

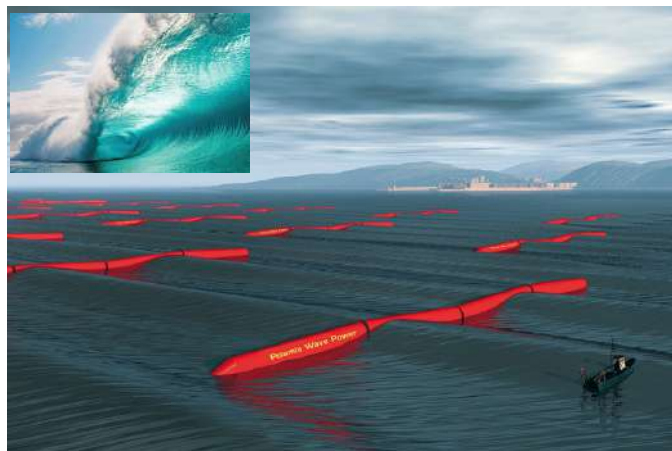


ENVC 24 : Energy and Environment

Part-3 : Non-conventional Energy Resources



Kanyakumari Windmills,
India



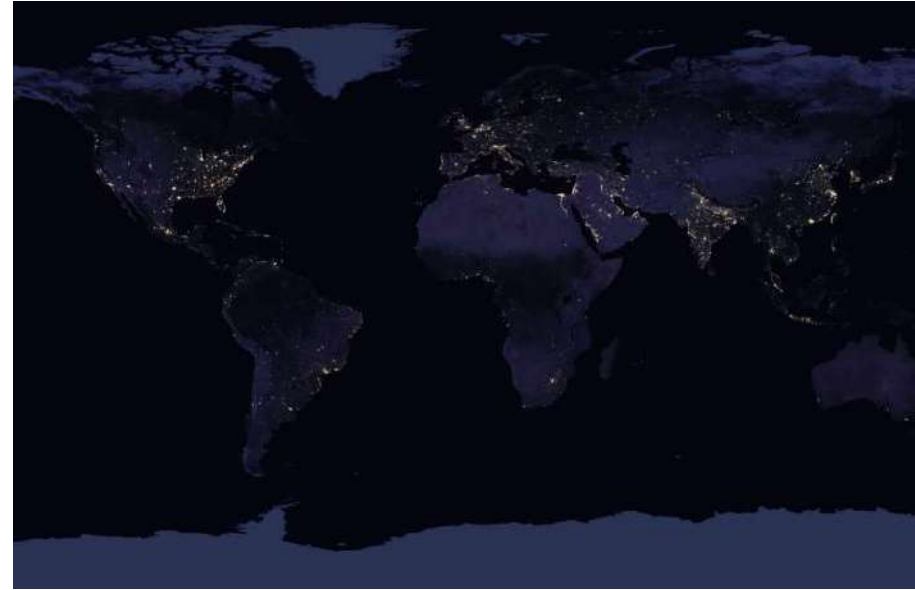
Pelamis Wave Energy
Converter, Scotland



Krafla Geo-thermal
Energy, Iceland

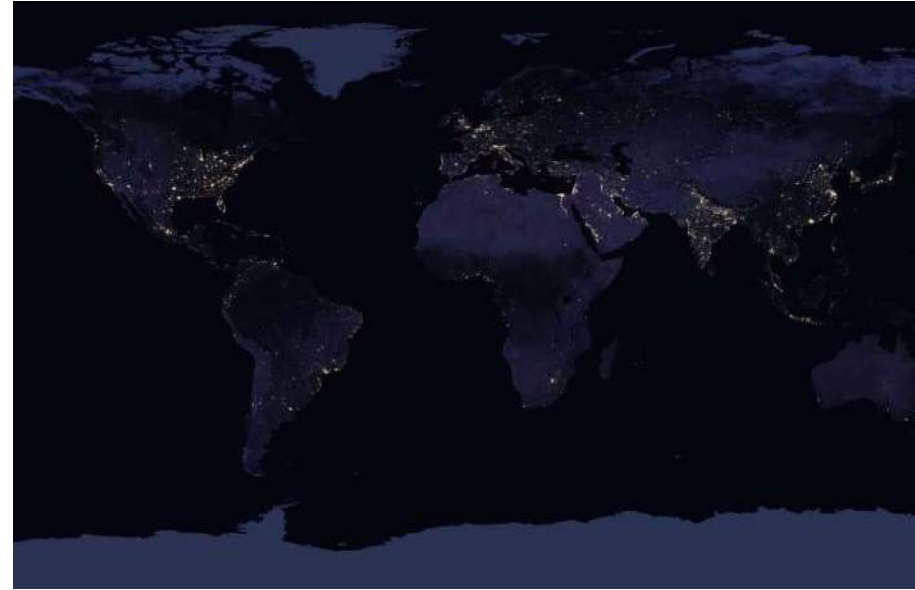
Earth & Atmosphere

- World energy usage/year ➡ 500 ExaJoules.



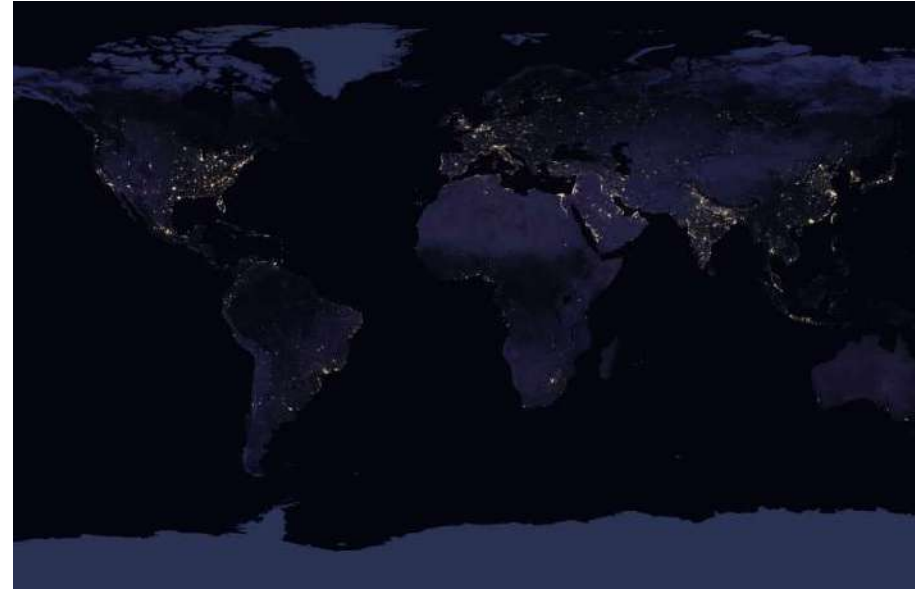
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- Major constituents of dry air by volume %
 - ➡ $N_2=78.084$, $O_2=20.946$, $Ar=0.934$, $CO_2=0.04$,
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- Layers of the atmosphere →

Troposphere → 0 – 12 km

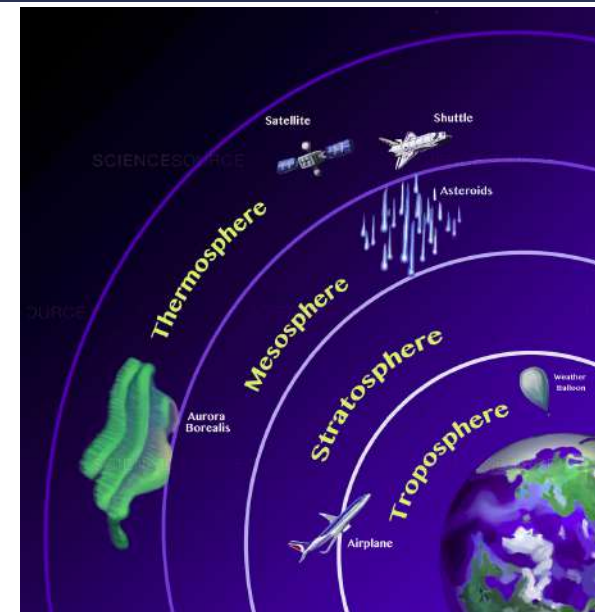
Stratosphere* → 12 – 50 km

Mesosphere → 50 – 80 km

Thermosphere → 80 – 700 km

Exosphere → 700 – 10^4 km

* → Ozone (O_3) layer



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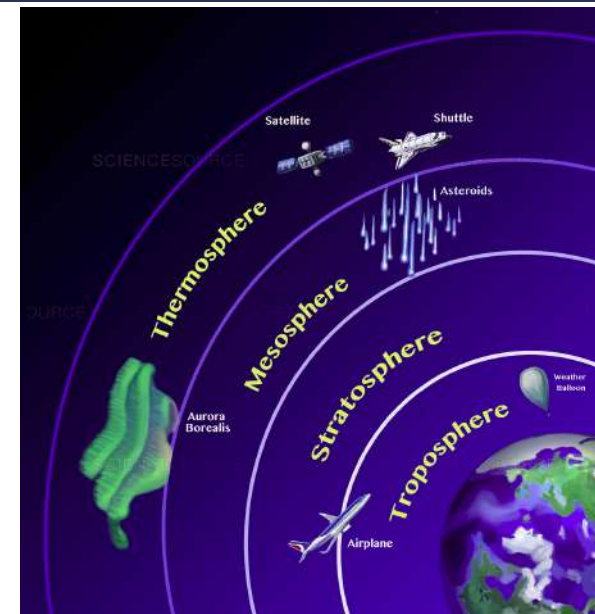
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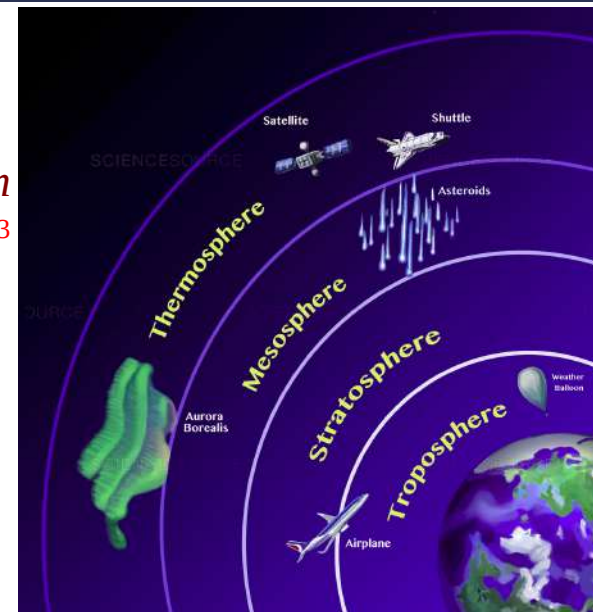
Earth Radius(R) → 6371 Km

Earth+Troposphere Radius(R') → 6383 Km

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

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

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Atmosphere

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

$$\frac{0.04}{100} \times 6.133 \times 10^{18} = 2.453 \times 10^{15} m^3.$$



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- World energy usage/year ➡ 500 ExaJoules. So, heat of formation of CO_2 is $\Delta H = -394 kJ/mol$ and therefore CO_2 emission amounts to an energy release/year ~
$$\frac{5 \times 10^{20} \times 22.4 \times 10^{-3}}{3.94 \times 10^5} = 2.843 \times 10^{13} m^3 \text{ of } CO_2 / yr.$$



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- Time required to double the amount of CO_2 in the atmosphere at the present usage is $\frac{2.453 \times 10^{15}}{2.843 \times 10^{13}} = 86 \text{ years}!!$ 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!



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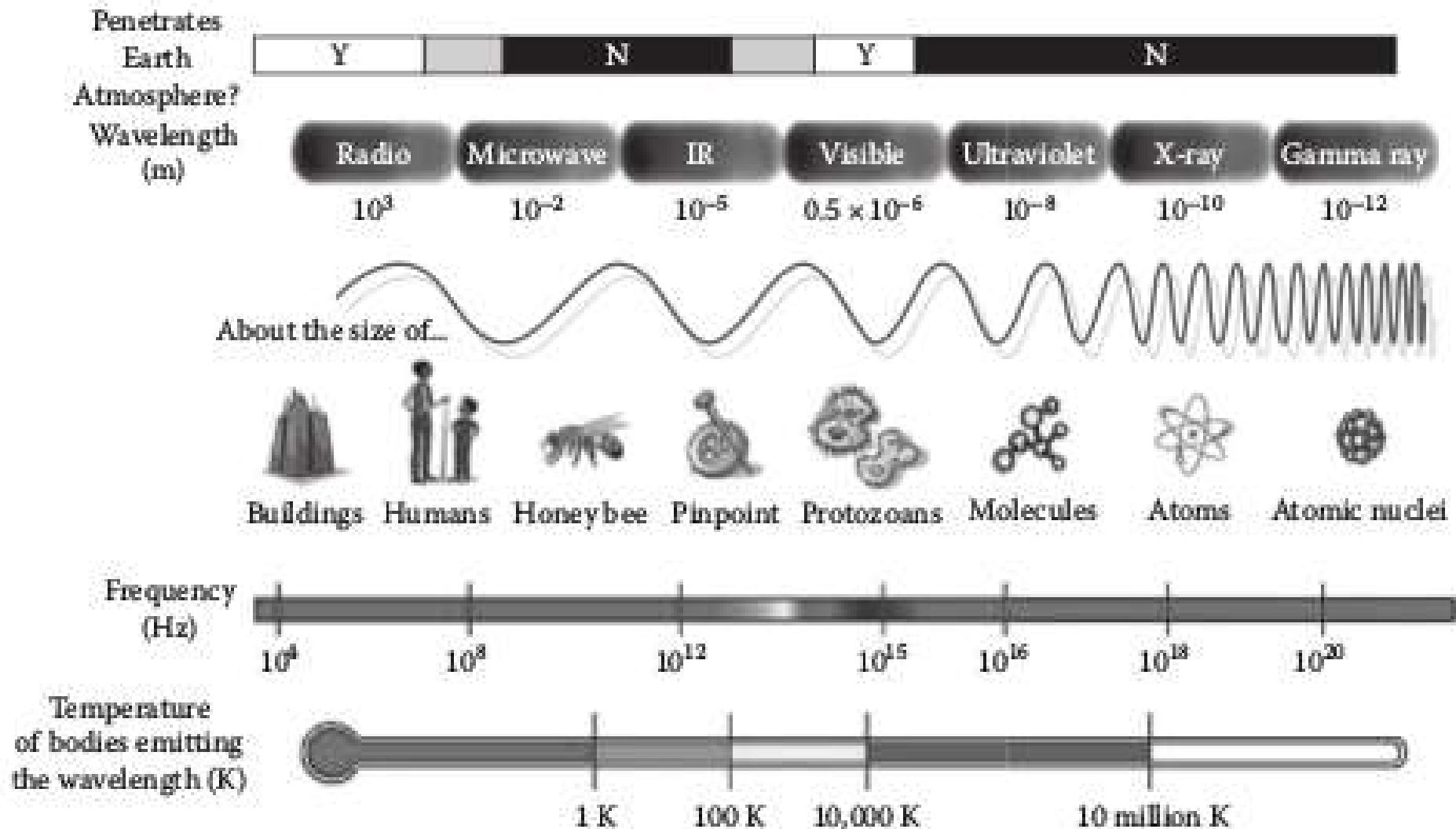
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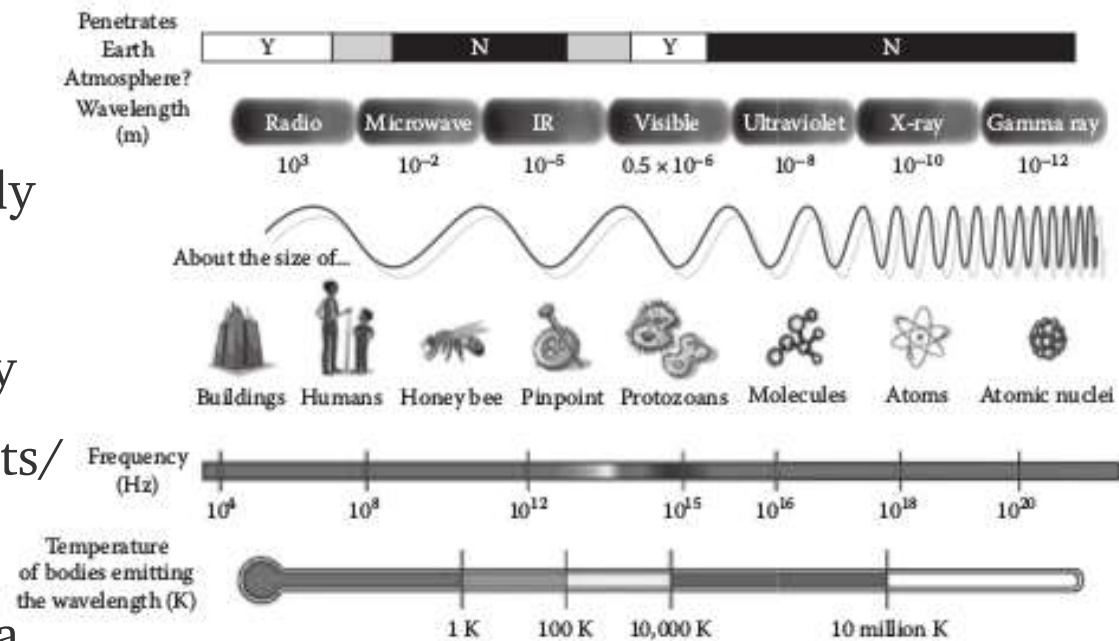
- Sun's energy radiates in all directions & during spreading it weakens. But even after crossing the Ether (void) between Sun & Earth, a flat plate placed above the atmosphere and oriented perpendicular to the rays would receive Sun's EM energy at a rate $\sim 1368 \text{ Watts/meter}^2$. This is called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



Blackbody Spectra



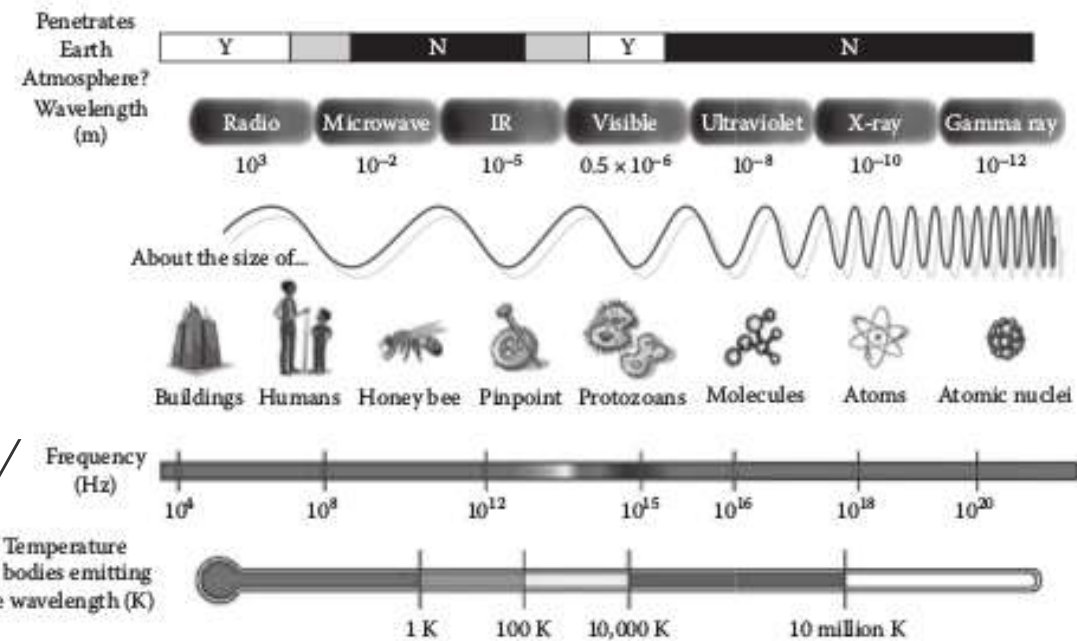
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- Planck's law** gives intensity of light as a

function of wavelength and temperature $\Rightarrow I(\lambda, T) = \frac{2hc}{\lambda^3} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$

h = Planck's constant = $6.626 \times 10^{-34} \text{ J s}$, k_B = Boltzmann constant = $1.38 \times 10^{-23} \text{ JK}^{-1}$

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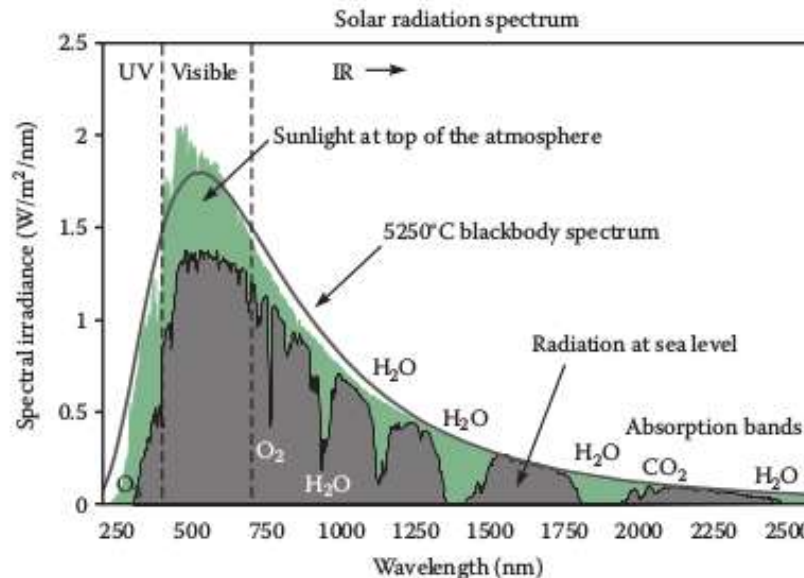
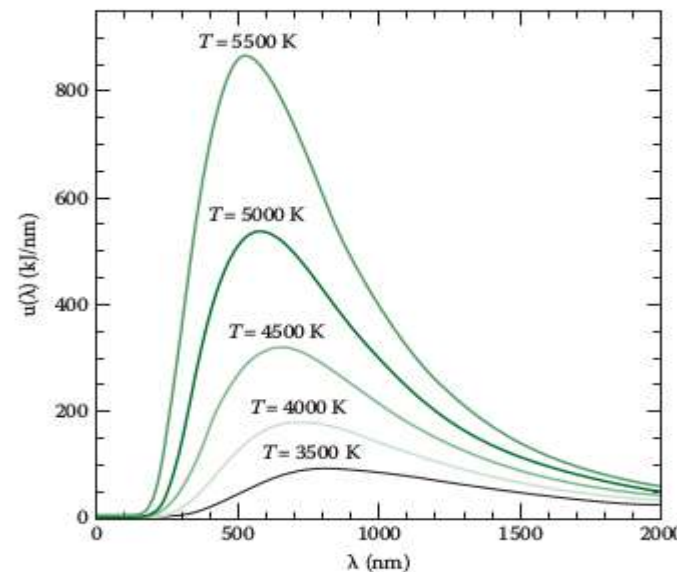


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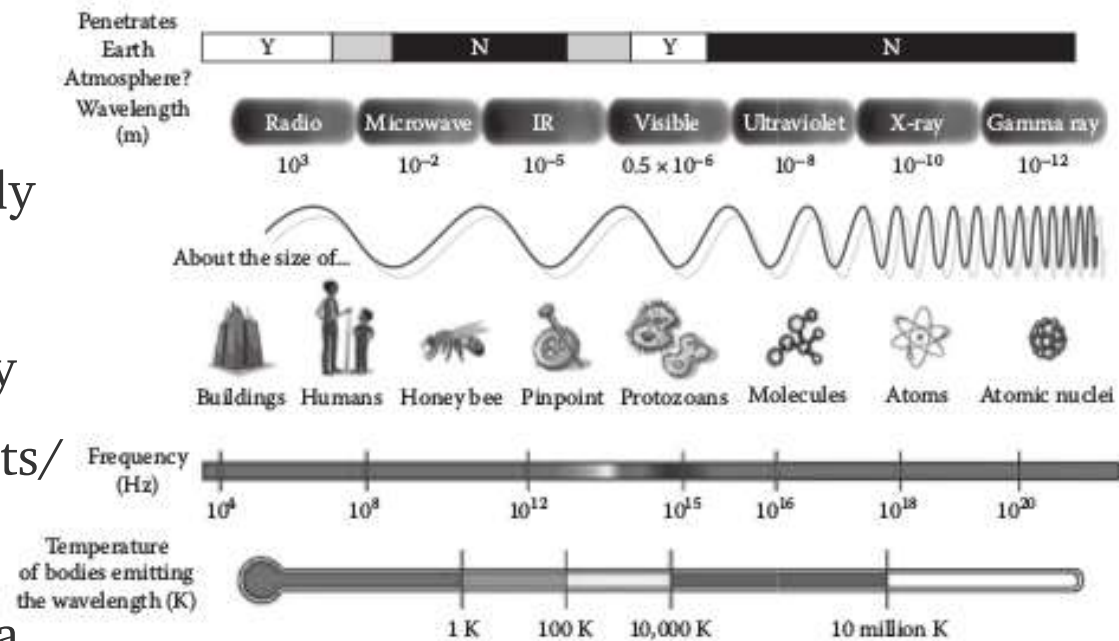
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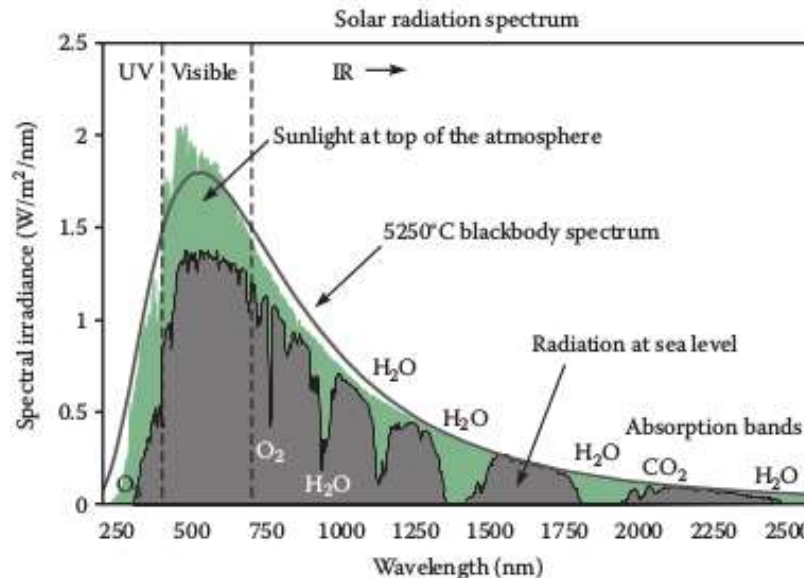
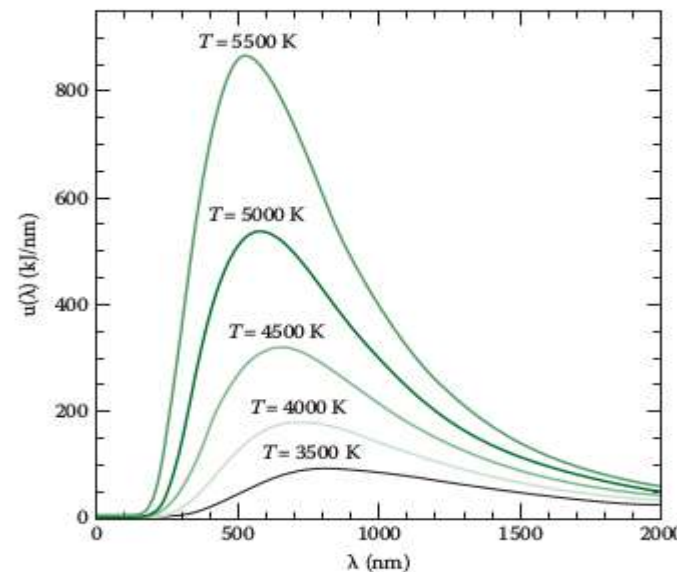


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\Rightarrow peak of the spectrum shifts toward shorter λ , the hotter the emitting blackbody is.

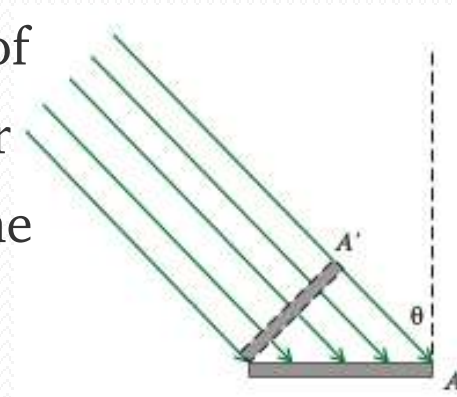
- Wien's law $\lambda_{max} = \frac{0.002898}{T} \text{ mK}$; $\lambda_{max}^{Sun} = 4900 \times 10^{-8} \text{ cm}$, so $T^{Sun}(\text{Photosphere}) = 5902 \text{ K}$ AKB

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/meter²*.

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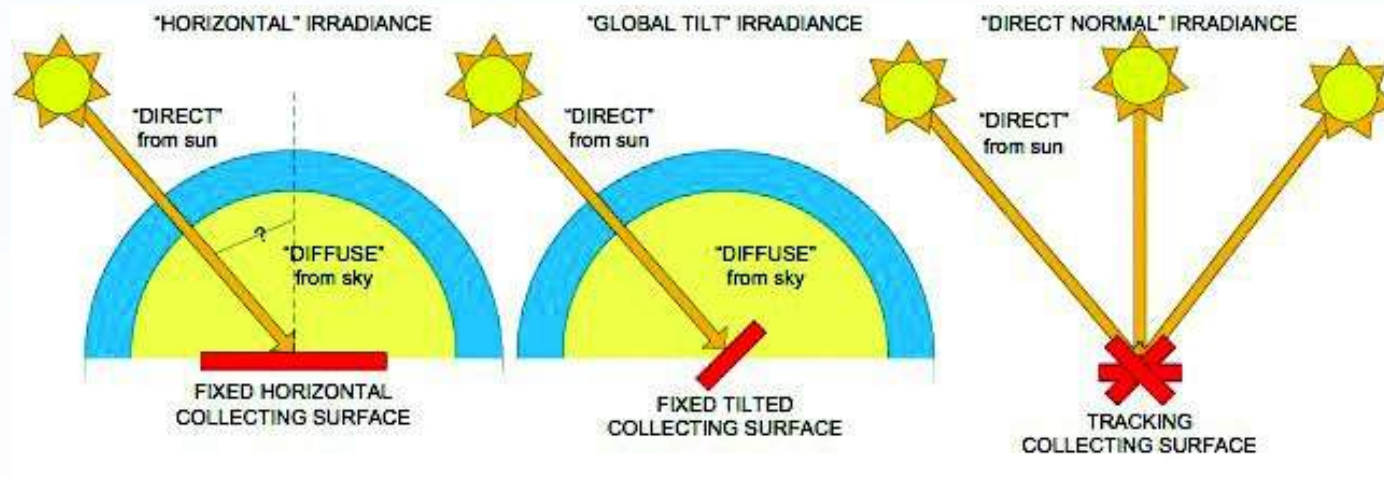
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- Amount of solar power per unit area of the Earth's surface is known as **Solar Irradiance** & it varies both spatiotemporally. Irradiance depends on the angle of Sun relative to the plane of the surface on which the incident power falls. Direct portion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



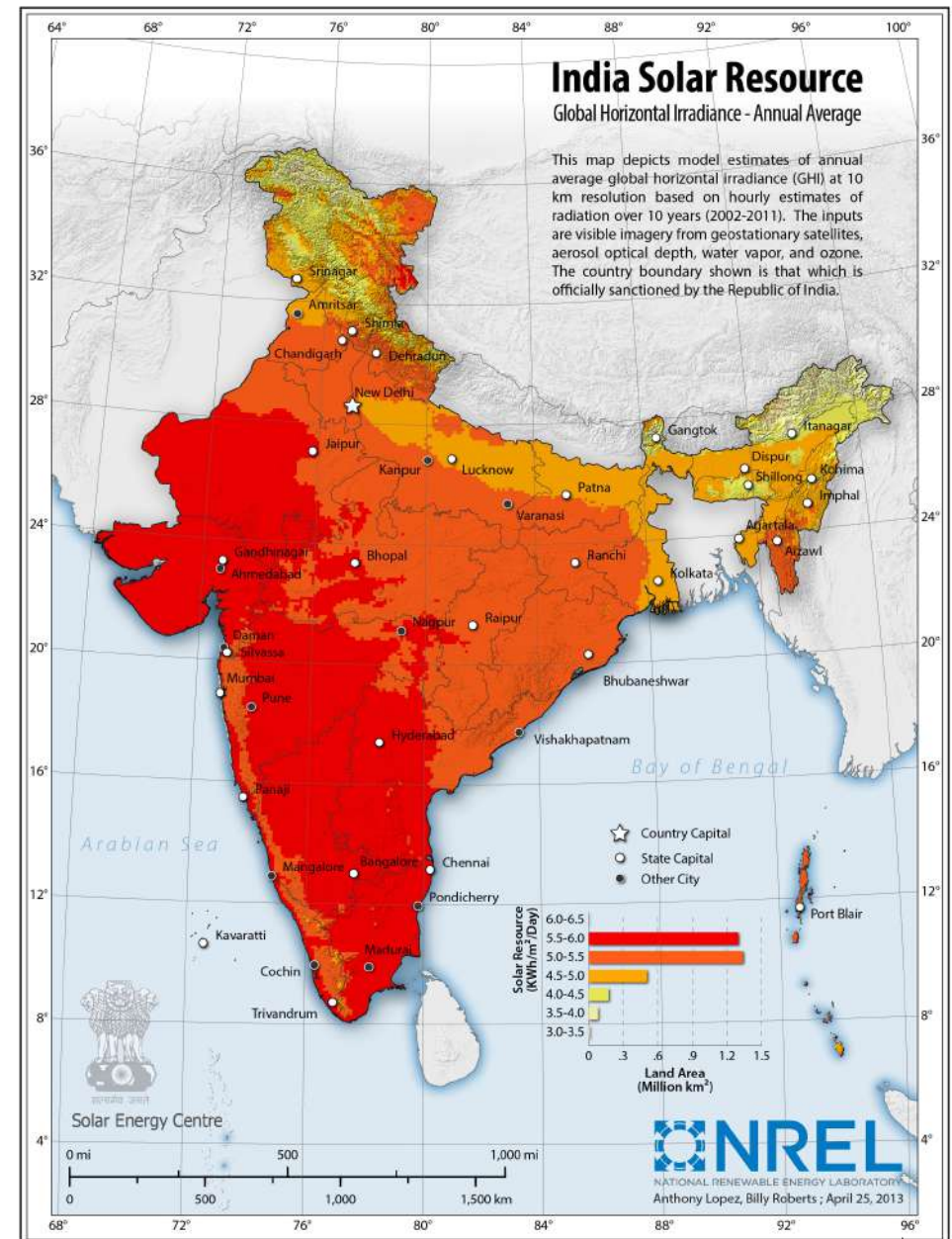
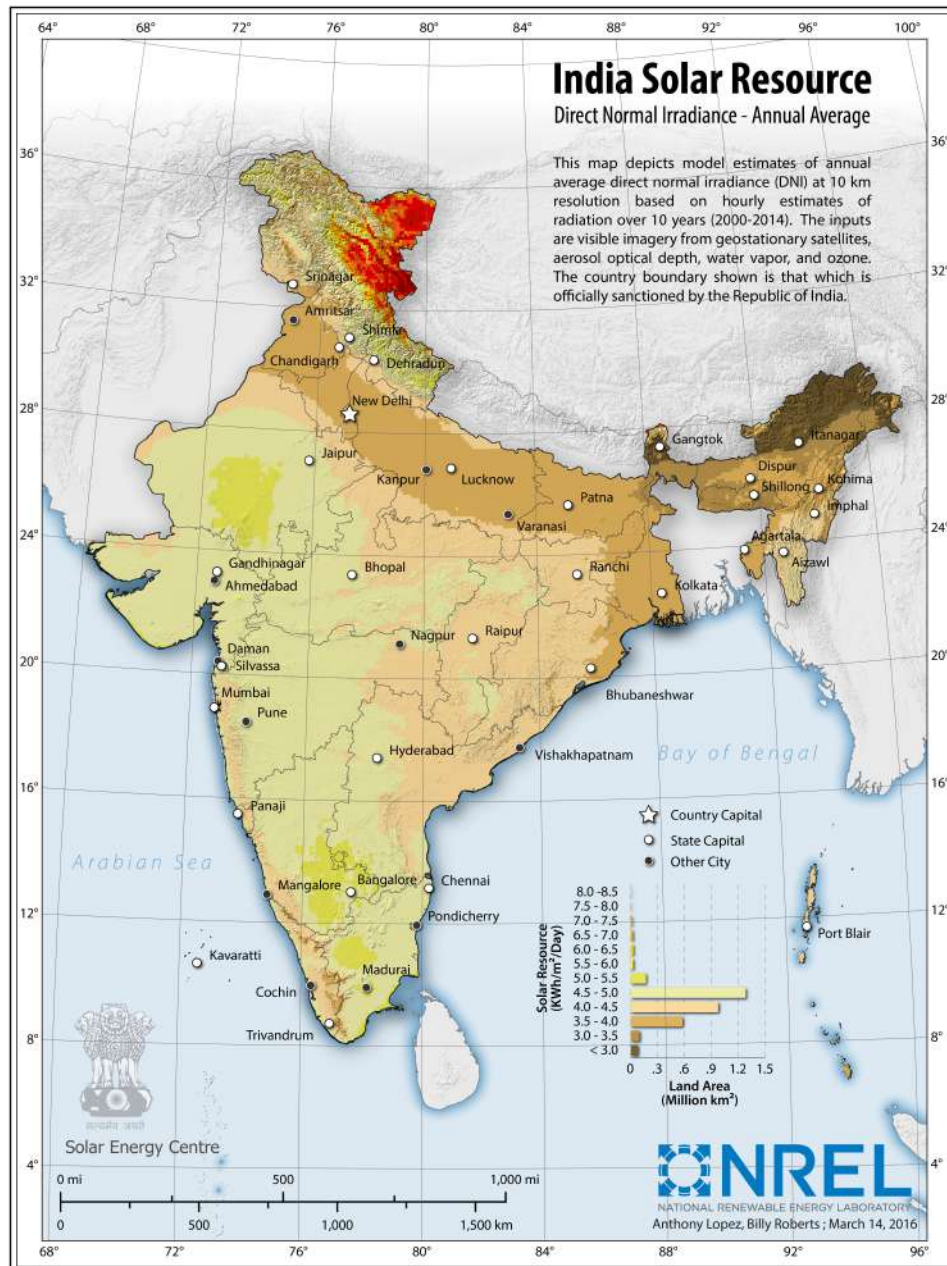
$$G_s = G^* \cos \theta; \quad G^* (\text{direct normal irradiance}) = 865 \text{ W/m}^2.$$

Average Daily Solar Radiation

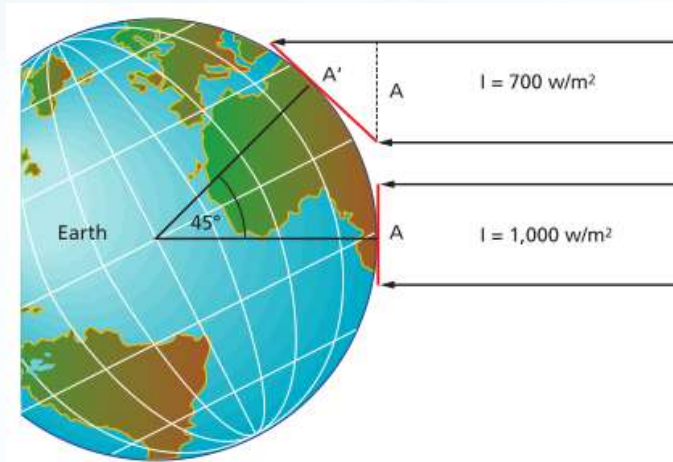
- **Direct Normal Irradiance (DNI)** is the amount of solar radiation received per unit area by a surface that is always held perpendicular to the rays that come in a straight line from the direction of the sun at its current position in the sky. **Global Horizontal Irradiance (GHI)** is the total amount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



Average Daily Solar Radiation



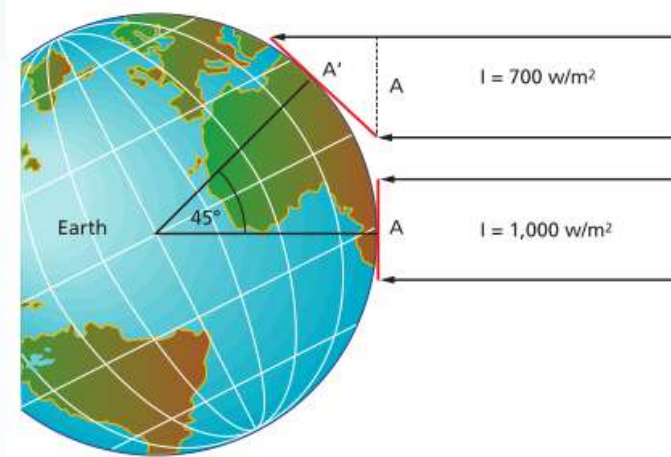
Sunlight & Geometry



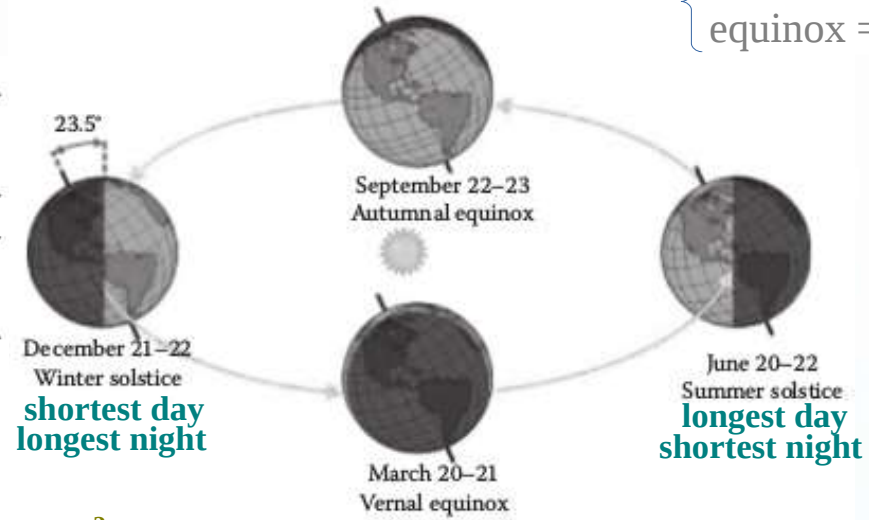
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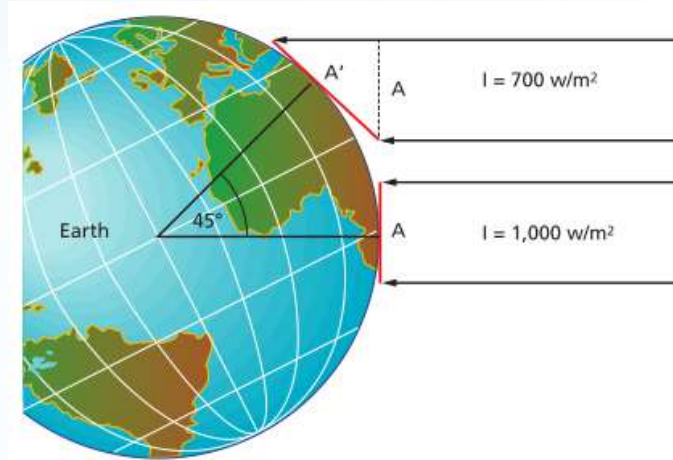
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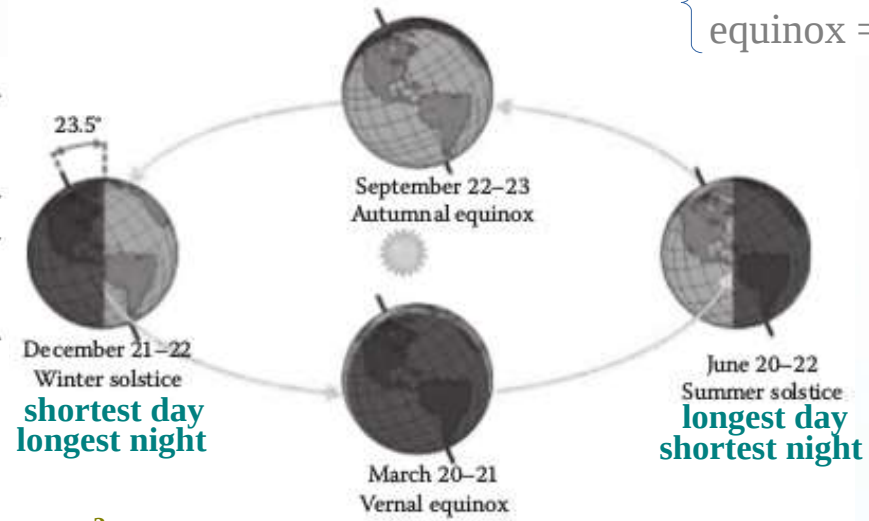
solstice = sun stands still
equinox = equal night

- 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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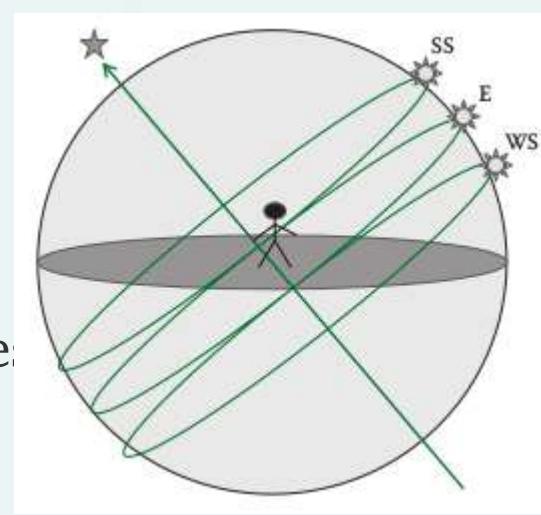
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Solar Declination

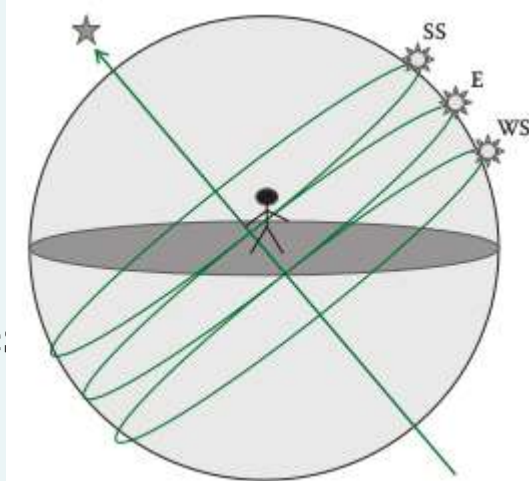
SS = Summer Solstice
E = Vernal & Autumnal equinox
WS = Winter Solstice

- To an observer on Earth watching the apparent motion of the sun across the sky during the course of a day as the Earth rotates on its axis.



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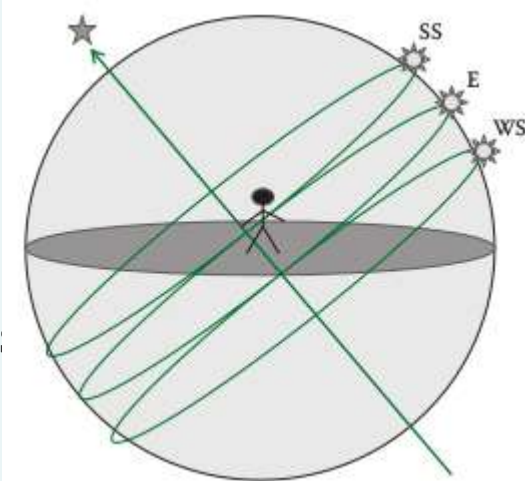
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- **Solar declination** ➡ is the angle δ between the position of the sun at noon on a given day and its position at noon on the date of the equinoxes at the same location. On the dates of the summer and winter solstices, we have $\delta = \delta_0 = \pm 23.44^\circ$, and on the dates of the two equinoxes, we have $\delta = 0^\circ$. For any other day $n=1,2,\dots,365$, we have

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



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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, $\delta = -18^\circ$. The negative declination means that the date is past the autumnal equinox.



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 ➡ $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$ If an object loses heat that passes through several layers in sequence, their resistances must be added in series ➡

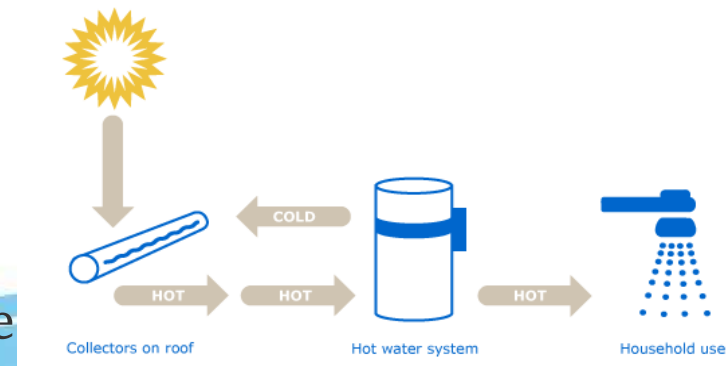
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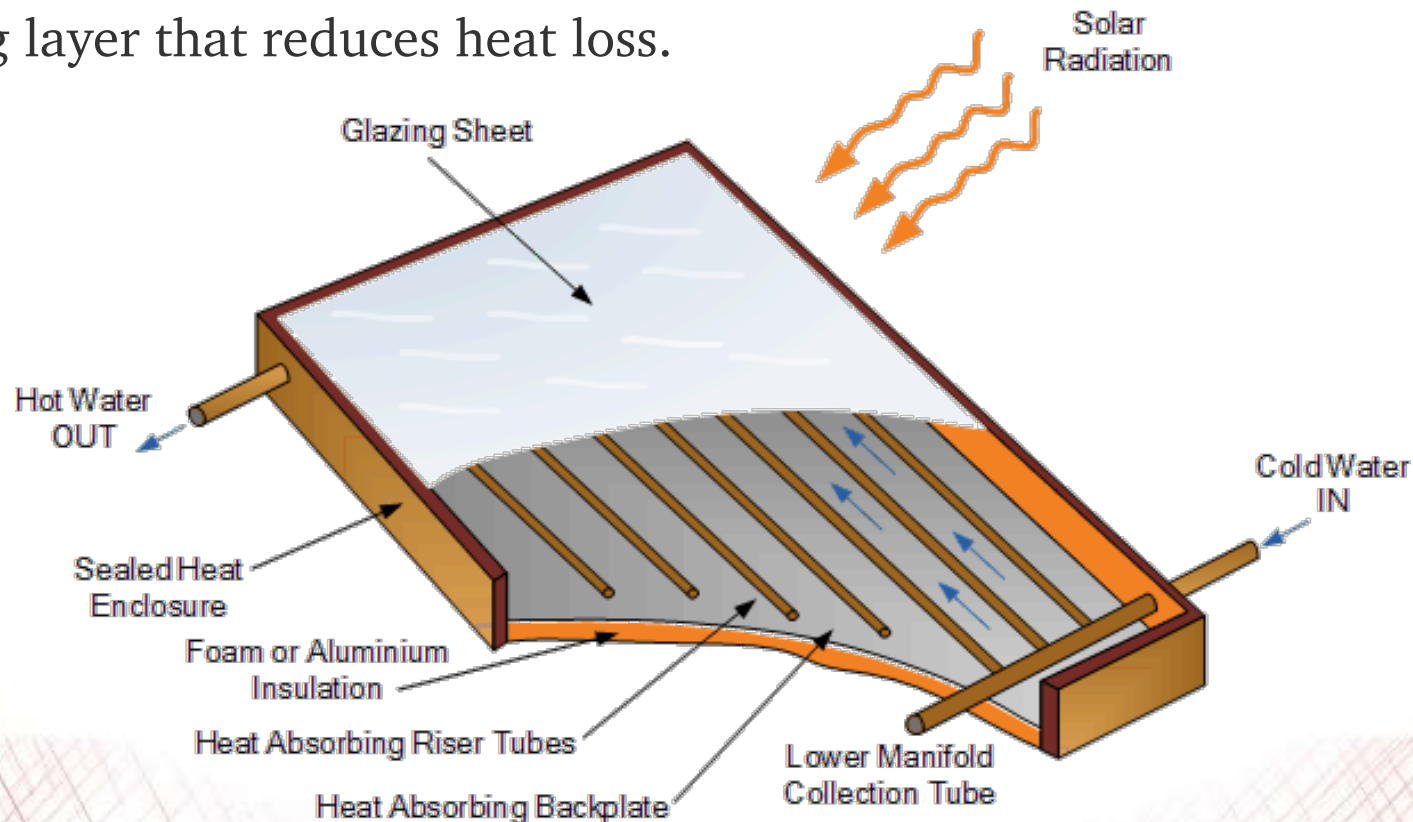
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- Solar Collector** \Rightarrow conversion of sunlight into heat for water heating using a solar thermal collector. 85% of Israel households use solar hot water heater (**SHW**) since '80s, that constitute 3% of Israel national energy consumption.



Solar Hot Water Heaters

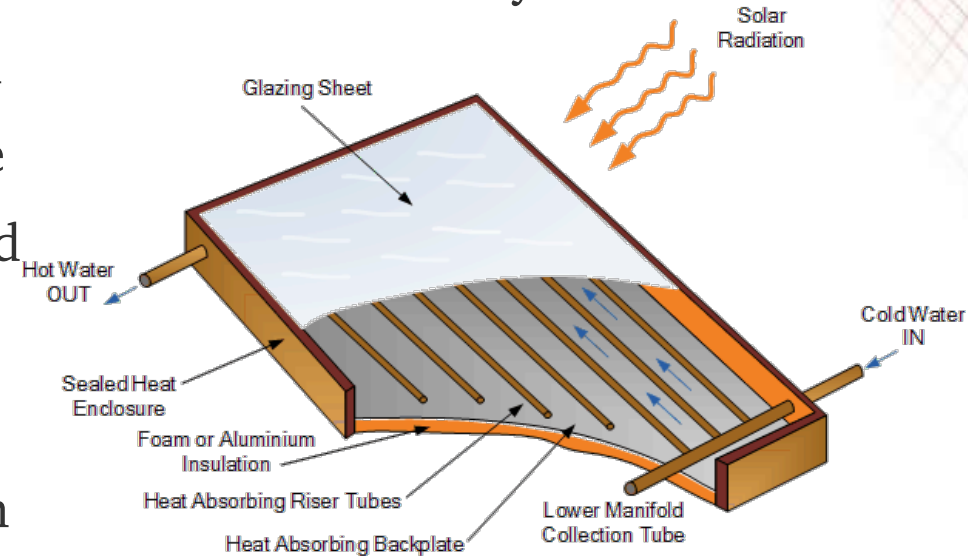
- Flat-plate collector has solar-absorbing surface/plate which is covered by a sheet of glass that allows the incident *shortwave* solar radiation to easily enter. The cover traps also the *longwave* radiation emitted from the heated absorber using the greenhouse effect. The tubing carries a fluid [water + 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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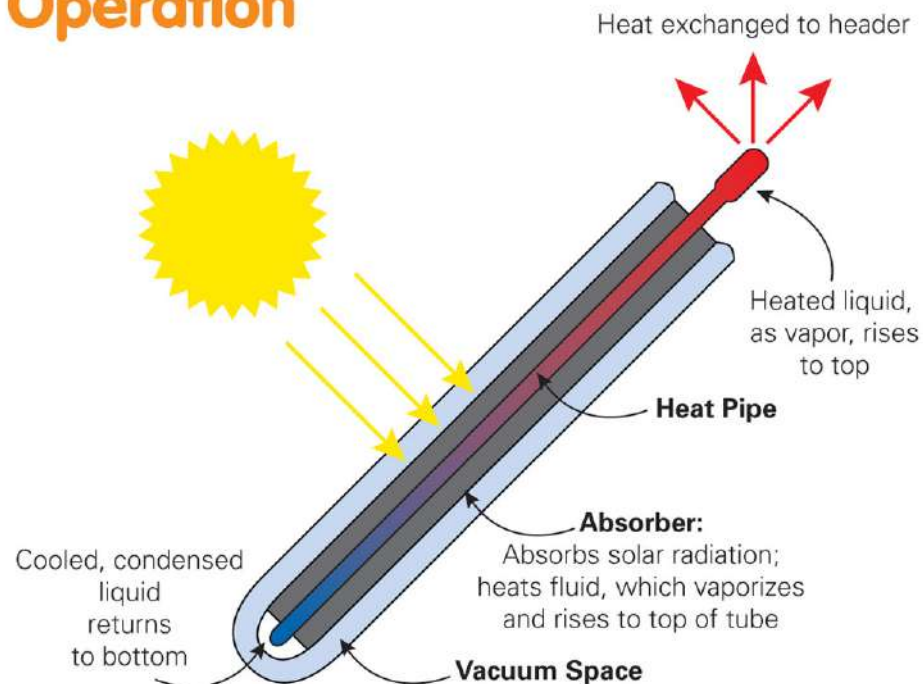


- Antifreeze* flows in a closed loop & does not mix with the household water supply. Once the antifreeze has been heated, it flows through heat exchanger that permits the flow of heat out of antifreeze & into home's water supply. At the heat exchanger, temperature of the home-water increases and antifreeze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

Evacuated Tube Operation

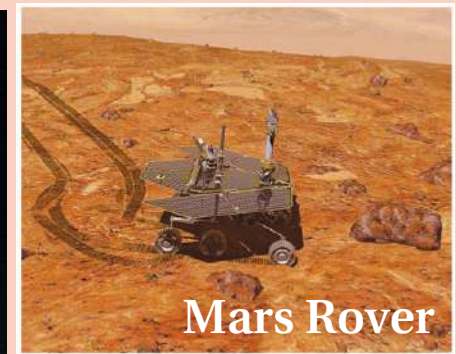
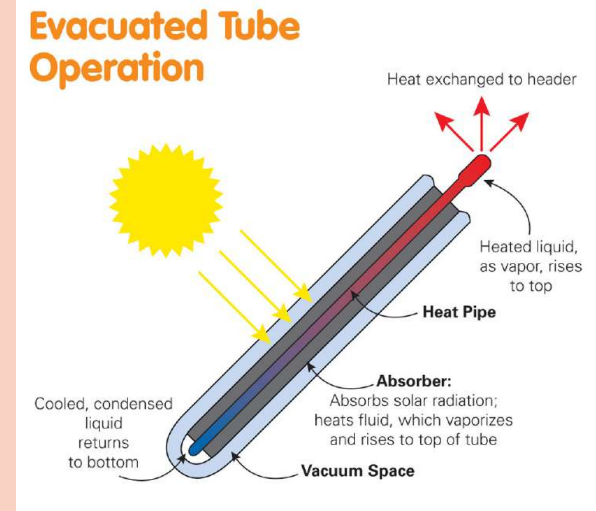


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- **Photovoltaics (PV)** ➡ conversion of light into electricity using semiconducting materials that exhibit PV effect. PV is the 3rd renewable energy in terms of global capacity. In 2016, worldwide PV capacity ~ 300 Gigawatts, covering 2% of global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



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

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’।

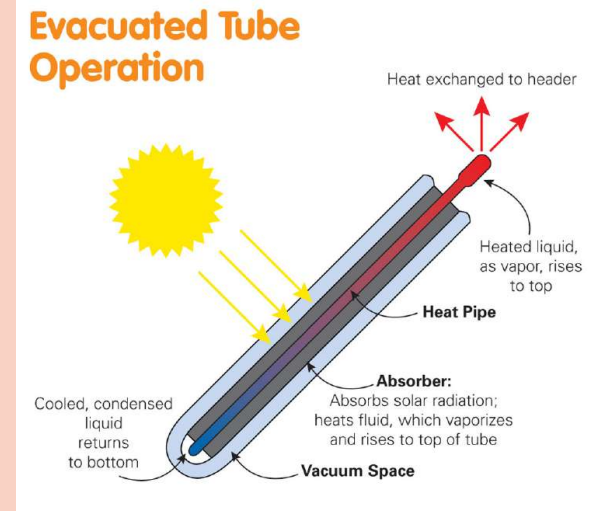
মেশিন চালাতে অপ্রচলিত শক্তির ব্যবহার শুরু করল কাশীপুর গান অ্যান্ড শেল ফ্যাক্টরি। শনিবার কারখানার পাঁচটি বাড়ির ছাদে সৌর প্যানেলের উদ্বোধন করেন কারখানার সিনিয়র জেনারেল ম্যানেজার রাজীব চক্রবর্তী। তিনি জানান, ১১৩০টি সৌর প্যানেল থেকে বছরে ৫ লক্ষ ৭৪ হাজার ইউনিট বিদ্যুৎ মিলবে। এতে বছরে প্রায় ৪৭ লক্ষ টাকা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

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

Solar Hot Water Heaters

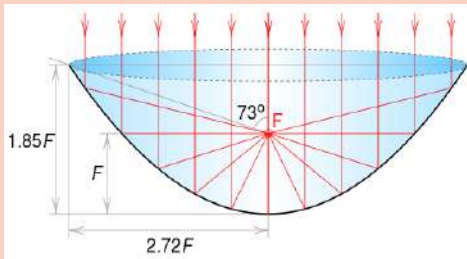
- Evacuated collectors eliminates both conductive & convective heat losses above the heated collector plate. Evacuated collectors have a cylindrical geometry, which has greater structural strength.

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 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**.





Tibet

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.



Auroville



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Auroville

Solar Pond

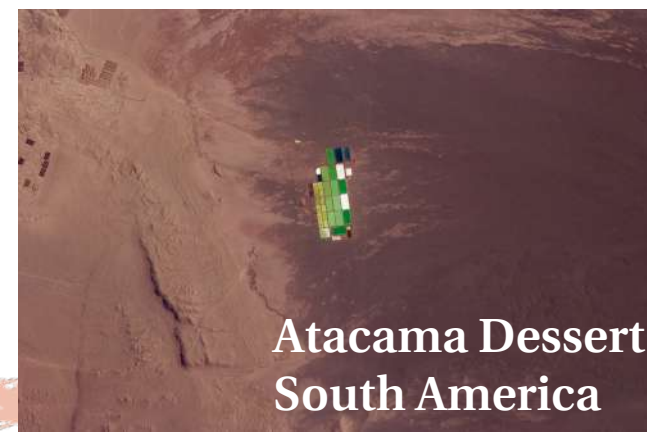
- Solar pond is a large scale solar thermal collector with an integrated arrangement for storage of heated saltwater. Saltwater naturally forms a vertical salinity gradient in which low-salinity water floats on top of high-salinity water. Below a certain depth, the solution has a uniformly high-salt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



Atacama Dessert
South America

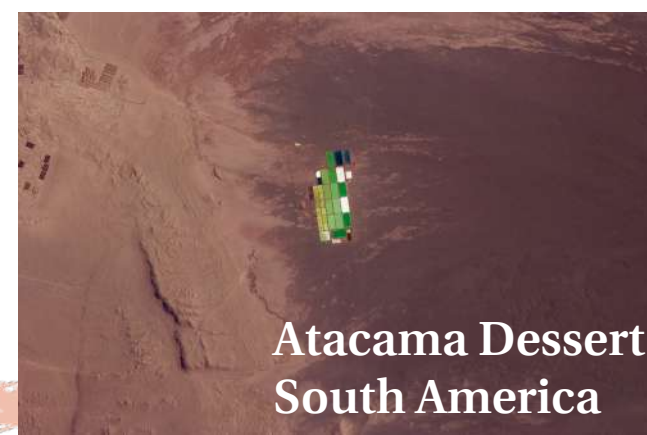
Solar Pond

- 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.



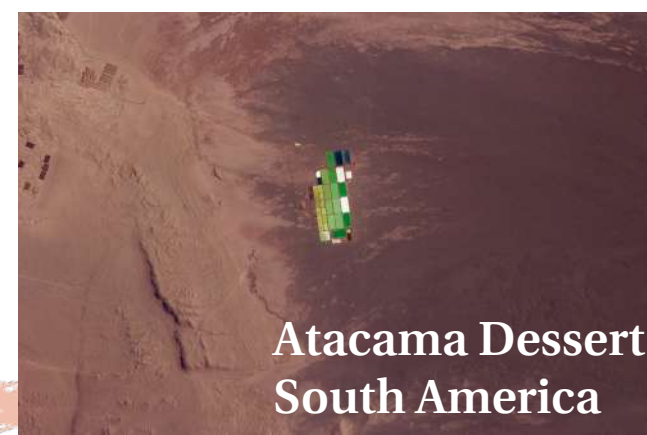
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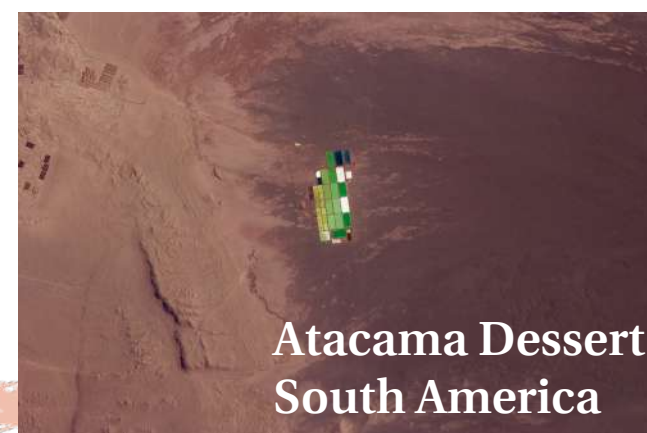
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- **Advantages/Disadvantages** ➡ (i) Attractive for rural areas in developing countries as large-area collectors can be setup for low-cost of clay/plasticpond. (ii) Accumulated salt-crystals are removed & are valuable by-product.



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%.
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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.

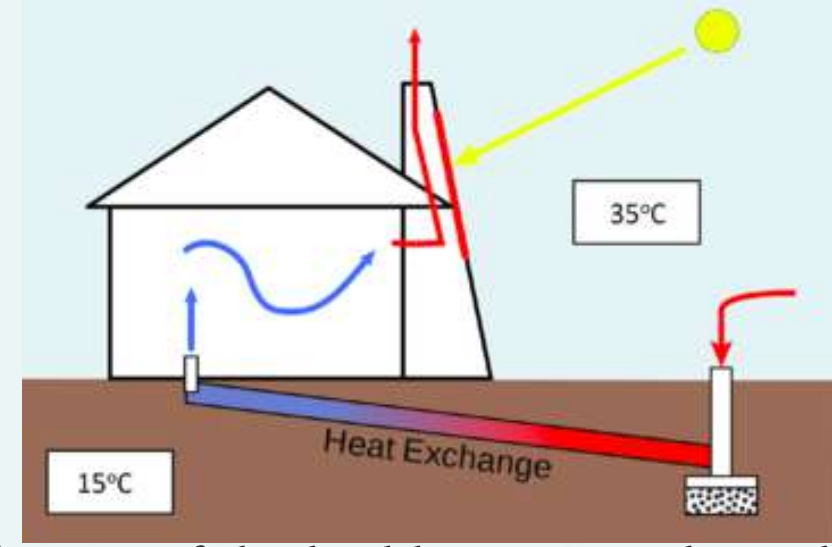


Salt evaporation pond



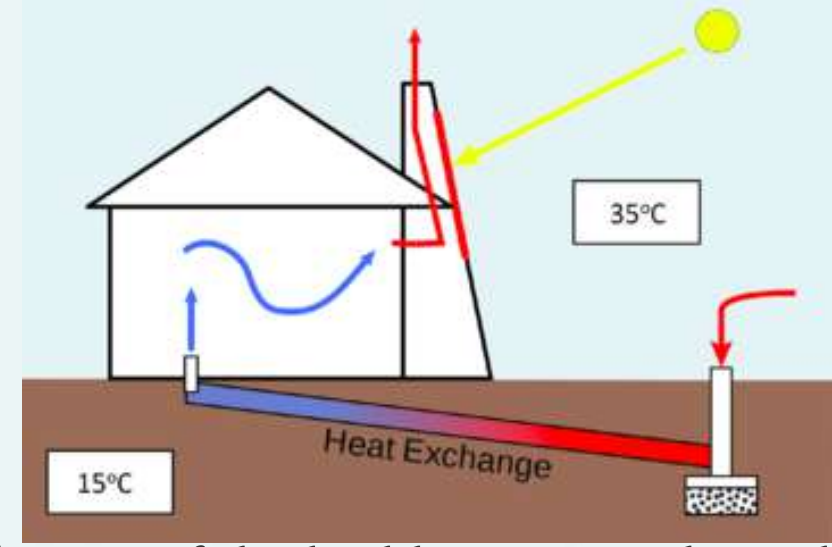
Solar Chimney

- 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.



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Geothermal Energy



Rincón de la Vieja
Costa Rica



Kilauea, Hawaii



Bilecik, Turkey



Krafla, Iceland

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).



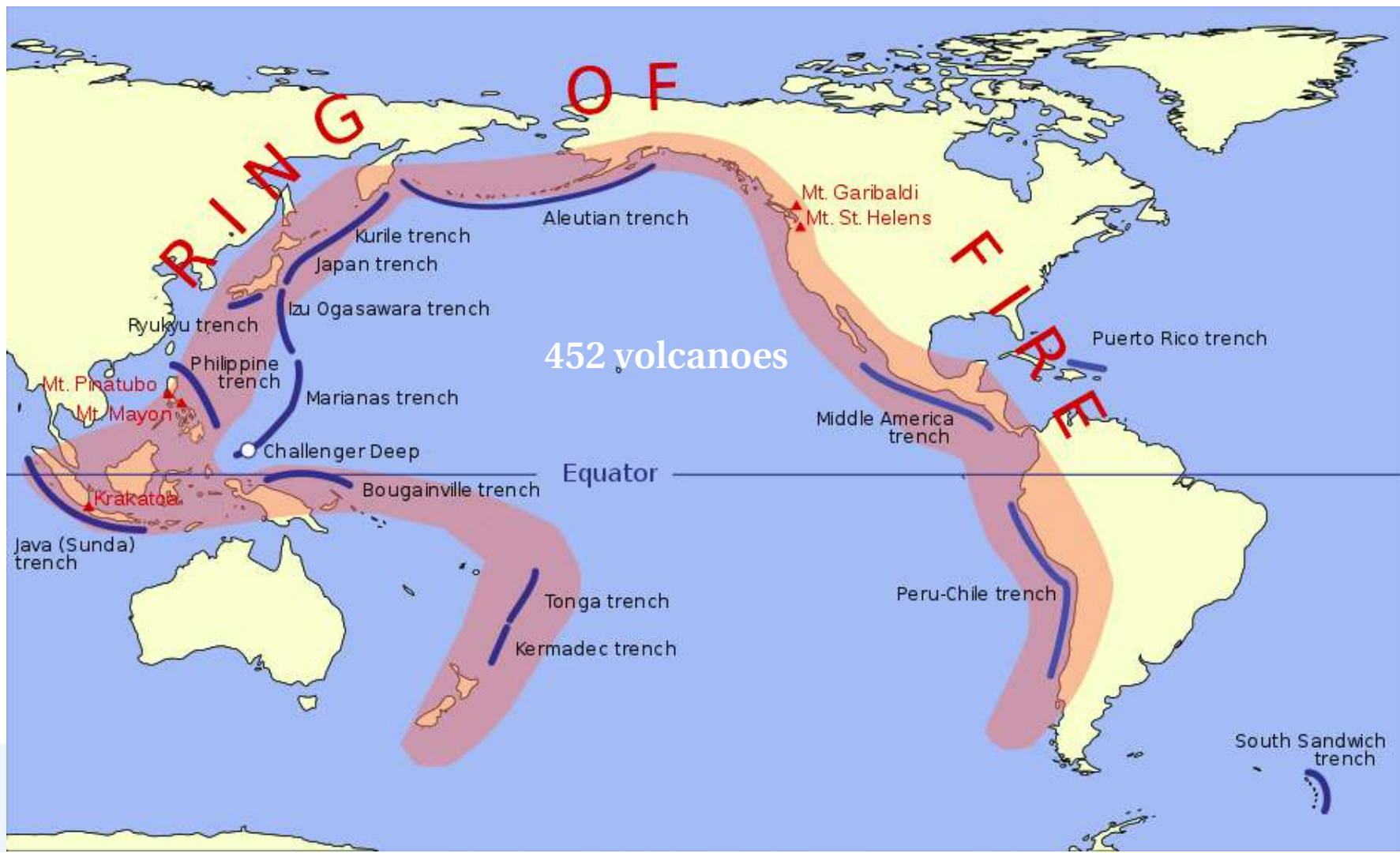
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- Geothermal energy is the heat from the Earth. Resources range from the moderate temperature hot springs to hot/molten rock. Below Earth's crust, magma layer contain hot and molten rocks. Heat is continually produced by decaying of radioactive materials (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.*



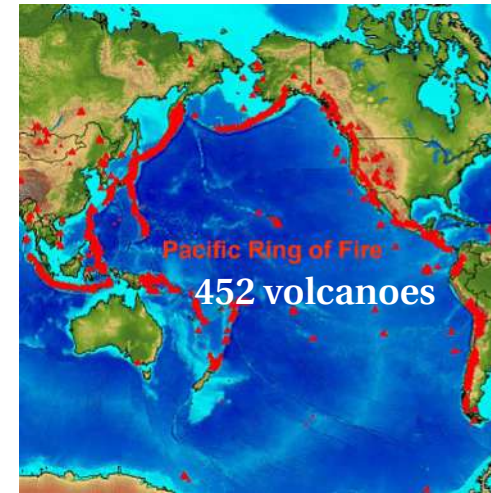
Volcanoes

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



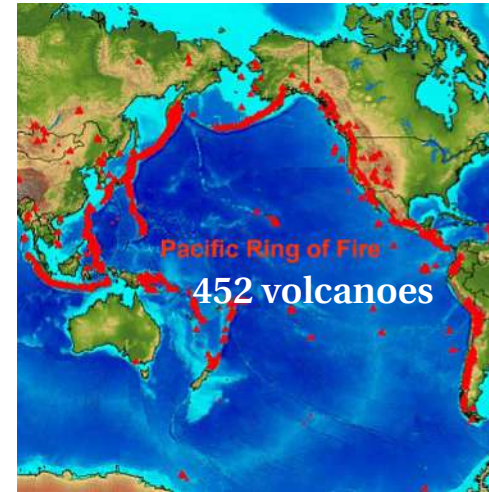
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- Plate tectonics , Earth's crust (lithosphere) consists of ~ 12 distinct, irregularly-shaped, rigid *plates*. They slide over weaker & more plastic layer of rock (asthenosphere), scraping/colliding against each other. Collision forces lower plate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



Volcanoes

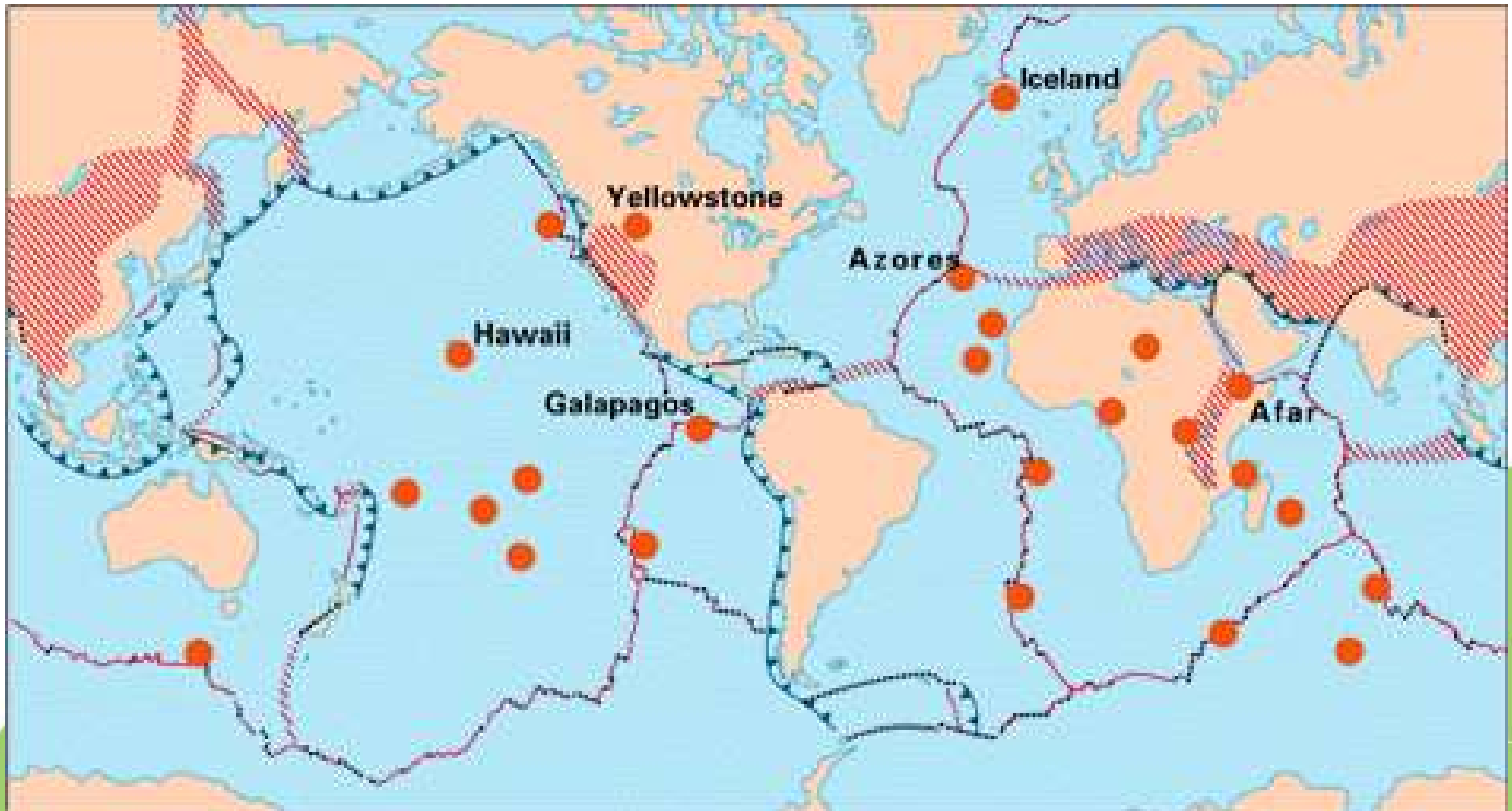
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- In **mid-Atlantic Ridge** (e.g. Iceland), two adjacent plates move away & during separation, magma wells upward to fill the resulting rift in the surface. Geothermal energy are available along the boundaries, where plates are diverging.

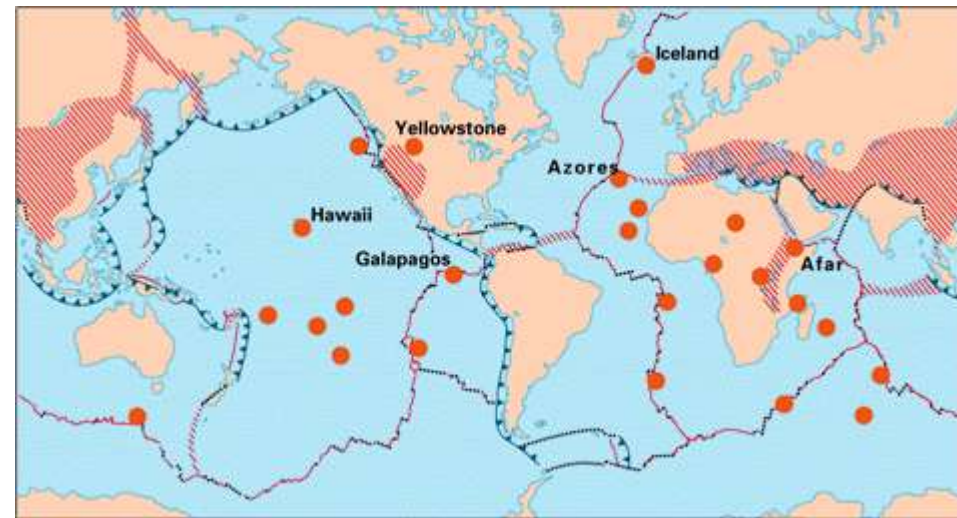
Volcanoes

- 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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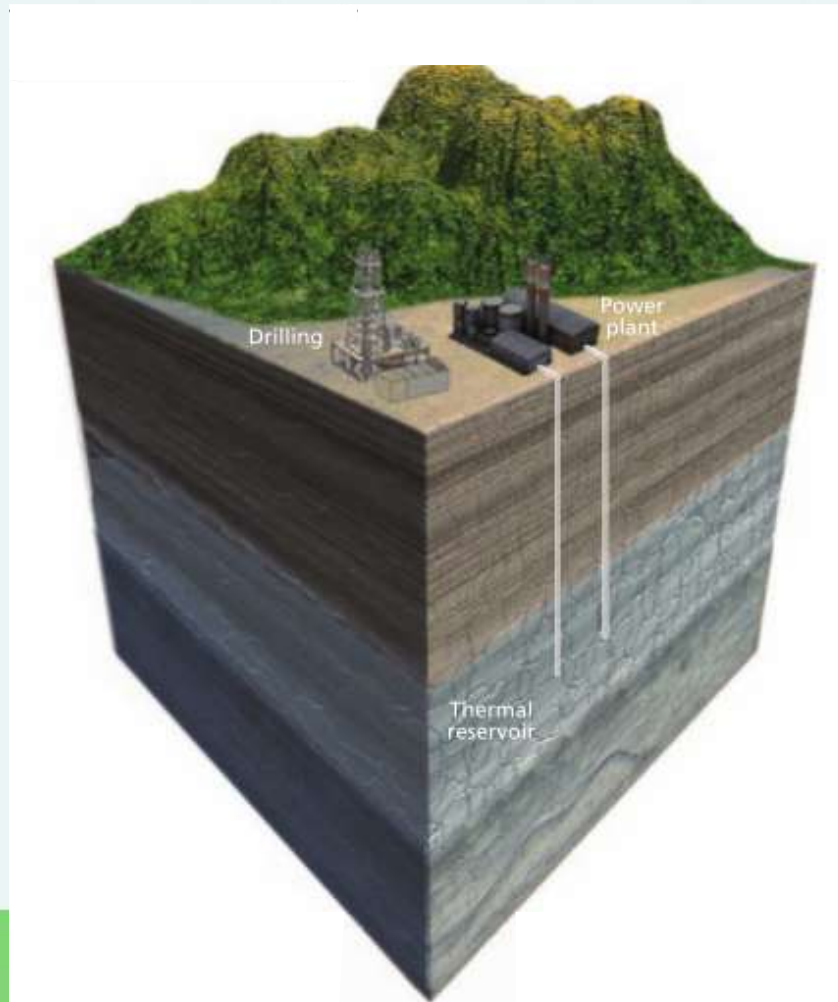


Mining Thermal Energy : *Hydrothermal Convection*

- 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.

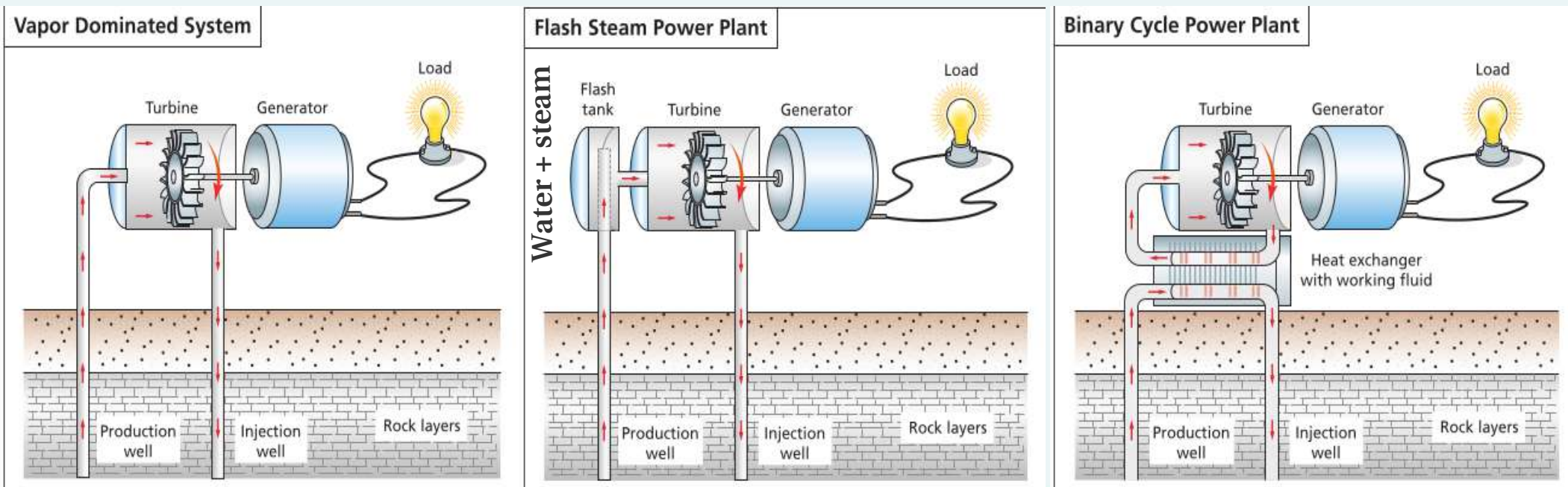
Mining Thermal Energy

- 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.



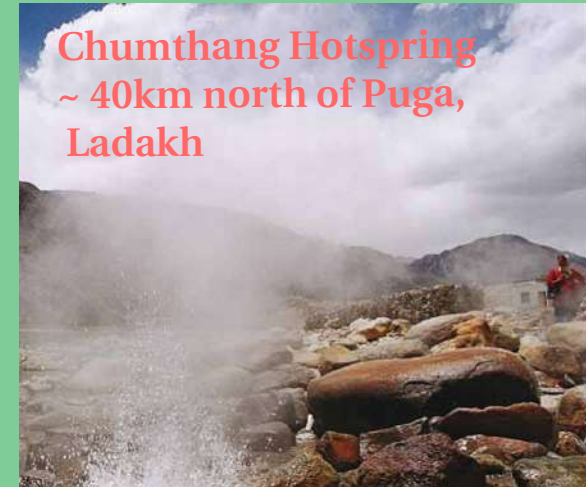
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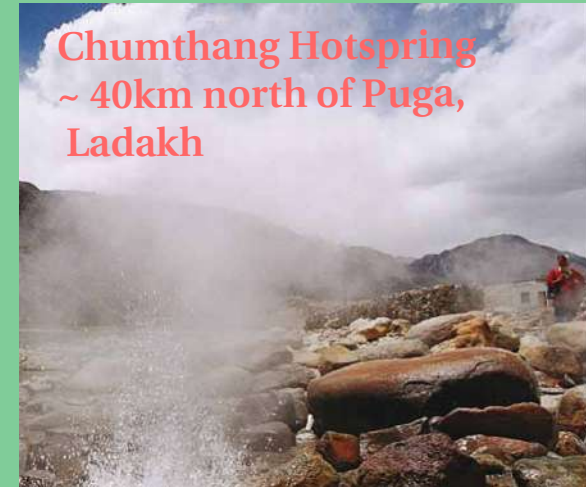
Geothermal Energy in India

- 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.



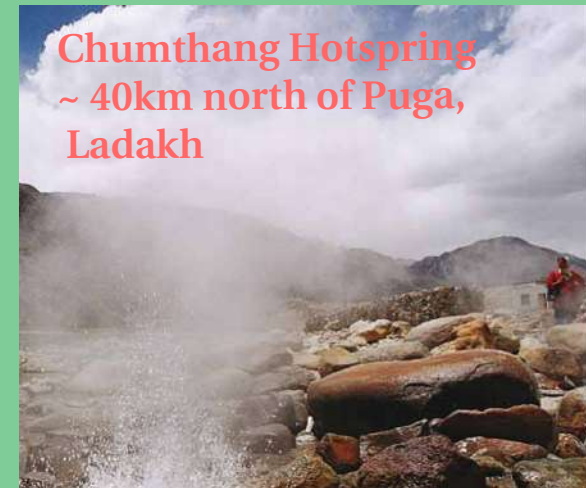
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- Springs are grouped into **7** geothermal provinces ➡ (i) Himalayan (Puga, Chumthang), (ii) Sahara Valley, (iii) Cambay Basin, (iv) Son-Narmada-Tapti (SONATA) belt, (v) West Coast, (vi) Godavari basin, and (vii) Mahanadi basin. Prominent geothermal 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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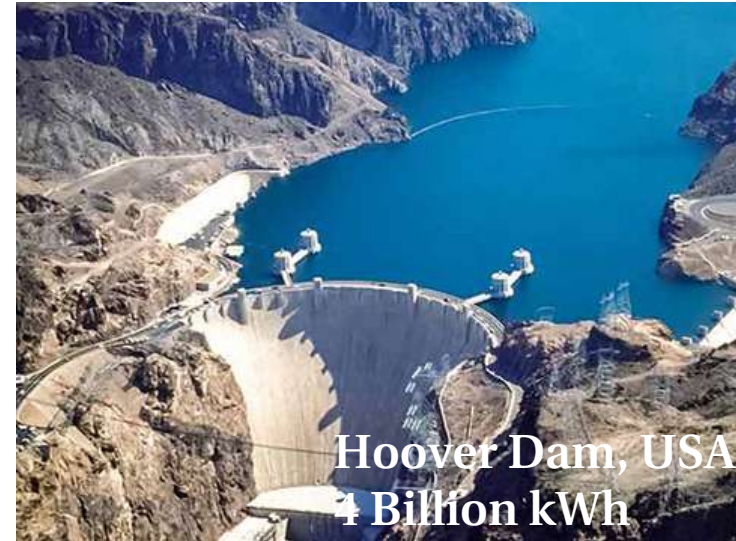
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- At **Tapovan** geothermal area, the highest temperature recorded is **65°C**. Discharge is **0.83-9.2 litre/second**. The surface manifestations show occurrence of white to dirty white deposits identified as silica and moderate to low sag activity. 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.





Hydroelectric Power



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.



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



Orontes, Syria



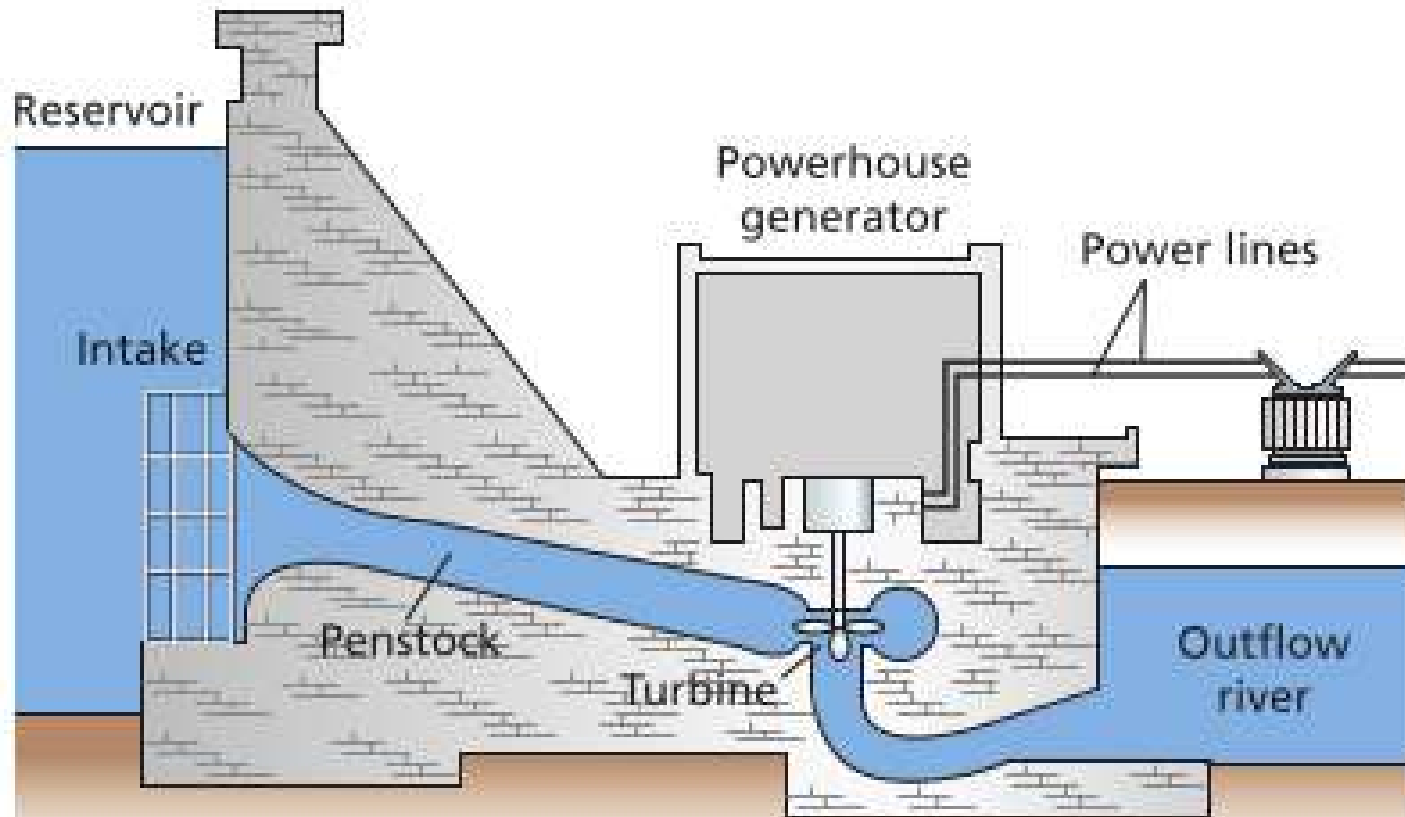
Niagara Gorge, 1900



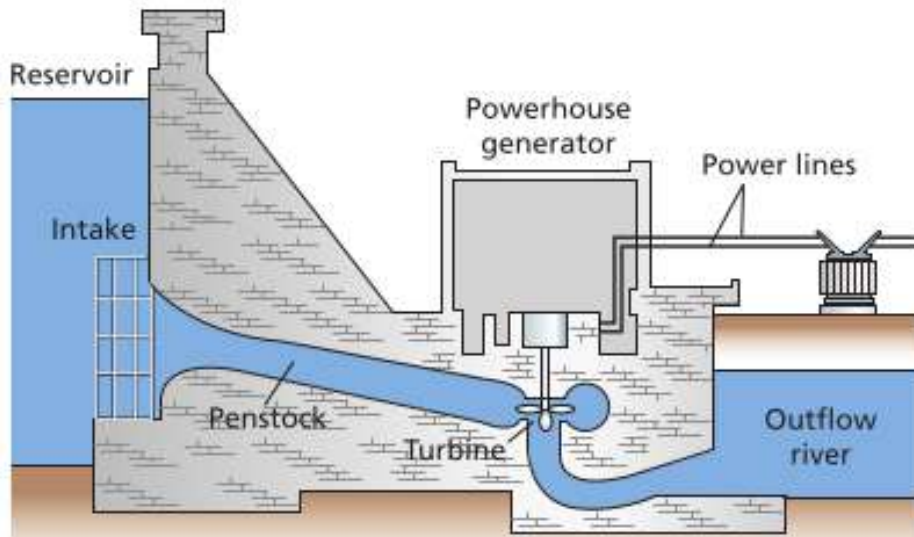
Niagara Gorge, 2014

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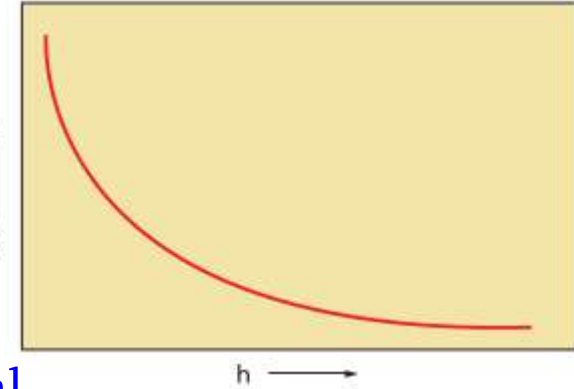
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- **Turbines** are two types: (a) **Waterwheel** turbines
 - (i) Impulse turbines, (ii) Pelton turbines, (b) **Reaction** turbines. In Pelton turbines, pressure of head produces water stream out of a nozzle aimed to series of buckets arranged around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



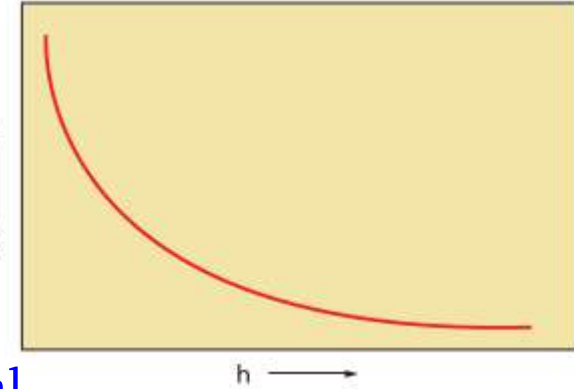
Hydroelectricity

- **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.





Wave & Tidal Power



Wave Power

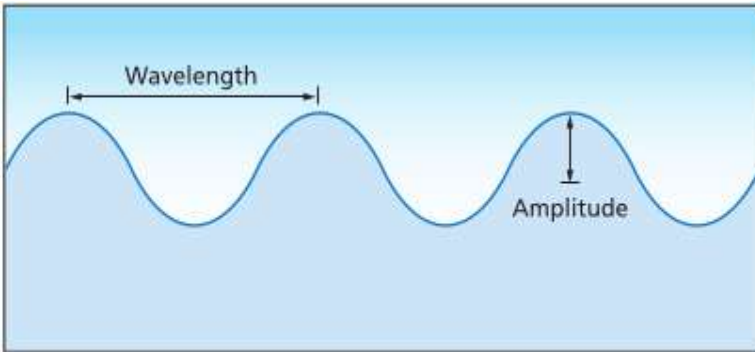
- Waves are powerful and destructive. Though a machine designed to convert wave to electrical energy in principle is promising, central problem is (a) wave power occurs in surges, and (b) the wave environment is a destructive one.



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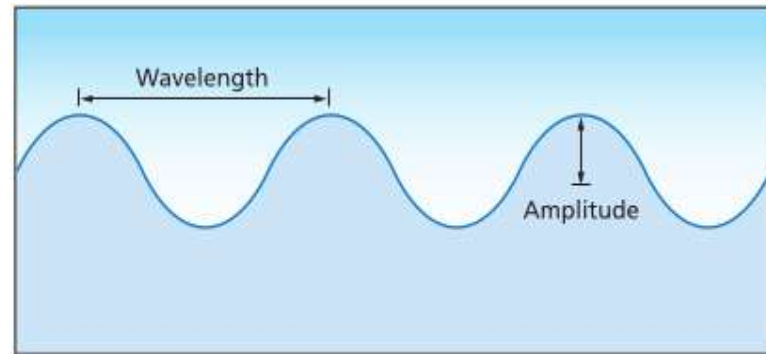
- Wave is a disturbance due to wind in the ocean's surface. The disturbance moves forward rather than water (which oscillates). Classification of waves ➡ (i) **amplitude** $\rightarrow \frac{1}{2}$ of the vertical distance from peak to trough, (ii) **wavelength** $\lambda \rightarrow$ distance in consecutive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

Wave Power



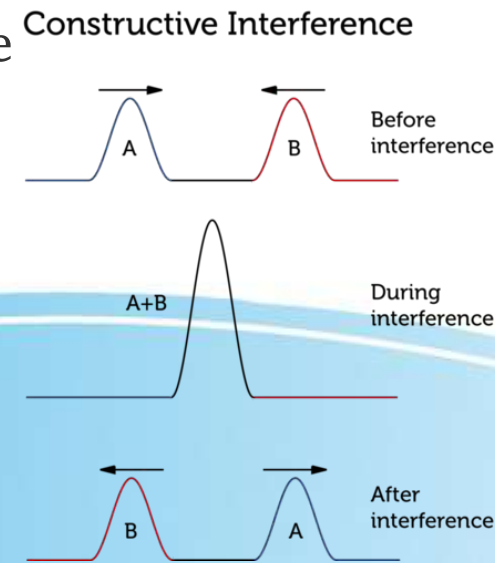
- Waves are powerful and destructive. Though a machine designed to convert wave to electrical energy in principle is promising, central problem is (a) wave power occurs in surges, and (b) the wave environment is a destructive one.

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- Wave 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.

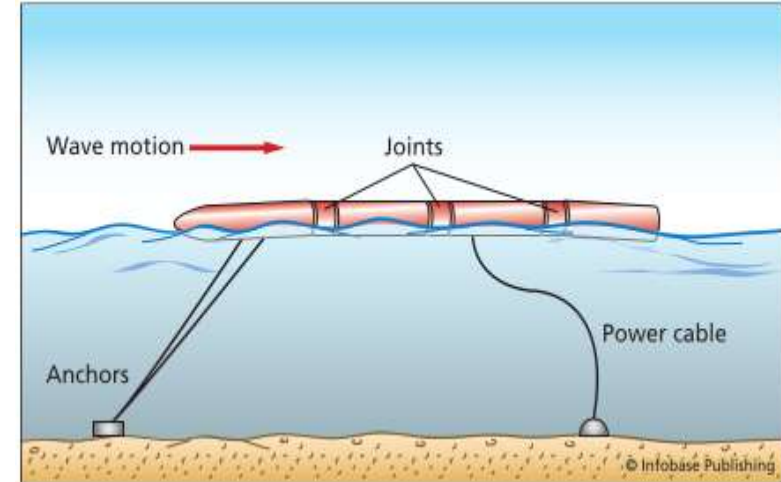


Sea Snakes

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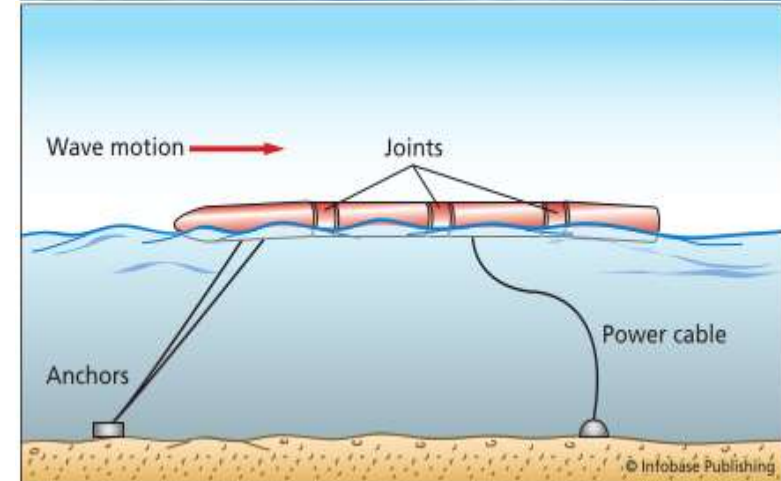
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Pelamis sag in the **wave troughs** and arch upwards in **wave crests**. As the joint between cylinders begins to flex, good volume of force is exerted at the joint by the steel cylinders, with which **hydraulic ram** is powered. The ram drives oil through a motor, like a hydroelectric turbine – motor drives a generator to produce electricity. Power is sent to a cable to transport electricity to shore.



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 **bicycle 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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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 $A_h \ll$, then $S_h \gg$. 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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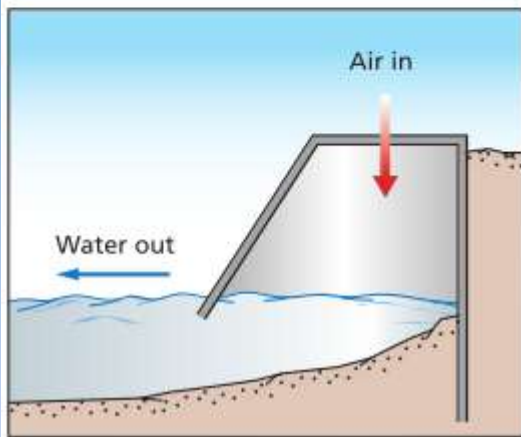
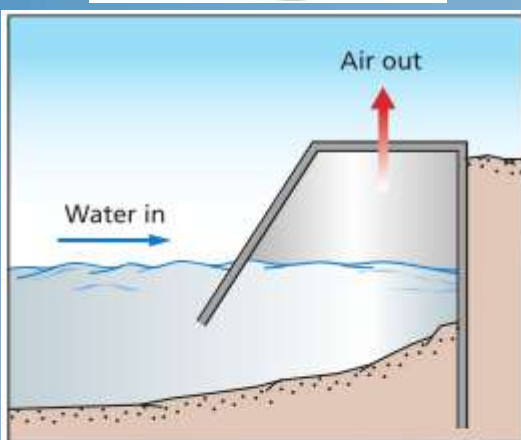
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Oscillating water Column (OWC) Energy Converter



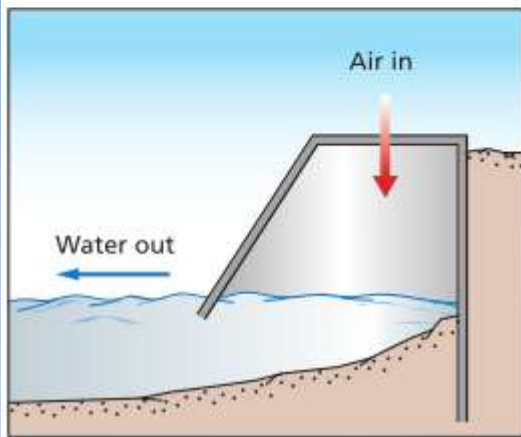
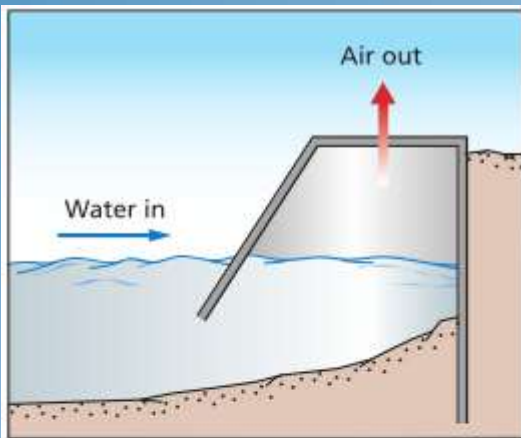
- OWC technology works on same principle as the pump. A large **box** with two openings is built in an area of strong wave action. A small **hole** lies atop the box & another **hole** is left open at the bottom of the box for water to flow in-out. Walls extend down below the waterline, so that the ocean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



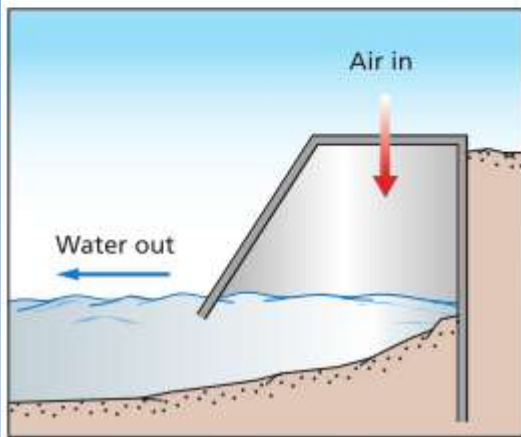
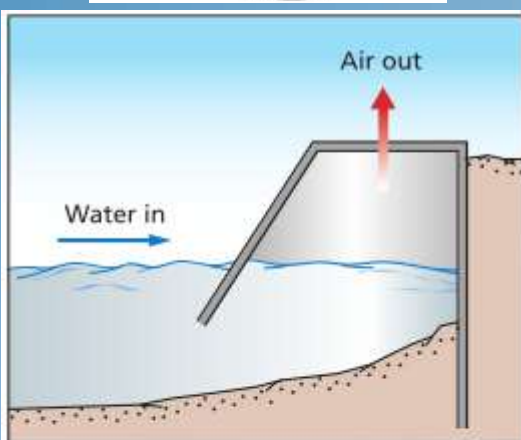
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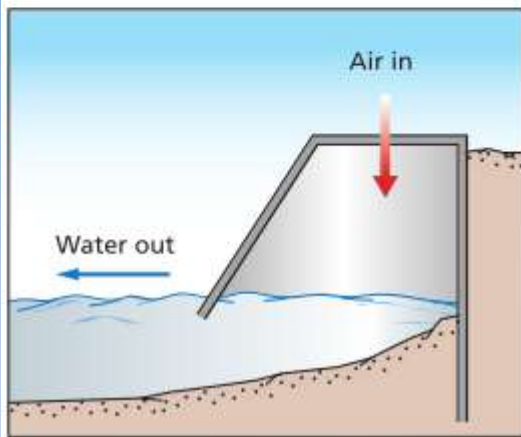
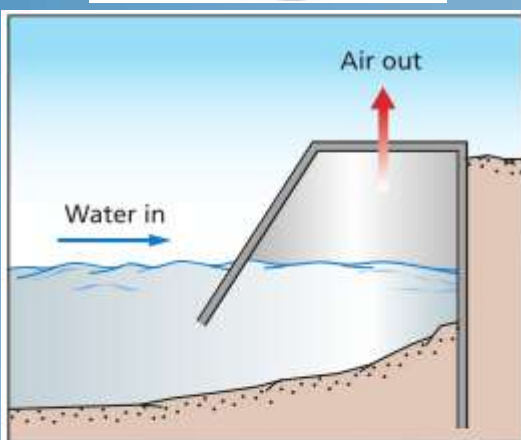


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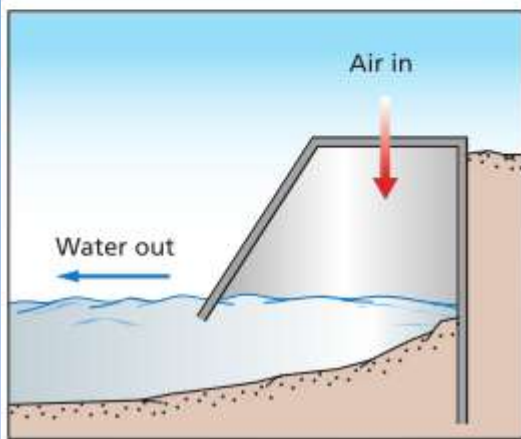
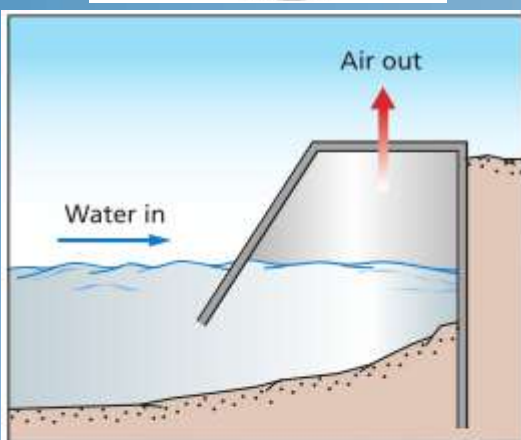
Oscillating water Column (OWC) Energy Converter



- 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.

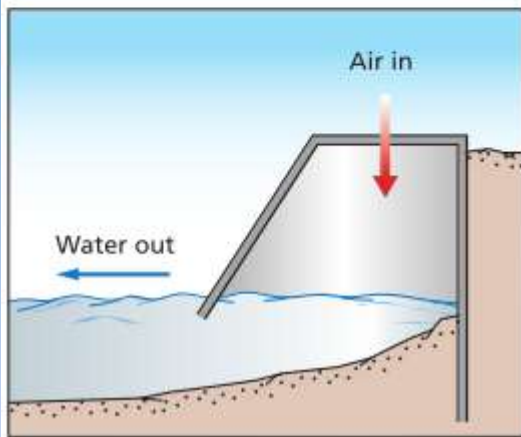
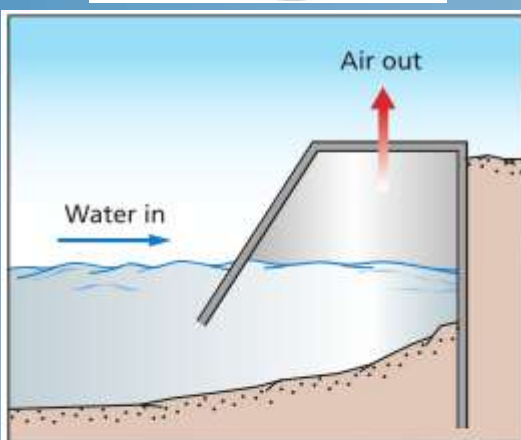


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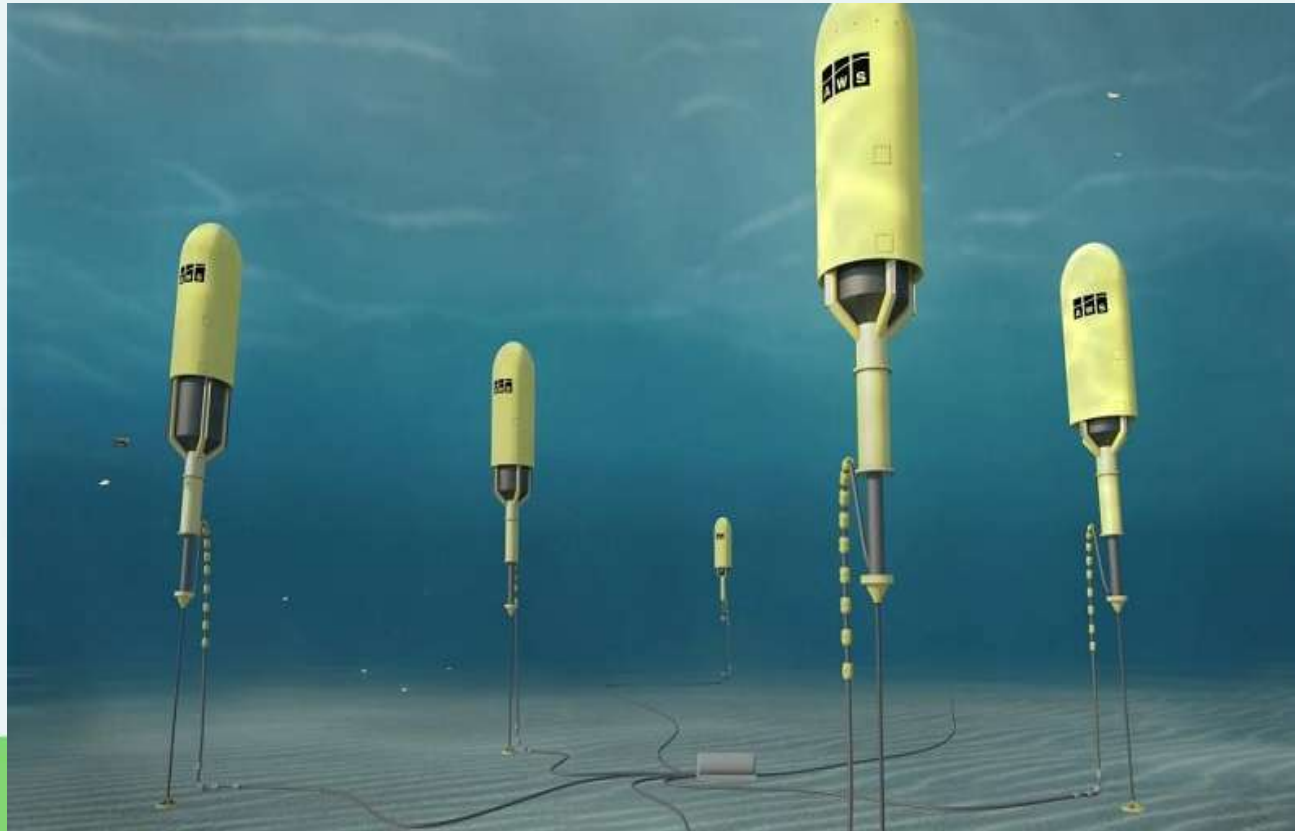
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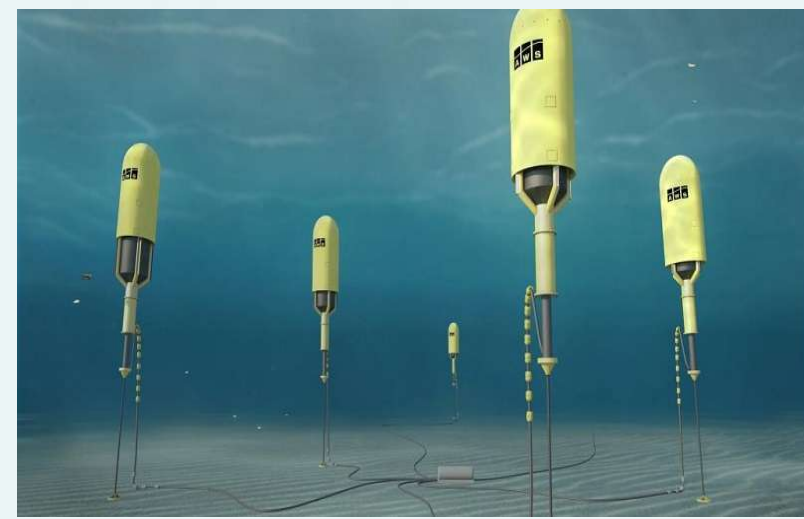
Archimedes Wave Swing (AWS)

- 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.
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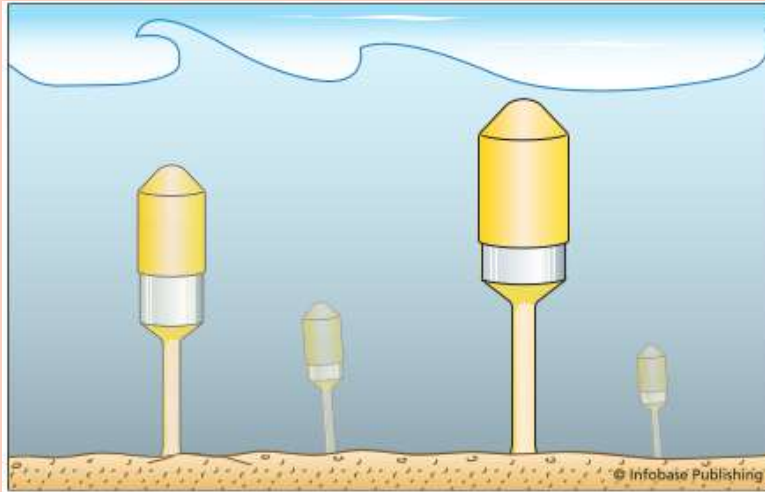
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- Working Principle** → AWS is large cylinder filled with air & firmly attached to the seafloor. The cylinder consists of a moveable upper section and a fixed lower section. The air acts as spring that serves to restore the cylinder after being compressed by pressure of passing waves.



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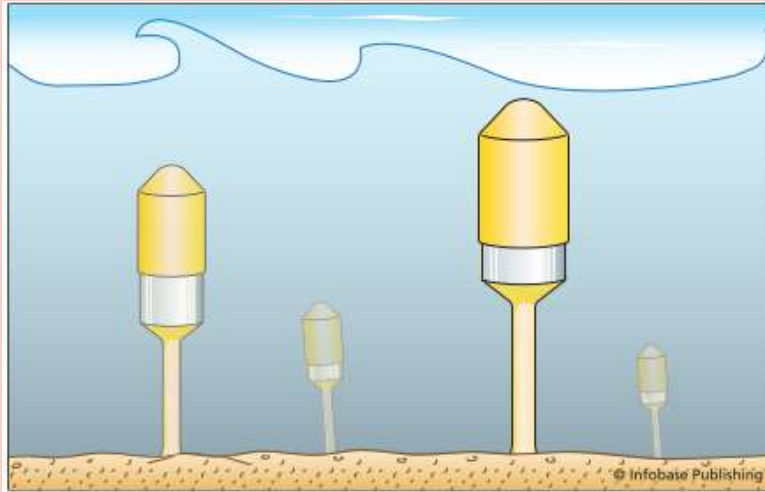
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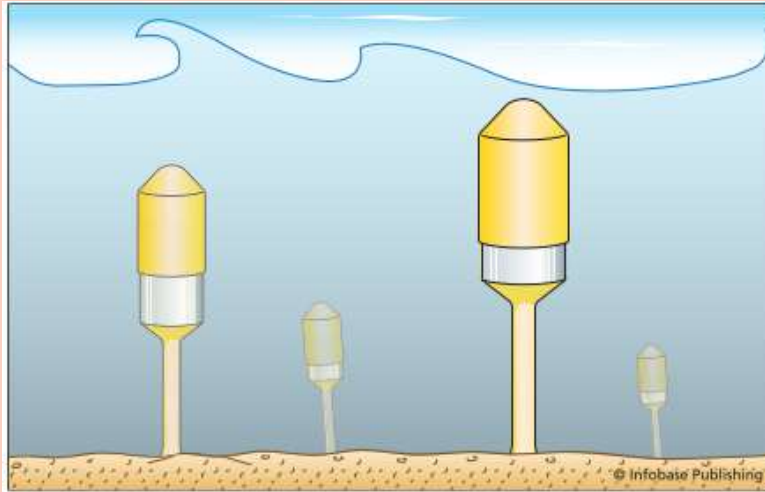


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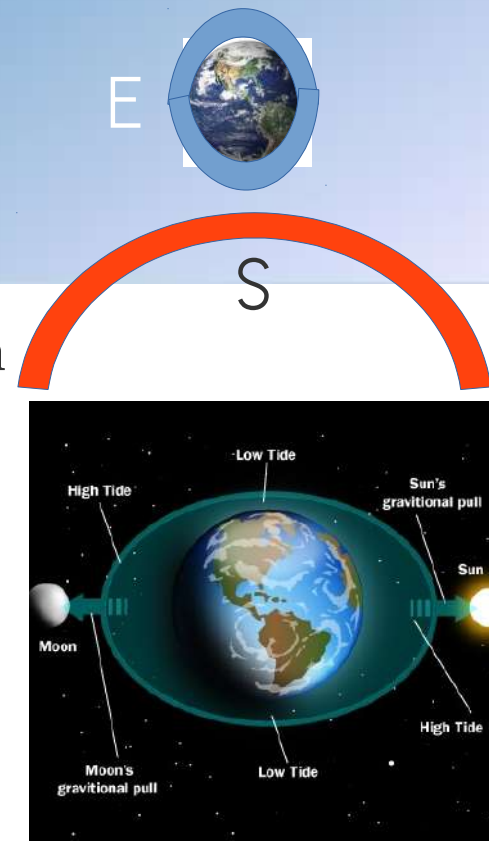


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Consequently, pressure on AWS is also minimum. Air inside the cylinder, which was compressed by the peak of wave, now expands outward, pushing upper part of the cylinder upward until the pressure inside the cylinder balances the pressure outside. The 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).



Tidal Energy

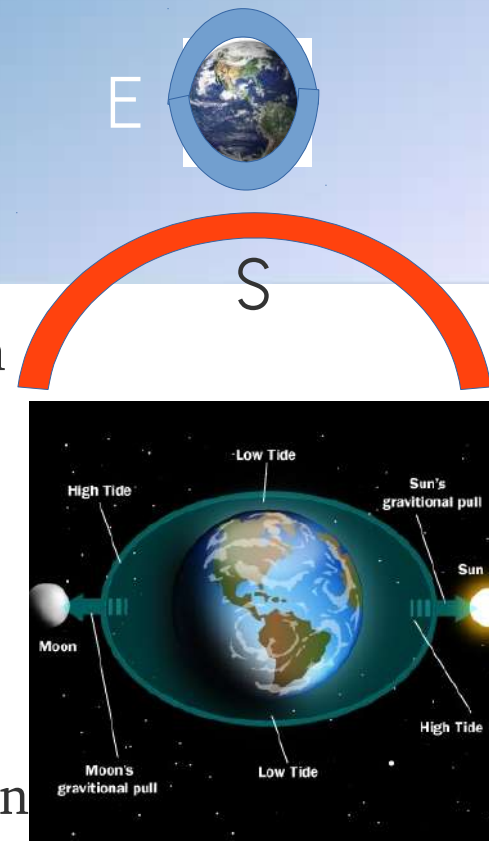
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Say, M_S, M_M are mass of Sun & Moon & D_S, D_M are distance between

Earth-Sun & Earth-Moon. Then, force due to Sun & Moon is,

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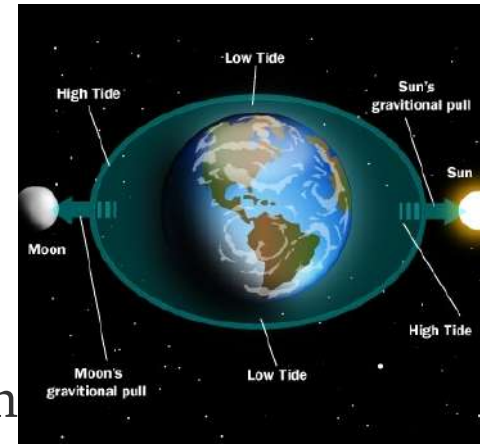
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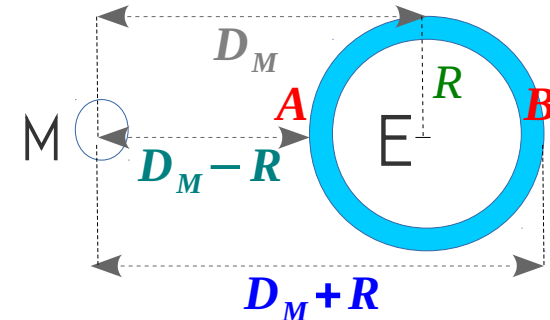
- **Difference of attraction between A & B point on Earth with hydrosphere (by any arbitrary mass m) due to Moon** →

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



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Tidal Energy

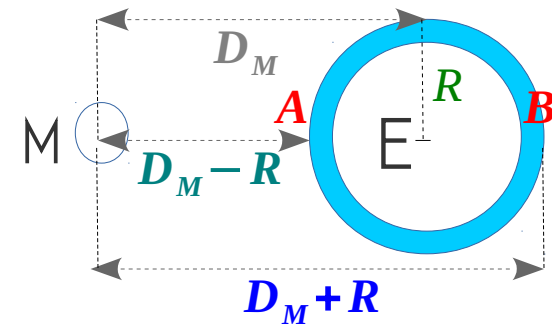
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$T_M \approx G M_M m \frac{4 R}{D_M^3}$. This is the differential pull by Moon on opposite points on the surface of the Earth. Similarly for Sun, $T_S \approx G M_S m \frac{4 R}{D_S^3}$.

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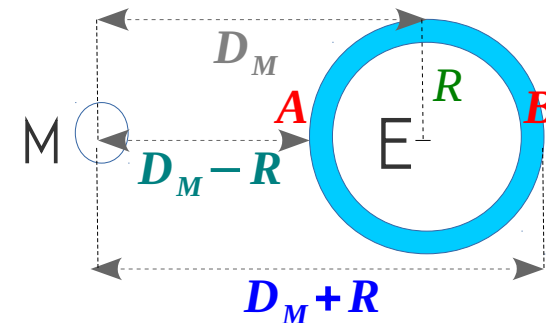
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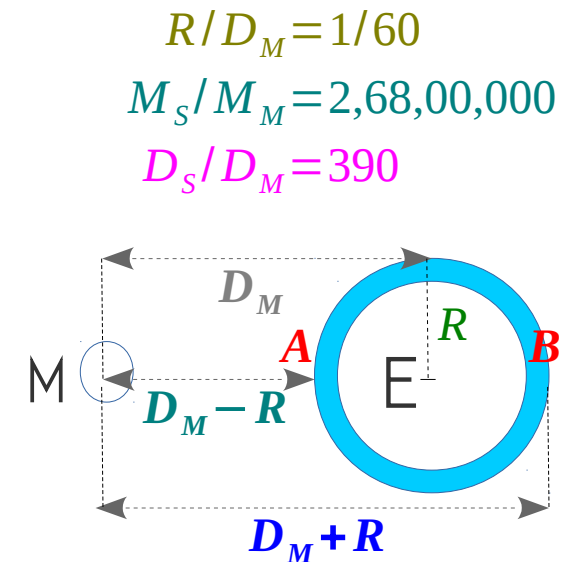
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■ So there will be **two** tidal bulges due to Moon & **two** other bulges due to Sun. In new-Moon phase (*Sun & Moon in almost same direction*), so bulge due to Moon & Sun will coincide to produce very strong tides (**spring tides**). In full-Moon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



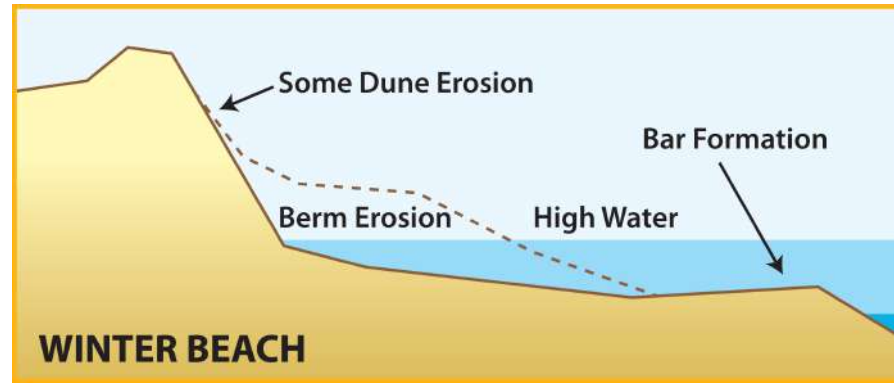
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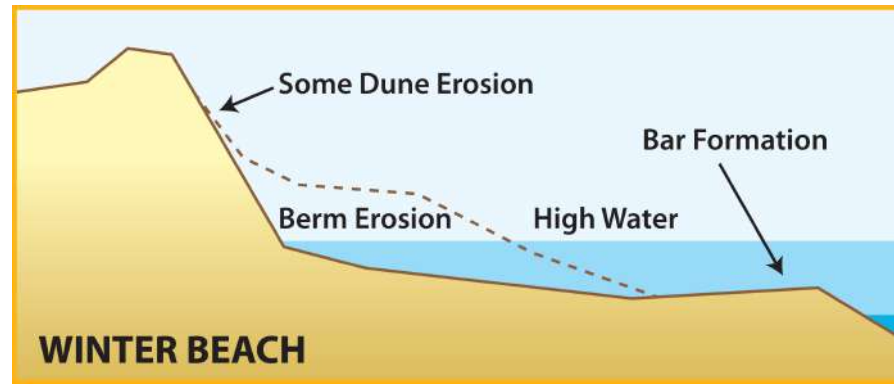
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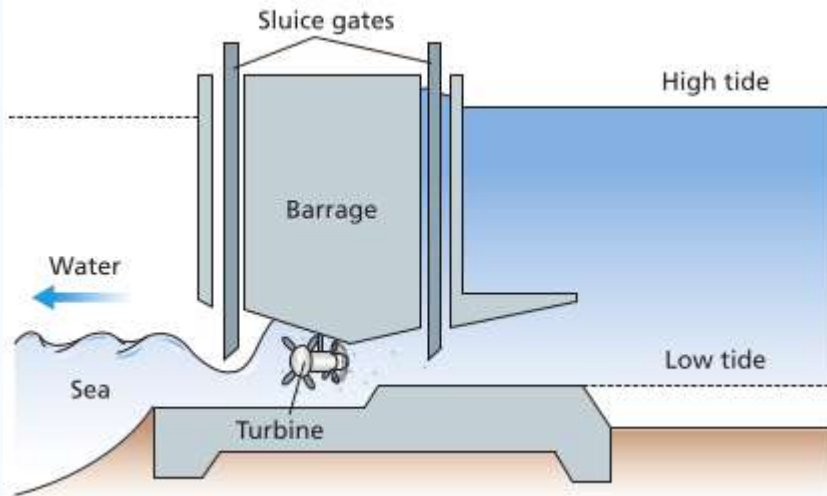
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- **Not every sea (e.g. Mediterranean) has a tidal activity!** Because tidal bulge moves from east to west due to rotation of Earth, it so happens that Mediterranean sea has opening only to the west & so the tidal bulge cannot enter.

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.

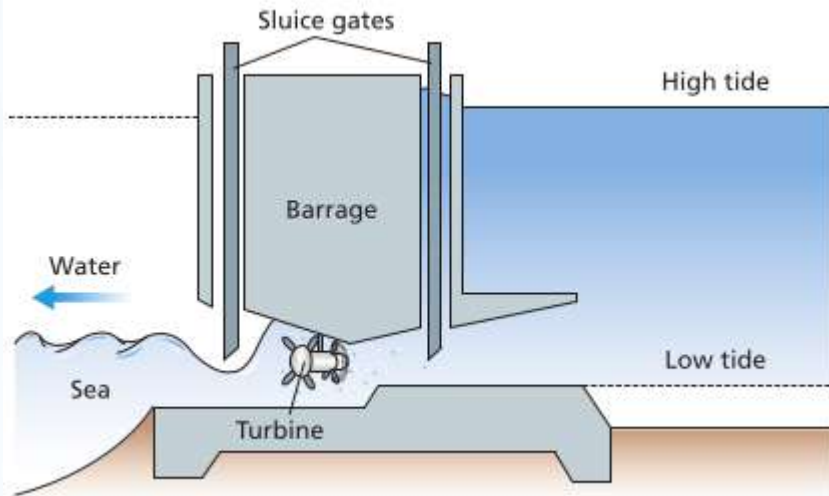


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La Rance, Brittany,
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closed, trapping the water behind the dam. As the tide ebbed, it created a difference between the height of the water behind the dam and the height of the sea in front of the dam. Water was released when the tide was low enough & the **hydraulic head** was high enough. As the water

flowed back to the sea it was used to drive a **waterwheel**. The waterwheel powered a mill, that ground grain. Unlike a waterwheel driven by a river or stream, the **tidal mill** only worked twice each day because of **two** tidal cycles.

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.
- 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.