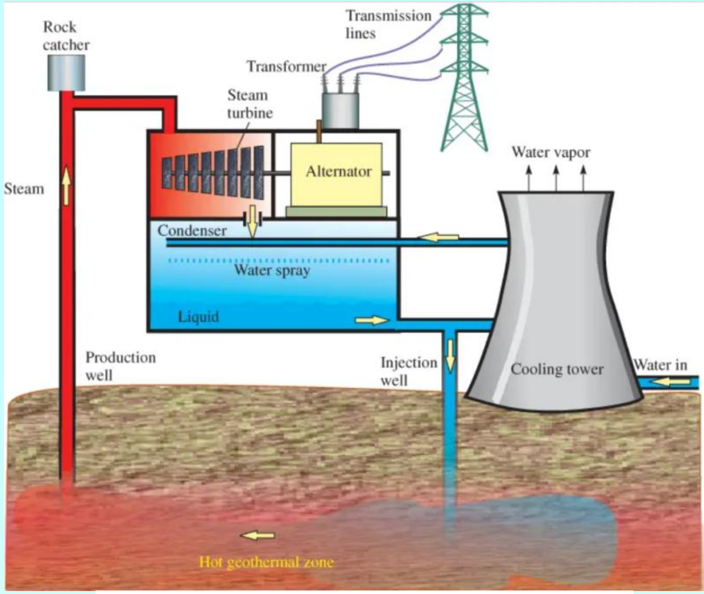
Thermal cycles of the geothermal power plants

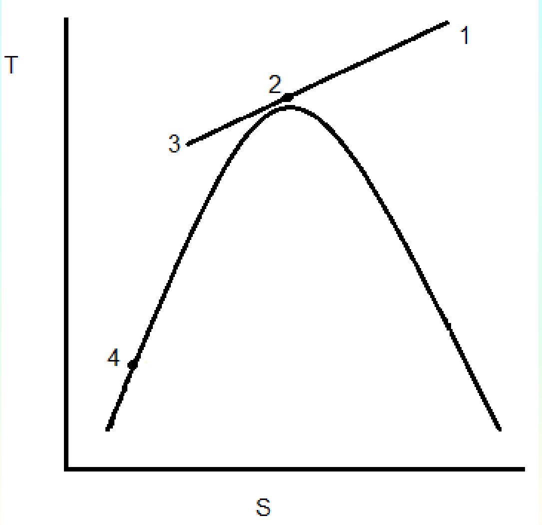
High pressure and temperature dry steam system

In this type of power plants, the steam will condensate directly to water without passing through intermundate of the phase changing because the pressure of the steam is over the pressure and temperature of the critical point of water.

The output power from the system will be:

$$P_{out} = m_1(h_1 - h_2)$$





Thermal cycles of the geothermal power plants

The net power out from the system will be:

$$P_{net} = P_{out} - P_c$$

$$P_{net} = \frac{m_1(h_1 - h_2)(1 - X)}{3.6}\eta_{isen}.\eta_{mech}.\eta_{elec}.$$

The net efficiency of the cycle:

$$\eta_{net} = \frac{3.6P_{net}}{m_1(h_1 - h_3)}$$

The maximum work produced by the system will be:

$$w_{max} = h_1 - h_4 - T_{env}(s_1 - s_4)$$

The utilized efficiency of the cycle:

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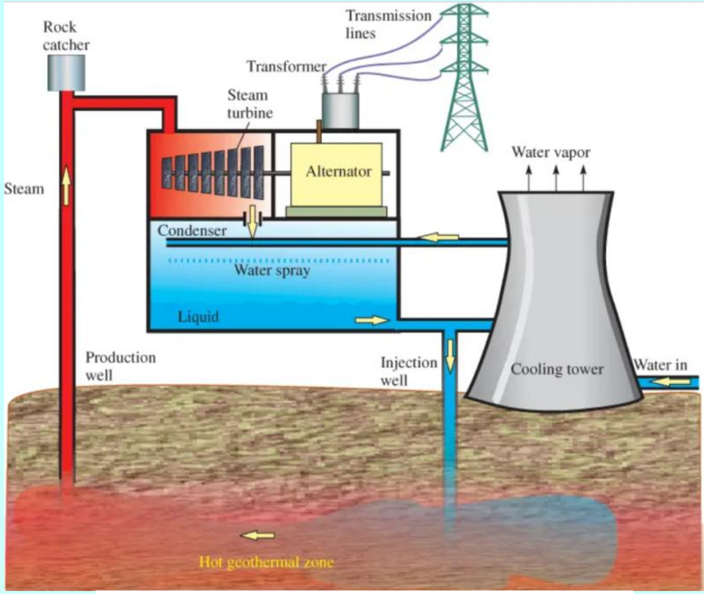
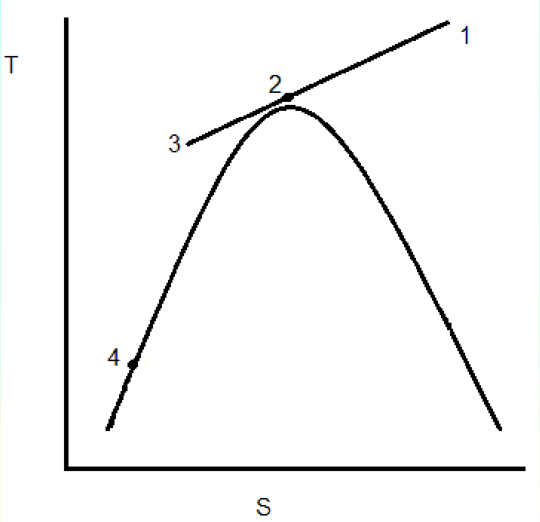


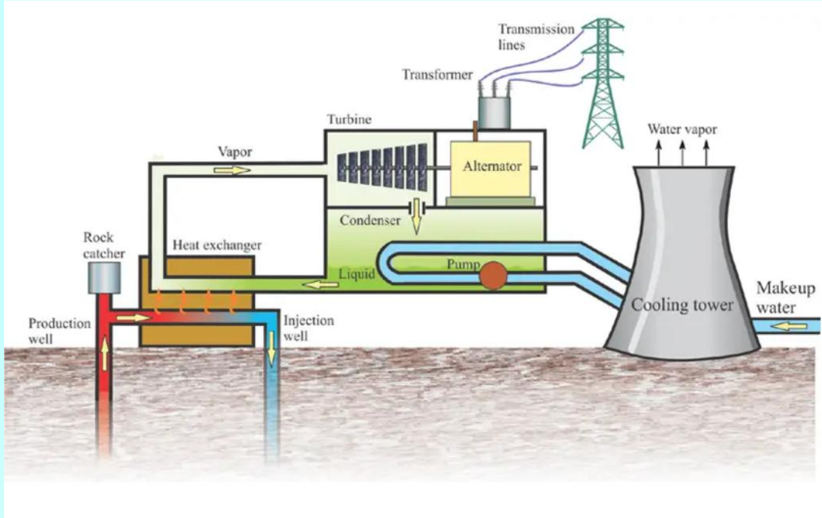


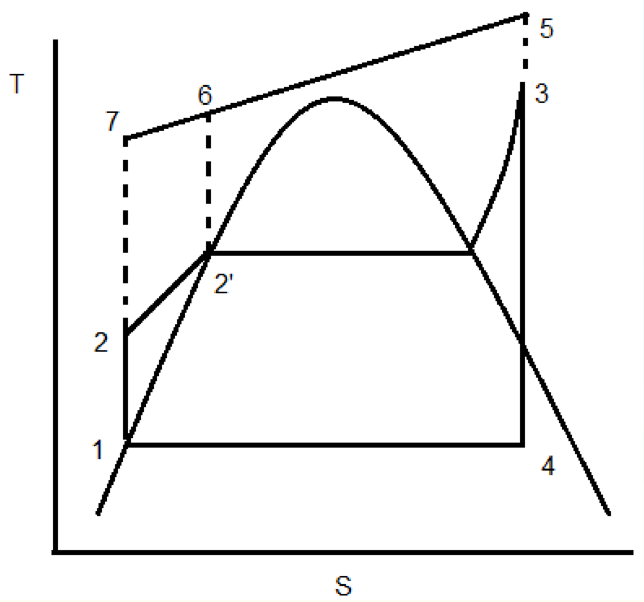
Thermal cycles of the geothermal power plants

Binary system

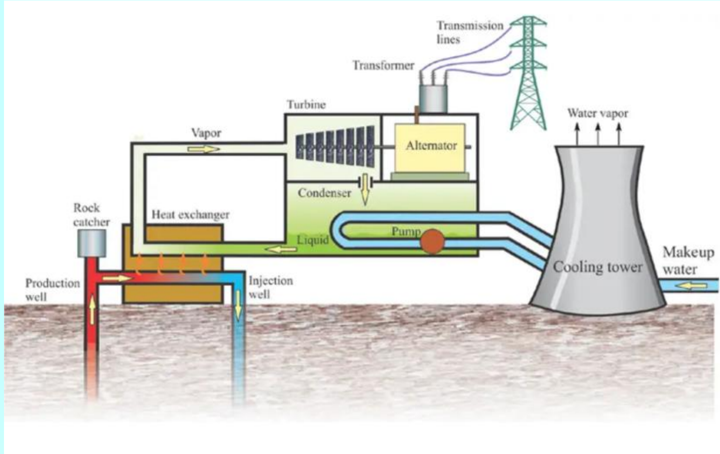
In this type of plants, the there are two thermal cycles, one of them is the source of the energy while the other is energy convertor. The first is just heat exchanger that will transfer heat from the deep of earth to the working material (usually water) in the second cycle causing its evaporation. The hot steam in the second cycle will turn the turbine and the output power will be:

$$P_{out} = m_1[(h_3 - h_4) - (h_2 - h_1)]$$





Thermal cycles of the geothermal power plants



From the heat and mass balance between two cycles we can get:

$$m_1(h_3 - h_2) = m_5(h_5 - h_7)$$

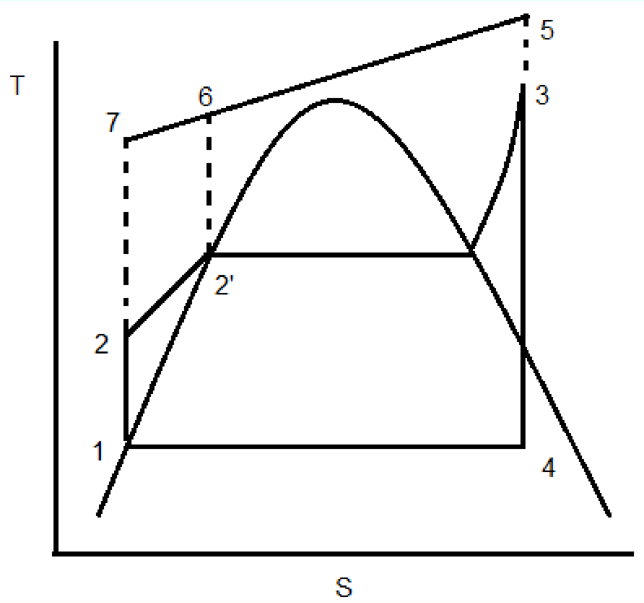
The net power of the system will be:

$$P_{net} = P_{out} - P_c$$

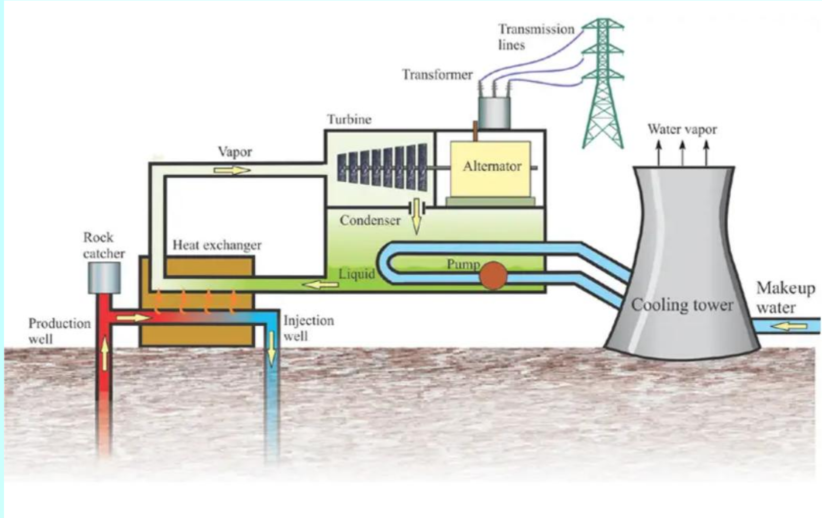
Therefore:

$$P_{net} = \frac{m_1[(h_3 - h_4) - (h_2 - h_1)](1 - X)}{3.6} \eta_{isen.} \eta_{mech.} \eta_{elec.}$$

The power ratio (X) must not exceed 0.25



Thermal cycles of the geothermal power plants



The net efficiency of the cycle:

$$\eta_{net} = \frac{3.6P_{net}}{m_1[(h_3 - h_4) - (h_2 - h_1)]}$$

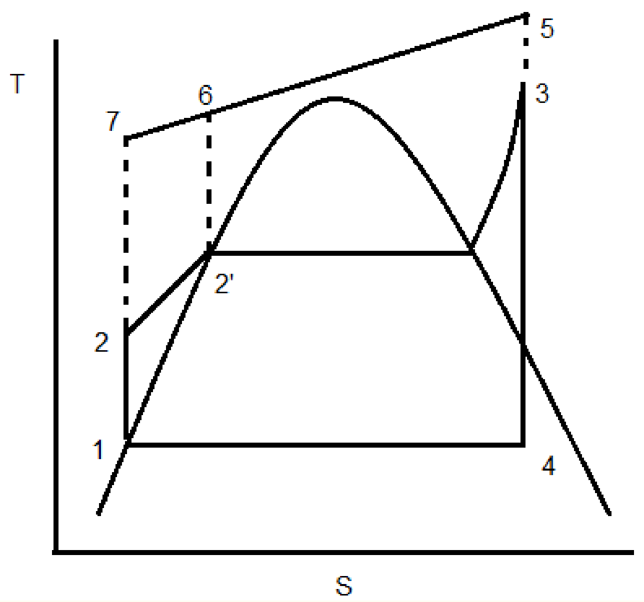
The maximum work produced by the system will be:

$$w_{max} = h_5 - h_8 - T_{env}(s_5 - s_8)$$

Where: h_8, s_8 are the enthalpy and entropy of the working material at environment temperature.

The utilized efficiency of the cycle:

$$\eta_{ut} = \frac{3.6P_{net}}{m_1 w_{max}}$$



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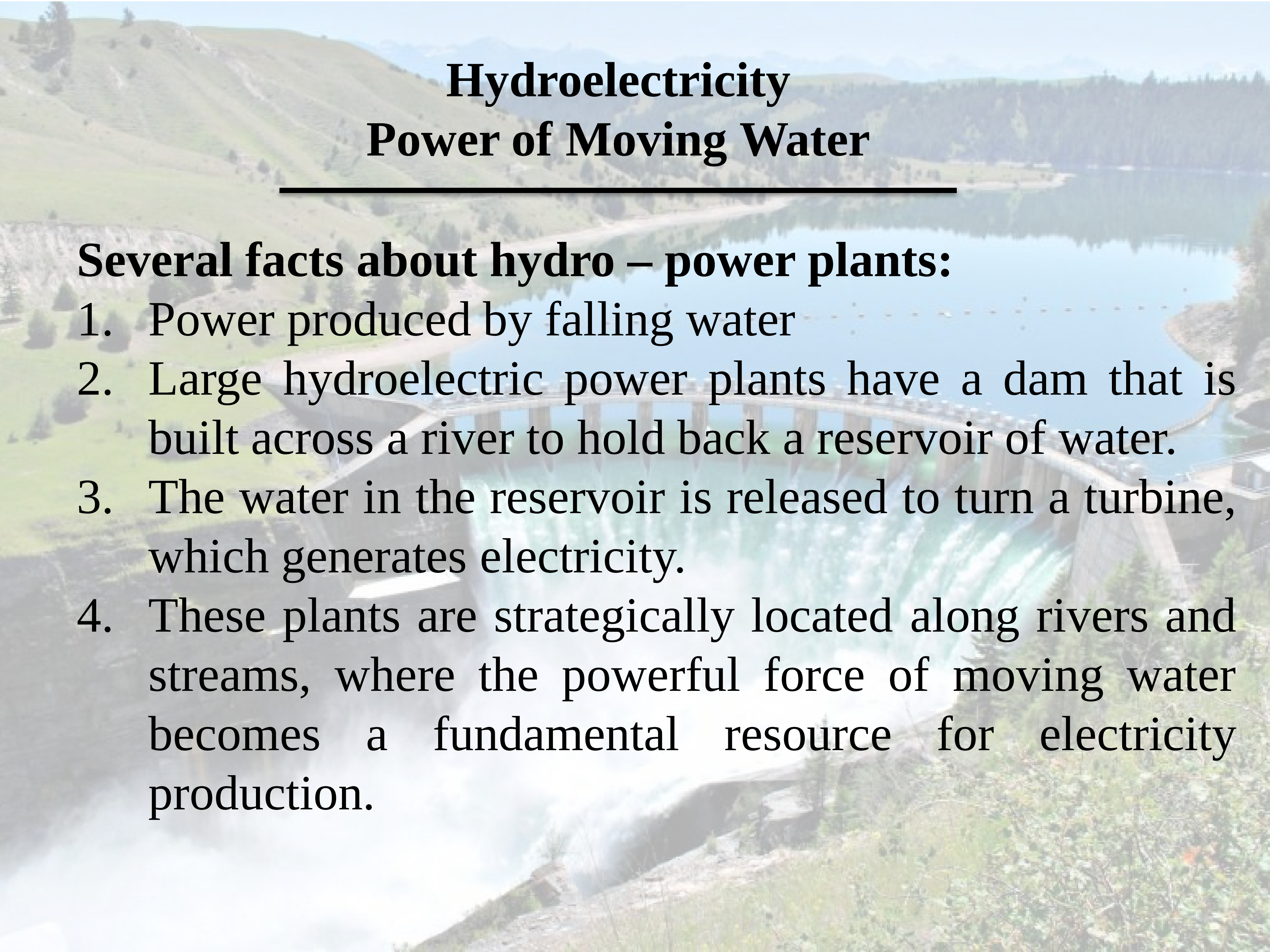
الطاقة المتجددة

المحاضرة الرابعة عشر: محطات الطاقة المائية

مدرس المادة: د. عمر عبد الهادي مصطفى

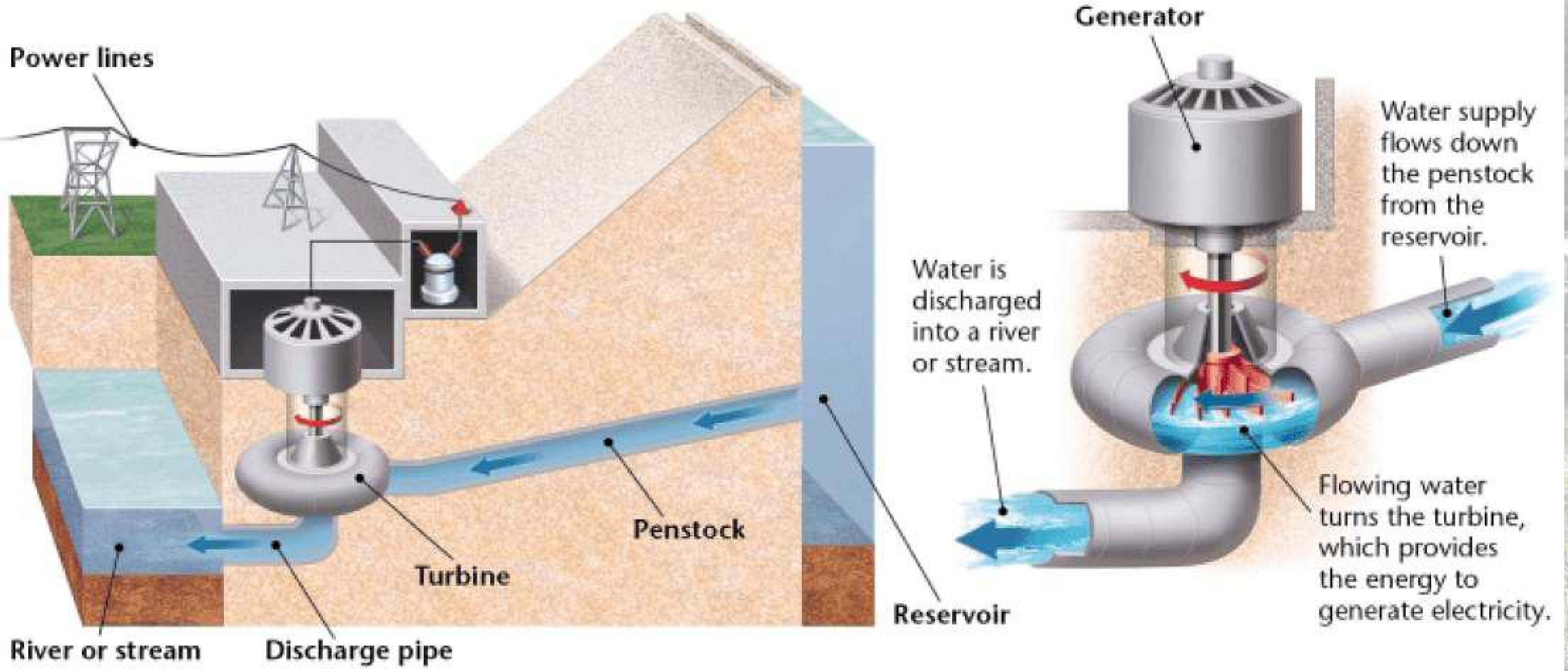


Hydroelectricity
Power of Moving Water

Several facts about hydro – power plants:

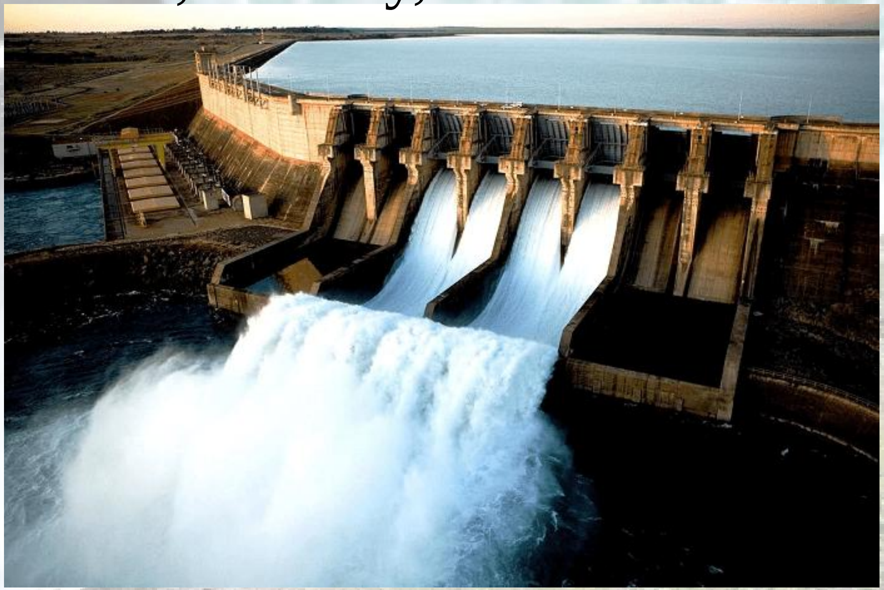
1. Power produced by falling water
2. Large hydroelectric power plants have a dam that is built across a river to hold back a reservoir of water.
3. The water in the reservoir is released to turn a turbine, which generates electricity.
4. These plants are strategically located along rivers and streams, where the powerful force of moving water becomes a fundamental resource for electricity production.

Hydroelectricity: Main Parts



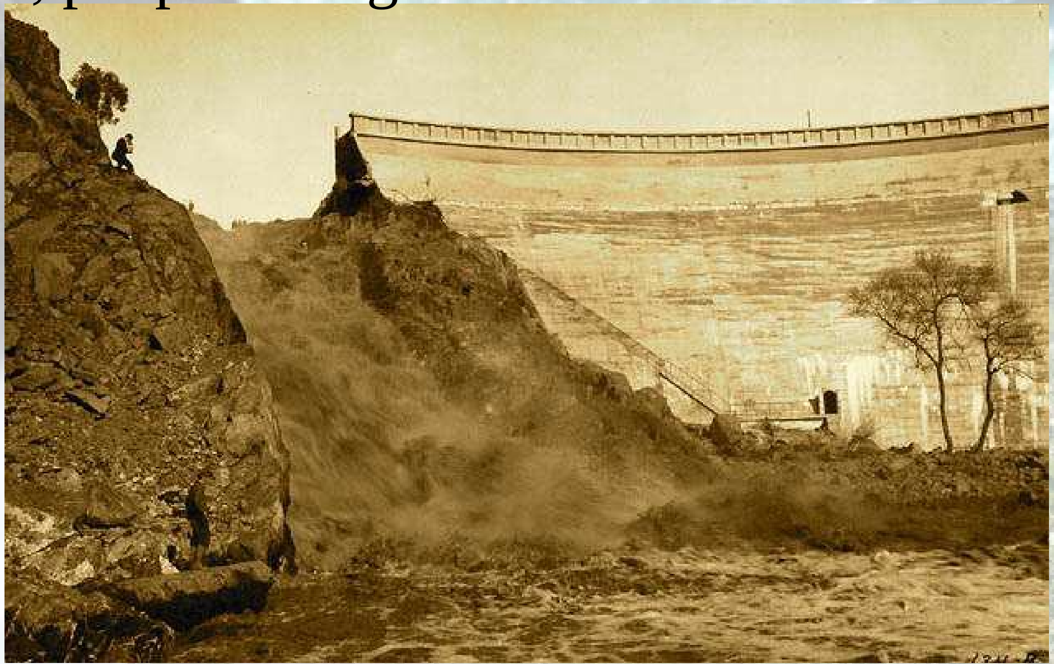
The Benefits of Hydropower

- Hydroelectric dams are expensive to build, but relatively **inexpensive** to operate.
- Unlike fossil fuel plants, hydroelectric dams do not release air pollutants that cause acid precipitation.
- Hydroelectric dams also tend to last much longer than fossil fuel-powered plants.
- Dams also provide other benefits such as flood control and water for drinking, agriculture, industry, and recreation.



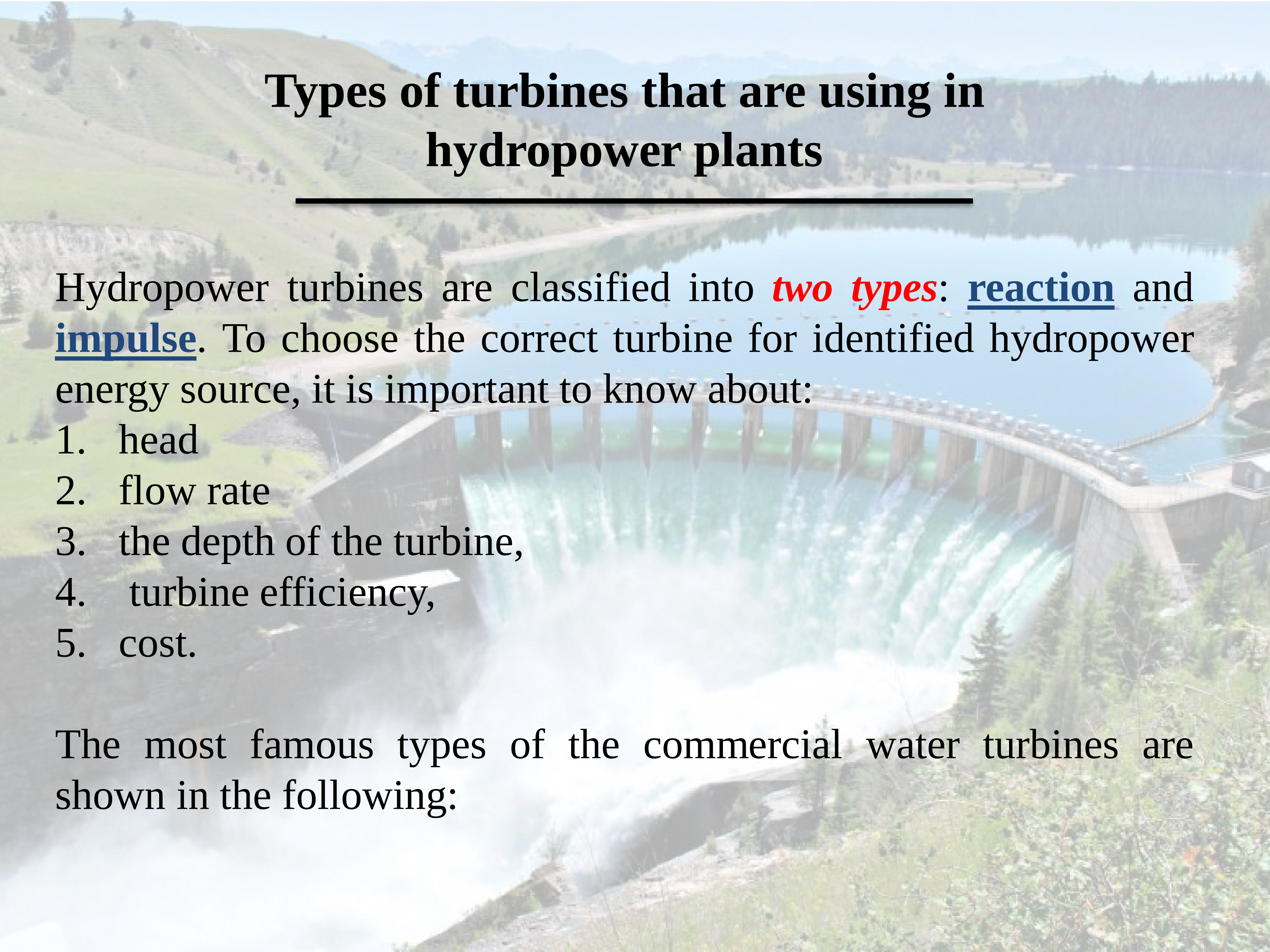
The Disadvantages of Hydropower

- A dam changes a river’s flow, which can have far reaching consequences.
- A reservoir floods large areas of habitat above the dam.
- Water flow below the dam is reduced, which disrupts ecosystems downstream.
- When the land behind a dam is flooded, people are often displaced. If a dam bursts, people living in areas below the dam can be killed.



The Disadvantages of Hydropower

- River sediments build up behind the dam instead of enriching land farther down the river, making farmland below the dam less productive.
- The decay of plant matter trapped in reservoirs can release large amounts of greenhouse gases sometimes more than a fossil-fuel powered plants.



Types of turbines that are using in hydropower plants

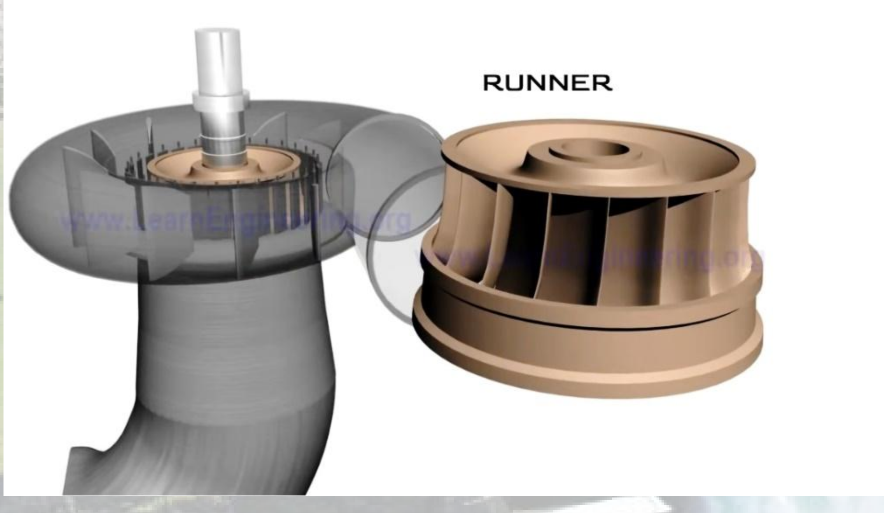
Hydropower turbines are classified into ***two types***: **reaction** and **impulse**. To choose the correct turbine for identified hydropower energy source, it is important to know about:

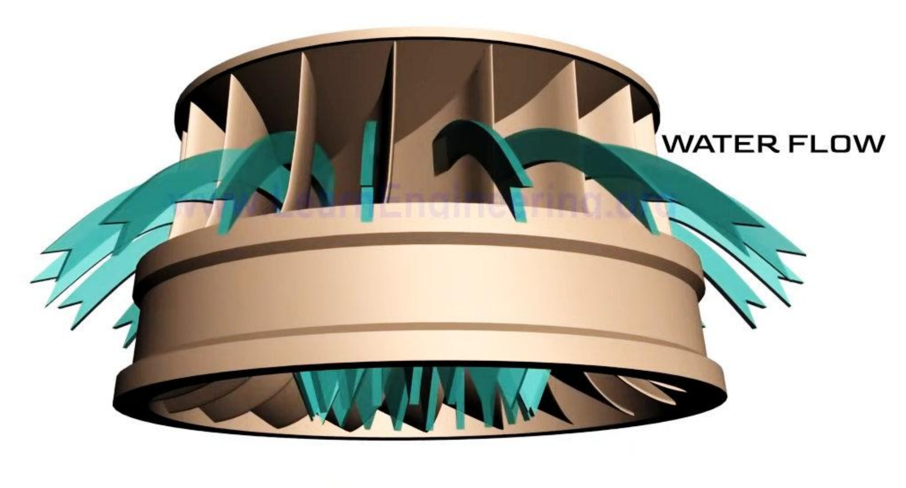
1. head
2. flow rate
3. the depth of the turbine,
4. turbine efficiency,
5. cost.

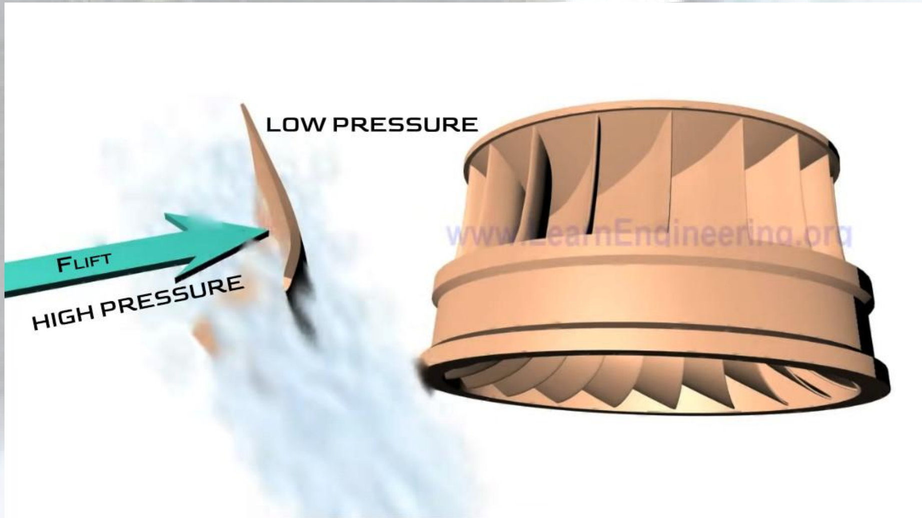
The most famous types of the commercial water turbines are shown in the following:

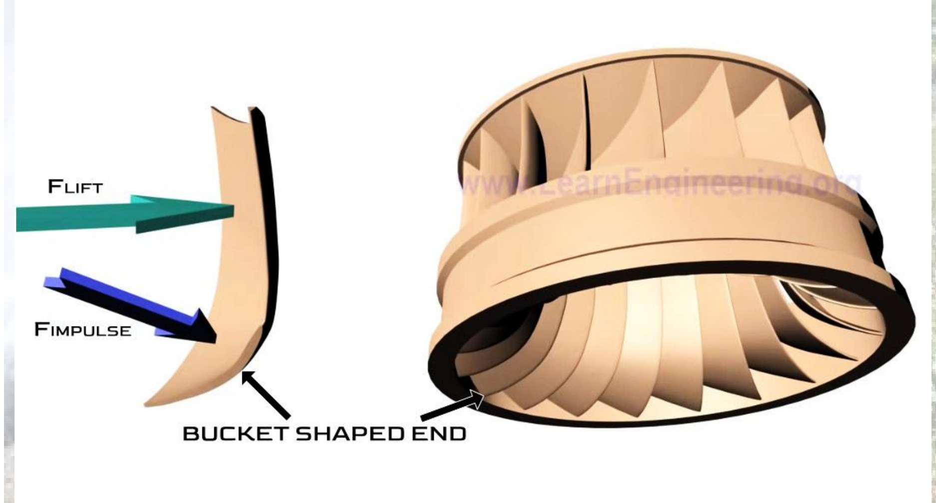
Commercial types of hydro-power plants

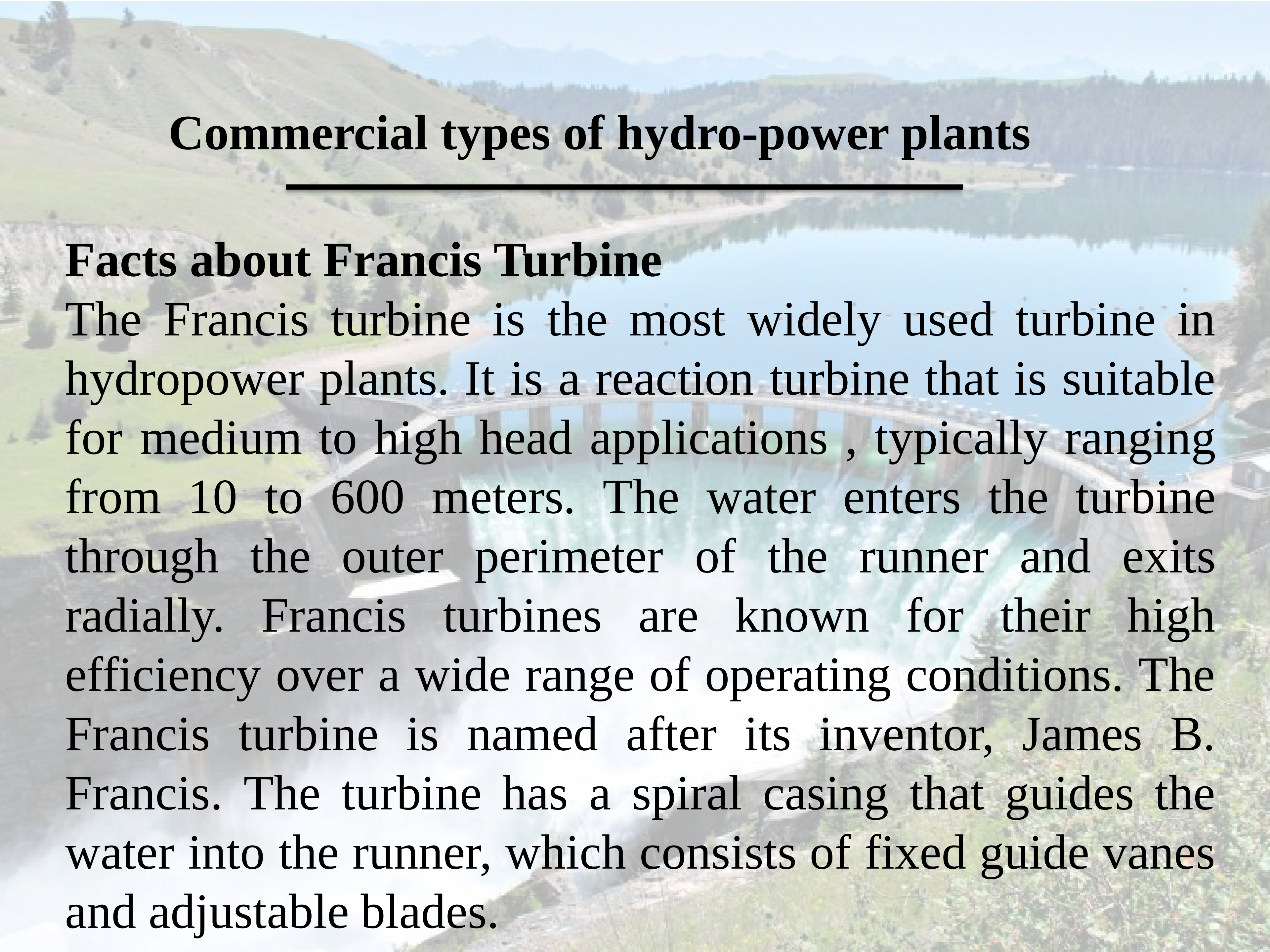
Francis Turbine:











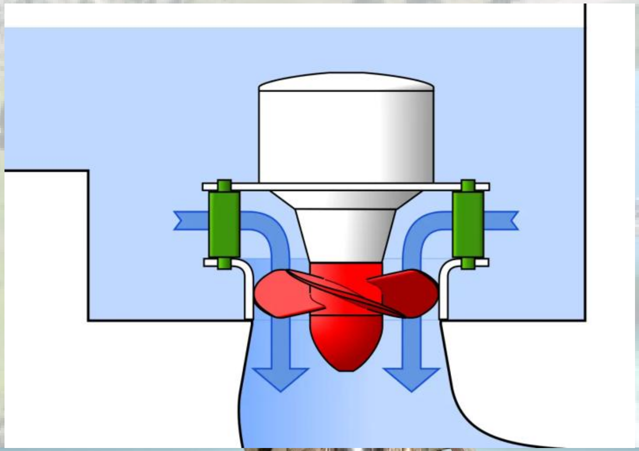
Commercial types of hydro-power plants

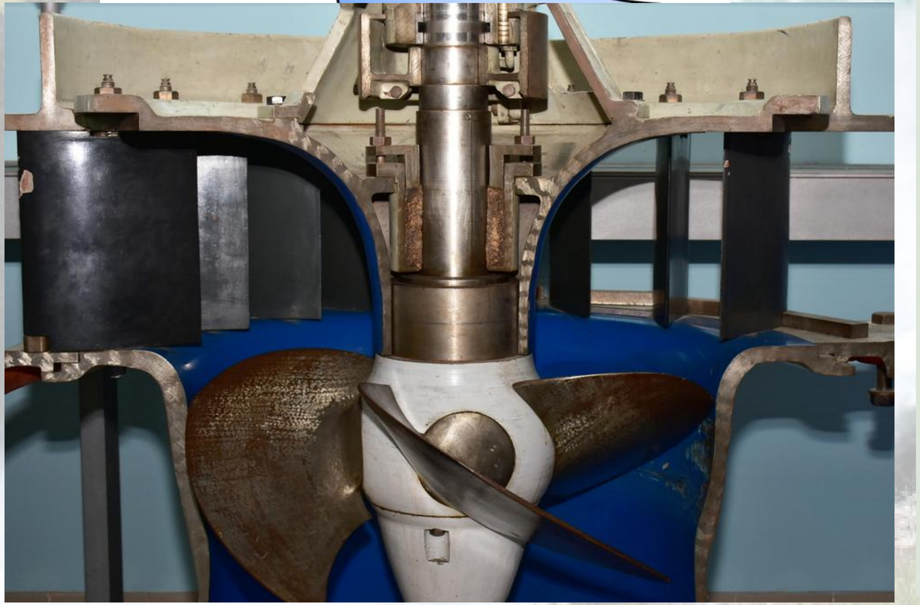
Facts about Francis Turbine

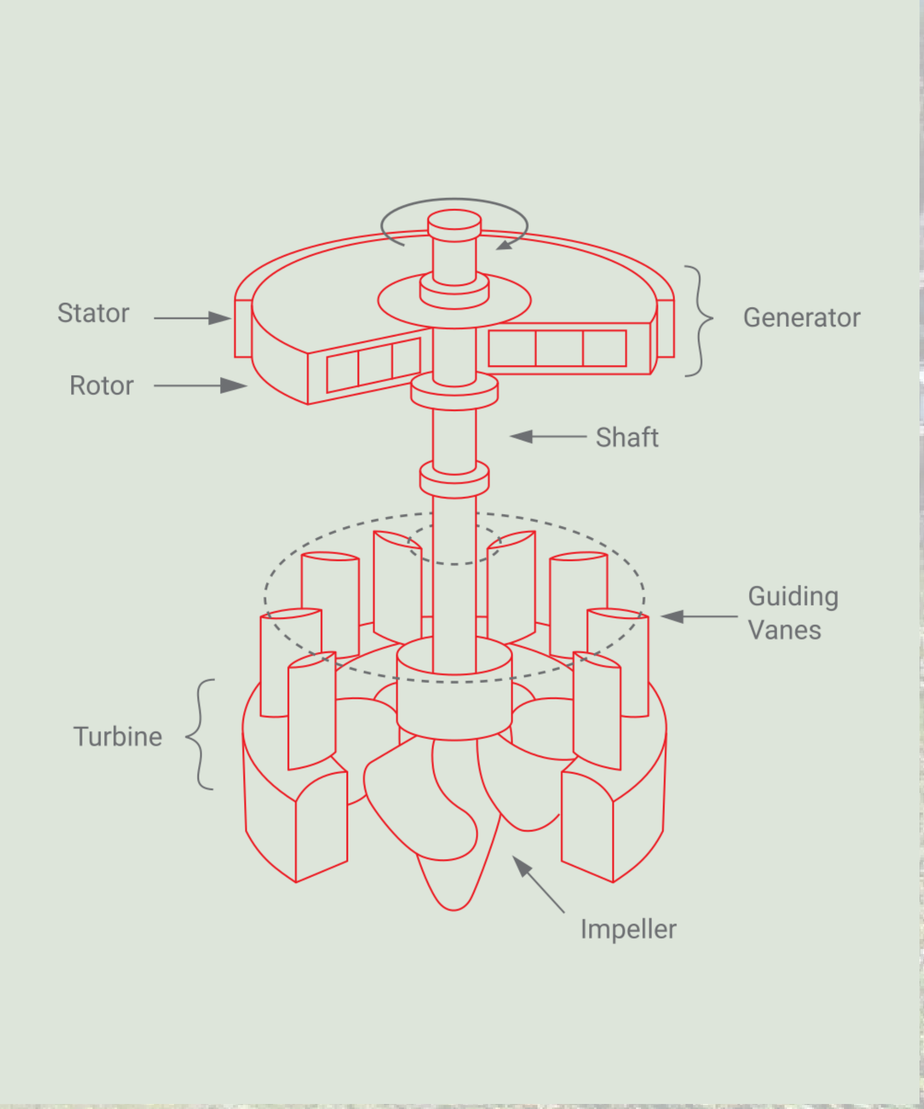
The Francis turbine is the most widely used turbine in hydropower plants. It is a reaction turbine that is suitable for medium to high head applications , typically ranging from 10 to 600 meters. The water enters the turbine through the outer perimeter of the runner and exits radially. Francis turbines are known for their high efficiency over a wide range of operating conditions. The Francis turbine is named after its inventor, James B. Francis. The turbine has a spiral casing that guides the water into the runner, which consists of fixed guide vanes and adjustable blades.

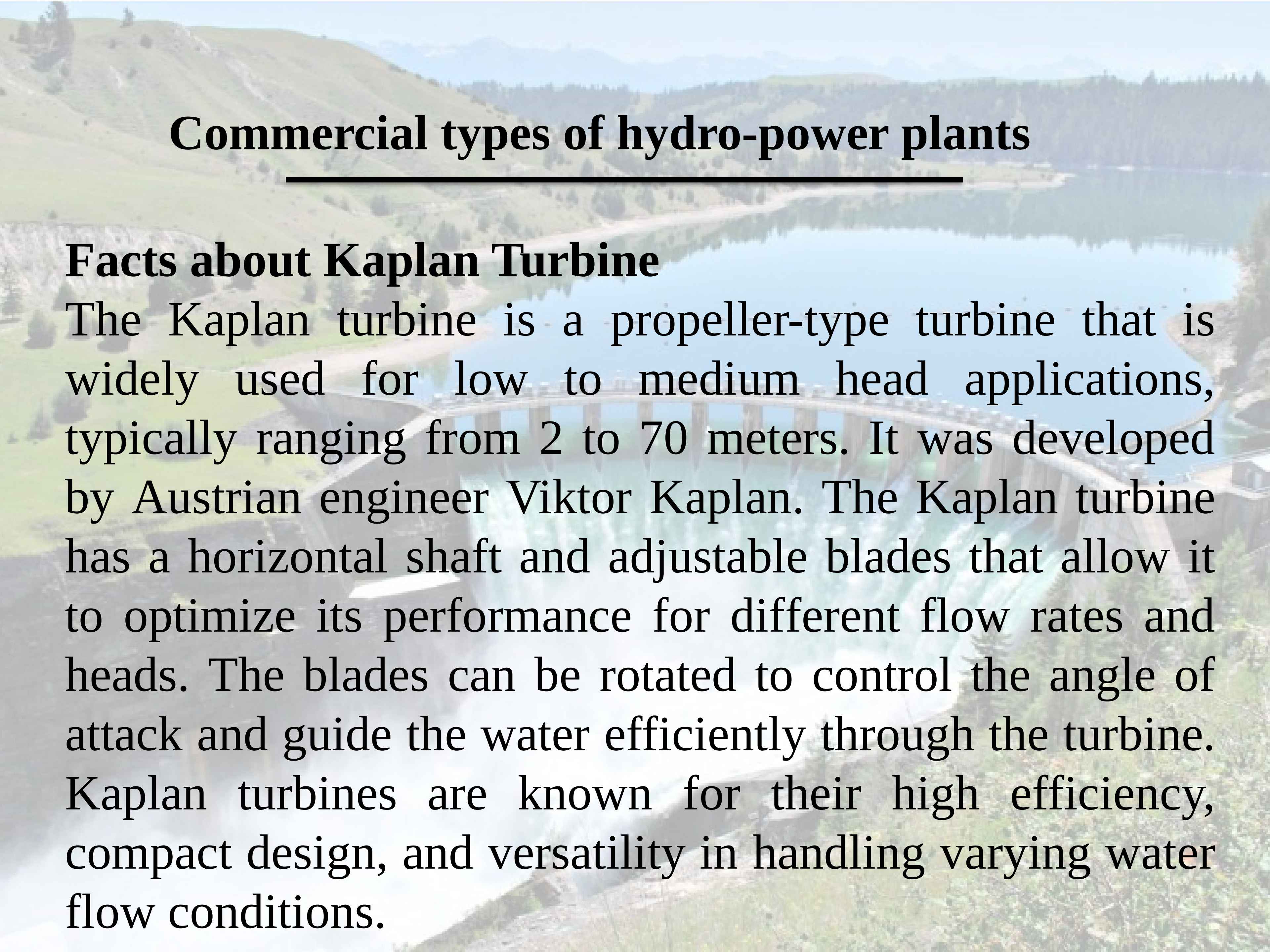
Commercial types of hydro-power plants

Kaplan Turbine:









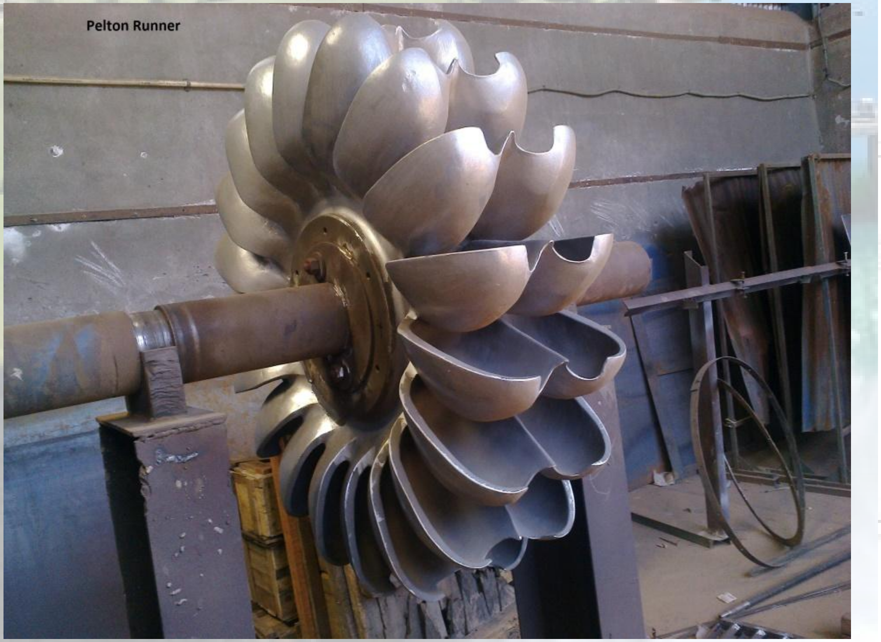
Commercial types of hydro-power plants

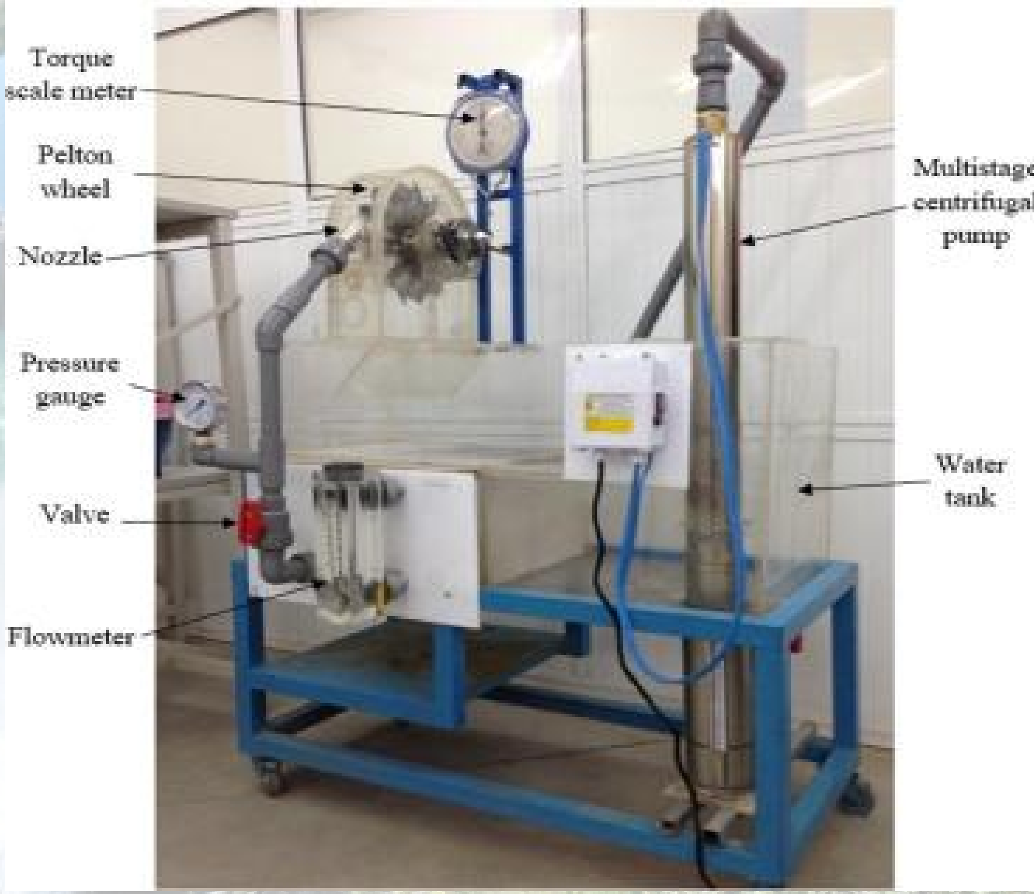
Facts about Kaplan Turbine

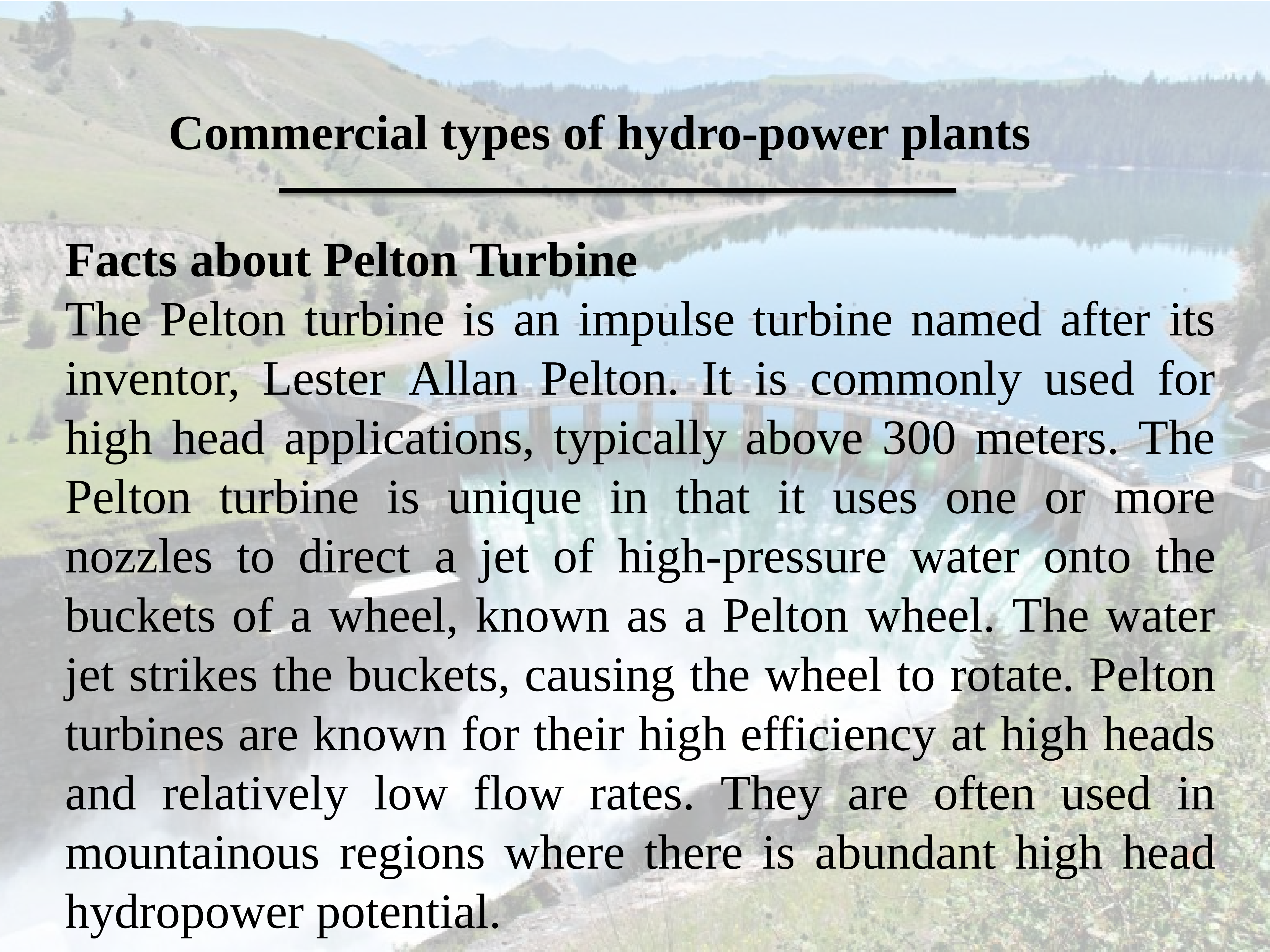
The Kaplan turbine is a propeller-type turbine that is widely used for low to medium head applications, typically ranging from 2 to 70 meters. It was developed by Austrian engineer Viktor Kaplan. The Kaplan turbine has a horizontal shaft and adjustable blades that allow it to optimize its performance for different flow rates and heads. The blades can be rotated to control the angle of attack and guide the water efficiently through the turbine. Kaplan turbines are known for their high efficiency, compact design, and versatility in handling varying water flow conditions.

Commercial types of hydro-power plants

Pelton Turbine:







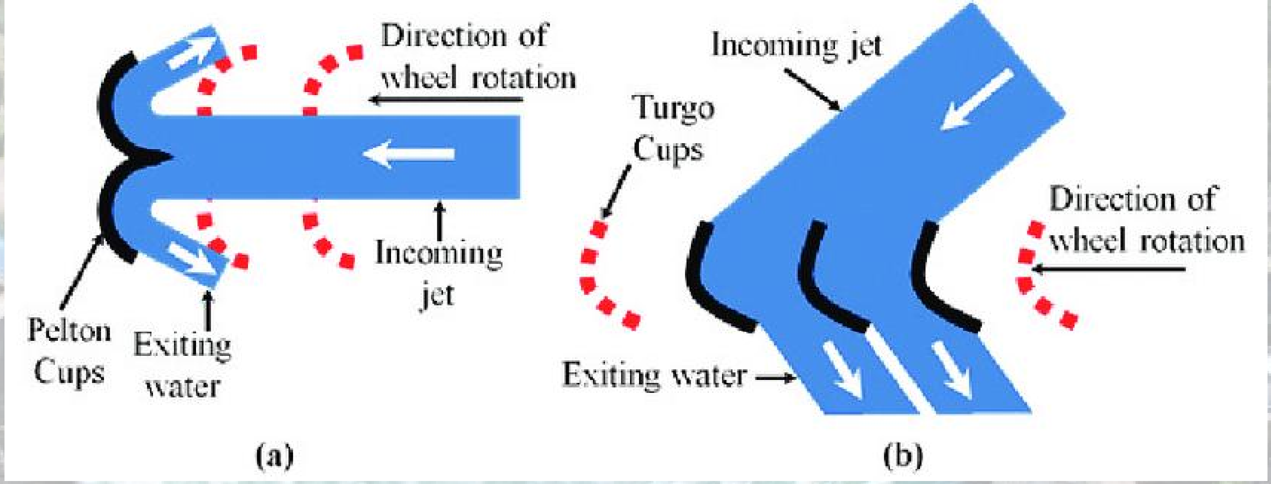
Commercial types of hydro-power plants

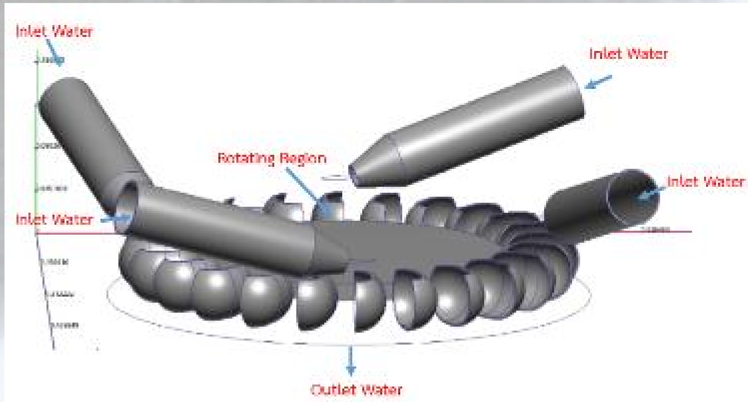
Facts about Pelton Turbine

The Pelton turbine is an impulse turbine named after its inventor, Lester Allan Pelton. It is commonly used for high head applications, typically above 300 meters. The Pelton turbine is unique in that it uses one or more nozzles to direct a jet of high-pressure water onto the buckets of a wheel, known as a Pelton wheel. The water jet strikes the buckets, causing the wheel to rotate. Pelton turbines are known for their high efficiency at high heads and relatively low flow rates. They are often used in mountainous regions where there is abundant high head hydropower potential.

Commercial types of hydro-power plants

Turgo Turbine:



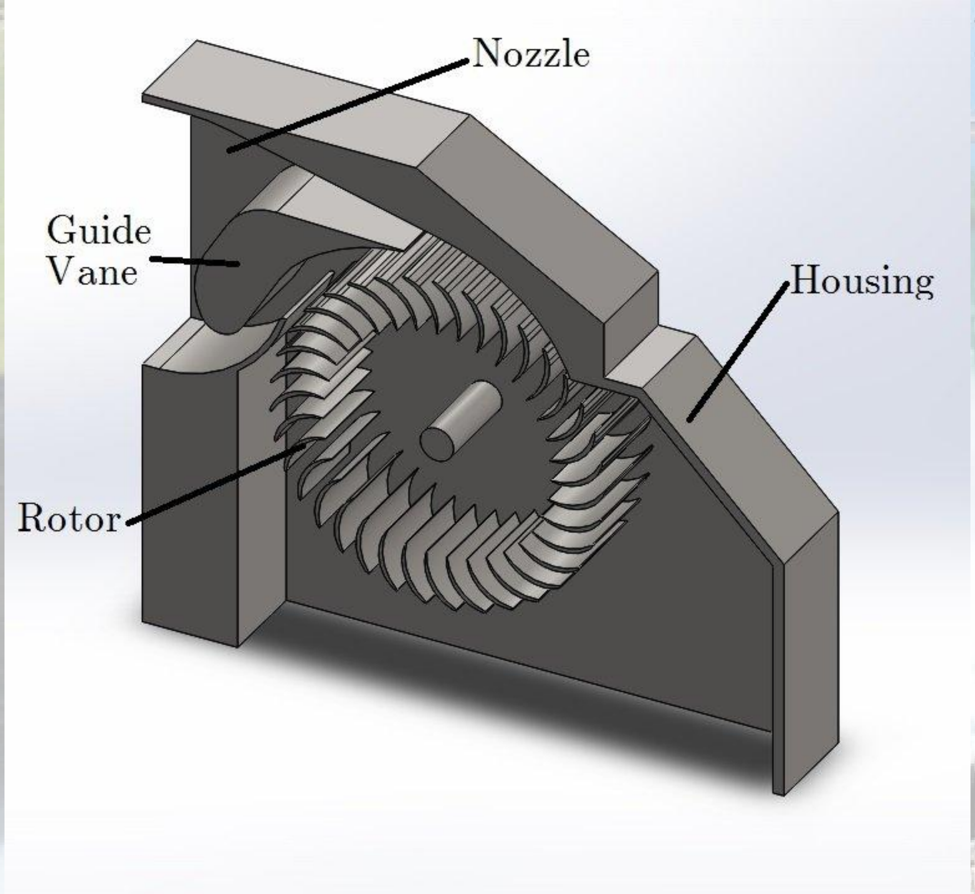


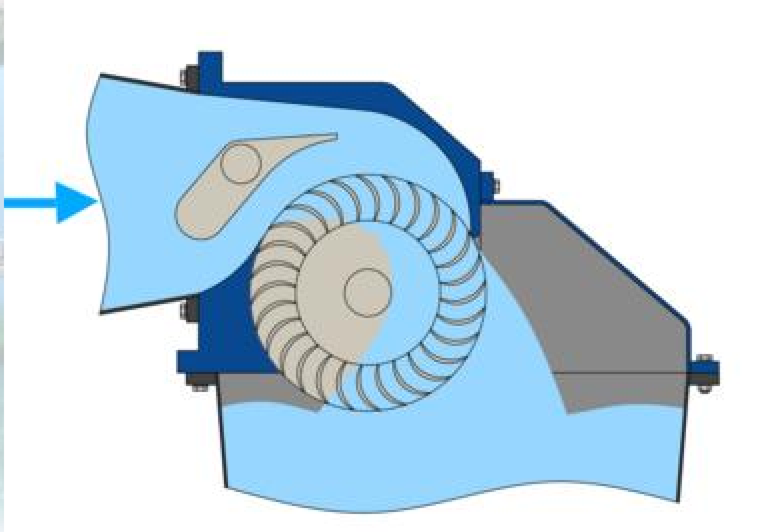
Commercial types of hydro-power plants

The Turgo turbine is another type of impulse turbine used for medium to high head applications, typically ranging from 30 to 300 meters. It was developed by Gilkes Energy Company Ltd. The Turgo turbine is similar to the Pelton turbine in principle but has a different bucket design. It uses a jet of high-pressure water that strikes the double-cupped buckets of the Turgo wheel, causing it to rotate. Turgo turbines are known for their simplicity, high efficiency, and ability to handle a wide range of flow rates. They are often used in small to medium-sized hydropower installations.

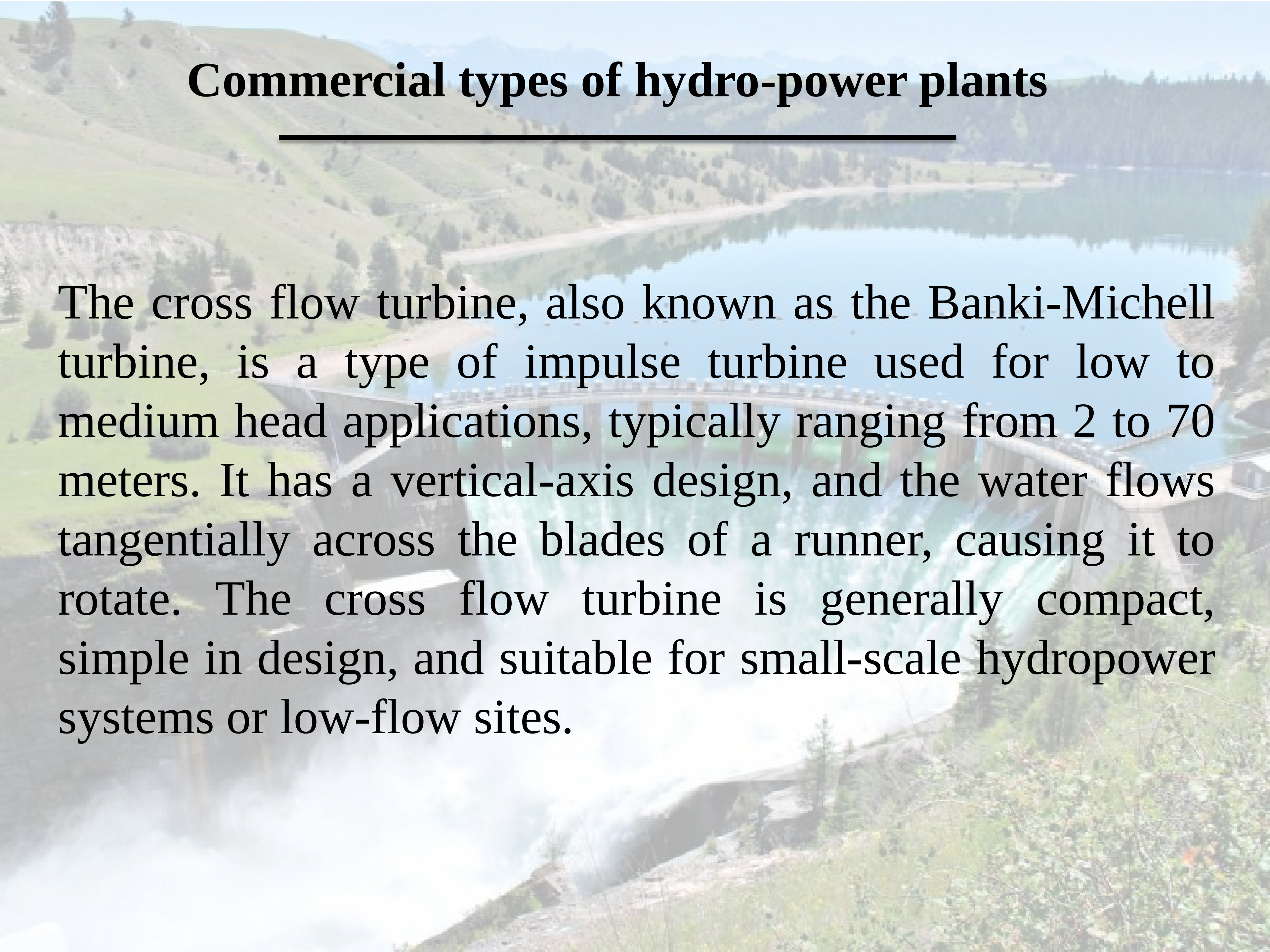
Commercial types of hydro-power plants

Cross flow Turbine





Commercial types of hydro-power plants



The cross flow turbine, also known as the Banki-Michell turbine, is a type of impulse turbine used for low to medium head applications, typically ranging from 2 to 70 meters. It has a vertical-axis design, and the water flows tangentially across the blades of a runner, causing it to rotate. The cross flow turbine is generally compact, simple in design, and suitable for small-scale hydropower systems or low-flow sites.