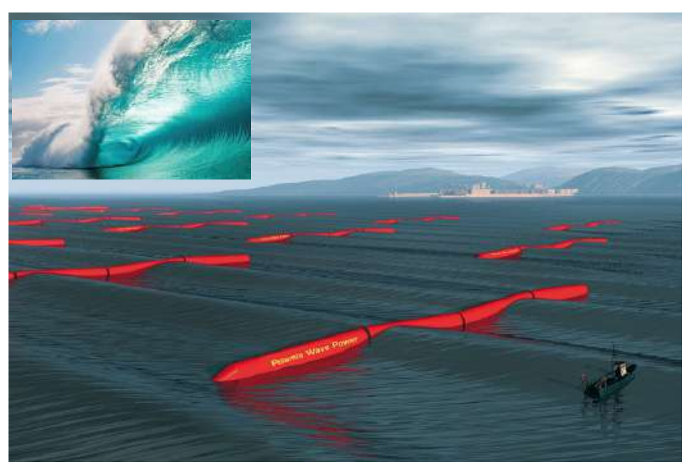



ENVC 24 : Energy and Environment

Part-3 : Non-conventional Energy Resources

Kanyakumari Windmills, India



Pelamis Wave Energy Converter, Scotland

Krafla Geo-thermal Enerrgy, Iceland

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Earth & Atmosphere

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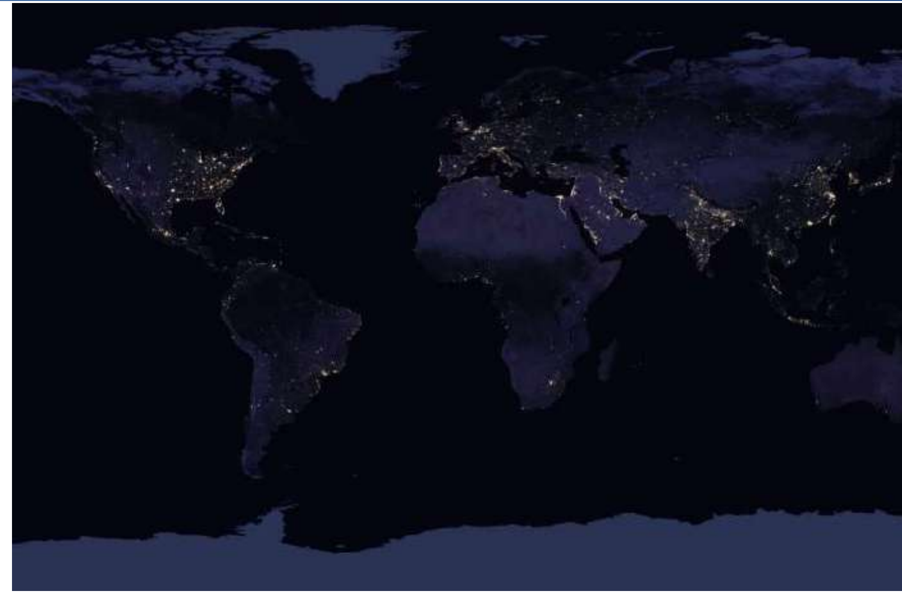

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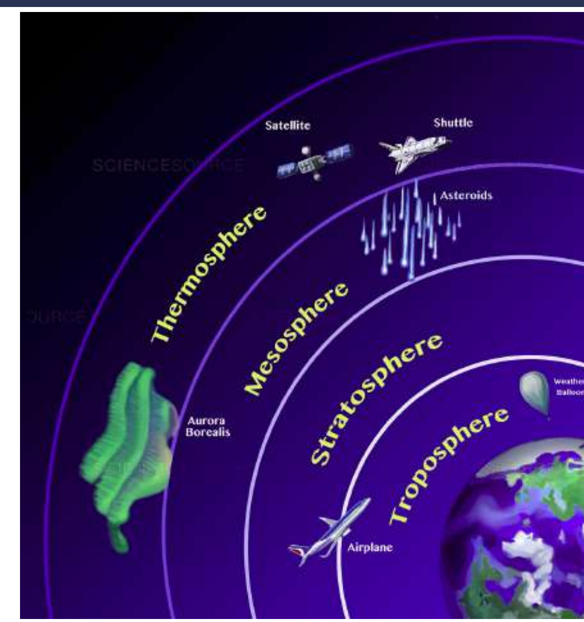

$$\left\{\begin{array}{lll}
\text{Troposphere} & \rightarrow & 0-12\ km \\
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\text{Mesosphere} & \rightarrow & 50-80\ km \\
\text{Thermosphere} & \rightarrow & 80-700\ km \\
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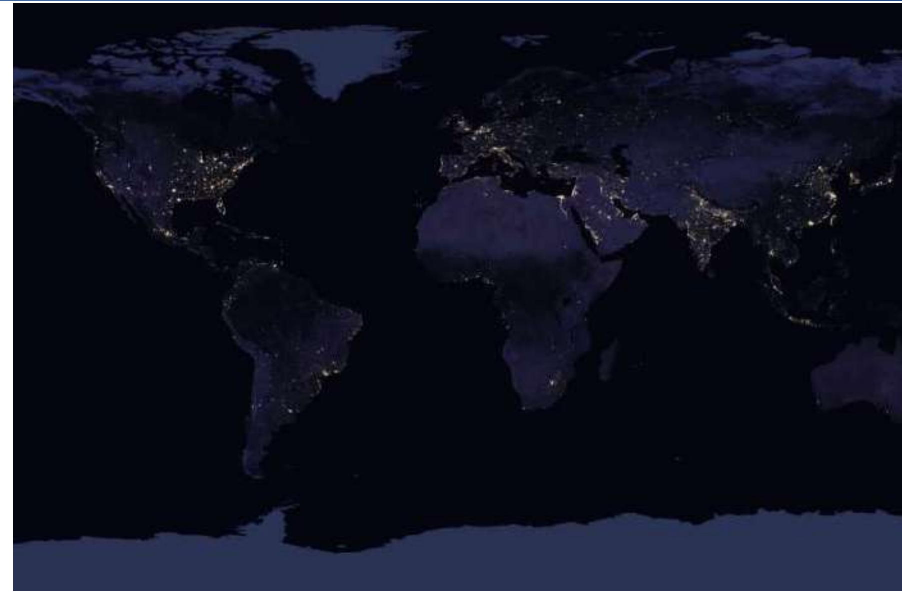

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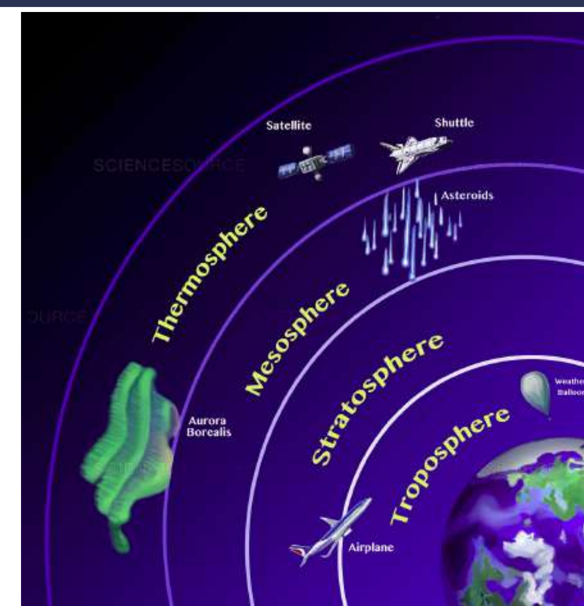

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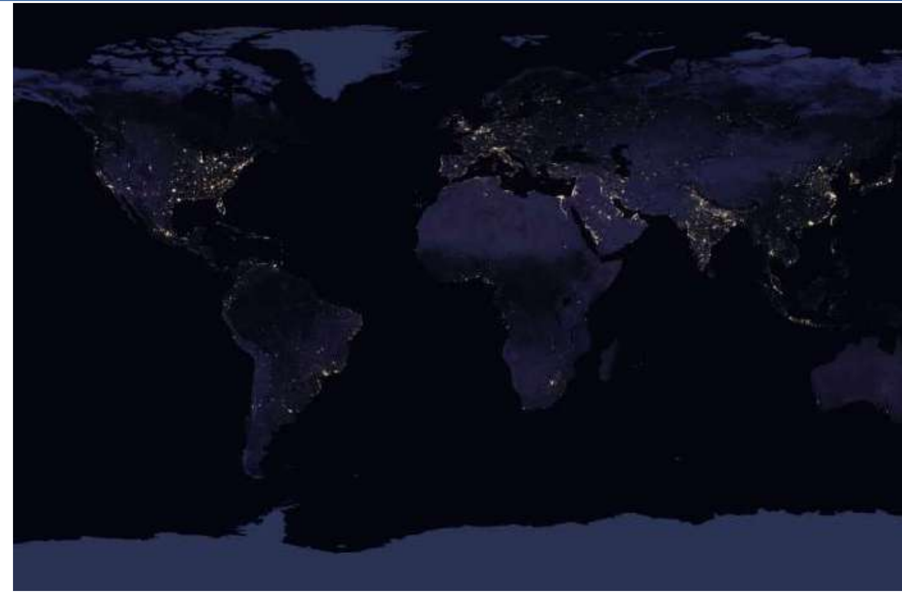

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Earth Radius(R) → $6371\,Km$

Earth+Troposphere Radius(R') → $6383\,Km$

Earth Volume → $\frac{4}{3}\pi R^3 \sim 1.083\,x\,10^{21}\,m^3$

Troposphere Volume → $\frac{4}{3}\pi R'^3 - \frac{4}{3}\pi R^3 = 6.133\,x\,10^{18}\,m^3$

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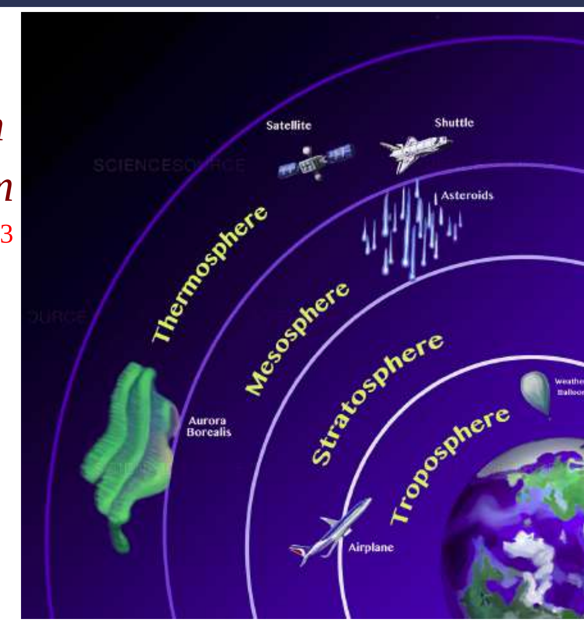

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Atmosphere

- As Volume of Troposphere is $6.133\,x\,10^{18}\,m^3$, then 0.04% of CO_2 accounts for $2.453\,x\,10^{15}\,m^3$. To moderate on Greenhouse gas, estimate have to add on this number!! 1 mole of CO_2 corresponds to 22.4 litre or $22.4\,x\,10^{-3}\,m^3$ at S.T.P.(1atm P, 0°C T).

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- Time required to double the amount of CO_2 in the atmosphere at the present usage is $\frac{2.453\,x\,10^{15}}{2.843\,x\,10^{13}} = 86\ years!!$ Big reasons to worry, as if we increase more, this time of doubling will be reduced and Greenhouse gas effects (global warming, snowstorms, ice-age?) can initiate towards a severe climate change. So energy usage by humans can significantly alter the composition of atmosphere within a very short period of time!

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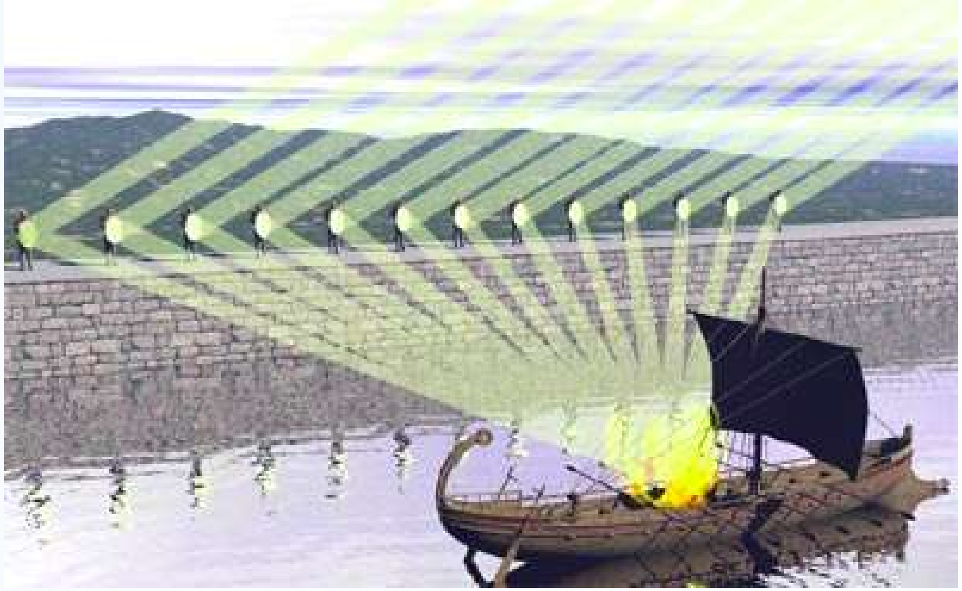
Renewable energy sources: Sun

- **Solar, Geothermal, Hydropower, Wind, Ocean Energy …**
- **Solar power were used since the day of Archimedes ➔Greeks knew that mirrors can concentrate sunlight & used in the defence at Syracuse (214-212 BC).**



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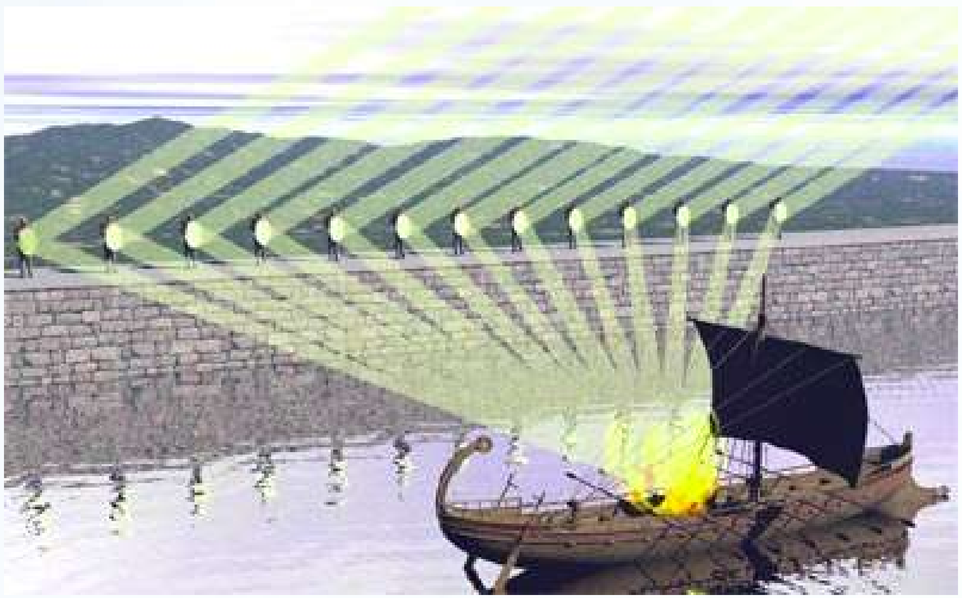
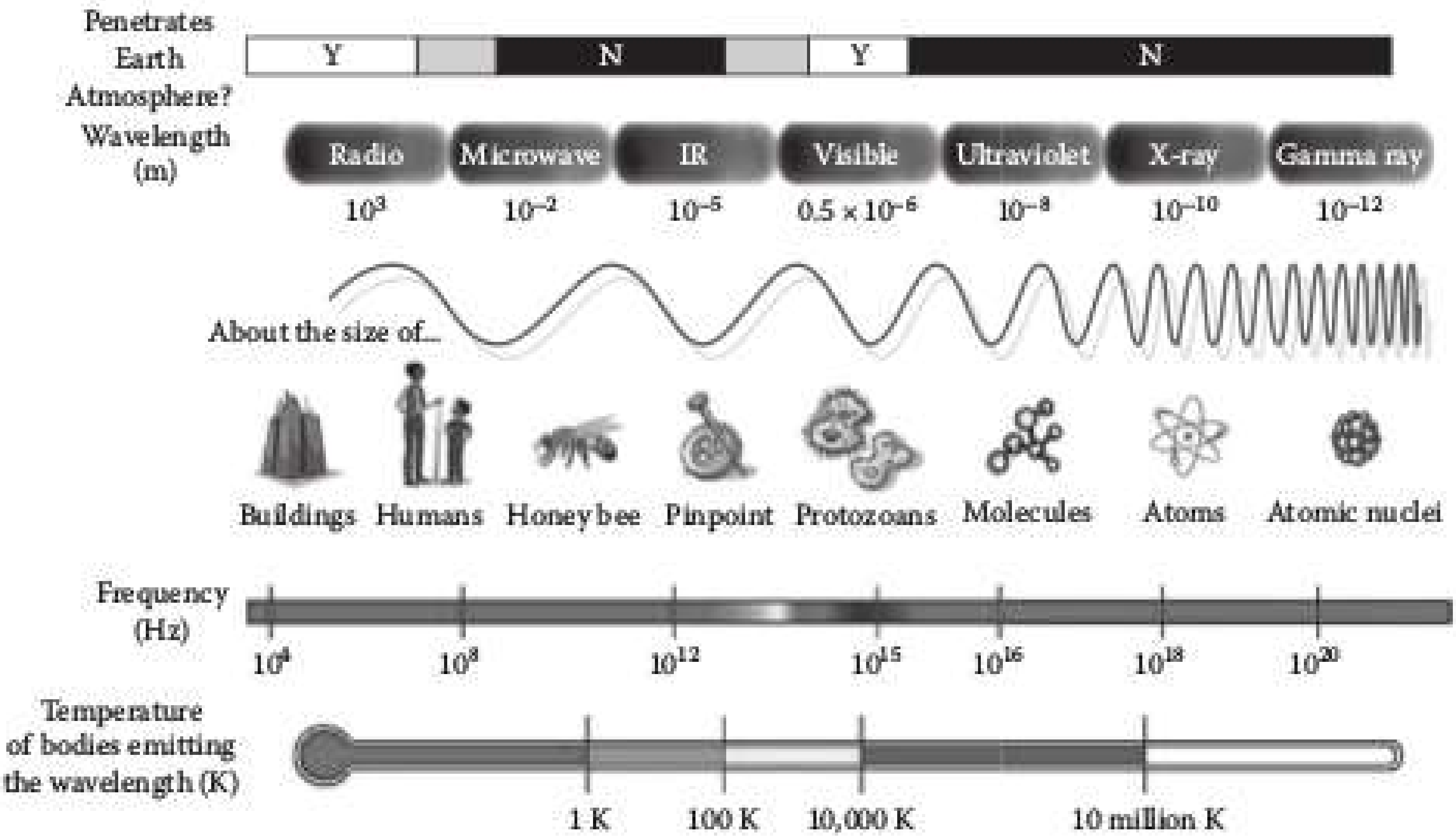



- **Sun's energy radiates in all directions & during spreading it weakens. But even after crossing the Ether (void) between Sun & Earth, a flat plate placed above the atmosphere and oriented perpendicular to the rays would receive Sun's EM energy at a rate ~ $1368\ Watts/meter^2$. This is called *Solar Constant*.**

Blackbody Spectra

- Blackbody spectrum is emitted by a body that is a perfect absorber of light at all wavelengths. Blackbody emits light only from thermal processes & neither reflects/ emits light.



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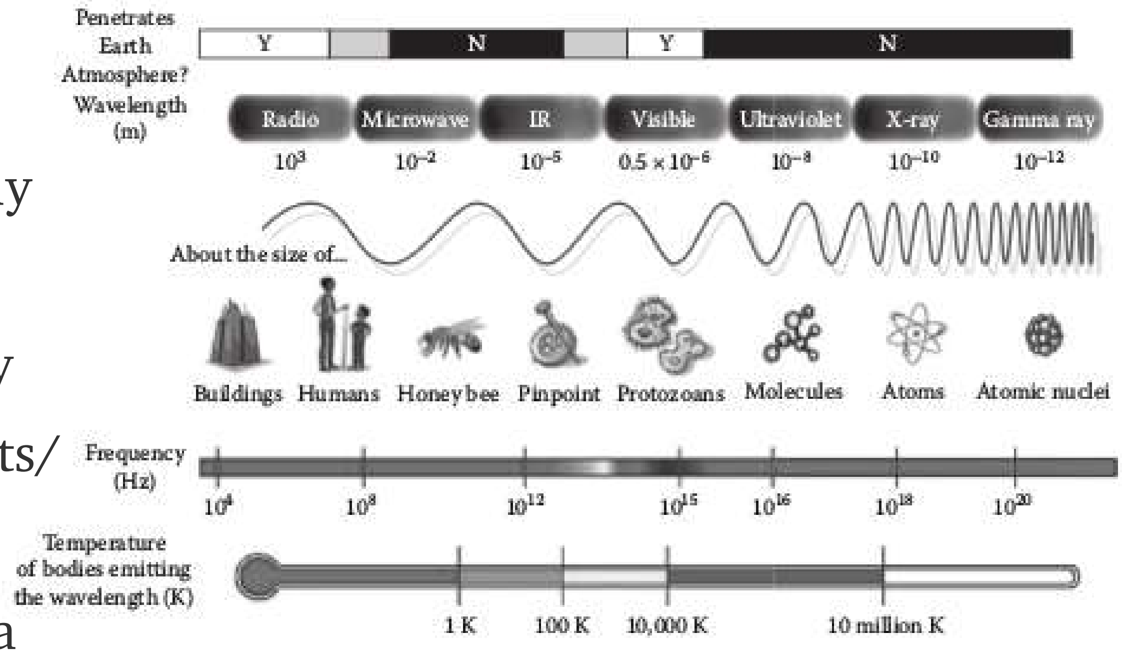

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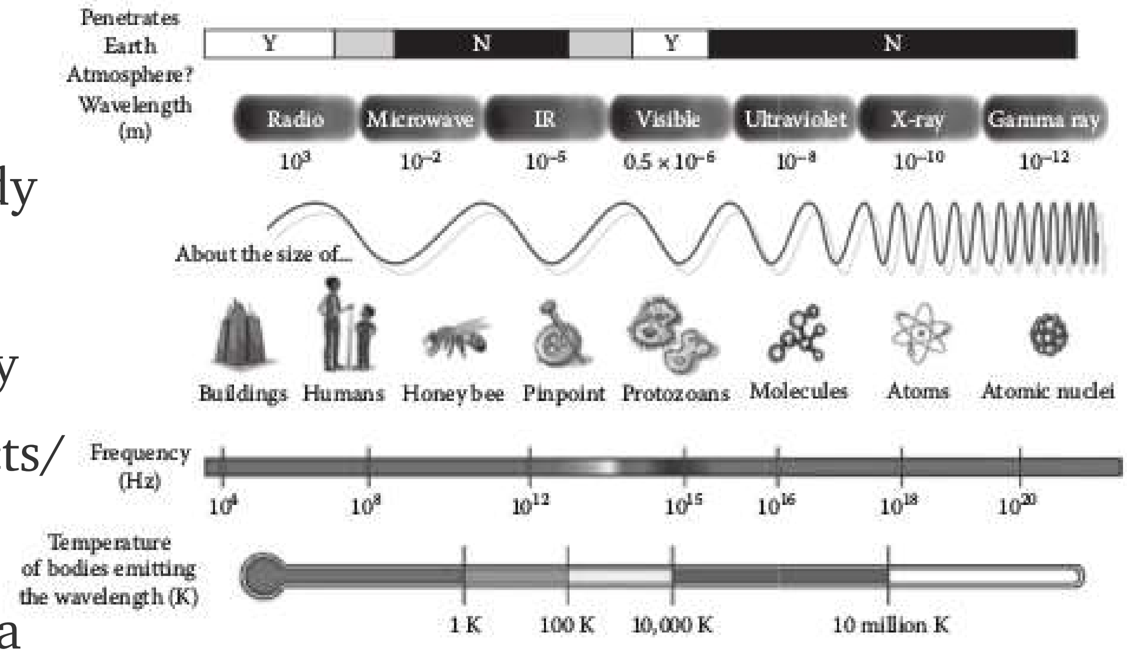

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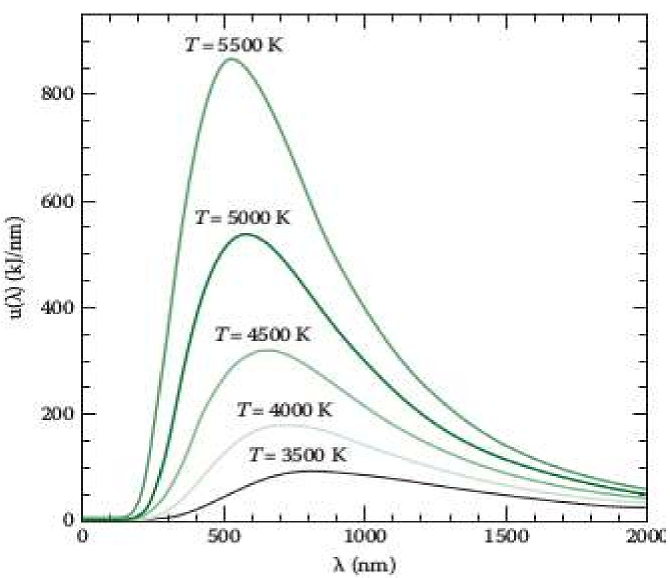

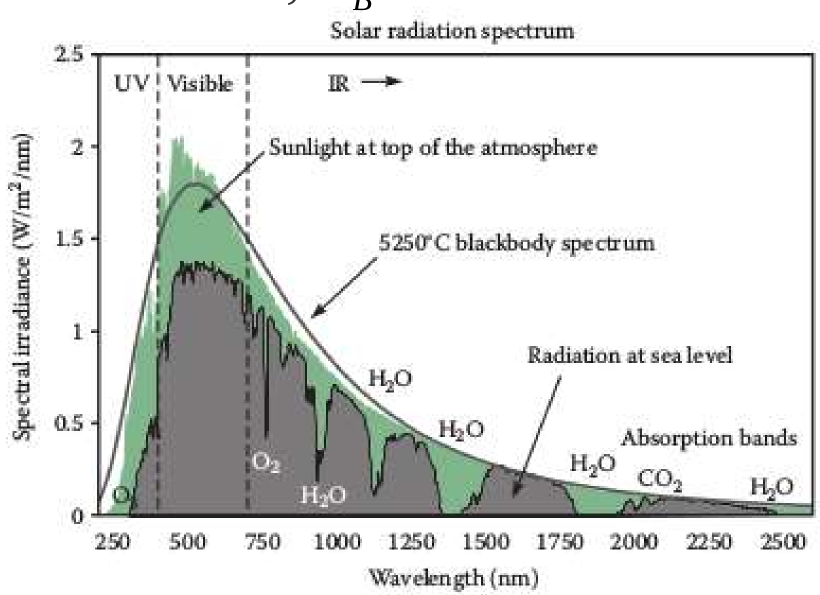

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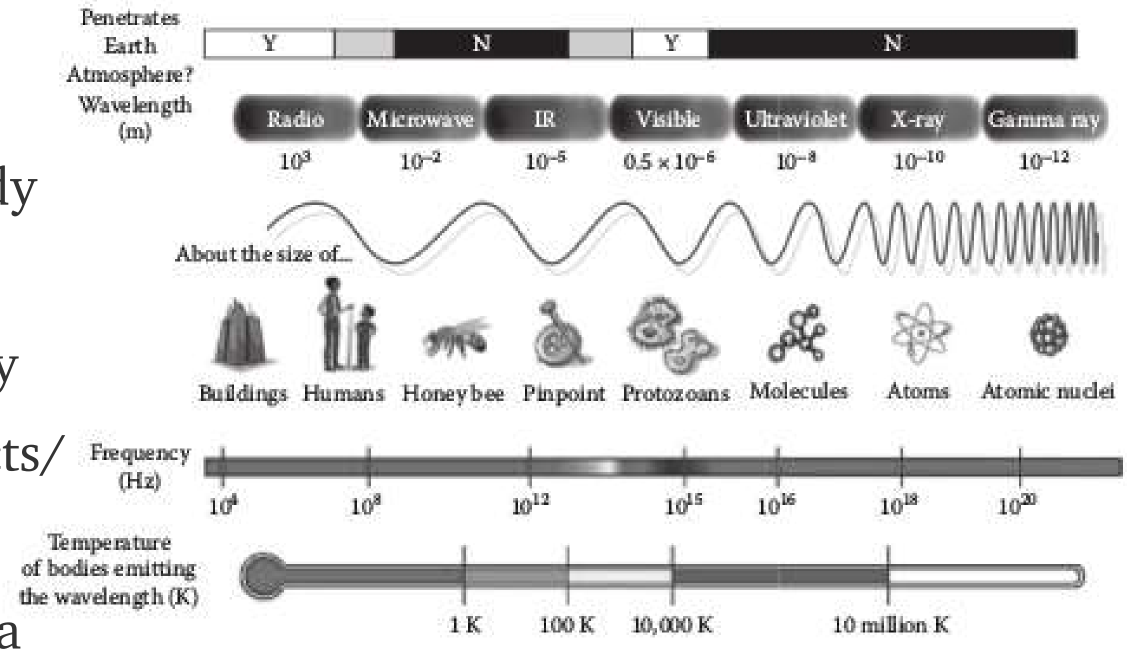

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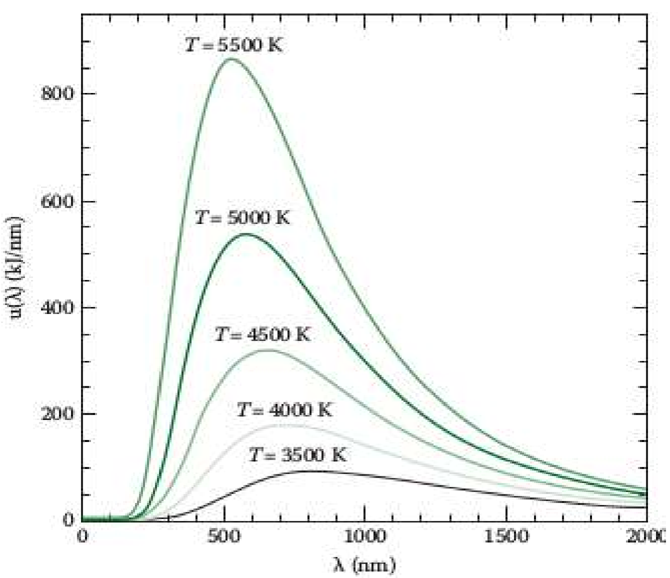

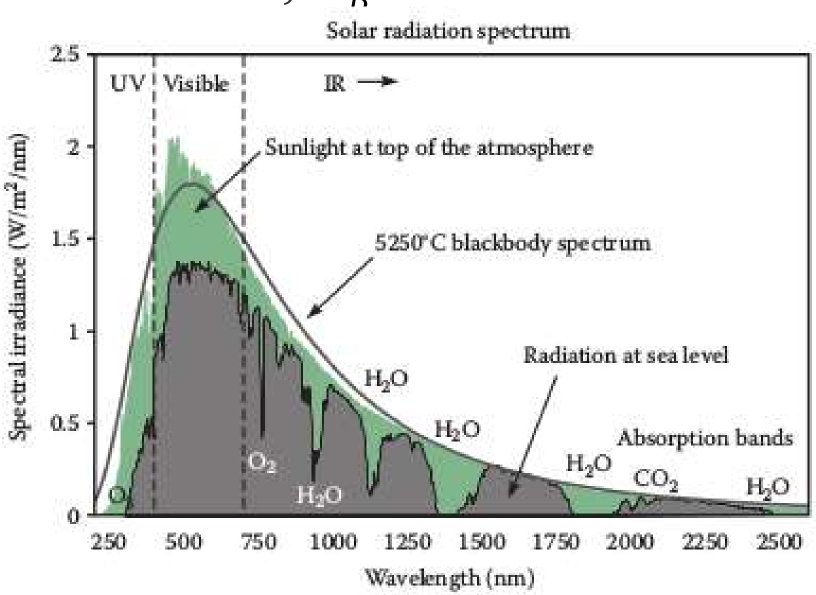

➲ peak of the spectrum shifts toward shorter λ, the hotter the emitting blackbody is.

- Wien's law $\lambda_{max} = \frac{0.002898}{T}\ mK$; $\lambda_{max}^{Sun} = 4900 \times 10^{-8}\ cm$, so $T^{Sun}(\text{Photosphere}) = \mathbf{5902\ K}$

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Solar Constant & Irradiance

- Solar Constant represents raw material with which solar engineers work. Solar cells convert solar energy into electrical energy. Consequently, output from photovoltaic cells cannot be greater than the input received from Sun. So no solar energy device located on Earth or in Earth Orbit can provide more than $1368\, Watts/meter^2$.

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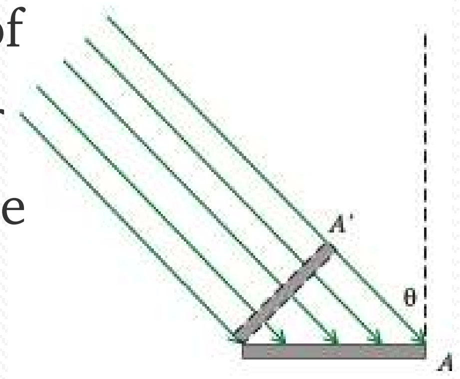
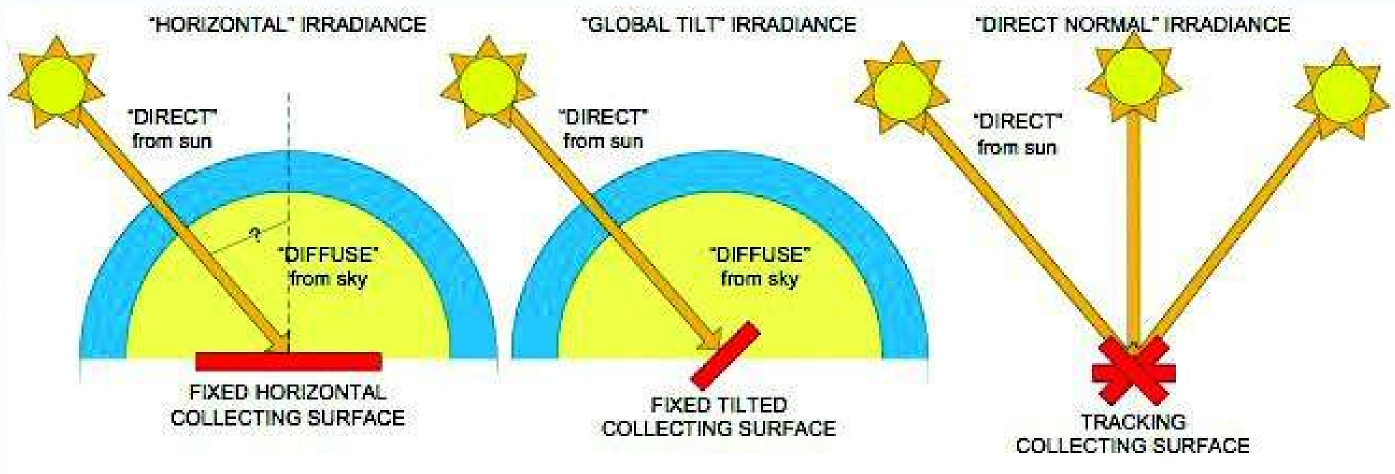
- Amount of solar power per unit area of the Earth's surface is known as Solar Irradiance & it varies both spatiotemporally. Irradiance depends on the angle of Sun relative to the plane of the surface on which the incident power falls. Direct portion of the irradiance depends on the angle θ that the Sunrays make with the normal to the surface according to the relationship



$$\mathbf{G_s = G^* \cos\theta;\quad G^*(\text{direct normal irradiance}) = 865\, W/m^2}.$$

Average Daily Solar Radiation

- Direct Normal Irradiance (DNI) is the amount of solar radiation received per unit area by a surface that is always held perpendicular to the rays that come in a straight line from the direction of the sun at its current position in the sky. Global Horizontal Irradiance (GHI) is the total amount of shortwave radiation received from above by a surface horizontal to the ground.



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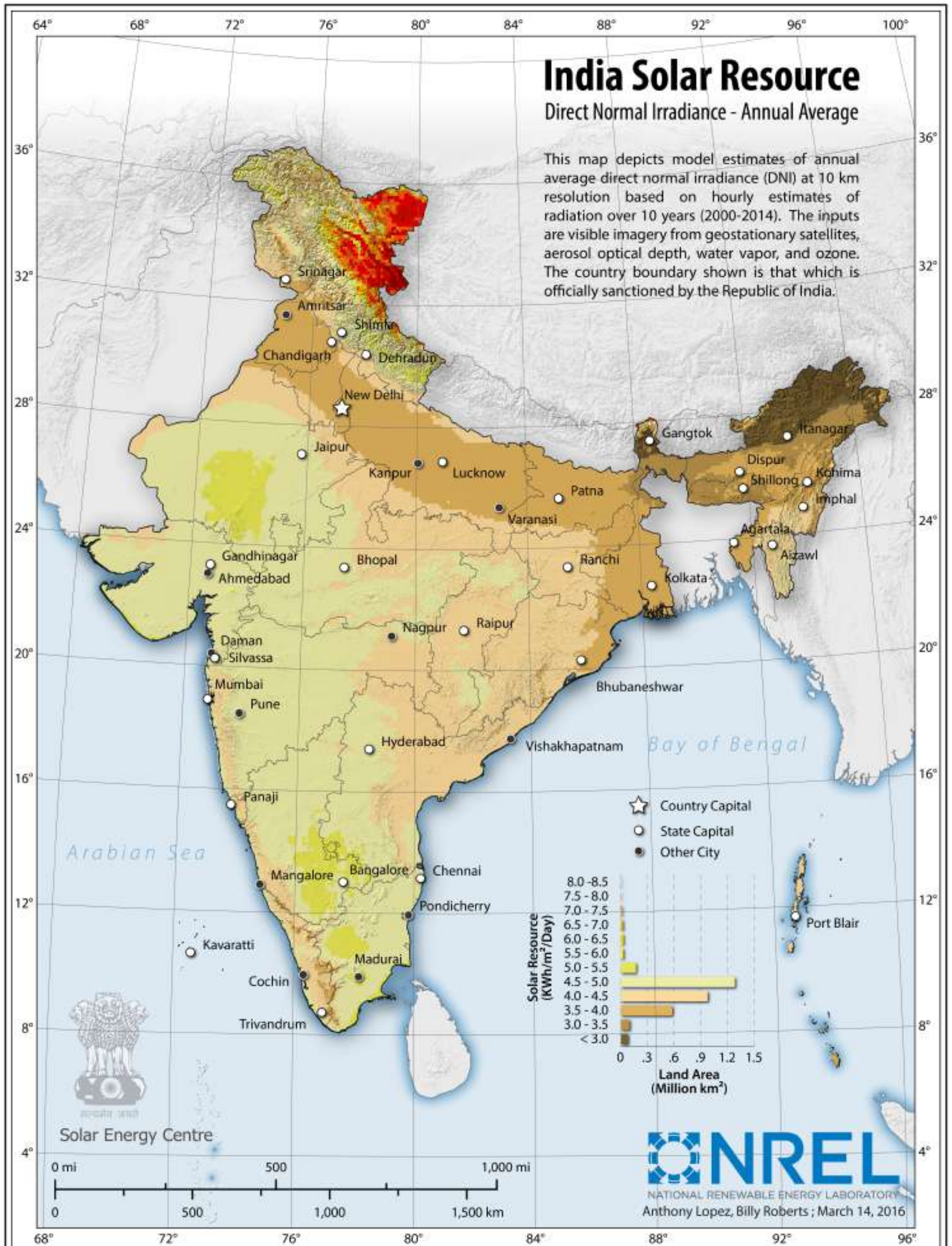

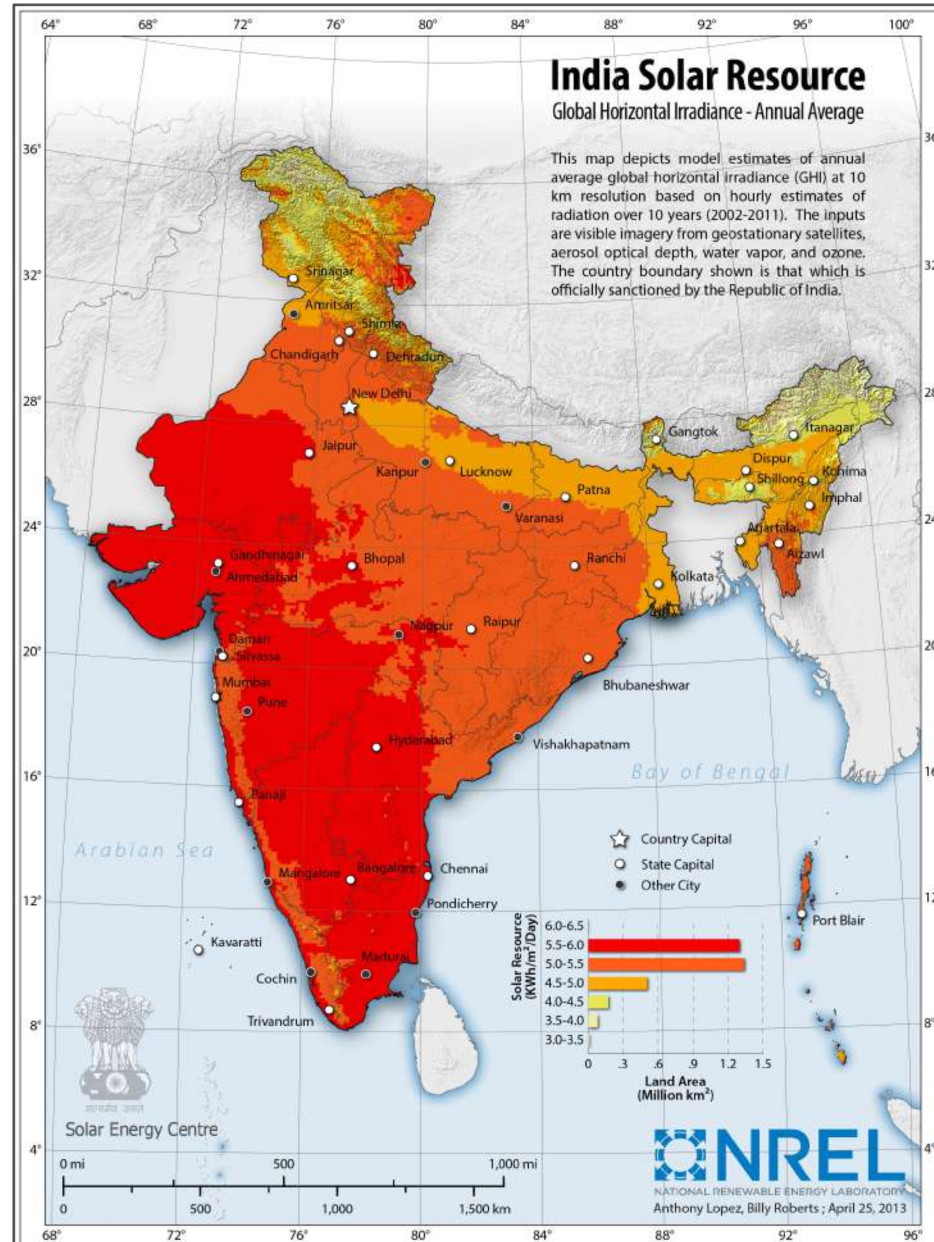

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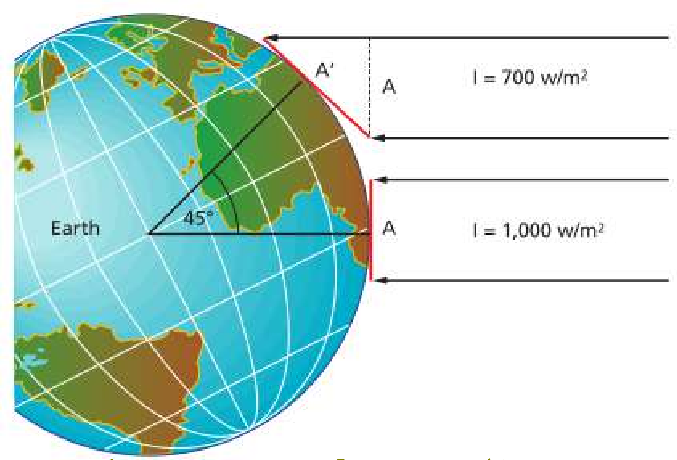
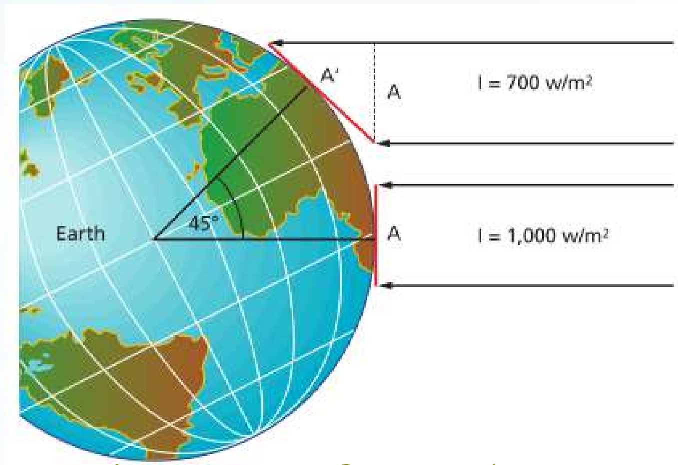
Sunlight & Geometry

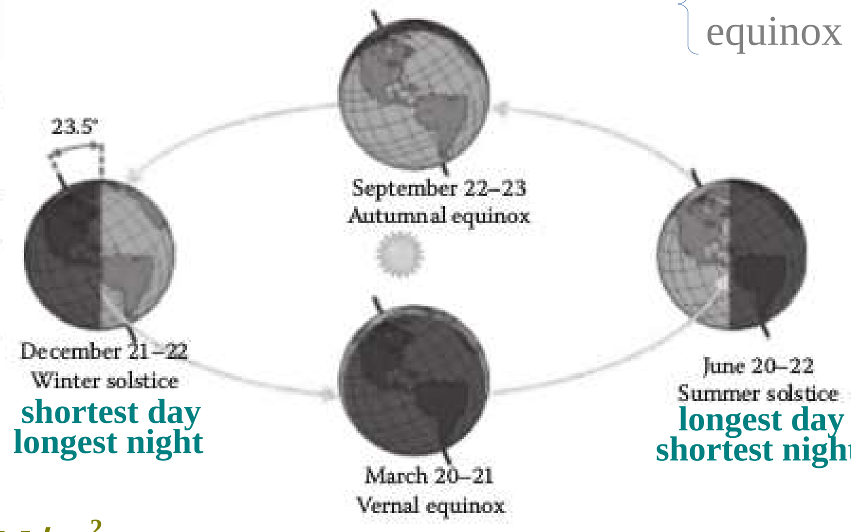


$$G_s = G^* \cos\theta \;=\; 10^3 x \cos\left(\frac{\pi}{4}\right) \;\sim\; 700\, W/m^2.$$

Sunlight & Geometry

solstice = sun stands still
equinox = equal night





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- During Earth's orbit around the sun, the axis of the Earth's spin makes an angle of 23.45° with respect to the normal of its orbital plane, pointing towards the North Star. There are two equinoxes and the two solstices in a year – during the spring and fall equinoxes, the Earth's axis is tilted neither toward, nor away from Sun & as a consequence, there are very nearly 12hr of daylight during a 24hr rotation.

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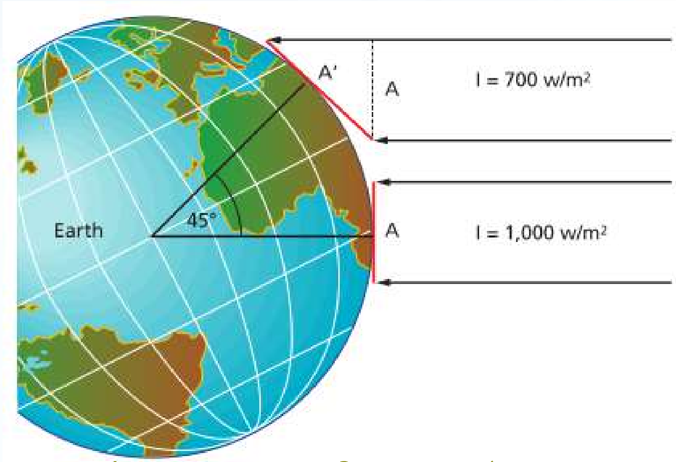

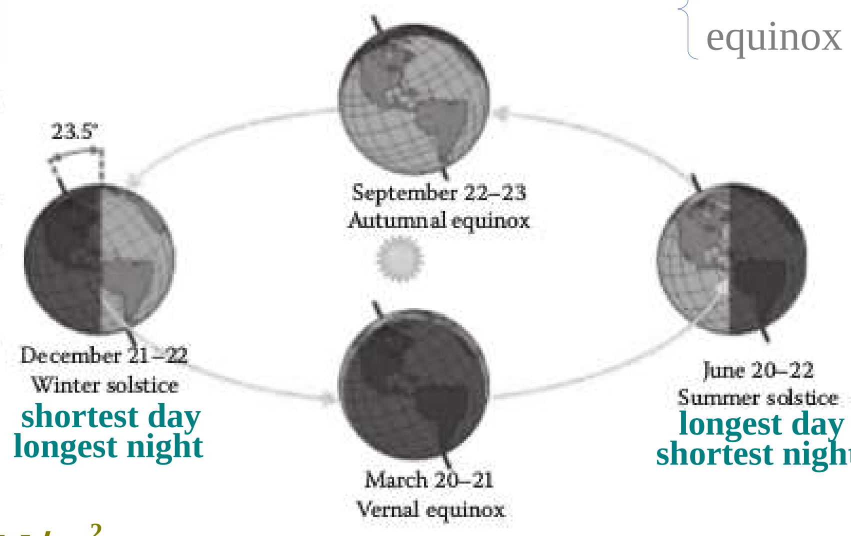

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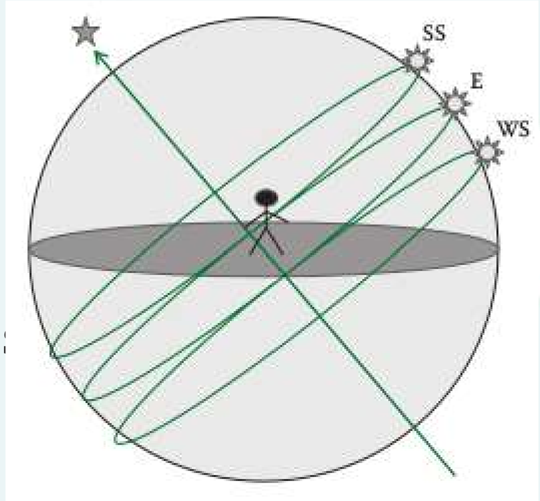
Solar Declination

SS = Summer Solstice
E = Vernal & Autumnal equinox
WS = Winter Solstice



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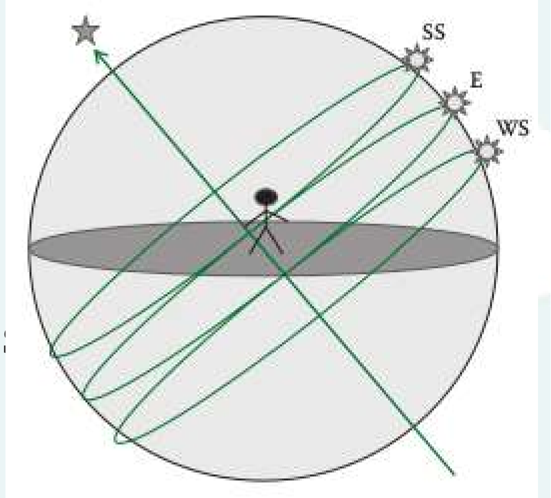

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$$\delta = \delta_0 \sin\left[\frac{360(284+n)}{365}\right].$$

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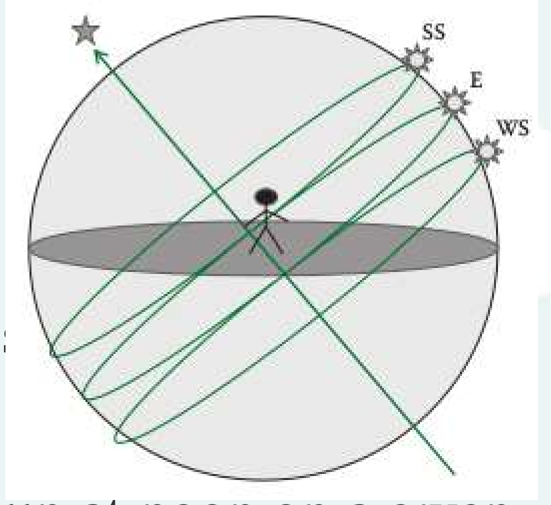

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- **Example : Find the Solar declination on October 4 at Asutosh College.**

➔ October 4 is the 277th day of the year; thus from above equation with n = 277 yields, $\delta = -18°$. The negative declination means that the date is past the autumnal equinox.

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Solar Thermal Renewable energy

- Two primary ways of harvesting solar energy use either solar collectors that convert the incident solar radiation into heat or photovoltaic (PV) cells that convert incident solar radiation into electricity. While 600 MW electricity were generated using solar thermal worldwide (2009), additional 14,000 MW is targeted.

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- An object may lose heat by several different mechanisms in parallel, e.g., *conduction*, *convection*, and *radiation*, each of which has a *specific resistance*. When several parallel mechanisms are involved, the object's net resistance R is found by adding these separate resistances in parallel ➔ $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\ldots$ If an object loses heat that passes through several layers in sequence, their resistances must be added in series ➔ $R=R_1+R_2+R_3+\ldots$

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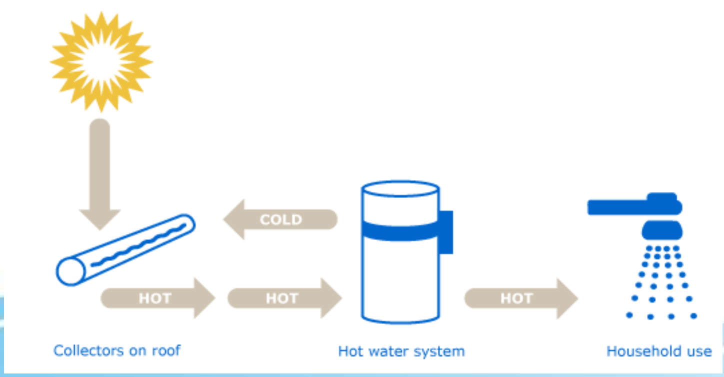
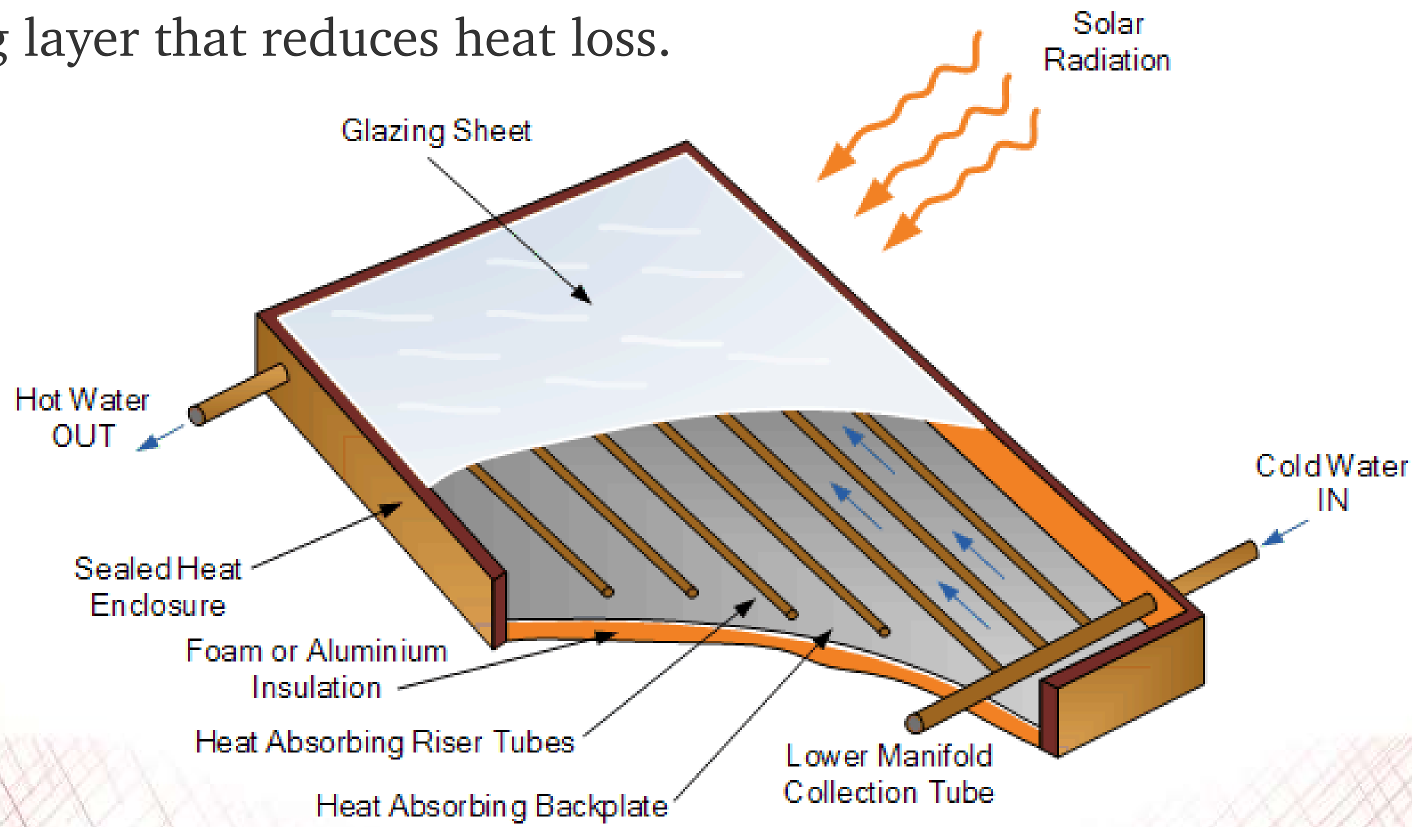
- Solar Collector ⇨ conversion of sunlight into heat for water heating using a solar thermal collector. 85% of Israel households use solar hot water heater (**SHW**) since '80s, that constitute 3% of Israel national energy consumption.



Solar Hot Water Heaters

- Flat-plate collector has solar-absorbing surface/plate which is covered by a sheet of glass that allows the incident *shortwave* solar radiation to easily enter. The cover traps also the *longwave* radiation emitted from the heated absorber using the greenhouse effect. The tubing carries a fluid [water + glycol (*antifreeze*)] is in thermal contact with dark-colored metal plate that absorbs the solar radiation. To cut down on thermal losses and achieve high efficiency, plate rests on a thick insulating layer that reduces heat loss.



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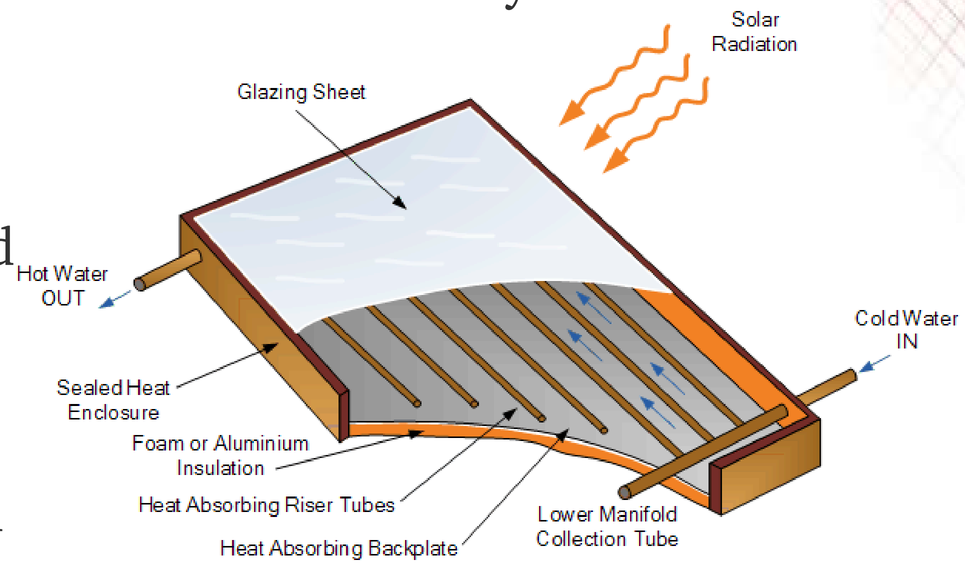
Solar Hot Water Heaters

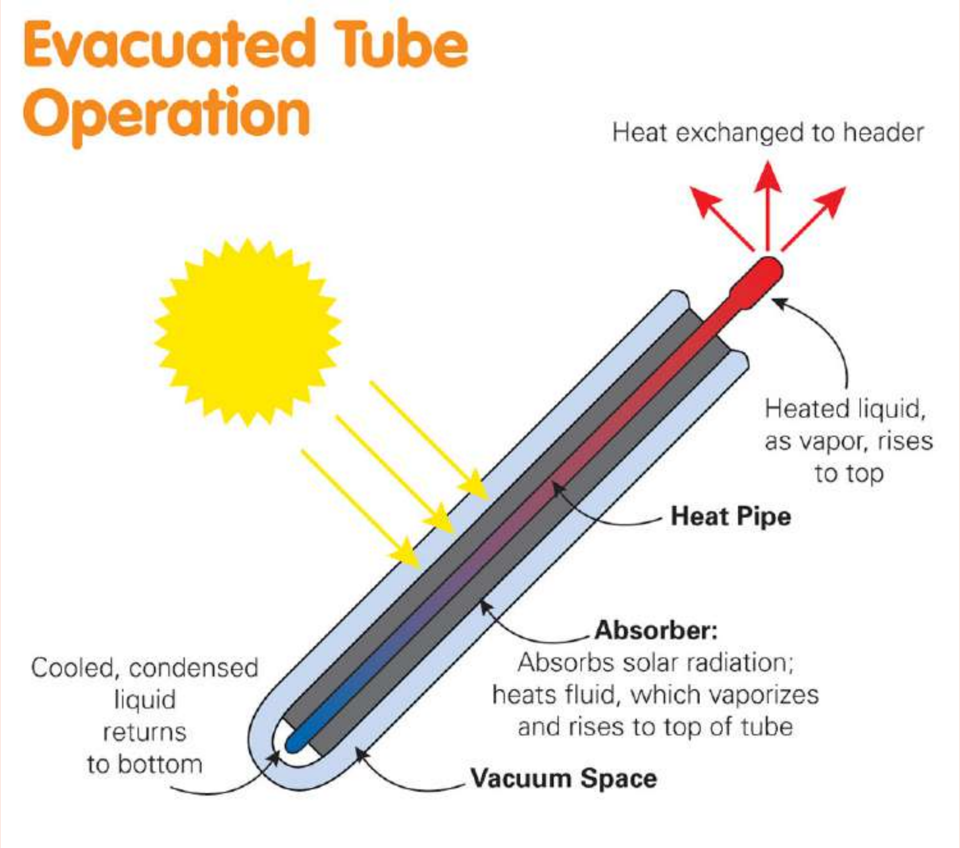
- Flat-plate collector has solar-absorbing surface/plate which is covered by a sheet of glass that allows the incident *shortwave* solar radiation to easily enter. The cover traps also the *longwave* radiation emitted from the heated absorber using the greenhouse effect. The tubing carries a fluid [water + glycol (*antifreeze*)] is in thermal contact with dark-colored metal plate that absorbs the solar radiation. To cut down on thermal losses and achieve high efficiency, plate rests on a thick insulating layer that reduces heat loss.



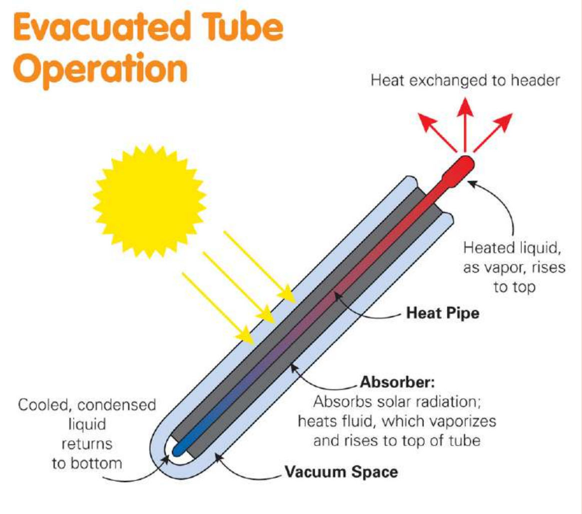
- *Antifreeze* flows in a closed loop & does not mix with the household water supply. Once the antifreeze has been heated, it flows through heat exchanger that permits the flow of heat out of antifreeze & into home's water supply. At the heat exchanger, temperature of the home-water increases and antifreeze decreases. Antifreeze is then pumped back to the collector to be reheated.

Solar Hot Water Heaters

- Evacuated collectors eliminates both conductive & convective heat losses above the heated collector plate. Evacuated collectors have a cylindrical geometry, which has greater structural strength. However, evacuated collectors of the flat plate variety can be problematic because their structural ability to withstand a vacuum is poor. Thus, evacuated flat-plate collectors tend to leak air over time.



Solar Hot Water Heaters



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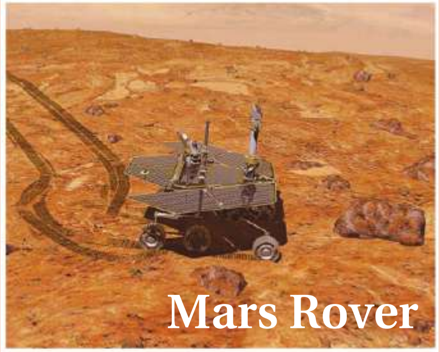
- **Photovoltaics (PV)** ➲ conversion of light into electricity using semiconducting materials that exhibit PV effect. PV is the 3rd renewable energy in terms of global capacity. In 2016, worldwide PV capacity ~ 300 Gigawatts, covering 2% of global electricity demand.

Solar cell

Charging Station, France

Juno on Jupiter



Mars Rover

AKB

অপ্রচলিত শক্তিতে চলবে মেশিন

18/03/2018, ABP

নিজস্ব সংবাদদাতা

১৮ মার্চ , ২০১৮, ০১:৫৮:৩২
শেষ আপডেট: ১৮ মার্চ , ২০১৮, ০১:৫৬:৪৯

আধুনিক: চায়ের দোকানে সৌর প্যানেল। শনিবার, ময়দানে। ছবি: সুমন বল্লভ

মেশিন চালাতে অপ্রচলিত শক্তির ব্যবহার শুরু করল কাশীপুর গান অ্যান্ড শেল ফ্যাক্টরি। শনিবার কারখানার পাঁচটি বাড়ির ছাদে সৌর প্যানেলের উদ্বোধন করেন কারখানার সিনিয়র জেনারেল ম্যানেজার রাজীব চক্রবর্তী। তিনি জানান, ১১৩০টি সৌর প্যানেল থেকে বছরে ৫ লক্ষ ৭৪ হাজার ইউনিট বিদ্যুৎ মিলবে। এতে বছরে প্রায় ৪৭ লক্ষ টাকা বাঁচবে।

কারখানা সূত্রের খবর, ইতিমধ্যেই কারখানায় সৌরশক্তিচালিত এলইডি বাল্ব ও টিউব ব্যবহার করা হচ্ছে। চলতি মাসের শেষে সব আলোই এলইডি-তে রূপান্তরিত করা হবে। এর ফলেও কয়েক লক্ষ টাকা বাঁচবে।

এই অস্ত্র কারখানাটি দুশো বছরের পুরনো। ১৮০১ সালে ফরাসিদের কাছ থেকে কাশীপুর গ্রাম কিনে শুরু হয় কারখানা গড়ার কাজ। ১৮৩০ সালে ফোর্ট উইলিয়াম থেকে অস্ত্র কারখানা পুরোপুরি সরে আসে কাশীপুরে। নানা চড়াই-উতরাই বেয়ে ১৯০৫ সালে নাম হয় 'গান অ্যান্ড শেল ফ্যাক্টরি'।

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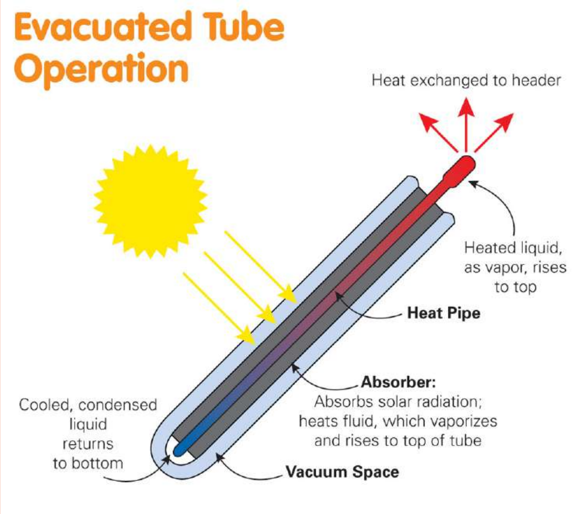
Solar Hot Water Heaters



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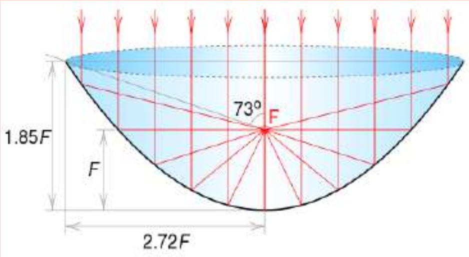

Solar Cookers

Solar cookers can avoid deforestation as well hazardous ways to gather firewood. Basic box-type cooker has insulated sides, transparent cover on top & can reach to baking temperature **65°C**. Complex concentrating versions using mirrors to reflect to attain grilling/searing temperatures **400°C**.

Solar Cookers

Heat convection is reduced by isolating the air inside the cooker from the air outside the cooker. Using a glass lid on the pot enhances light absorption from the top of the pan and provides a greenhouse effect that improves heat retention and minimizes convection loss.

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Solar Pond

- Solar pond is a large scale solar thermal collector with an integrated arrangement for storage of heated saltwater. Saltwater naturally forms a vertical salinity gradient in which low-salinity water floats on top of high-salinity water. Below a certain depth, the solution has a uniformly high-salt concentration.

Solar Pond

- When the sunrays contact the bottom of a shallow pool, they heat the water adjacent to the bottom. When water at the bottom of the pool is heated, it becomes less dense than the cooler water above it, and **convection** begins. Solar ponds heat water by impeding this convection.

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- Advantages/Disadvantages ➔ (i) Attractive for rural areas in developing countries as large-area collectors can be setup for low-cost of clay/plasticpond. (ii) Accumulated salt-crystals are removed & are valuable by-product.

Solar Pond

(iii) Extremely large thermal mass, means power is generated day & night.

(iv) Relatively low-temperature operation means solar energy conversion is typically less than **2%**.

(v) Due to evaporation, non-saline water is constantly required to maintain salinity gradients.

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- India was the first Asian country to have established a solar pond in **Bhuj (Gujarat)**. By supplying 80K Litres of hot water daily to the plant, it was designed to supply about 22M kWh of thermal energy/year.

Salt evaporation pond

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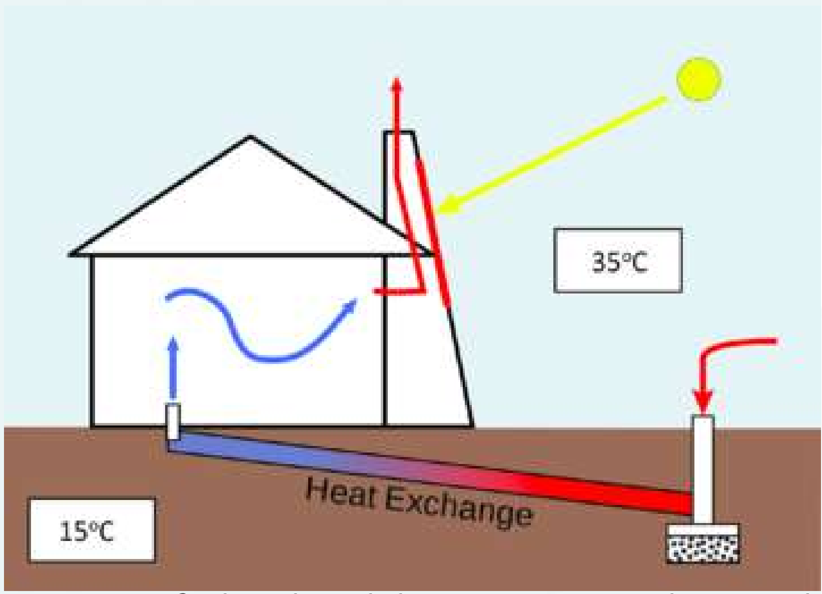
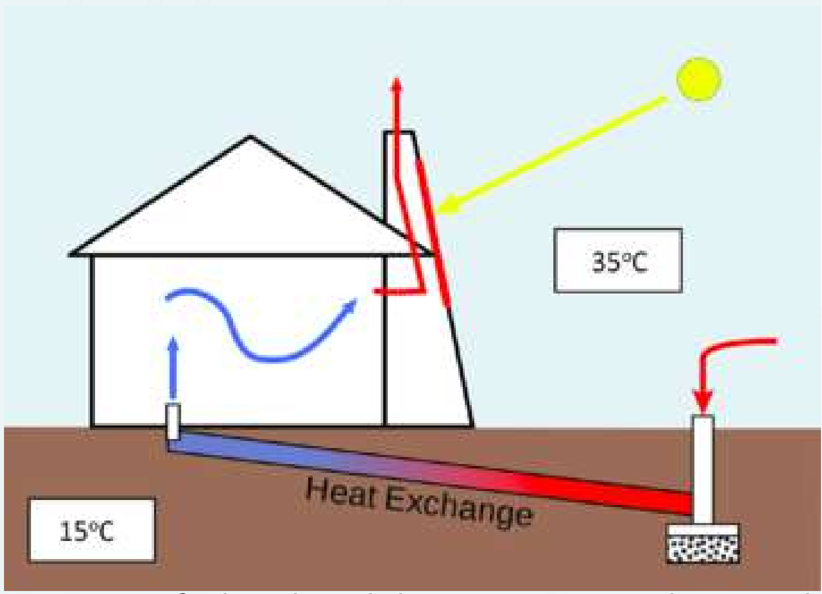
Solar Chimney

- Type of passive solar heating and cooling system used to regulate temperature of a building as well as providing ventilation to achieve energy efficient building design. Solar chimneys are hollow containers that connect the inside part to the outside part of the building. It is coloured **black** because this minimizes the amount of sunlight reflected off the chimney, absorbing more heat & transferring to the air inside the building. A secondary vent that travels below ground cools the intake air, when the chimney is used for cooling.



Solar Chimney



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Geothermal Energy

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Geothermal Energy

- During one-decade, renewable energy based applications in India have contributed **12.5%** in national electric installed capacity. Geothermal plants generate ~ 10000 MW power in 24 countries – such energy is being used for heating in ~ 78 countries (e.g. USA generates ~ 3086 MW of electricity).

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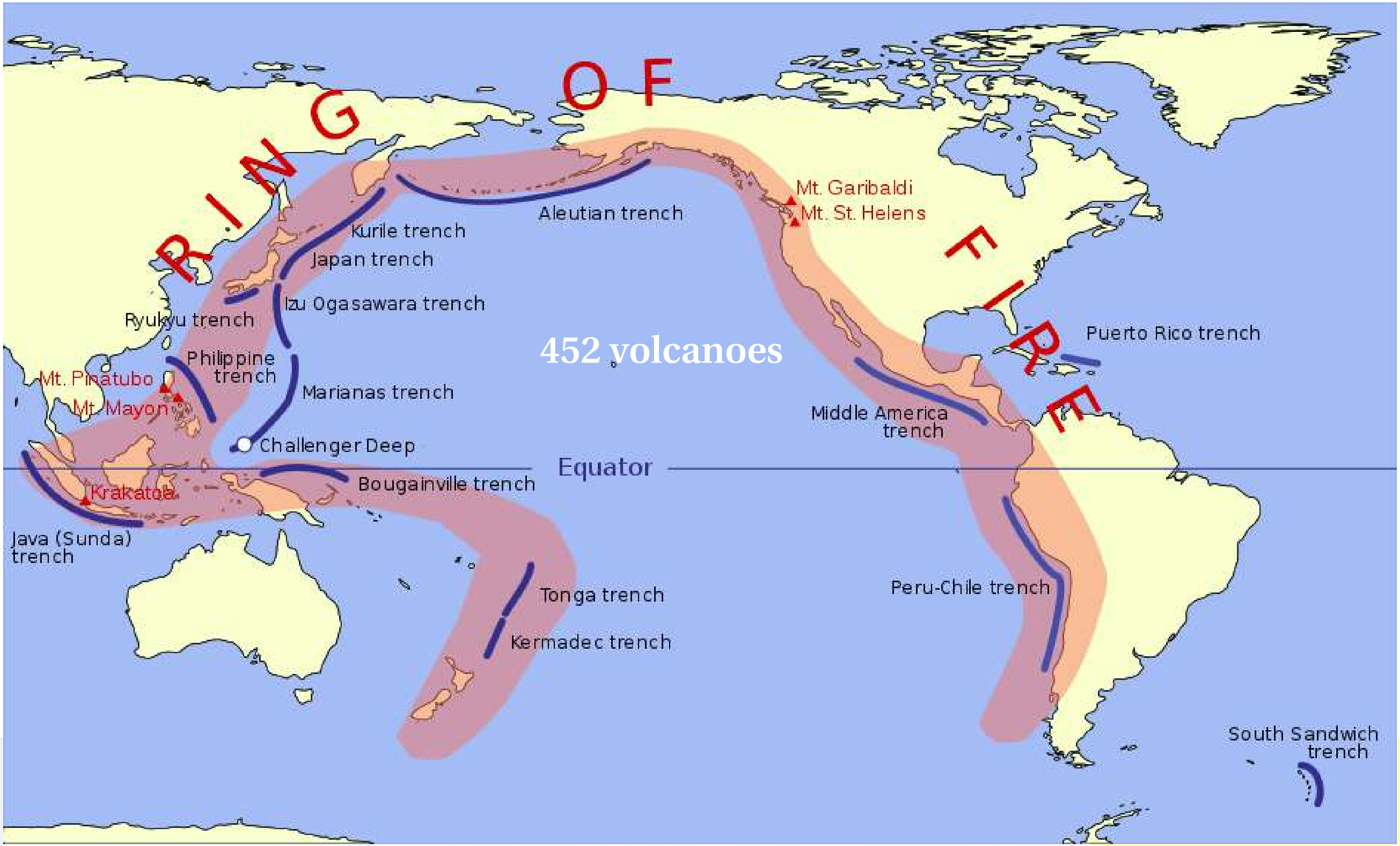
- Geothermal energy is the heat from the Earth. Resources range from the moderate temperature hot springs to hot/molten rock. Below Earth's crust, magma layer contain hot and molten rocks. Heat is continually produced by decaying of radioactive materials (Uranium & Potassium). Mantle is semi-molten with liquid outer-core & solid inner-core. *The amount of heat within 10000 meters of earth's surface is 50000 times more energy than all the oil and natural gas resources in the world.*

Volcanoes

- Map of Earth's volcanoes show that they are located along great arcs (horseshoe shape) – **Pacific Ring of Fire** encircling the Pacific Ocean.



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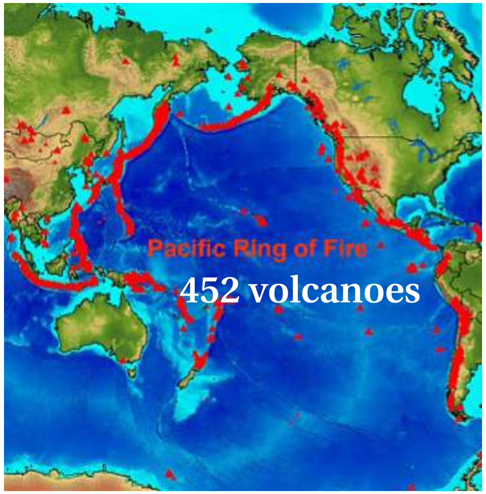
- Plate tectonics , Earth's crust (lithosphere) consists of ~ 12 distinct, irregularly-shaped, rigid *plates*. They slide over weaker & more plastic layer of rock (asthenosphere), scraping/colliding against each other. Collision forces lower plate to descend into asthenosphere to melt, causing the formation of volcanoes above the descending slab.



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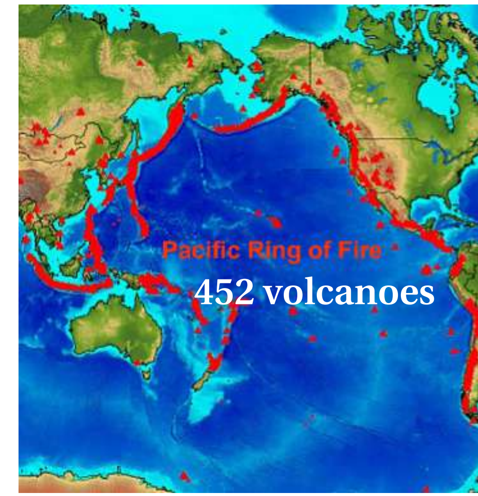

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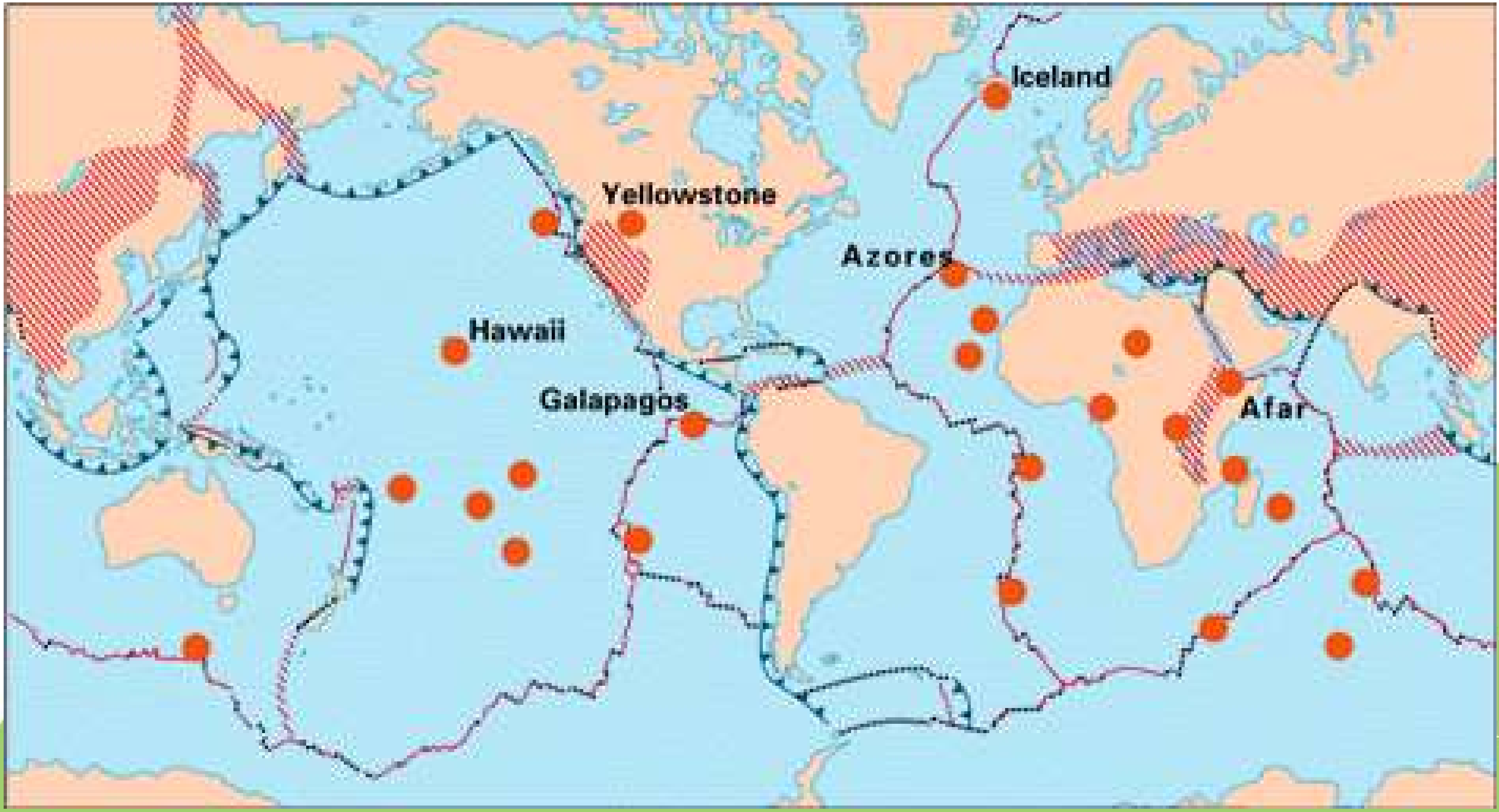
- In **mid-Atlantic Ridge** (e.g. Iceland), two adjacent plates move away & during separation, magma wells upward to fill the resulting rift in the surface. Geothermal energy are available along the boundaries, where plates are diverging.

Volcanoes

- Few volcanoes in Pacific Ocean are located above ***hot spots*** which is a fountain of lava derived from a source located deep within the Earth. The fountain bursts through the plate above it to form a volcano. Because the plate above the stationary hot spot is in continual motion, the volcano is active only when it is above the hot spot.



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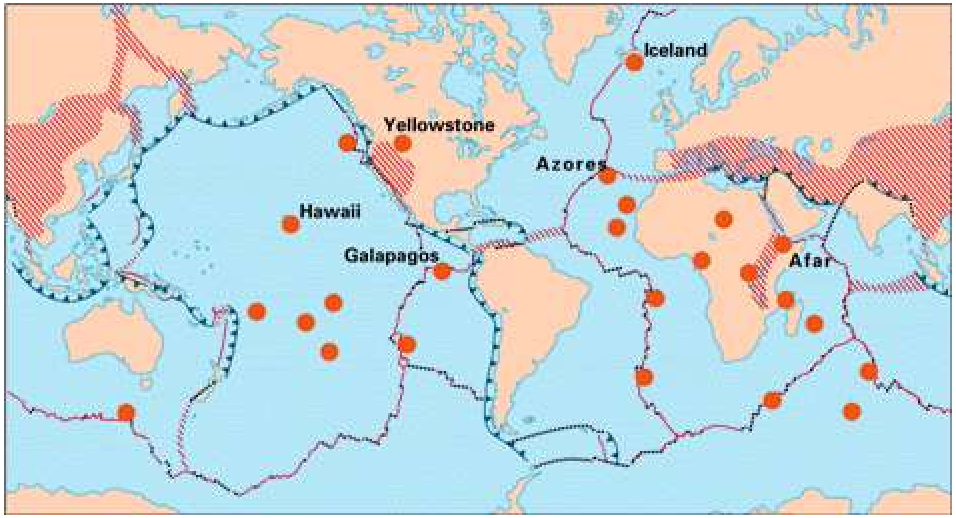

Mining Thermal Energy : Hydrothermal Convection

- Geothermal power stations are heat engines that are designed to use thermal energy within the Earth to turn a shaft connected to a generator to produce electricity. They don't generate their own heat, while Coal-fired power plant emissions have polluted lakes with mercury, formed acid rains, and greenhouse effect. After a deposit of thermal energy has been located at a depth that is accessible and affordable, *water* brings the thermal energy up to where it can be converted into electrical energy.

Mining Thermal Energy

- Sulfur dioxide is found deep below the surface & dissolves easily in water to form acid. Mining large volumes acidic water to dump on surface is environmentally fatal. So this wastewater is *recycled* by drilling a set of wells to inject used+supplemental water back to hot rock. As rock is permeable, injected water rapidly diffuses through the hot rock to reheat.

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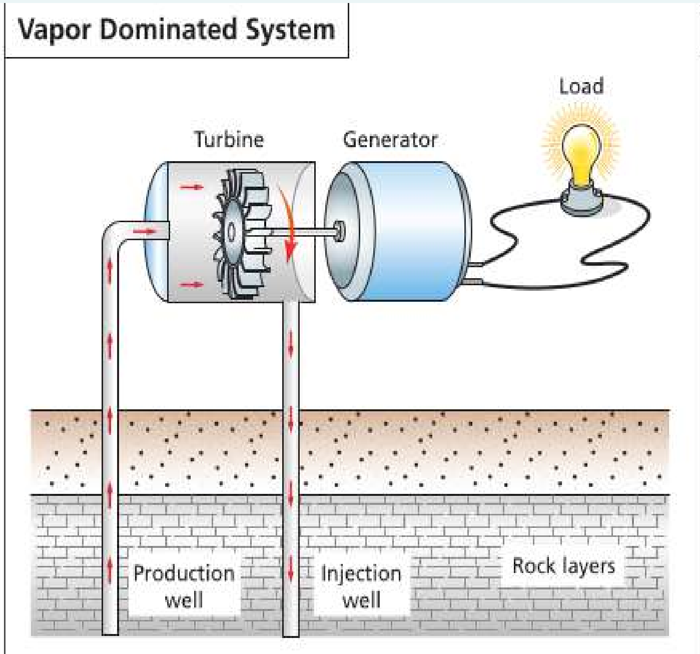

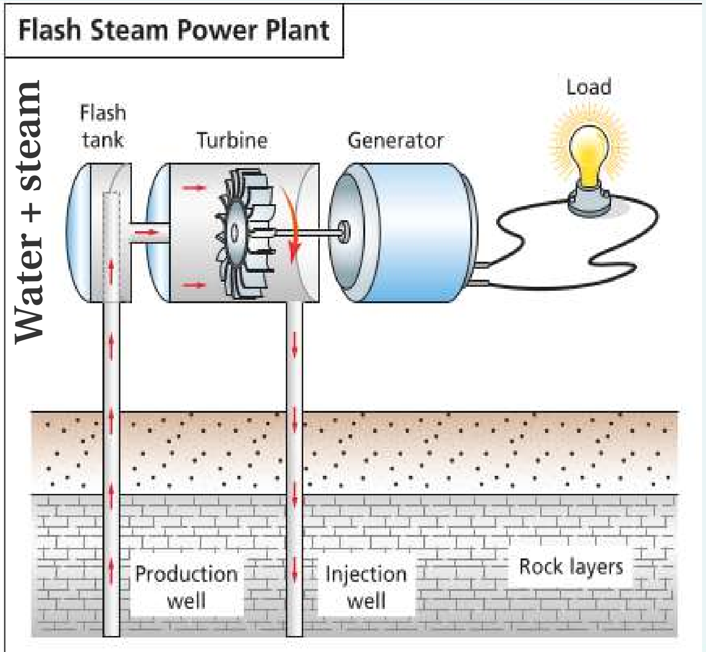

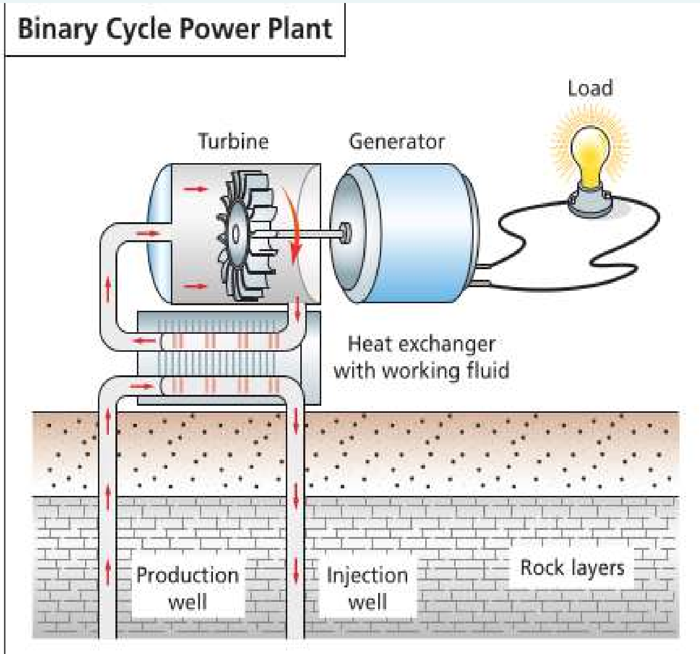

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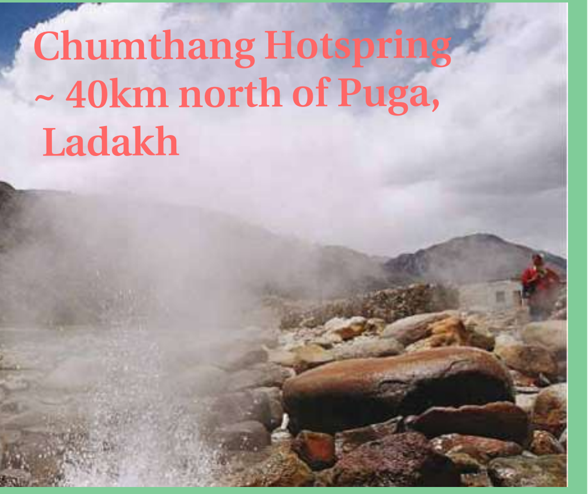
Geothermal Energy in India

- Though ecofriendly, disadvantages are: if harnessed incorrectly, geothermal energy can produce pollutants. Improper drilling into the Earth can release hazardous minerals and gases. It is also feared that the geothermal power plant sites may run out of steam in the long run.



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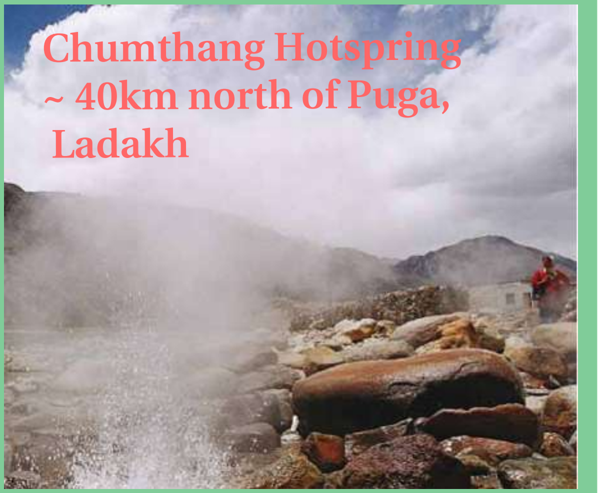

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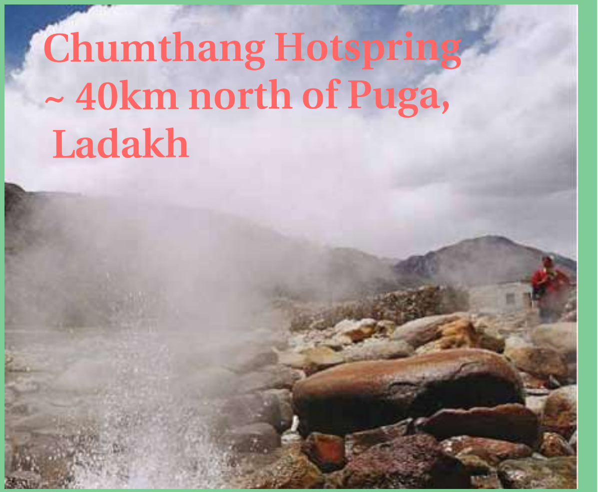

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- Springs are grouped into **7** geothermal provinces ➜ (i) Himalayan (Puga, Chumthang), (ii) Sahara Valley, (iii) Cambay Basin, (iv) Son-Narmada-Tapti (SONATA) belt, (v) West Coast, (vi) Godavari basin, and (vii) Mahanadi basin. Prominent geothermal resources include Manikaran (Himachal Pradesh), Jalgaon (Maharashtra) and Tapovan (Uttarakhand) with a new location at Tattapani (Chhattisgarh).

Geothermal Energy in India

- In **Puga** (180 km from Leh) at Himalayan range, hot spring temperatures are 30-84°C & discharge up to 300 liters/minute. 34 boreholes ranging in depths from 28.5-384.7 meters are drilled. Hottest thermal spring is at temperature 84°C and maximum discharge from a single spring is 5 liters/second. Chumthang spring is located at 40 km north of Puga. Thermal water is similar, except that its water has relatively higher pH and sulphate.

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- At **Tapovan** geothermal area, the highest temperature recorded is 65°C. Discharge is 0.83-9.2 litre/second. The surface manifestations show occurrence of white to dirty white deposits identified as silica and moderate to low sag activity. 60 thermal water springs occur at 18 localities in the West Coast hot spring belt with 1 project having capacity of 25MW. Himurja, Himachal Pradesh has selected resources in Beas valley, Parvati valley, Satluj valley and Spiti valley (Himachal Pradesh) for drilling up to 2 km.

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Hydroelectric Power

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Historical Development

- Conventional hydroelectric power technology relies on converting moving water energy into electricity. Waterwheels were used earlier for grilling crops, were used to harvest energy. By increasing water levels (thus force of water on blades), waterwheel efficiency (work per unit of water) could be increased.

Orontes, Syria

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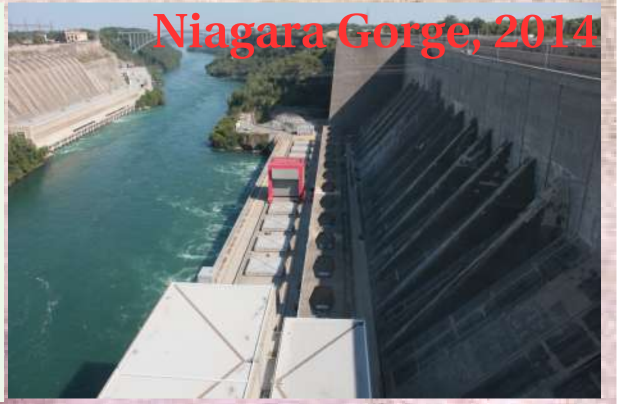
- It's technology is now outdated, but in 1920s, around 40% of national electricity needs were met via hydropower.



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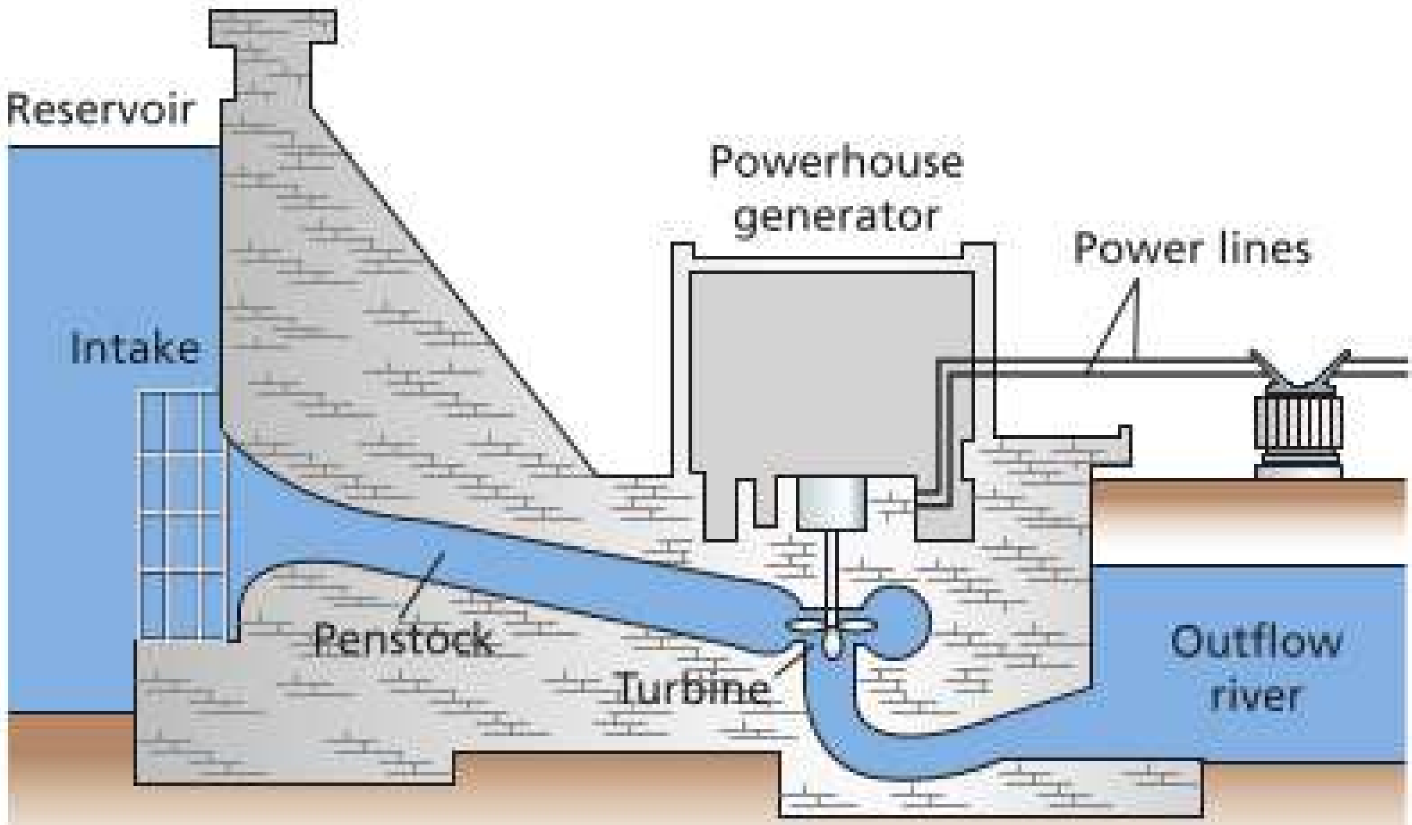
Hydroelectric Plant

- Purpose of hydroelectric plant is to convert power (energy per unit time) of flowing water (P) into electric power – **P = eqha**, q = volume of flowing water/unit time, h = height of the water column above turbine (hydraulic head), a = constant, e= efficiency. P (watts) = q (cubic meters/sec), h (meters), a (9800 Newtons/meter cubed).



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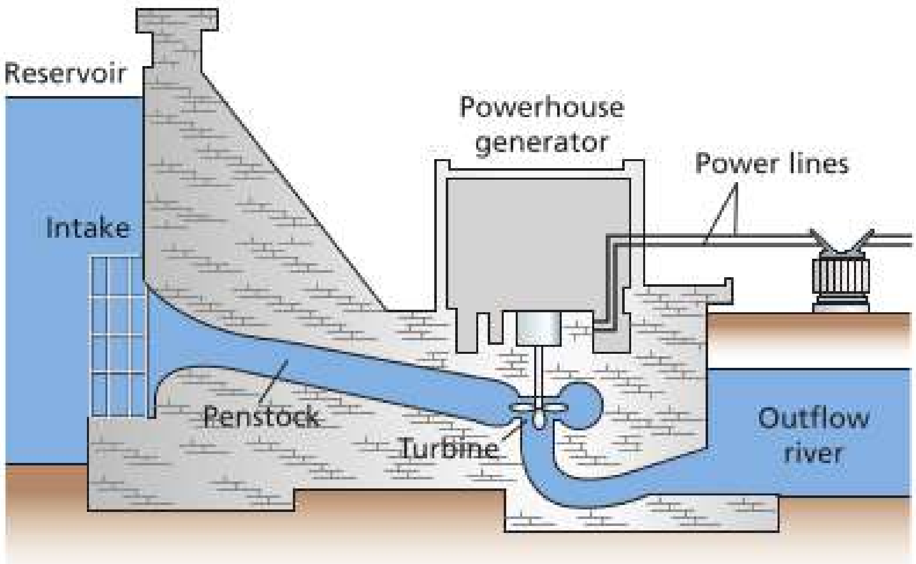


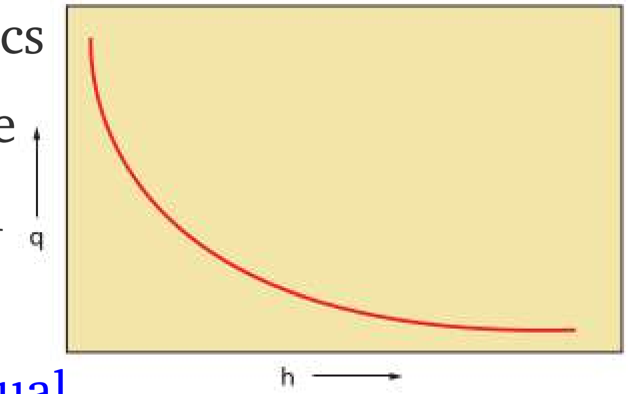
- Purpose of hydroelectric plant is to convert power (energy per unit time) of flowing water (P) into electric power – $P = eqha$, q = volume of flowing water/unit time, h = height of the water column above turbine (hydraulic head), a = constant, e= efficiency. P (watts) = q (cubic meters/sec), h (meters), a (9800 Newtons/meter cubed).

- Turbines are two types: (a) Waterwheel turbines – (i) Impulse turbines, (ii) Pelton turbines, (b) Reaction turbines. In Pelton turbines, pressure of head produces water stream out of a nozzle aimed to series of buckets arranged around the turbine wheel or runner. Reaction turbines are completely submerged in water & spins in reaction to changing pressure of water over its surface.

AKB

Hydroelecricity

- **Isoquant Curve** is the line of constant power. Characteristics of the curve do not depend on the value of a. Product of the coordinates of any point on a given isoquant equals a given power output equals the product of the coordinates of any other point on the same isoquant. All other things being equal, taller dams are more efficient than shorter ones because they generate more power per unit of water.



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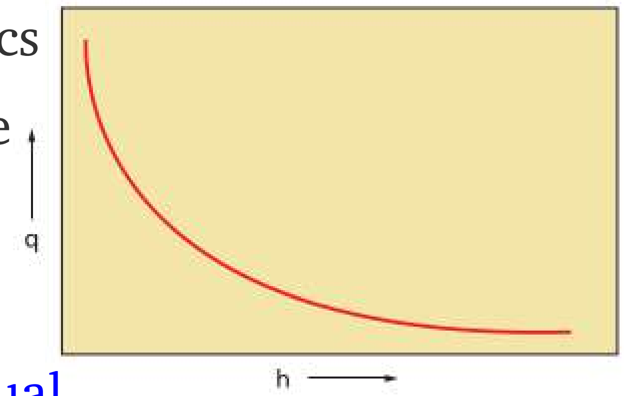

- **Base and Peak Load** ➡ Electricity demand fluctuates unpredictably with weather. Assuming fluctuations to a minimum that also sets a base for power-requirement, electricity required to meet the sum of these minimum power demands is called the **base load**. Base load power plants shut down only for maintenance & repairs. Electricity produced to meet demand fluctuation above the base load requirement is the **peak load** power. Gas-fired & oil-fired power plants are more reliable peak load power producers, but being expensive & longer initiation time, hydroelectric is faster.

AKB

Wave & Tidal Power

Cornwall, UK

Pelamis, UK

AKB

Wave Power

- Waves are powerful and destructive. Though a machine designed to convert wave to electrical energy in principle is promising, central problem is (a) wave power occurs in surges, and (b) the wave environment is a destructive one.

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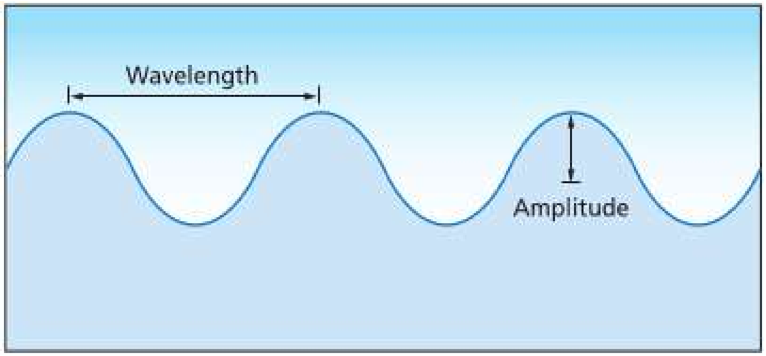

- Wave is a disturbance due to wind in the ocean's surface. The disturbance moves forward rather than water (which oscillates). Classification of waves ➔ (i) amplitude ➔ $\frac{1}{2}$ of the vertical distance from peak to trough, (ii) wavelength λ ➔ distance in consecutive peak, (iii) wave period T ➔ elapsed time between passing of wave crests. In deep sea, wave speed $v=\lambda/T$.

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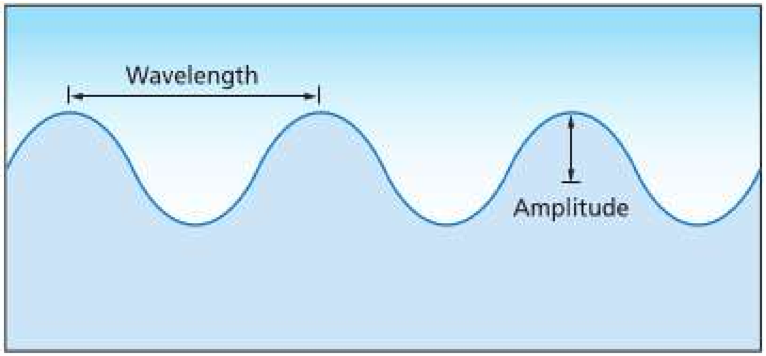

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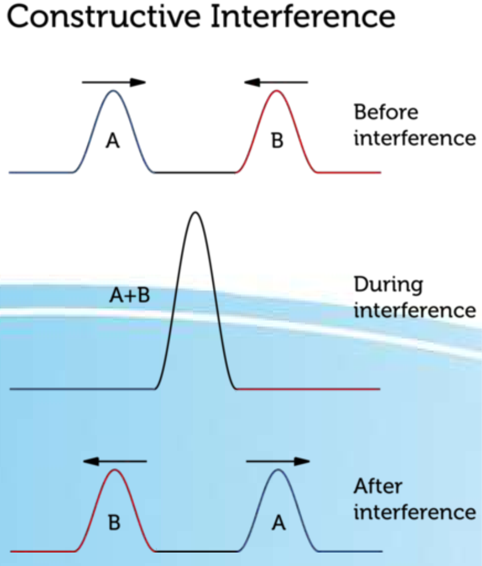

- **Wave Interference** ➲ Waves travel at different speeds. A slow & fast wave can collide & briefly form a wave with bigger amplitude & separate in time. Their characteristics - amplitude, wavelength, period will be same after the encounter as they were before.

AKB

Sea Snakes

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  Pelamis is a ***snake*** that swims across sea surface.

  It is so tethered to swing perpendicular to waves.

  Force exerted by the water against the body (buoyancy force) varies spatially.

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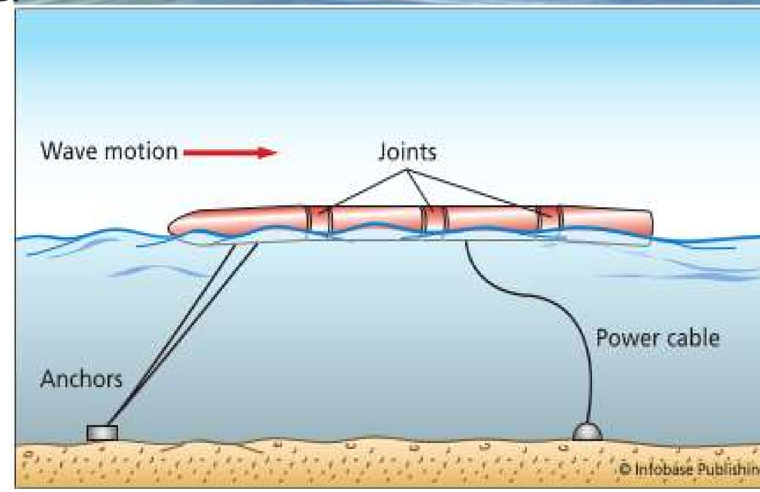

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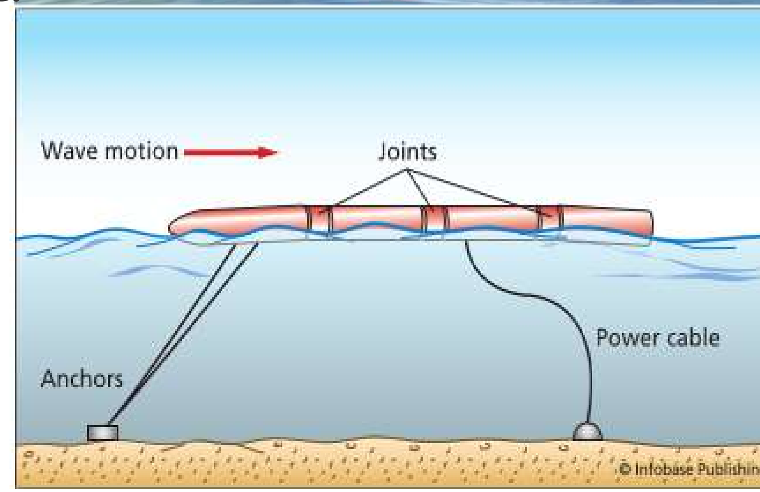

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Pelamis Wave energy converter

- Advantages/Disadvantages

(i) Produce power with zero emissions,

(ii) low visual profile compared to visually intrusive windmills,

(iii) Water-waves are more predictable than wind – so in principle, Pelamis wave farms could produce large amounts of power while occupying a small area of Earth's surface than wind farms with similar outputs.

(iv) Power from Pelamis unit costs ~ **2** x power generated by wind turbines.

(v) Each snake has a power output of **750 kW**, but unlike conventional energy resources, variable amount of power is produced by each unit beyond the control of the operator.

(vi) By design, Pelamis is shut down during periods of ***intense*** wave activity to prevent damage. This increases its unreliability as a source of energy.

Oscillating water Column (OWC) Energy Converter

- Limpet at the coast of Scotland in 2000 was the first device to provide electricity to the grid using OWC technology.
- **Working Principle** ⮊ Pushing on the handle of bicyle pump drives the piston downward through the cylinder. The piston pushes the air to rush out of the hose at the bottom of the cylinder. The cross-sectional area of the hose is smaller than the surface area of the piston & so the speed of air flowing out is greater than the speed of the piston.

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$$S_p A_p = S_h A_h$$

where S_p & A_p represent speed & area of piston & S_h & A_h represent speed of the air in the hose & cross-sectional area of the hose. If A_h <<, then S_h >>. Given $S_p A_p$, to force the air to rush quickly out of hose, one need small cross-section hose.

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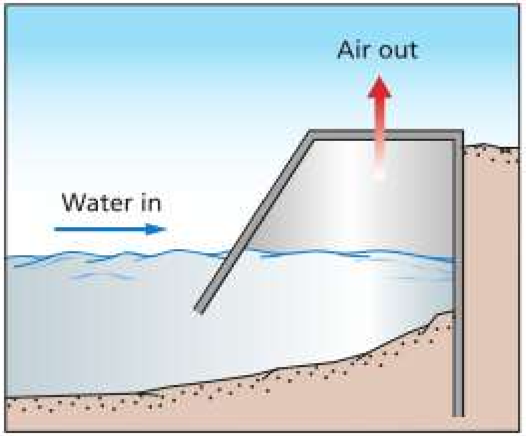
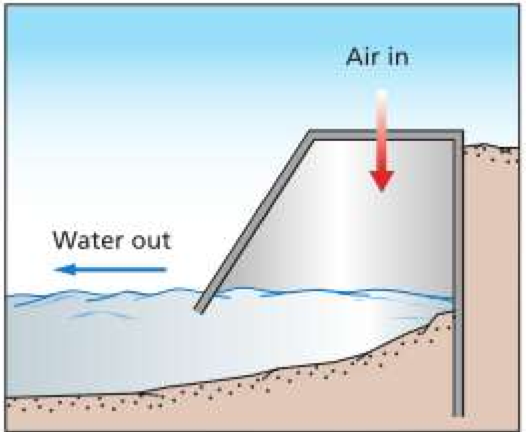
AKB

Oscillating water Column (OWC) Energy Converter





- **OWC technology works on same principle as the pump.** **A large box with two openings is built in an area of strong wave action. A small hole lies atop the box & another hole is left open at the bottom of the box for water to flow in-out. Walls extend down below the waterline, so that the ocean forms an airtight seal at the base of the box.**

AKB

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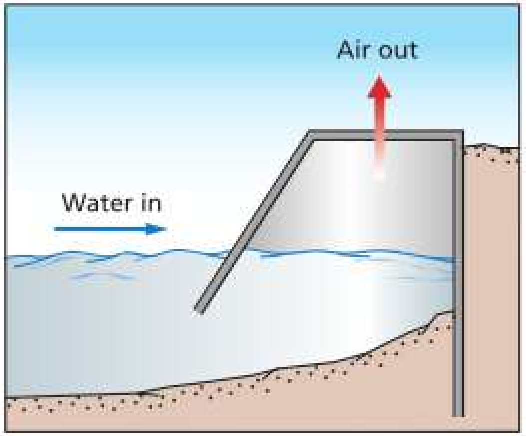

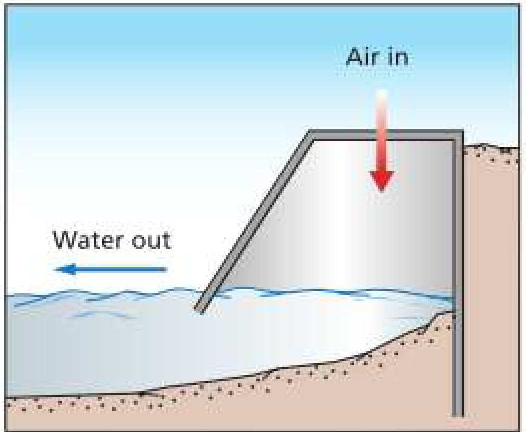

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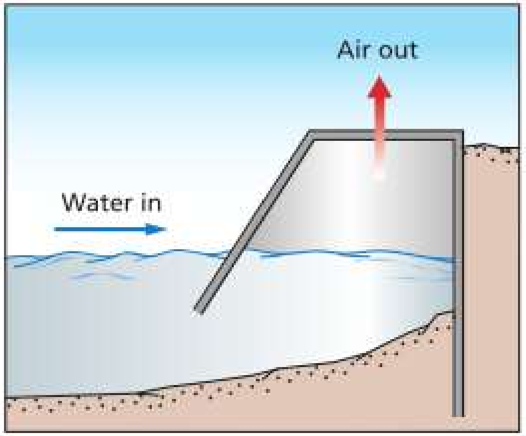

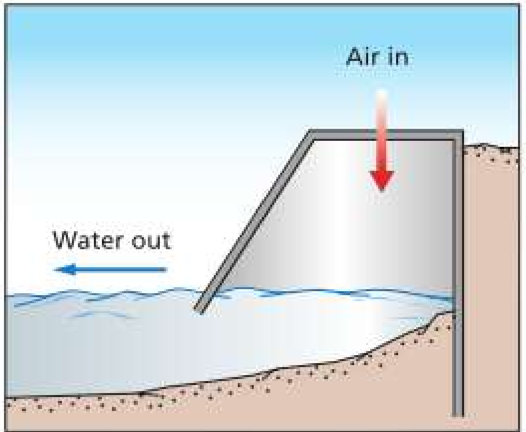

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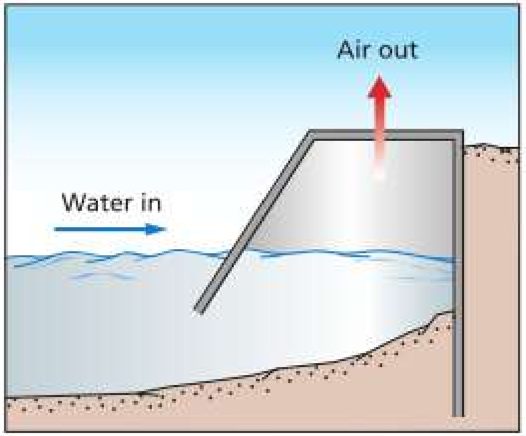

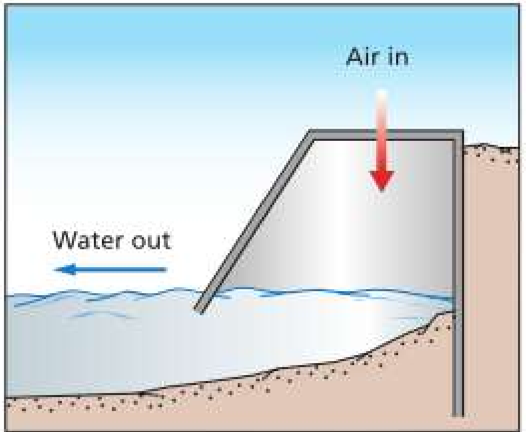

- To convert the up-and-down oscillations of the waves into electrical power, the next step is to place a turbine in each opening at the top of the structure. As air rushes in and out through the blades, the turbine converts the linear motion of the air into rotary motion, and rotary motion of each turbine is used to drive a generator.

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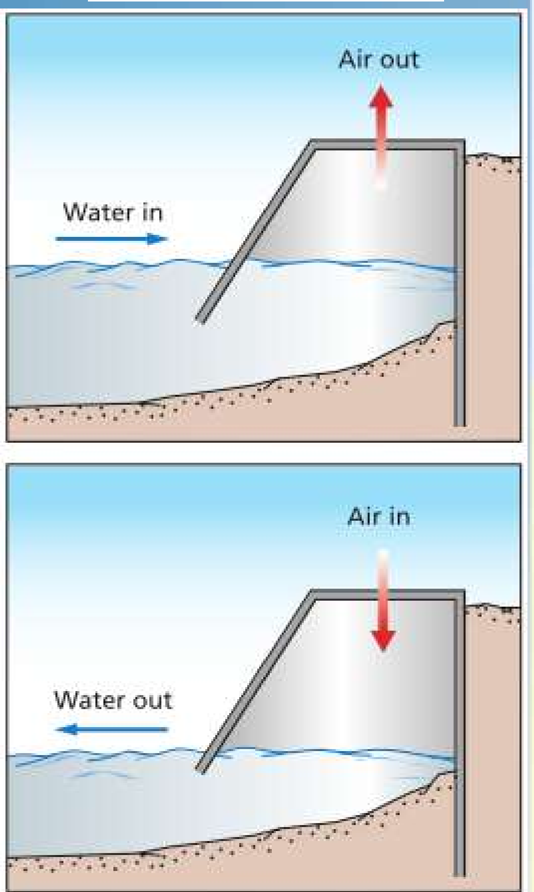

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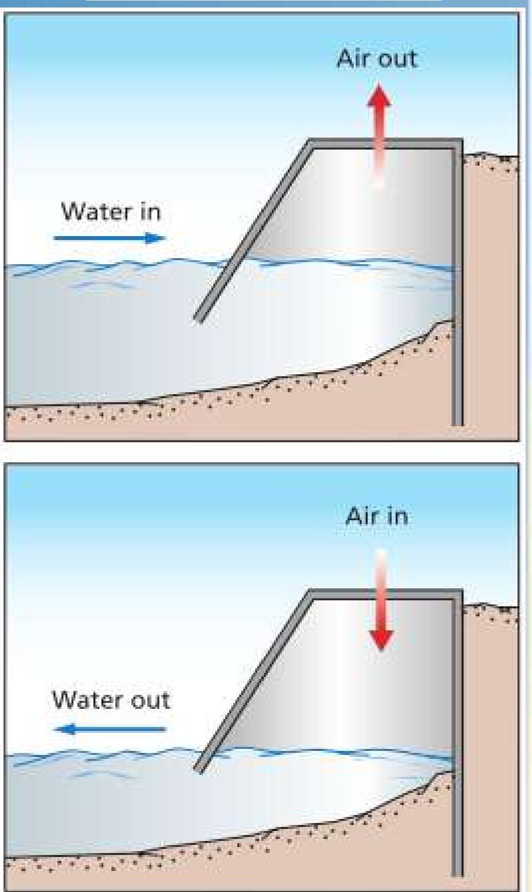

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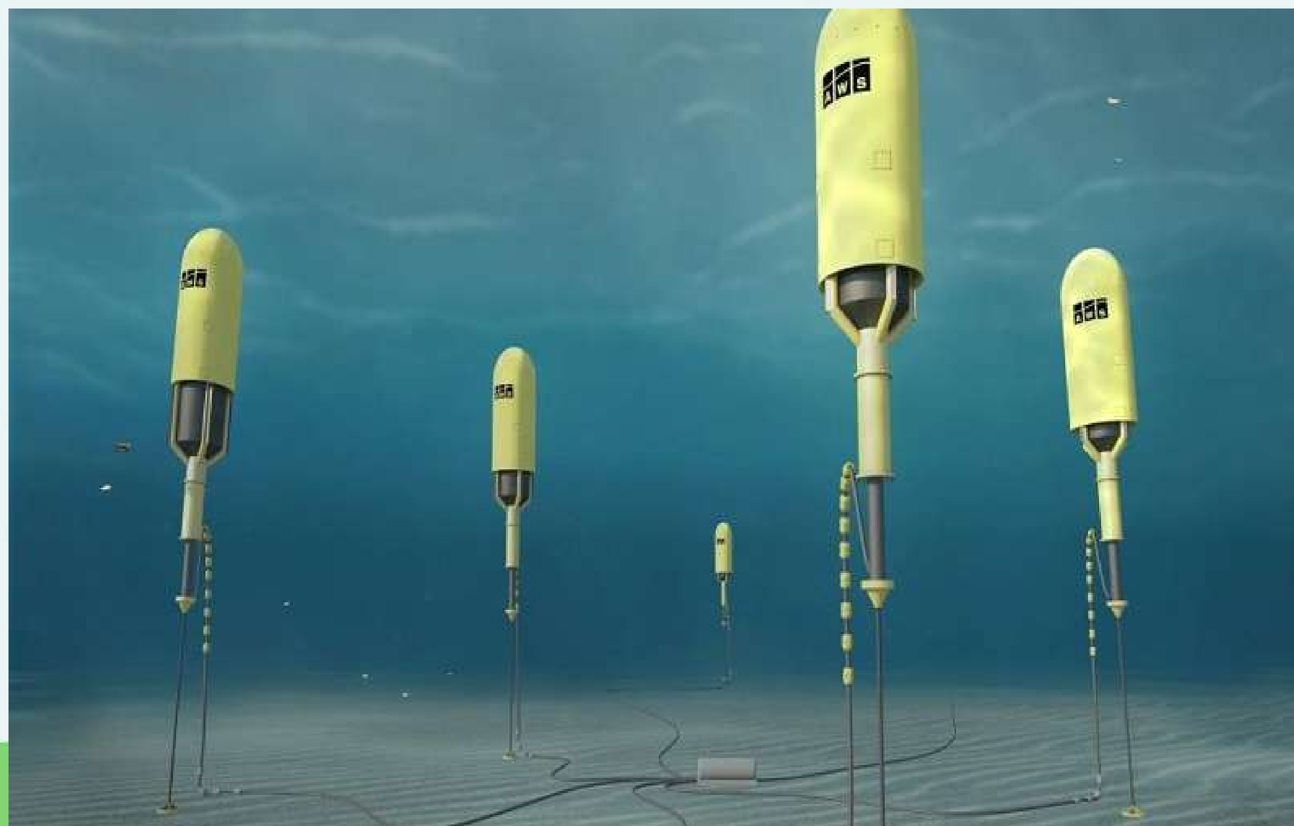
Archimedes Wave Swing (AWS)

- Waves pass under the Pelamis & crash into the Limpet whereas AWS is completely submerged so that waves pass over it & operates on a pressure difference caused by each passing wave. Pressure increase beneath the ocean **$P = wh$**, where w is weight of the water per unit volume & h is the distance to the surface.
- AWS is a large piston activated by pressure differences caused by incoming waves. The up-and-down motion of the piston drives generator to yield electricity.



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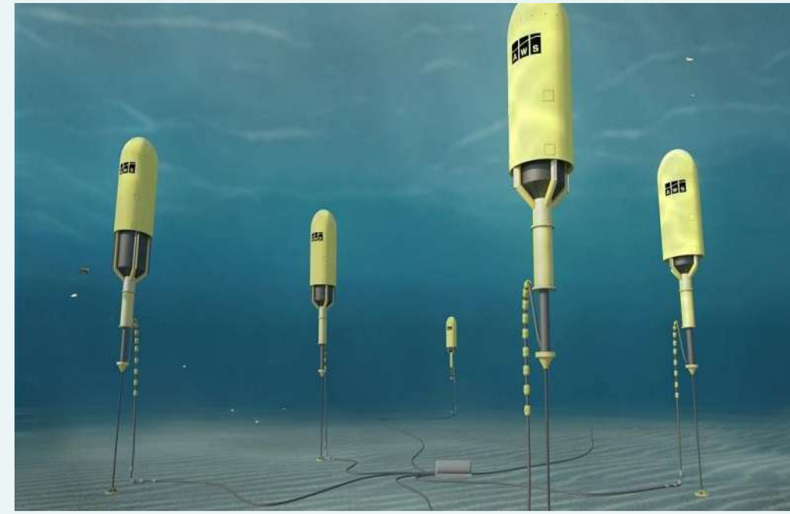

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- AWS is a large piston activated by pressure differences caused by incoming waves. The up-and-down motion of the piston drives generator to yield electricity.
- **Working Principle** → AWS is large cylinder filled with air & firmly attached to the seafloor. The cylinder consists of a moveable upper section and a fixed lower section. The air acts as spring that serves to restore the cylinder after being compressed by pressure of passing waves.

AKB

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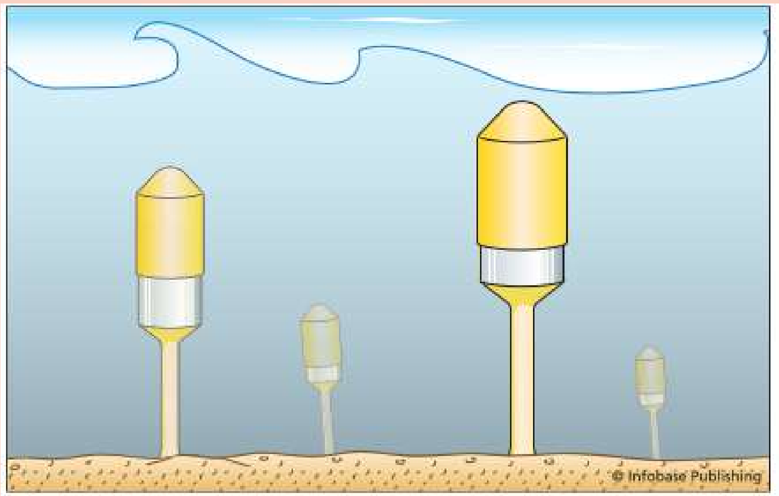
When the peak of a passing wave is positioned above the cylinder, it increases h that forces the upper part of the cylinder to descend. The air inside the cylinder compresses & the pressure increases until sufficient to



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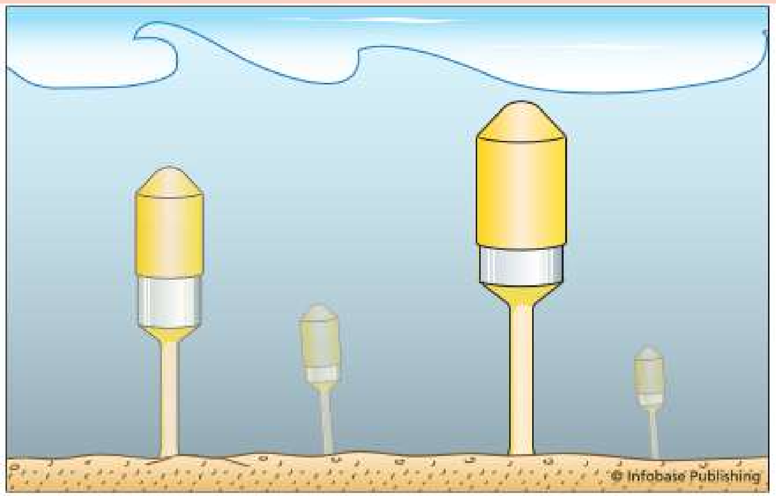

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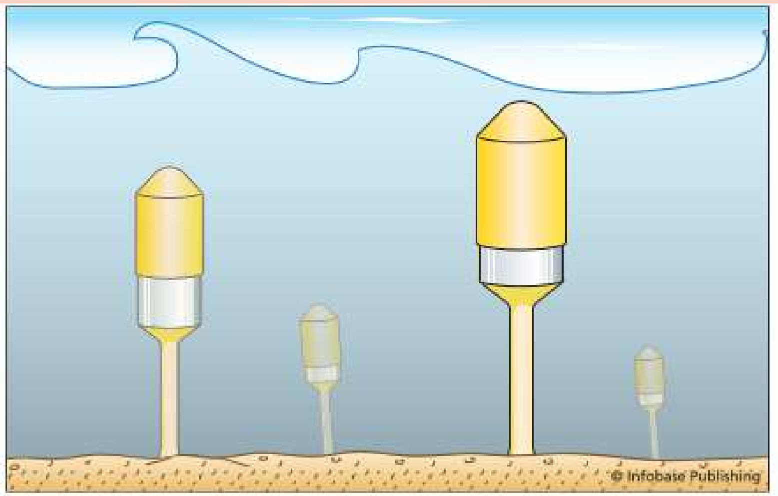
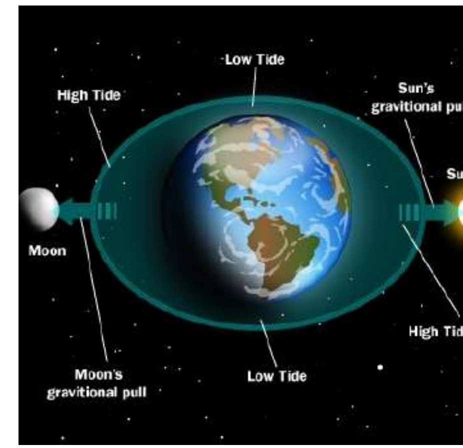


balance the pressure outside. Crest of wave oscillates around AWS. The peak is followed by the trough of wave & as it passes over AWS, height of the water column above the AWS become minimum. Consequently, pressure on AWS is also minimum. Air inside the cylinder, which was compressed by the peak of wave, now expands outward, pushing upper part of the cylinder upward until the pressure inside the cylinder balances the pressure outside. The cycle is repeated with each passing wave.

Tidal Energy

- Tidal Reasoning ➔ Two high-tide & two low-tides/day. Because of a ***differential attraction*** of the sun between opposite points, tides appear (e.g. Comet Shoemaker–Levy broke on **21** fragments in 1992 to fall on Jupiter).



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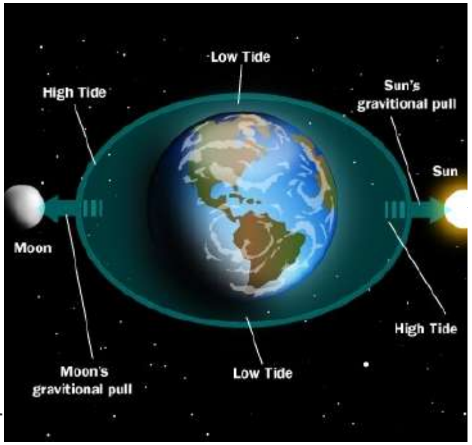
- **Attraction of Moon > Attraction of Sun?** ➔

  Say, M_S, M_M are mass of Sun & Moon & D_S, D_M are distance between Earth-Sun & Earth-Moon. Then, force due to Sun & Moon is,

  $$F_S = \frac{G M_E M_S}{D_S^2}, \quad F_M = \frac{G M_E M_M}{D_M^2}. \text{ So, } \frac{F_S}{F_M} = \frac{M_S}{M_M} x \frac{D_M^2}{D_S^2} \sim \mathbf{176}.$$

  ➔ **So this force is NOT the reason for tidal force !!!!**



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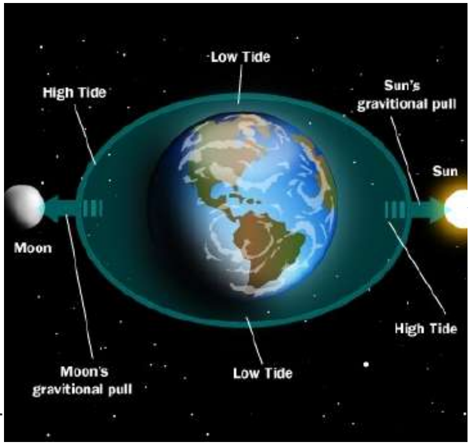

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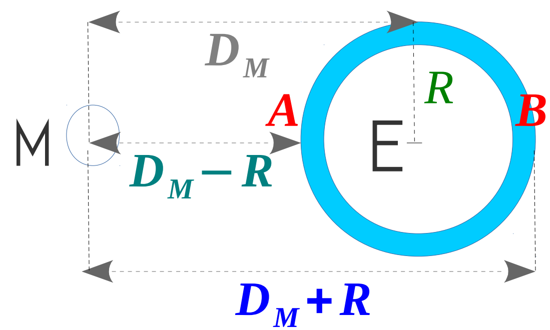
- **Difference of attraction between A & B point on Earth with hydrosphere (by any arbitrary mass m) due to Moon** ➔



Attraction at point A, $F_A = \frac{G M_M m}{(D_M - R)^2}$ & at point B, $F_B = \frac{G M_M m}{(D_M + R)^2}$.

Tidal Energy

- So $T_M = F_A - F_B \;=\; G M_M m \dfrac{(D_M+R)^2-(D_M-R)^2}{(D_M-R)^2(D_M+R)^2} \;=\; G M_M m \dfrac{4 D_M R}{(D_M^2-R^2)^2} \;=\; G M_M m \dfrac{4 D_M R}{D_M^4 (1-\overbrace{R^2/D_M^2}^{0})^2}$

$T_M \;\approx\; G M_M m \dfrac{4R}{D_M^3}$. This is the differential pull by Moon on opposite points on the surface of the Earth. Similarly for Sun, $T_S \;\approx\; G M_S m \dfrac{4R}{D_S^3}$.

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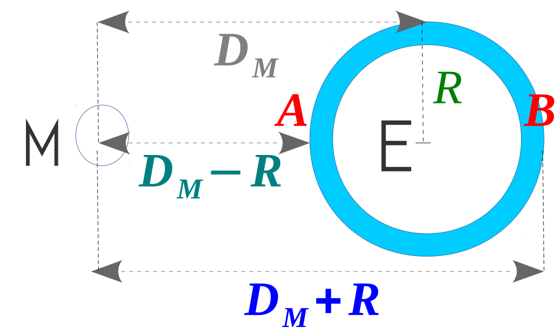

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- So, $\dfrac{T_M}{T_S} \;=\; \dfrac{M_M}{M_S} x \dfrac{D_S^3}{D_M^3} \;\sim\;$ **2.2**. Because Moon is nearer, even though the actual attraction due to Moon is far smaller than the attraction of the sun, but due to differential attraction, tidal force is more.

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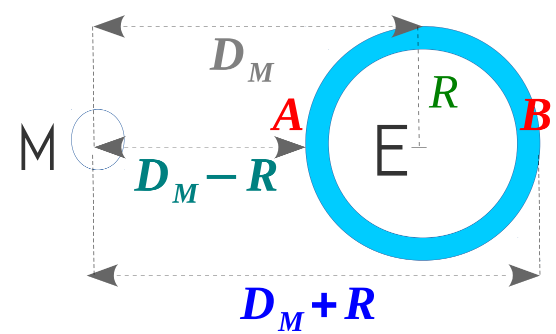


Tidal Energy

- So $T_M = F_A - F_B = G M_M m \dfrac{(D_M+R)^2-(D_M-R)^2}{(D_M-R)^2 (D_M+R)^2} = G M_M m \dfrac{4 D_M R}{(D_M^2 - R^2)^2} = G M_M m \dfrac{4 D_M R}{D_M^4 (1 - \overbrace{R^2/D_M^2}^{0})^2}$

  $T_M \approx G M_M m \dfrac{4R}{D_M^3}$. This is the differential pull by Moon on opposite points on the surface of the Earth. Similarly for Sun, $T_S \approx G M_S m \dfrac{4R}{D_S^3}$.

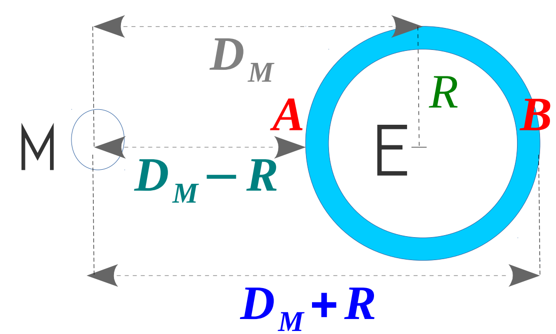
- So, $\dfrac{T_M}{T_S} = \dfrac{M_M}{M_S} x \dfrac{D_S^3}{D_M^3} \sim$ **2.2**. Because Moon is nearer, even though the actual attraction due to Moon is far smaller than the attraction of the sun, but due to differential attraction, tidal force is more.

$R/D_M = 1/60$

$M_S/M_M = 2{,}68{,}00{,}000$

$D_S/D_M = 390$

- So there will be two tidal bulges due to Moon & two other bulges due to Sun. In new-Moon phase (*Sun & Moon in almost same direction*), so bulge due to Moon & Sun will coincide to produce very strong tides (**spring tides**). In full-Moon phase (*Sun & Moon in opposite direction*), opposite bulge due to Moon coincide with bulge due to Sun to produce very strong tides.



Tidal Power

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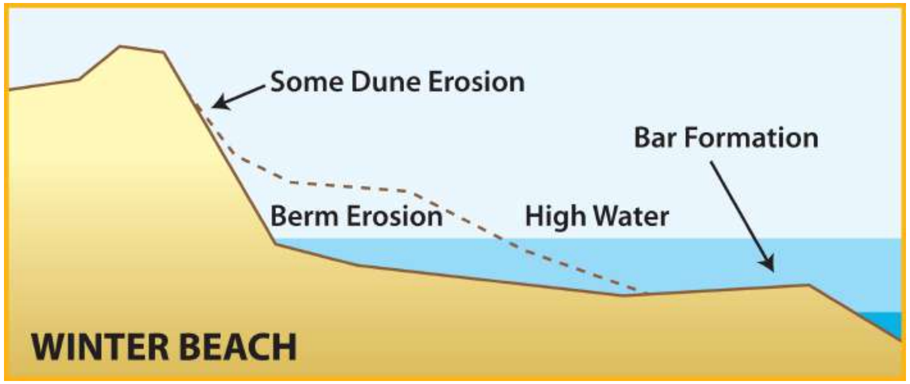

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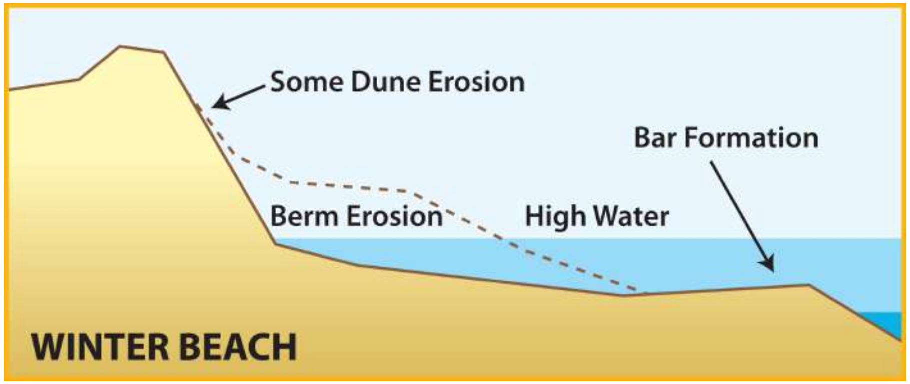
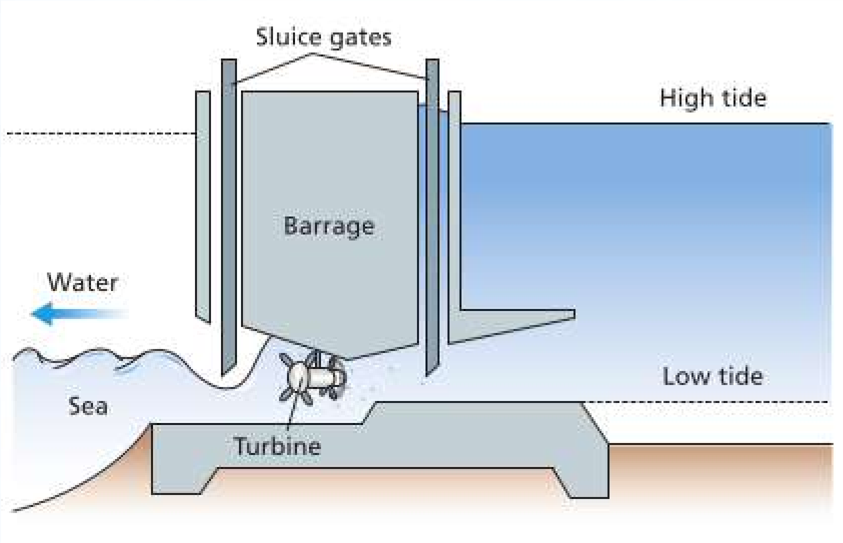


- *Not every sea (e.g. Mediterranean) has a tidal activity*! Because tidal bulge moves from east to west due to rotation of Earth, it so happens that Mediterranean sea has opening only to the west & so the tidal bulge cannot enter.

Harnessing Tidal Power: Tidal Barrage

- A **tidal cycle** (high tide to low tide and back to high) occurs ~ once every 12 hours and 25 minutes. A dam is made with a small inlet, equipped with a gate called ***sluice***. As the tide rose, the sluice was opened, allowing water to flow through it and accumulate behind the dam. At high tide the sluice was closed, trapping the water behind the dam.



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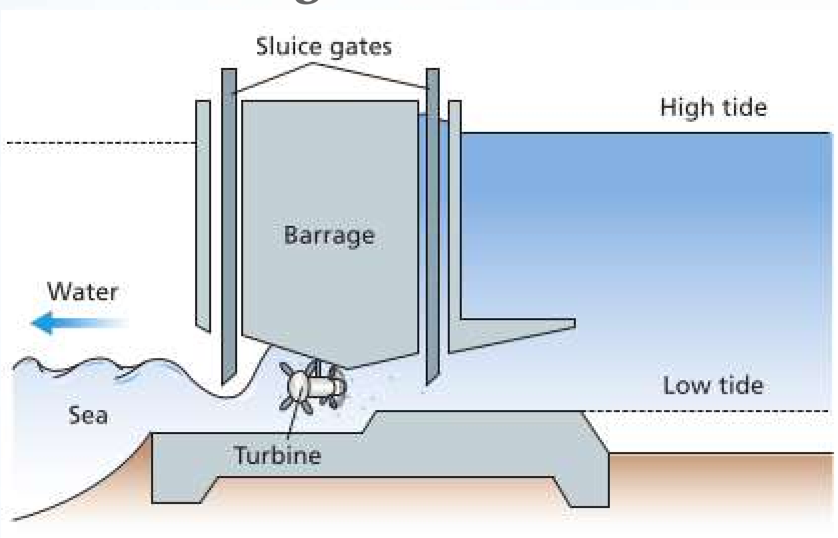

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Maximal Tidal Power

- Maximum power that can be converted into electricity from an ocean current is $P_{max} = \frac{CdAv^3}{2}$, where d represents the density of the water, v the speed of the flow before it encounters the tidal mill, A the cross-sectional area swept out by the mill's rotors & C the maximum efficiency attainable by the mill.

$$d_{water} = 1\, gm/cc = 1000\, kg/m^3$$

$$d_{saline\ water} = 1.027\, gm/cc = 1027\, kg/m^3$$

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- A 8km per hour current possesses double the power of a 6km per hour current, because $P_{max} \propto v^3$. Therefore, even small increases in velocity can lead to substantial changes in the amount of available power. By contrast, the cross-sectional area of the flow passing through the mill's blades has less of an effect on the mill's output. The density of the water d is completely outside the control of an engineer, so with respect to producing the maximum possible power, it is important to build a tidal mill with the largest possible rotor and position it in the area with the fastest possible current.

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Wind Power

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Wind Power

- Wind power were utilized by Pharaohs to sail in Nile & later Europeans to roam by sea throughout the World, grind grains, pump water & so on. Coal-fired power-plants tackle the base-load while peak-load is usually distributed from natural-gas fired & wind engines. Wind energy has an optimized cost structure than natural gas & its average rate of supply is predictable. On a negative side, wind turbines also have environmental effects like fossil fuel engines.

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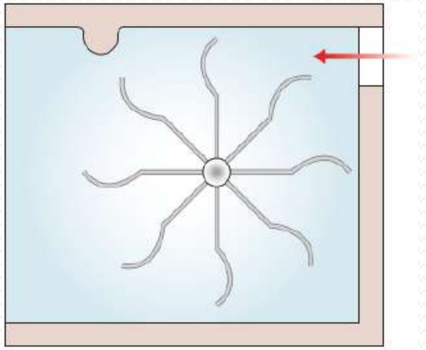
- As the wind blew on the sails on one side of the windshaft (axle where sails are affixed), it would also blow on the sails on the other side of the windshaft. Larger is area of sails, more wind power could be transmitted to windshaft (**Post mill**). But it's hard to support on a single post & to turn, which were rectified in ~ 30m tall **Smock mill** & **Tower mill**. These were used to harness mechanical energy like to pump water.



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Harnessing Wind Energy

- ***Wind Turbines*** ➡ Windmills that convert kinetic energy of wind into electricity, also called **Brush Turbines** (19m tall) named after Charles F. Brush (1888). Later, Pour la Cour's mill produced power on windless days – where electricity produced by wind turbine was used for *electrolysis* (separation of H_2O molecules into O_2 gas & H_2 gas). H_2 was stored/burned & the resulting heat were harnessed.

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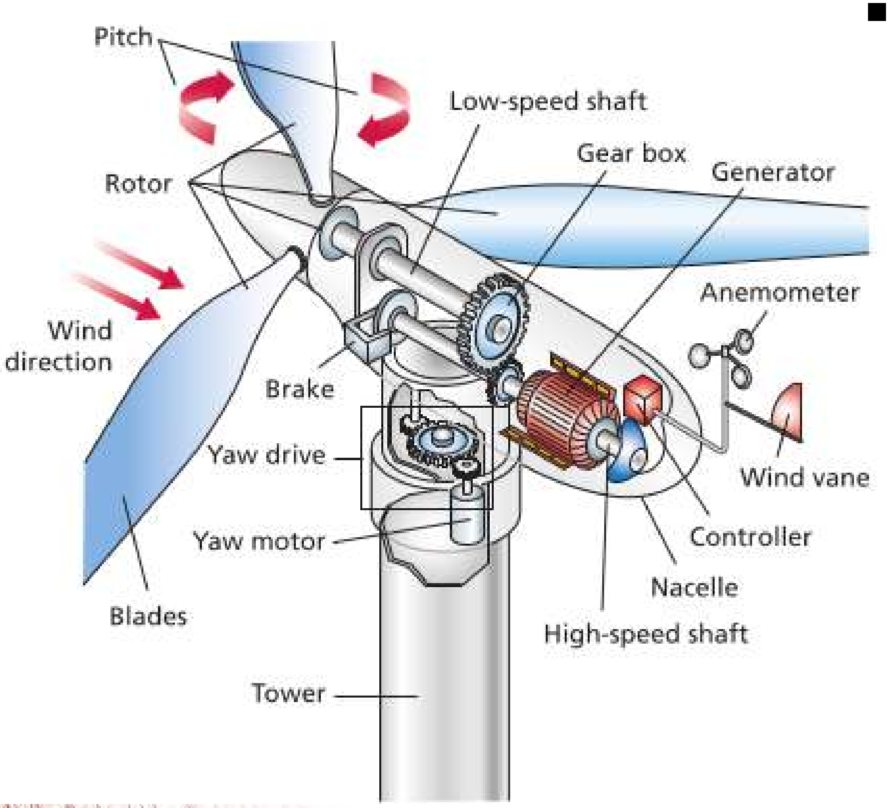
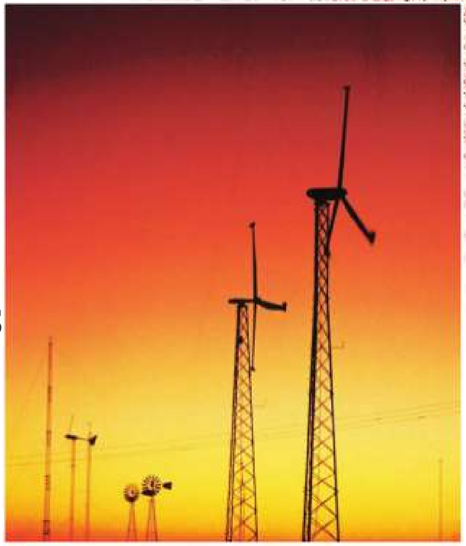


- In grid-connected Wind Turbines, rotor (analogous to sail in windmill) is mounted on a horizontal shaft, which is connected to a transmission (gearbox) between the windshaft & generator to optimize the speed. Necessity of 1200-1800 rpm speed in generator is achieved using gearbox. Analogous to large sails, longer rotors are used as power converted is $\propto$ area swept by rotor.

Wind Turbines

- On an open unobstructed landscape, wind speed increases by ~ **25%** as elevation above ground increases from 50ft (15m) to 200ft (61m). So, engineers often mount turbines on towers that exceed 275ft (84m) in height.



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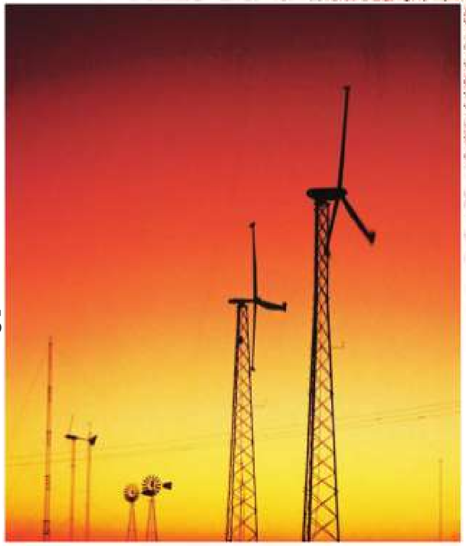

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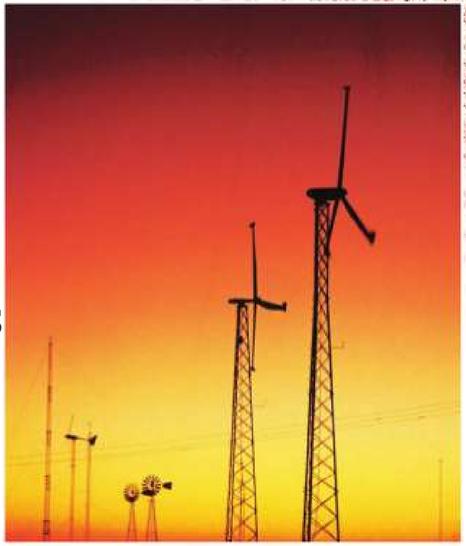

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- GE manufactures wind turbines in the 1.5–3.6 MW range. On an average, home draws ~ 2-4 kW. So a 3MW turbine can power 750-1500 homes at windy condition.

Nature of Wind Power

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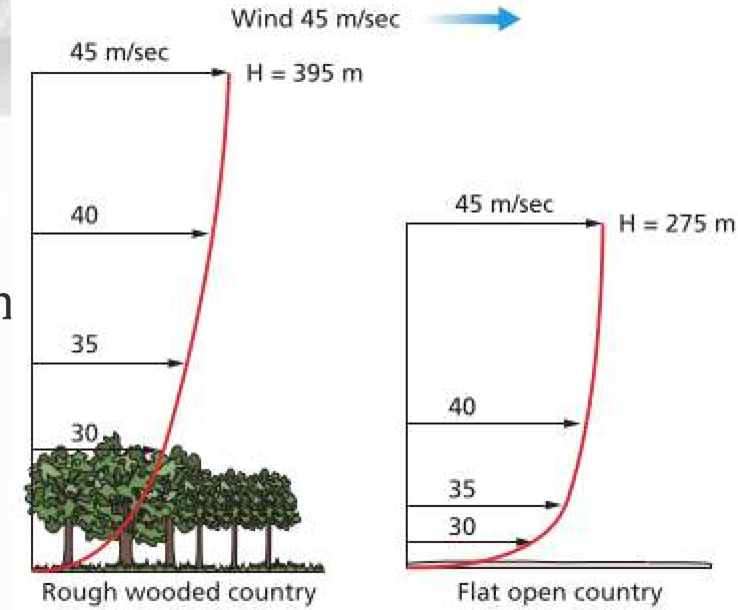
- Winds are form of solar energy as they are driven by unequal heating of Earth's atmosphere. Land at Equator moves about Earth's axis of rotation at ~ **1600kmph**. Earth's atmosphere is heated from below, not from above due to surface radiation. Uneven heating causes density and pressure change of the air near Earth's surface, causing the air to move. The path that large scale motion of air take across Earth's surface is influenced by the planet's rotation. This process produces moving regions of low & high pressure air that form & dissipate to produce winds.

Wind Energy



- Winds close to the ground are very ***turbulent*** & are accelerated & deflected during their passage between tall buildings, mountain passes to form eddies. Turbulent eddies, small-scale unsteady air contain huge K.E. whose energy is *hard* to harness into electric energy. It is easier to harness the steady streamline flow of air above ~ 100ft, as at higher altitudes the wind is unobstructed and less turbulent.

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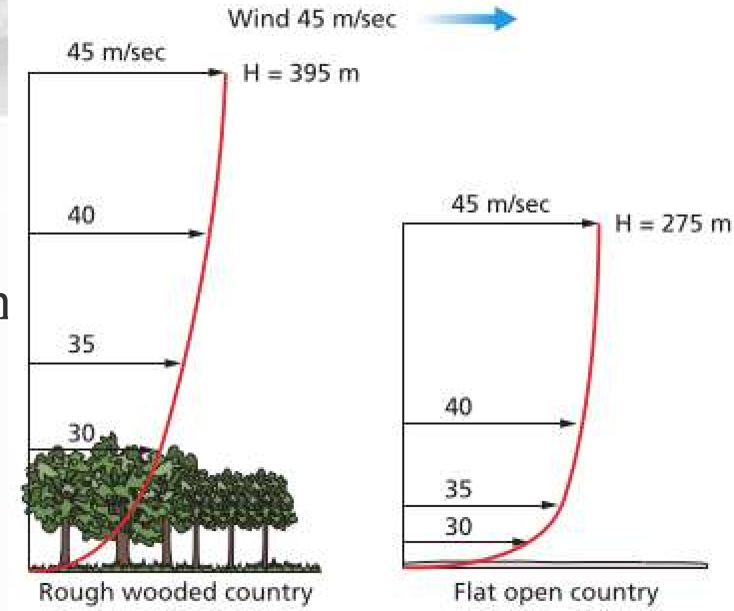

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- **Maximum power that can be converted into electricity from air current is $P_{max} = \frac{CdAv^3}{2}$, d is air density, A is area swept out by the spinning wind turbine blades, v is the speed of the wind & C represents the maximum % of the winds energy that can be harnessed.**

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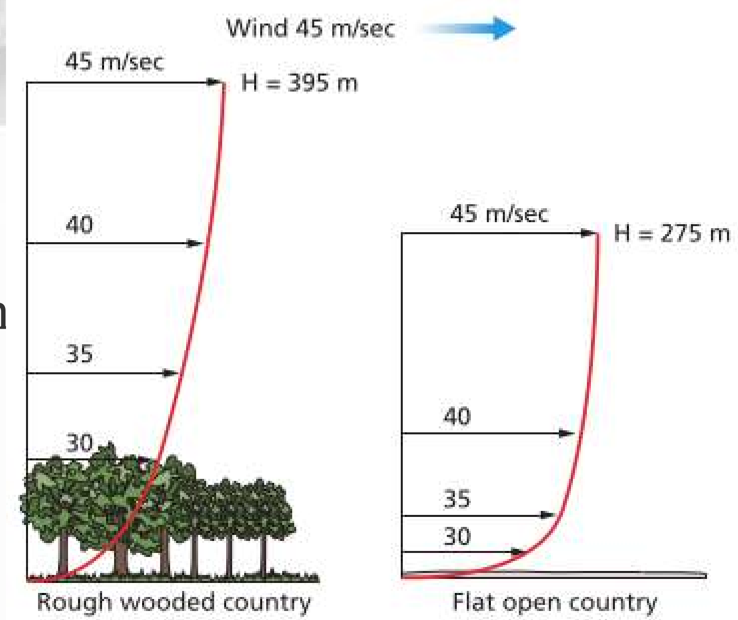

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- Density of seawater = 900 x density of air (at sea level). So, tidal mills produce much electricity from slow moving ocean currents, although velocity of the ocean current << velocity of wind currents. This is purely due to "**d**".

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Wind Energy

- Density of air decreases rapidly with height – so even if the wind may blow steadily atop a tall mountain, there won't be much energy to convert compared to less altitude. For example, air density atop Mt. Everest = 1/3 x density of air at sea level. Like tidal energy, a wind turbine operating in a wind that blows at 20 km/hr can generate twice the power of a turbine operating in a 16 km/hr wind, as $P_{max} \propto v^3$.

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- In terms of reliability, wind turbines are better than conventional sources as each power source is occasionally unavailable because of scheduled maintenance or because of mechanical failure. Weather reports are useful in predicting wind speeds ~ 1 or 2 days into the future & in next 1-2 hours. Accurate weather forecasting models make the producers confident in ***spot market*** on peak power demand.

Summary

Solar Energy

$$I(\lambda, T) = \frac{2hc}{\lambda^3}\frac{1}{e^{hc/\lambda k_B T} - 1}$$

Geothermal Energy

$$\sim$$

Hydroelectric Energy

$$P = eqha$$

Wave Energy

$$E = cA^2(\text{Pelamis}), \quad P = wh(\text{Archimedes Wave Swing})$$

Tidal Energy

$$\boldsymbol{P = \frac{CdAv^3}{2}}$$

Wind Energy

$$\boldsymbol{P = \frac{CdAv^3}{2}}$$

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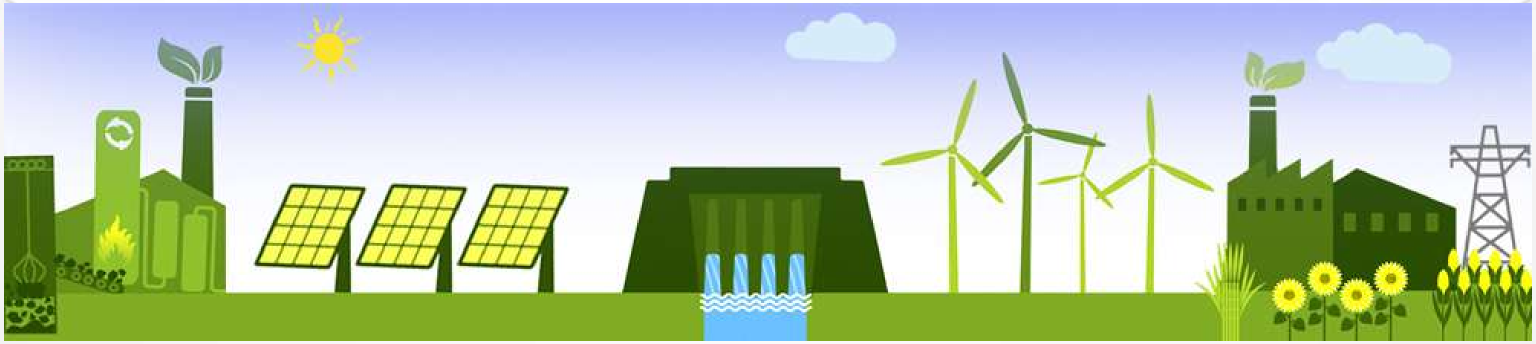
Non-conventional Energy

We posed Solar, Geothermal, Hydroelectric, Wave, Tidal & Wind energy as a futuristic non-conventional & renewable contribution as alternative to energy production, energy consumption & energy utilization. Energy use pattern as base & peak load indicate sustainability of NCER in future.



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