Energy Science and Engineering

Unit-I Energy and its Usage: Units and scales of energy use, Mechanical energy and transport, Heat energy: Conversion between heat and mechanical energy, Electromagnetic energy: Storage, conversion, transmission and radiation, Introduction to the quantum, energy quantization, Energy in chemical systems and processes, flow of CO2, Entropy and temperature, carnot and Stirling heat engines, Phase change energy conversion, refrigeration and heat pumps, Internal combustion engines, Steam and gas power cycles, the physics of power plants. Solid-state phenomena including photo, thermal and electrical aspects

Unit-II Nuclear Energy: Fundamental forces in the universe, Quantum mechanics relevant for nuclear physics, Nuclear forces, energy scales and structure, Nuclear binding energy systematics, reactions and decays, Nuclear fusion, Nuclear fission and fission reactor physics, Nuclear fission reactor design, safety, operation and fuel cycles

Unit-III Solar Energy: Introduction to solar energy, fundamentals of solar radiation and its measurement aspects, Basic physics of semiconductors, Carrier transport, generation and recombination in semiconductors, Semiconductor junctions: metal-semiconductor junction & p-n junction, Essential characteristics of solar photovoltaic devices, First Generation Solar Cells, Second Generation Solar Cells, Third Generation Solar Cells

Unit-IV Conventional & non-conventional energy source: Biological energy sources and fossil fuels, Fluid dynamics and power in the wind, available resources, fluids, viscosity, types of fluid flow, lift, Wind turbine dynamics and design, wind farms, Geothermal power and ocean thermal energy conversion, Tidal/wave/hydro power

Unit-V Systems and Synthesis: Overview of World Energy Scenario, Nuclear radiation, fuel cycles, waste and proliferation, Climate change, Energy storage, Energy conservation. Engineering for Energy conservation: Concept of Green Building and Green Architecture; Green building concepts, LEED ratings; Identification of energy related enterprises that represent the breath of the industry and prioritizing these as candidates; Embodied energy analysis and use as a tool for measuring sustainability. Energy Audit of Facilities and optimization of energy consumption

Reference/Text Books

1. Energy and the Challenge of Sustainability, World Energy Assessment, UNDP, New York, (2000).
2. Perspective of Modern Physics, A. Beiser, McGraw-Hill International Editions (1968).
3. Introduction to Modern Physics, H.S. Mani and G.K.Mehta, East-West Press (1988).
4. Introduction to Electrodynamics, D. J. Griffiths, Fourth Edition, Prentice Hall (2013).
5. Introductory Nuclear Physics, R. K. Puri and V.K. Babbar, Narosa Publishing House (1996).
6. Physics of Solar Cells: From Basic Principles to Advanced Concepts by Peter Wurfel, John Wiley & Sons, 2016
7. Principles of Solar Engineering, D.Y. Goswami, F.Kreith and J.F. Kreider, Taylor and Francis, Philadelphia, 2000.

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Electricity Companies in India 2021

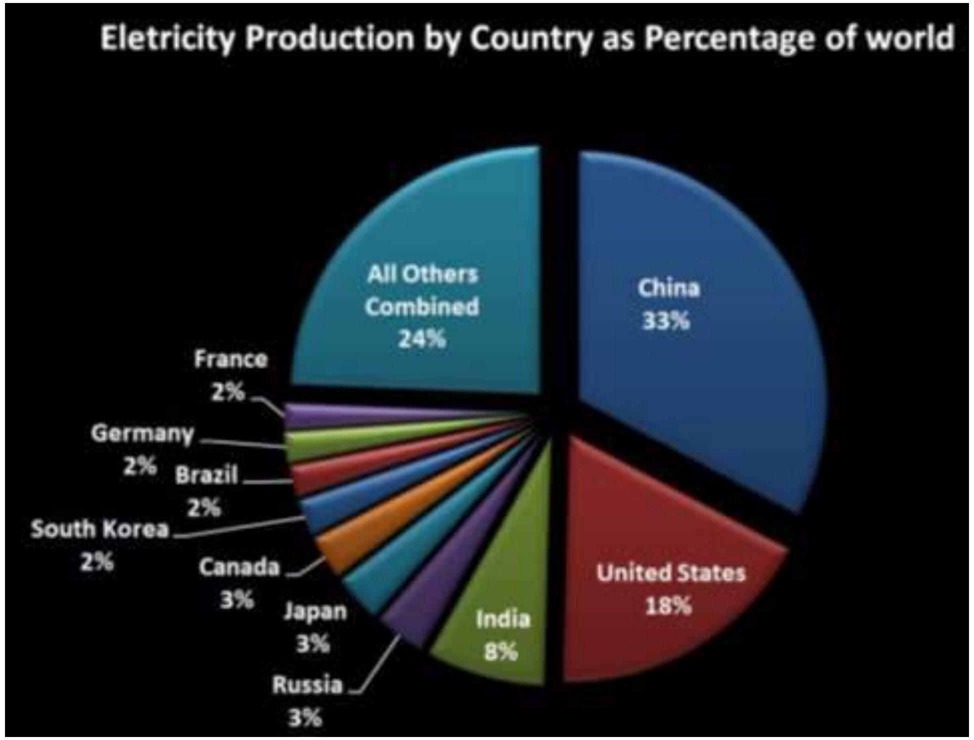
According to the Central Electricity Authority, the total installed power generation capacity of the country stood at 3,56,818 MW in May 2019. This included 2,26,279 MW of thermal power generation capacity, 45,399 MW of hydropower generation, and 78,359 MW of renewable energy generation capacity.

Top Electricity Companies in India

1. NTPC Ltd
2. Tata Power Company Ltd
3. Adani Power Limited
4. Torrent Power Ltd
5. JSW Energy Ltd
6. SJVN Ltd
7. Adani Green Energy Ltd

Production [edit]

Rank	Country/region	Electricity production (GWh)	Date of information
N/A	*World total*	27,644,800	2019[1]
1	China	7,503,400	2019[2]
2	United States	4,401,300	2019[2]
3	India	1,558,700	2019[2]
4	Russia	1,118,100	2019[2]
5	Japan	1,036,300	2019[2]
6	Canada	954,400	2018[1]
7	South Korea	794,300	2018[1]
8	Brazil	688,000	2018[1]
9	Germany	648,700	2018[1]
10	France	574,200	2018[1]



- **All India Installed Capacity (MW)**

As on 31.10.2016 (In MW)

Sector	Thermal	Nuclear	Hydro	Renewable	Grand Total	Sector wise %
Central	58,751	5,780	11,651	-	76,182	25%
State	71,155		28,341	1,975	1,01,471	33%
Private	82,563		3,120	43,942	1,29,625	42%
All India	2,12,469	5,780	43,112	45,917	3,07,278	
Discipline wise %	69%	2%	14%	15%		

In MW

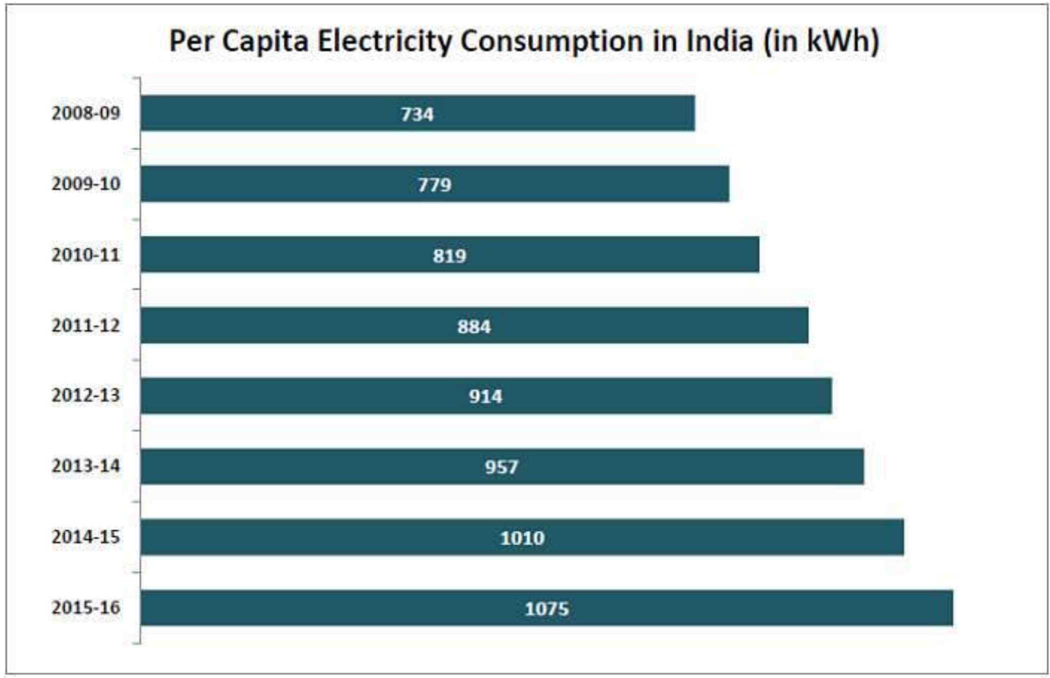
- **Summary of Capacity Addition Targets for XII Plan**

	Thermal	Nuclear	Hydro	Total	Sector wise %
Central	14,878	5,300	6,004	**26,182**	**30%**
State	13,922	-	1,608	**15,530**	**18%**
Private	43,540	-	3,285	**46,825**	**52%**
Total	**72,340**	**5,300**	**10,897**	**88,537**	
Discipline wise %	**82%**	**6%**	**12%**		

- Per capita power consumption at 1075 kWh - Low as compared to world average (2015-16)
- Present Peak shortage – 3.20% (2015-16)
- Present Energy shortage – 2.10% (2015-16)

Increase in demand of power due to following factors

- Rural Electrification
- GDP Growth Rate
- 24x7 Power for All



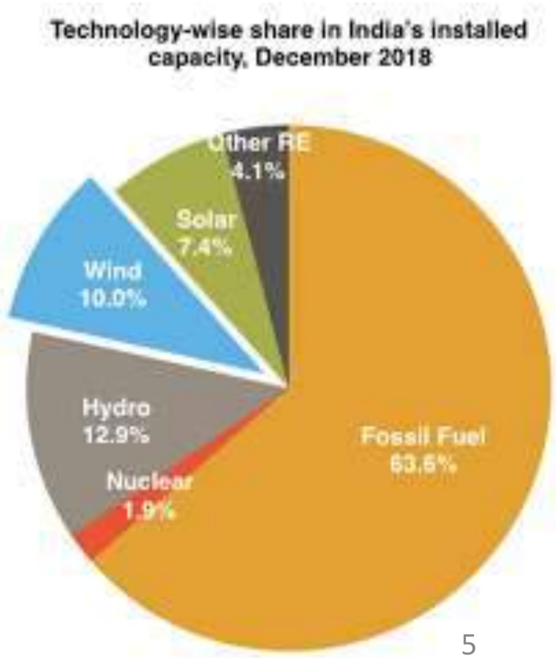
Push to Renewables

Target by 2022 : 100 GW of solar and 60 GW of wind energy

•Solar projects 20,900 MW tendered

•Green Energy Corridors of $ 5.6 billion envisaged for transmission of renewable energy

•33 Solar parks in 20 states are envisaged



24X7 Power For All (PFA) by 2019 - Uninterrupted power supply 24X7

A comprehensive programme encompasses overall development of power sector including reforms at all India level

•Envisages building generation, transmission and distribution capacities

•Operational efficiency & reform measures

WHICH COUNTRIES LED THE WAY IN 2019?

Annual Investment / Net Capacity Additions / Production in 2019

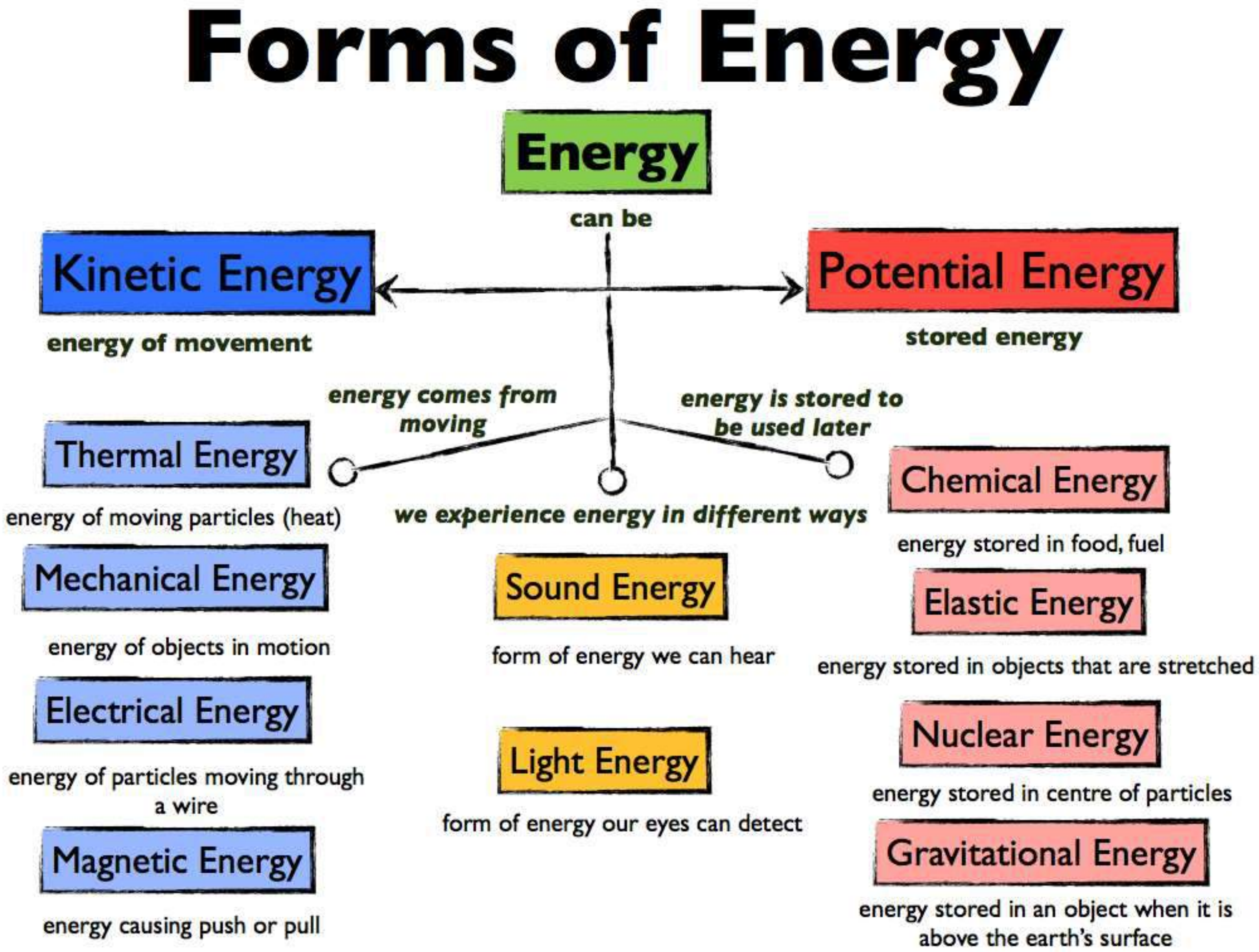
Technologies ordered based on total capacity additions in 2019.

	1	2	3	4	5
Investment in renewable power and fuels capacity (not including hydropower over 50 MW)	**China**	United States	Japan	India	Chinese Taipei
Solar PV capacity	**China**	United States	India	Japan	Vietnam
Wind power capacity	**China**	United States	United Kingdom	India	Spain
Hydropower capacity	**Brazil**	China	Lao PDR	Bhutan	Tajikistan
Geothermal power capacity	**Turkey**	Indonesia	Kenya	Costa Rica	Japan
Concentrating solar thermal power (CSP) capacity	**Israel**	China	South Africa	Kuwait	France
Solar water heating capacity	**China**	Turkey	India	Brazil	United States
Ethanol production	**United States**	Brazil	China	India	Canada
Biodiesel production	**Indonesia**	United States	Brazil	Germany	France

As in past years, **China** led many key annual categories for renewable energy in 2019.

Energy the capacity for doing work.

It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms. There are, moreover, heat and work—i.e., energy in the process of transfer from one body to another. After it has been transferred, energy is always designated according to its nature. Hence, heat transferred may become thermal energy, while work done may manifest itself in the form of mechanical energy.



SI units for energy

- The SI unit of energy is a Joule: 1 kg*m^2/s^2 = 1 Newton*m (Newton is the unit of Force)
  - mass * velocity ^{2}
  - mass * g * height (on earth, g = 9.81 m/s^2)
  - for an ideal gas = $c_v k_B T$ (c_v =3/2 for a monatomic gas)
- Power is energy per time: 1 Watt = 1 Joule/s = 1 kg*m^2/s^3
  - most commonly used in electricity, but also for vehicles in horsepower (acceleration time)

	System of Units		
	SI	Metric	English
Energy and Exergy	Joule (J)	kcal	Btu
Work	N×m= J	kg_f×m	lb_f×ft
Heat[a]	cal	kcal (1000 cal)	Btu
Power	J/s = W (Watt)	KWh	hp

[a] Heat needed to warm by one degree of temperature a unit of mass of water (cal: 1 gram, 1°C; kcal: 1kg, 1°C; Btu: 1lb, 1°F).

Source: Based on Kostic (2004, p. 529) and Levenspiel (1997, p. 6).

Other common energy units

http://www.onlineconversion.com/energy.htm

Energy conversion			
Unit	**Quantity**	**to**	**Note**
1 calorie =	4.1868000	Joule	
1 kiloWatt hour = kWh =	3600000	Joule	A power of 1 kW for a duration of 1 hour.
1 British Thermal Unit = btu	1055.06	Joule	It is a is a unit of energy used in North America.
1 ton oil equivalent = 1 toe	4.19E+010	Joule	It is the rounded-off amount of energy that would be produced by burning one metric ton of crude oil.
1 ton coal equivalent	2.93E+10	Joule	
1 ton oil equivalent = 1 toe	1 / 7.33	Barrel of oil	or 1 / 7.1 or 1 / 7.4 ...
1 cubic meter of natural gas	3.70E+07	Joule	or roughly 1000 btu/ft3
1000 Watts for one year	3.16E+010	Joule	for the 2000 Watt society
1000 Watts for one year	8.77E+006	kWh	for the 2000 Watt society
1 horsepower	7.46E+002	Watts	

Mechanical Energy Transfers

Any time a force causes energy to go from one store into another, it is a mechanical energy transfer. A mechanical energy transfer takes place when work is done by a force over a displacement (parallel with that force).

	
When an object falls energy is **transferred by gravity** from the Gravitational Potential Energy Store of the object to the Kinetic Energy Store of the object.	The front brakes of this car are glowing from the high temperature. Energy has been **transferred by friction** from the Kinetic Energy Store of the car to the Thermal Energy Store of the brakes.

Any object that possesses mechanical energy - whether it is in the form of potential energy or kinetic energy - is able to do work. That is, its mechanical energy enables that object to apply a force to another object in order to cause it to be displaced.

Heat is a form of energy that transfers from the higher temperature object to the lower temperature object, and is transferred through the conduction, the convection and the radiation.

Temperature is the degree of hotness or coldness of a body.

Thermal energy refers to the energy contained within a system that is responsible for its temperature.

Temperature vs. Thermal Energy

temperature —**average** kinetic energy (energy of motion) or **average speed** of all the particles in a material

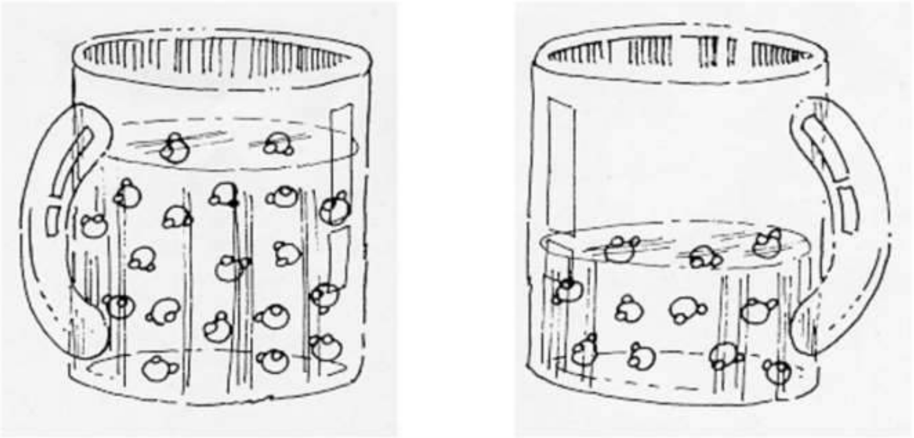
a. higher temp. = particles move faster and farther apart
b. lower temp. = particles move slower and closer together

thermal energy—**total** kinetic energy of all the particles in a material

heat—energy transferred between two objects of **different temperature**

more molecules = more thermal energy

95°C 100°C



← heat transfer

more thermal energy less thermal energy

The importance of the heat

- The heat is very important in our daily life in warming the house, cooking, heating the water and drying the washed clothes.
- The heat has many usages in the industry as making and processing the food and manufacture of the glass, the paper, the textile, ………etc.
- The steam has a high specific heat (more than the water), It is used to carry a lot of heat energy at high pressures to run the rail engines or the rotors in AC generators.

Heat is transported in 3 primary ways:

Conduction: Heat transfer between adjacent molecules.

Ex. Metal spoon in cup of hot coffee

Convection: Heat transfer through flow of liquid/gas

Ex. Air rising over hot blacktop parking lot

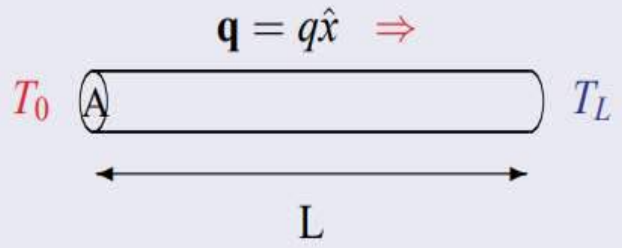
Radiation: Hot object → T^4 EM radiation

Ex. Solar, earth radiation

Heat conduction from Fourier law $\mathbf{q} = -k\nabla T$

—Analogy with electric conductivity $[\mathbf{j} = -\sigma\nabla V]$

Example: 1D problem: thin bar, length L, area $A \rightarrow \mathbf{q} = q\hat{x}$



Solve for $T(x), q(x)$ constant in time with fixed boundary conditions

- No change in time ⇒ q constant in x (or T changes locally in time)

$\Rightarrow q = -k\frac{dT}{dx} = \text{constant} \Rightarrow T(x) = T_0 + (T_L - T_0)\frac{x}{L}, \quad q = -k\frac{T_L - T_0}{L}$

Rate of heat transfer:

"thermal resistance"

$$qA = \frac{-k(T_L - T_0)A}{L} \Rightarrow T_L - T_0 = (qA)\left(\frac{L}{Ak}\right) \sim V = IR$$

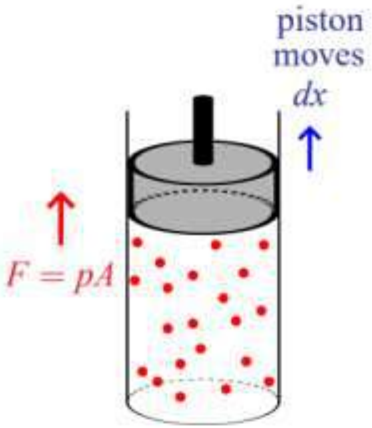
Heat conduction: example

Heat xfer through 0.2m concrete

material	k [W/mK]
air	0.026
fiberglass insulation	0.043
hard wood	0.16
concrete	1.4
steel	52

$$q = -k\frac{\Delta T}{L} = (1.4\ \text{W/mK})(20\ \text{K}/0.2\ \text{m}) = 140\ \text{W/m}^2$$

Expansion



Now, heat up air in cylinder

p increases $\Rightarrow$ piston moves

Work done by gas:

$$dW = Fdx = pAdx = pdV$$

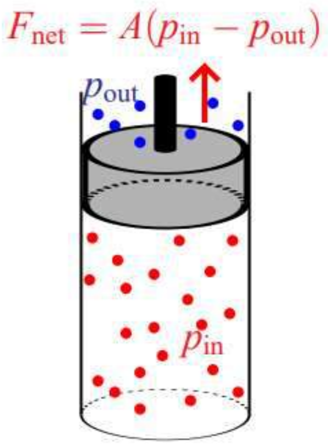
So dU = -pdV

First Law of Thermodynamics

heat input $dQ \Rightarrow \quad dQ = dU + p\,dV$

Heat engine: Raise T $\Rightarrow$ Raise p $\rightarrow$ expand + do work $\Rightarrow$ cycle
Question: how much thermal energy can be used?

How much useful work can we get from thermal energy?

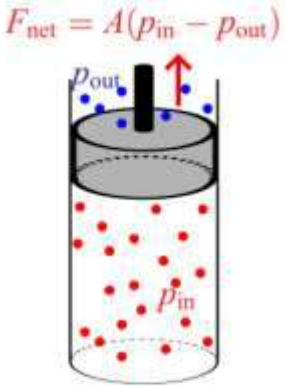


Work done when piston moves dx:
$dW = p_{\rm in} dV$.

Some is work on outside gas
$dW_{\rm lost} = p_{\rm out} dV$.

Usable work is $dW_{\rm useful} = (p_{\rm in} - p_{\rm out})dV$.

Enthalpy



Recall specific heat at constant volume
$dU = dQ = C_V dT \;\Rightarrow\; C_V = \left(\frac{\partial U}{\partial T}\right)_V$

At constant p, some energy $\rightarrow pdV$ work

$$dU + pdV = dQ = C_p dT$$

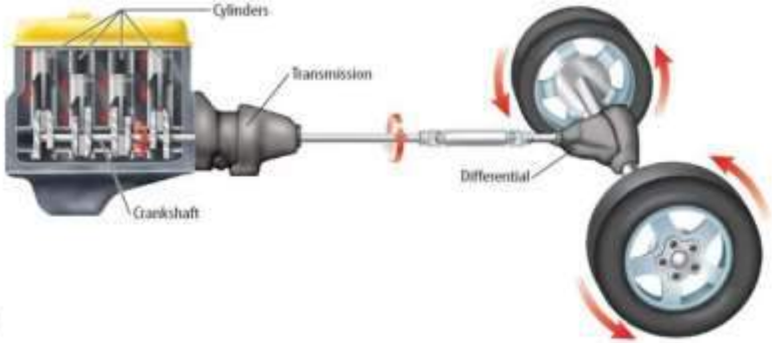
Define Enthalpy: $H = U + pV$ at constant pressure

so $dH = d(U + pV)_p = dU + pdV = C_p dT \quad \Rightarrow \quad C_p = \left(\frac{\partial H}{\partial T}\right)_p$

Converting Thermal Energy to Mechanical Energy

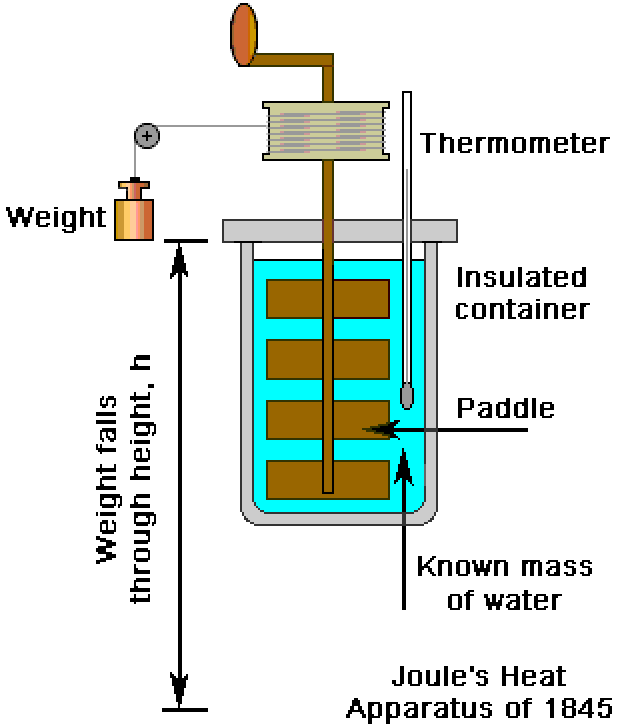
A device that converts thermal energy into mechanical energy is a **HEAT ENGINE**.

- A car's engine converts the chemical energy in gasoline into thermal energy.
- The engine then **TRANSFORMS** some of the thermal energy into mechanical energy by rotating the car's wheels.

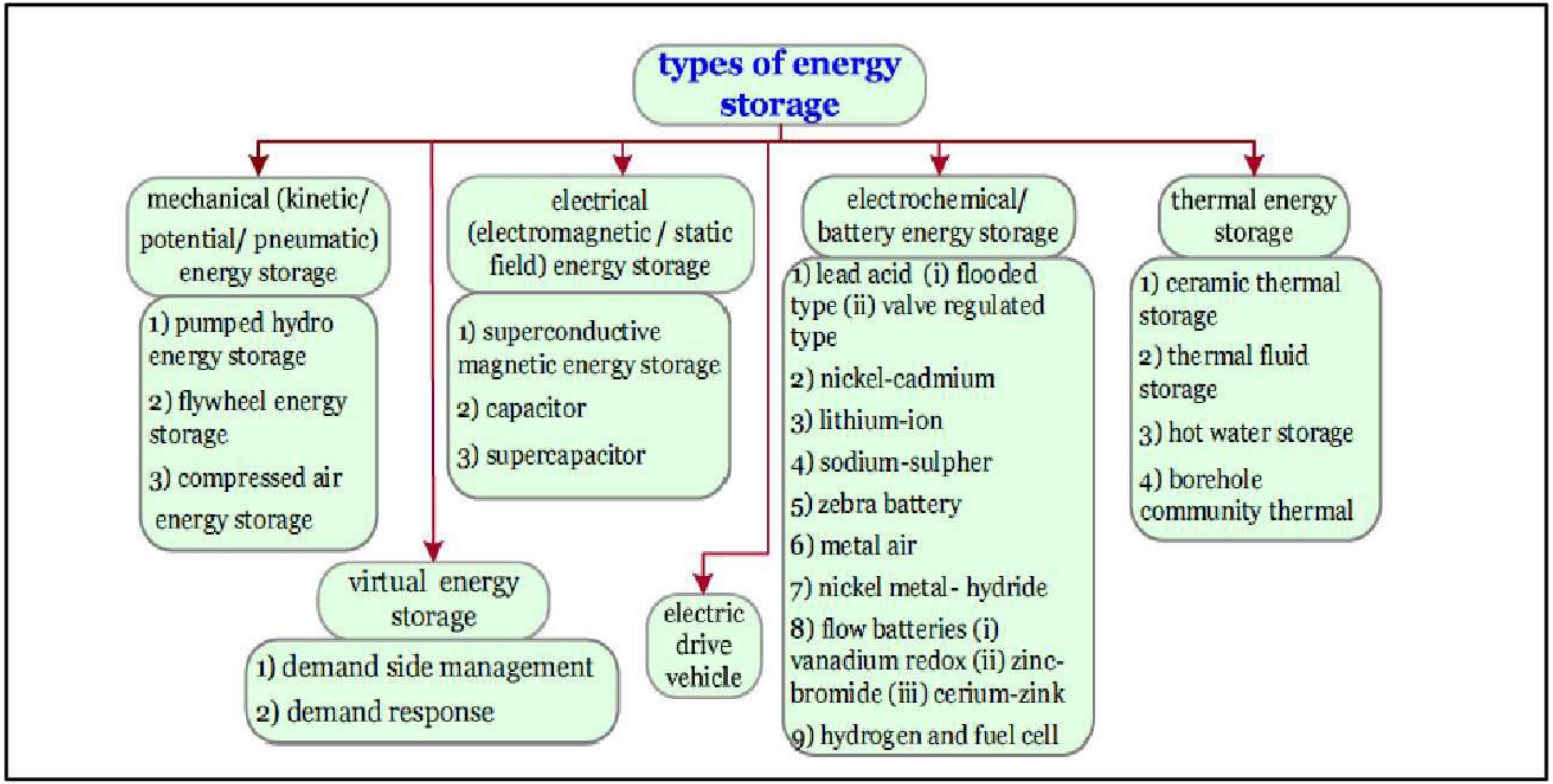


Using Thermal Energy

converting mechanical energy to thermal energy



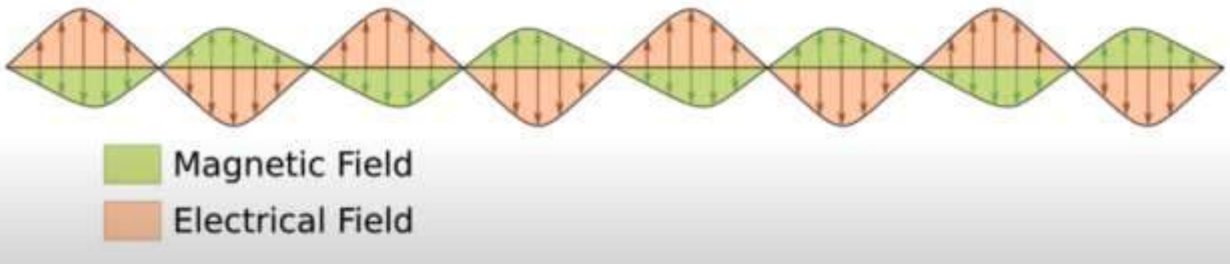
Energy storage is the capture of energy produced at one time for use at a later time.



Electromagnetic energy: Storage, conversion, transmission and radiation

Electromagnetic energy is released when an electrical charge is **accelerated** by an **external force**.

The acceleration creates a wave of alternating electrical and magnetic fields that separates from the charge and move off into space.



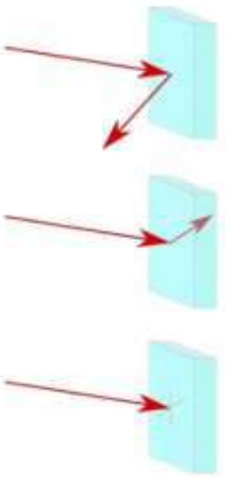
Electromagnetic Energy has wavelike and particle like properties

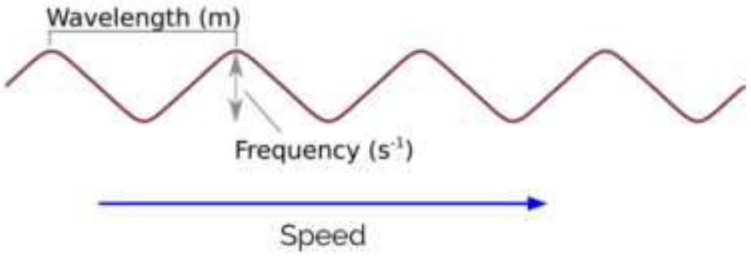
When an electromagnetic wave encounters matter it does one of 3 things:

It is Reflected

It Passes Through

It is Absorbed





Wavelength = λ (m)

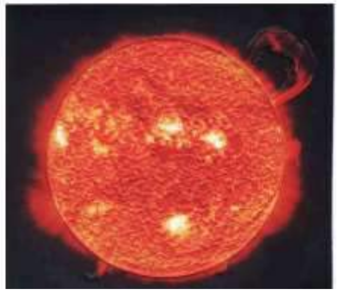
Frequency = f (s^{-1})

Speed = c (m/s)

Scale of EM energy use...

- All solar energy is transmitted to earth as electromagnetic waves. Total yearly solar input,

$$1.74 \times 10^{17}\ \mathrm{W} \quad \Rightarrow \quad 5.46 \times 10^{24}\ \mathrm{J/year}$$



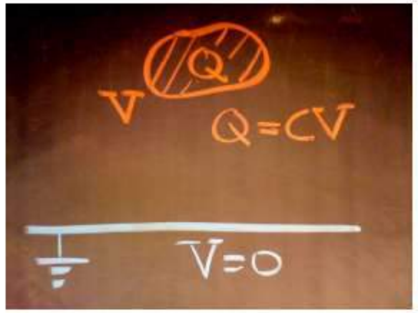
Increase capacitance:

- Increase effective surface area: gels, nanostructures
- Increase dielectric constant (polarizable but non-conducting materials)
- Decrease effective separation

Electromagnetic energy storage: capacitors

General idea of a capacitor:

- Place a charge Q on a conductor
- Voltage on the conductor is proportional to Q.



- Capacitance is proportionality constant

$$Q = C\,V$$

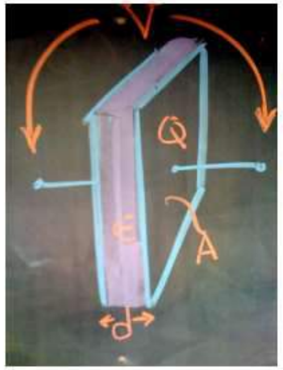
"Capacity" of conductor to store charge.

- Energy stored in a capacitor:

It takes work to move each little bit of charge through the electric field and onto the conductor.

$$\boxed{U = \frac{1}{2} C V^2}$$

Parallel plate capacitor



- Two plates, area A,
- Separation d,
- Filled with dielectric with dielectric constant $\epsilon = k\epsilon_0$

For parallel plates $C = \dfrac{\epsilon A}{d}$

To increase capacitance: increase Area (size limitations); decrease distance (charge leakage); or increase dielectric constant (material limitations)

For a parallel plate capacitor with $\epsilon = k\epsilon_0$

So typical scale for a capacitive circuit element is pico farads: 1 picofarad $= 1 \times 10^{-12}$

Electrical energy storage?

- Batteries are expensive, heavy, involve relatively rare and unusual materials (eg. lithium, mercury, cadmium,...), toxic.
- Storing electrical energy in capacitors is not a new idea, but using novel materials to make "ultra" capacitors is!

"Super" or "Ultra" Capacitors

Using sophisticated materials technology, capable of tens or even thousands of farad capacitors in relatively modest volumes.

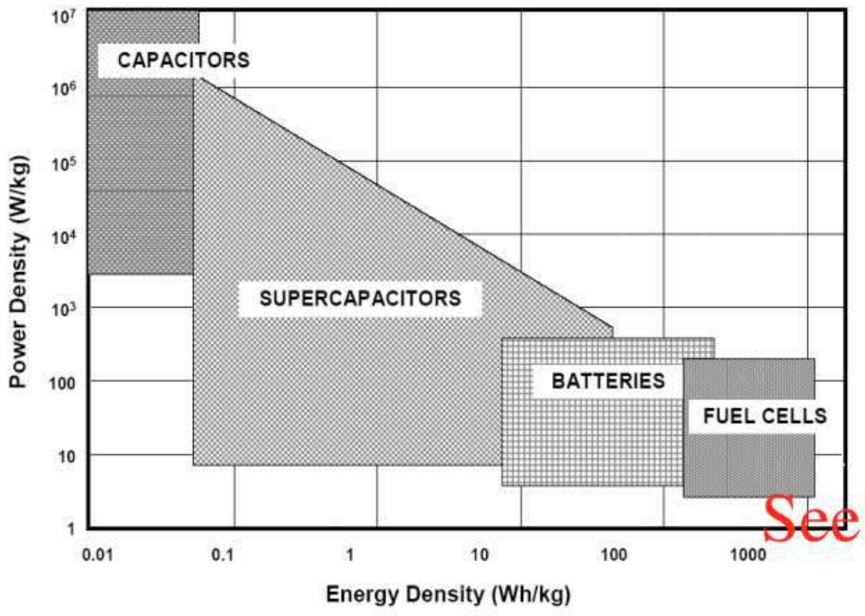
Compare with conventional rechargeable (*e.g.* NiMH) battery

Advantages

- Discharge and charge rapidly $\Rightarrow$ high power
- Vastly greater number of power cycles
- No environmental disposal issues
- Very low internal resistance (low heating)

Disadvantages

- Low total energy
- Intrinsically low voltage cell
- Voltage drops linearly with discharge
- Leakage times ranging from hours (electrolytic) to months



See

Resistive energy loss

Electric current passing through a resistance generates heat.

- Resistive energy loss in transmission of electric power is a major impediment to long distance energy transmission.
- Resistance converts electrical energy to heat at nearly 100% efficiency, but that's not the whole story.

Electric space heating — GOOD??

Transmission losses — BAD

Power lines: losses in transmission of electromagnetic energy

Transmission of energy over long distances is problematic.

- Oil & Gas — TANKERS & PIPELINE
- Coal & Nuclear — MINES & TRANSS
- Wind, solar, hydro, tidal — ELECTRICAL

So the process

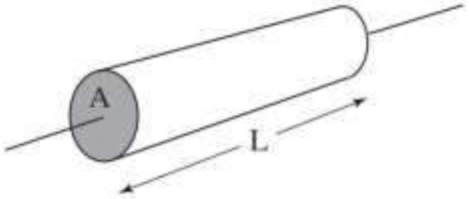
WIND / SOLAR / HYDRO } $\xrightarrow{\text{conversion losses}}$ ELECTRICITY $\xrightarrow{\text{transmission losses}}$ SUBSTATION $\xrightarrow{\text{conversion losses}}$ USE

Is essential in a world where renewable energy plays a major role

Transmission losses NEXT
Conversion losses STAY TUNED

Cable

- Resistance grows linearly with length
- Resistance falls linearly with area



$$R = \frac{\rho L}{A}$$

$$\rho = \frac{RA}{L} \qquad \rho \equiv \text{resistivity}$$

$$[\rho] = [R][A/L] = \text{ohm-meter } (\Omega\text{-m})$$

Notice resemblance to heat conduction!

Design a cable

Resistivities:

- $\rho[\mathrm{Cu}] = 1.8 \times 10^{-8}\ \Omega$-m
- $\rho[\mathrm{Al}] = 2.82 \times 10^{-8}\ \Omega$-m
- $\rho[\mathrm{Fe}] = 1.0 \times 10^{-7}\ \Omega$-m

Material properties influencing choice:

- Light: Al > Cu > Fe
- Strong: Fe > Al, Cu
- Good conductor: Cu > Al > Fe
- Not subject to significant corrosion: Al > Cu > Fe
- Cost: Fe > Al > Cu

Transforming (to and from) Electromagnetic Energy

- Dynamos/motors
- Phases and Power
- Transformers

Basic idea: Induction

Time changing magnetic field induces an electric field.

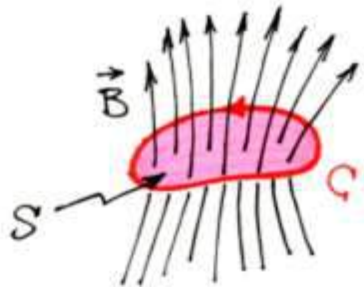
- Dynamos/motors

Long range transmission ⇒ electromagnetic forms. Hence

MECHANICAL ENERGY GENERATION ⟶ EM TRANSMISSION ⟶ MECHANICAL ENERGY USE

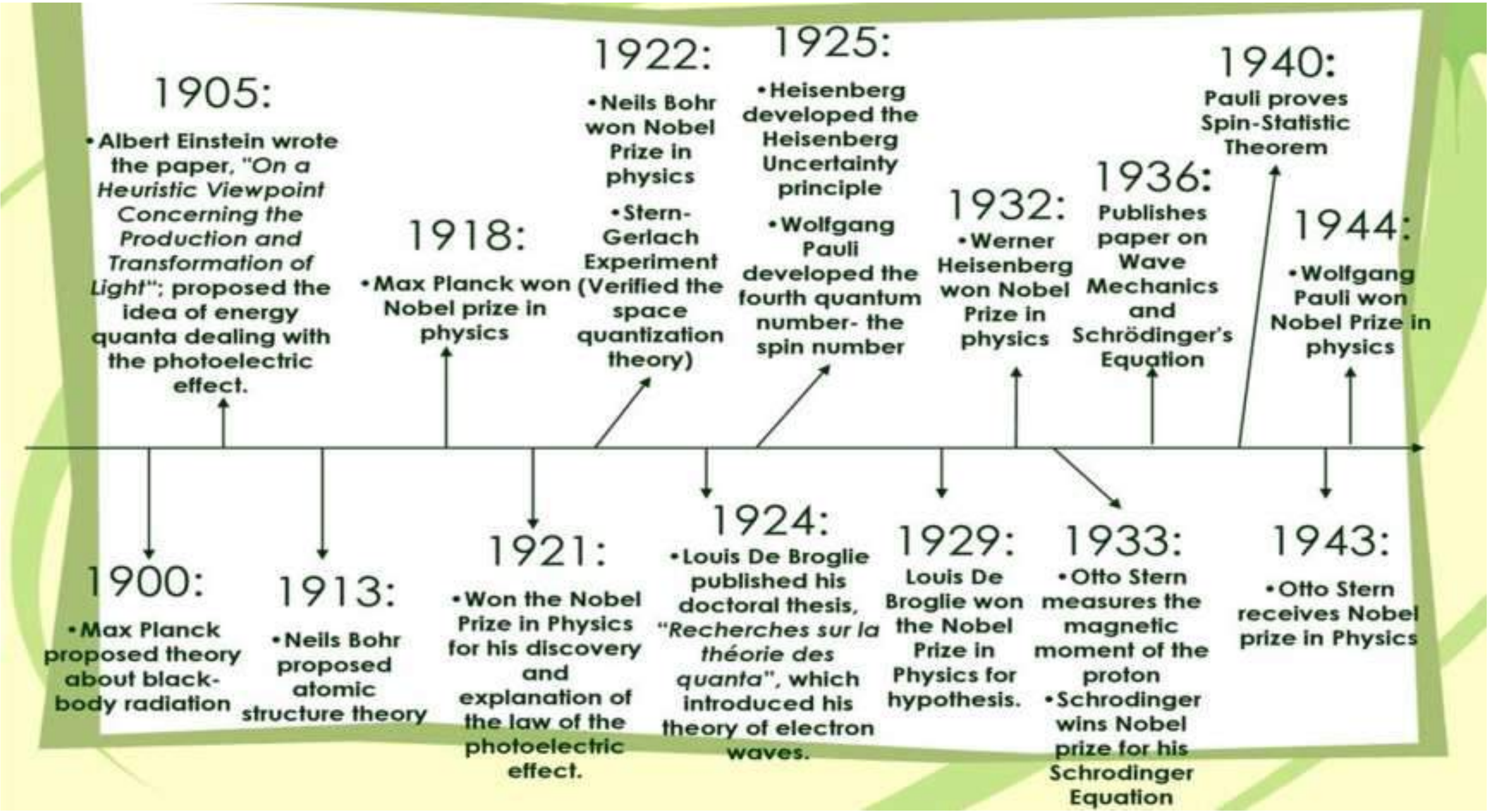
All based on Faraday's Law of Induction

$$\oint_C \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \iint_S \vec{B} \cdot d\vec{A}$$



Quantum Mechanics

Quantum mechanics is the study of how atomic particles exist and interact with each other.
Classical mechanics allows scientists to make very accurate predictions for big objects. But these predictions do not work as well when you look at objects on a smaller scale. This is where quantum mechanics comes in. It describes laws of energy on the scale of atoms. The best way to understand quantum mechanics is through the history of its major discoveries.

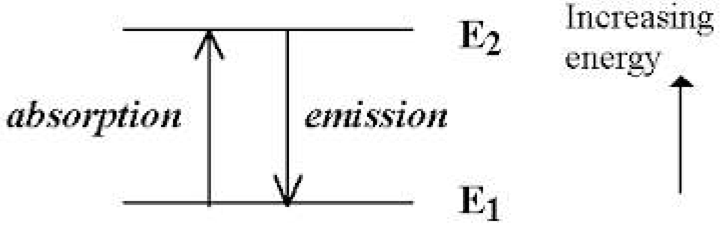


Energy quantization

- The **quantization** of **energy** refers to the absorption or emission of **energy** in discreet packets, or quanta.
- As the intensity of electromagnetic **energy** increases or decreases, it steps up or down from one **quantized** level to another, rather than follow a smooth and continuous curve.
- The establishment of energy quantization called for the replacement of classical mechanics
- Energy quantization became evident under three main studies
  - ❖ The black-body radiation
  - ❖ Heat capacities
  - ❖ Atomic and molecular spectra

Potential energy of person walking up steps increases in stepwise, quantized manner

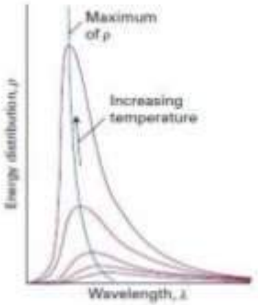
Potential energy of person walking up ramp increases in uniform, continuous manner



Energy quantization

Black Body Radiation

- Black body is a material capable of emitting and absorbing all wavelengths of radiations uniformly.
- The classical approach to the description of black-body radiation results in the ultraviolet catastrophe.
- The prediction of classical physics that an ideal black body at thermal equilibrium will emit radiation in all frequency ranges, emitting more energy as the frequency increases.
- The sum of emissions in all frequency ranges suggest that a blackbody would release an infinite amount of energy, contradicting the principles of conservation of energy
- This drew attention to the need of a new model for the behavior of blackbodies



Chemical systems and processes, flow of CO2

Chemical (and Biological) Energy

SOURCES

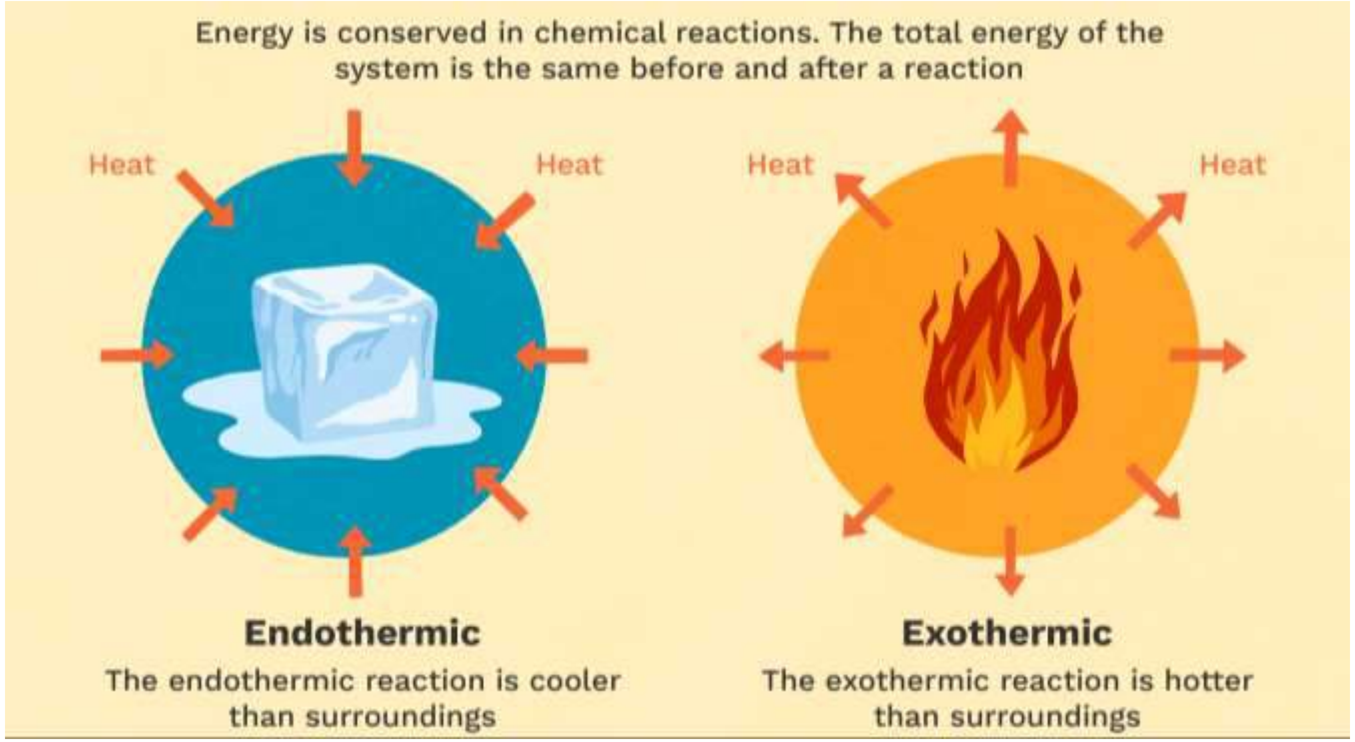
- Fossil fuels
- Biofuels
- Wood, waste, etc.

TRANS FORMATION AND STORAGE

• Batteries	Chemical$\leftrightarrow$ Electrical
• Fuel Cells	Chemical$\leftrightarrow$ Electrical
• Engines	$\left.\begin{matrix}\text{Bio}\\ \text{Chemical}\end{matrix}\right\} \leftrightarrow$ Mechanical
• Working fluids	Mechanical$\leftrightarrow$ Heat
• Photosynthesis	Radiation$\leftrightarrow$ Biochemical

USES

- Heating & Cooling
- Transportation
- Manufacturing
- ...



Summary

- Internal energy is the energy that is stored in the system as potential or kinetic (thermal) energy when a system is put together from its pieces.
- Only *changes in internal energy* are observable. (Usually we omit rest mass energy of protons and neutrons when considering internal energy of H_2O.)
- The kinds of internal energy we should consider are dictated by the circumstances — chemical binding for chemistry, nuclear binding for nuclear processes.
- Enthalpy $H = U + pV \quad \Delta H = \Delta U + p\Delta V$ is the energy that must be added to a mechanical system to change the internal energy. Includes energy needed to perform "pdV work".
- Enthalpy of formation is the energy necessary to form a chemical compound out of its (molecular) constituents, including pdV work.
- If enthalpy must be added to a system to enable a reaction (eg. ionization) the process is endothermic. If energy is given off (eg. condensation of a gas) the process is exothermic.

Some useful heat capacities

Substance	Specific Heat Capacity KJ/kg K	Molar Heat Capacity J/mol K
Ice	2.09	37
Water	4.19	75
Steam	2.01	34
Ethanol(l)	2.42	113
Copper	0.38	33
Liquid sodium	1.39	32
Air	0.73	21
Helium	3.125	12.5

Substance	Specific Heat Capacity KJ/kg K
Steel	0.51
Glass	0.78
Granite	0.80
Wood	1.67
Soil	1.05

Lots of stories here!

Enthalpy of Reaction and Combustion

- Need to know how much energy is liberated when a particular reaction takes place.
- Strategy: Combine Enthalpies of formation (ΔH^f) to obtain the reaction of interest:
- Want $\Delta H_{\text{reaction}}$ for $A + B \to C + D$
- Again note the sign: $\Delta H_{\text{reaction}}$ is the change in the internal enthalpy of the products relative to the reactants, so $-\Delta H_{\text{reaction}}$ is the enthalpy given off to the environment.

General Result: For a reaction Reactants $\to$ products

- In a reaction you are forming the products and unforming the reactants
- So (Hess's Law)

$$\boxed{\Delta H(\text{Reaction}) = \sum_{\text{products}} \Delta H^f - \sum_{\text{reactants}} \Delta H^f}$$

- And $-H(\text{reaction})$ is given off to the environment

General Result: For a reaction Reactants $\to$ products

$$\text{Reactants} \to \text{Products} + \sum_{\text{reactants}} \Delta H^f - \sum_{\text{products}} \Delta H^f$$

$$\Delta H(\text{Reaction}) = \sum_{\text{products}} \Delta H^f - \sum_{\text{reactants}} \Delta H^f$$

(1) "Burning ethanol produces less CO_2 than burning gasoline."

Need a diversion to introduce the ideas of

Enthalpy of Reaction and Combustion

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- And $-H(\text{reaction})$ is given off to the environment

Compound	Chemical Formula	Enthalpy of Formation
Diatomic gases	H_2, O_2, Cl_2,...	0 kJ/mol (by definition)
Methane	$CH_4(g)$	– 75 kJ/mol
Water vapor	$H_2O(g)$	– 242 kJ/mol
Octane	$C_8H_{18}(l)$	– 250 kJ/mol
Ethanol liquid	$C_2H_5OH(l)$	– 278 kJ/mol
Carbon dioxide	$CO_2(g)$	– 394 kJ/mol
Calcium oxide	CaO	– 635 kJ/mol
Iron Ore (Hematite)	Fe_2O_3	– 824 kJ/mol
Calcium carbonate	$CaCO_3$	– 1207 kJ/mol
Sucrose	$C_6H_{12}O_6$	– 1270 kJ/mol

Example: Partial oxidation of octane to ethanol. Balanced chemical reaction:

$$C_8H_{18}(l) + \frac{7}{2}O_2(g) \rightarrow 3\,C_2H_5OH(l) + 2\,CO_2(g)$$

$$\begin{aligned} \Delta H_{\text{reaction}} &= 3\,\Delta H^f_{\text{ethanol}} + 2\,\Delta H^f_{\text{CO}_2} - \Delta H^f_{\text{octane}} \\ &= 3(-278\,\text{kJ/mol}) + 2(-394\,\text{kJ/mol}) - 1(-250\,\text{kJ/mol}) \\ &= -1372\,\text{kJ/mol} \end{aligned}$$

- Examples
  - ⋆ Combustion of methane $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  - ⋆ Combustion of ethanol $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$
  - ⋆ Combustion of glycine $4C_2H_5NO_2 + 9O_2 \rightarrow 8CO_2 + 10H_2O + 2N_2$

(3) "Hydrogen is the fuel of the future!"

- If what you mean by a fuel is something that provides primary energy input to human activities, the answer is NO!
  - ⋆ It is not found on earth — there are no hydrogen mines!
  - ⋆ It takes at least as much energy to create H_2 from other sources as it yields when the hydrogen is burned.
- Hydrogen is a energy storage system. And a good one — in principle
- Energy content of hydrogen

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

$\Delta H^f_{\text{water}}(l) = -285.83$ kJ/mole

- Enthalpy of H_2O liquid is 285.83 kJ/mole less than enthalpy of H_2 and (1/2) O_2, so burning hydrogen in oxygen is quite exothermic.
- Energy density of hydrogen:

$$(286\,\text{kJ/mole}) \div (2\,\text{gm H}_2\text{/mole}) = 143\,\text{MJ/kg}$$

A very large number (because hydrogen is so light.)

- Hydrogen: 143 MJ/kg
- Other energy storage systems:
  - ⋆ Methane: 56 MJ/kg
  - ⋆ Octane: 48 MJ/kg
  - ⋆ Ethanol: 31 MJ/kg
  - ⋆ Flywheel: ~ 0.5 MJ/kg
  - ⋆ NiMH Battery: ~ 0.22 MJ/kg
  - ⋆ Li Ion Battery: ~ 0.25 MJ/kg
- Hot water storage: H_2O at 100°C compared to 25°C: 0.314 MJ/kg. Very much smaller, but water is very easy to heat and very cheap to gather and store!

Energetics of making hydrogen

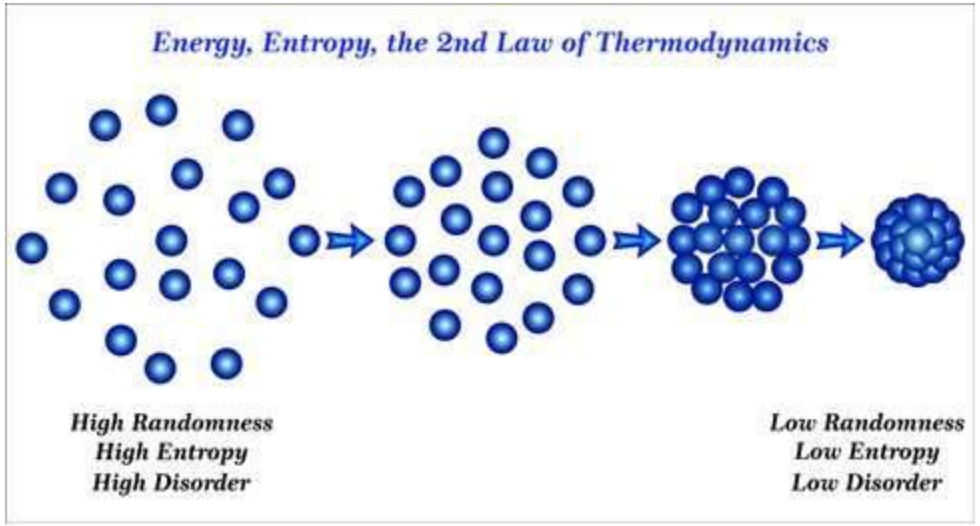
It all depends on the original energy source

Electrolysis:

- Pass a current through a solution of an electrolyte in water, producing hydrogen gas and oxygen gas at the electrodes.
- Efficiency depends on source of electric current.
  - ⋆ Efficiency for conversion of original energy source (hydro, nuclear, solar, wind, coal?) to electricity, including transmission losses: η_1.
  - ⋆ Efficiency of electrolysis: η_2.
  - ⋆ Efficiency of infrastructure (recovery, compression, transport, storage): η_3.
  - ⋆ Efficiency for useful work from combustion of hydrogen (or fuel cell): η_4.
  - ⋆ Efficiency if original energy source were converted directly to useful work, η^*.

Entropy

- There is a tendency in nature to proceed in a direction that increases the randomness of a system.
  - A random system is one that lacks a regular arrangement of its parts.
- This tendency toward randomness is called *entropy*.
  - **Entropy is a measure of chaos or disorder**
- **Entropy,** *S,* can be defined in a simple qualitative way as a measure of the degree of randomness of the particles, such as molecules, in a system.



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Entropy

1. Entropy is a measure of the disorder (or randomness) of a system
2. For reversible processes, entropy change is measured as the ratio of heat energy gained to the state temperature:

$$dS = \left(\frac{dQ}{T}\right)_{rev} \quad \text{or} \quad \Delta S_{rev} = S_{final} - S_{initial} = \int_i^f \frac{dQ}{T}$$

   a. When net heat flow is positive for a system, the system entropy increases (and lost by the surrounding environment)
   b. When net heat flow is negative, system entropy decreases (and gained by the surrounding environment)

3. The net entropy change by a system due to a completely (reversible) thermodynamic cycle operating between 2 defined constant temperature reservoirs:

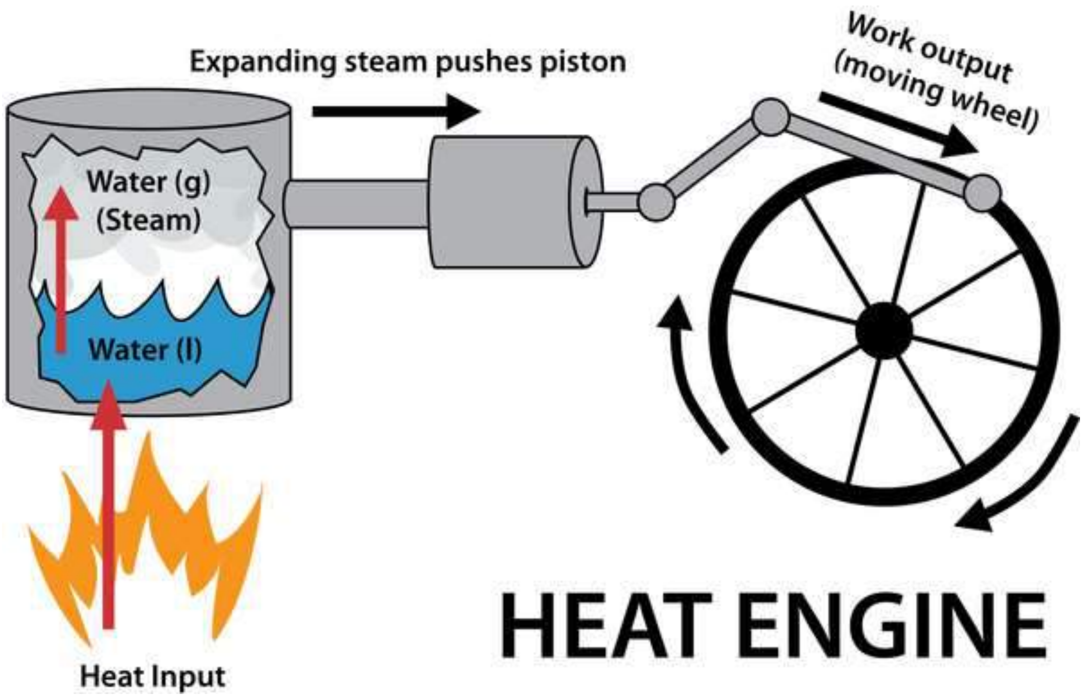
$$\Delta S_{system} = S_{gained} - S_{lost} = \frac{Q_{hot}}{T_{hot}} - \frac{Q_{cold}}{T_{cold}}$$

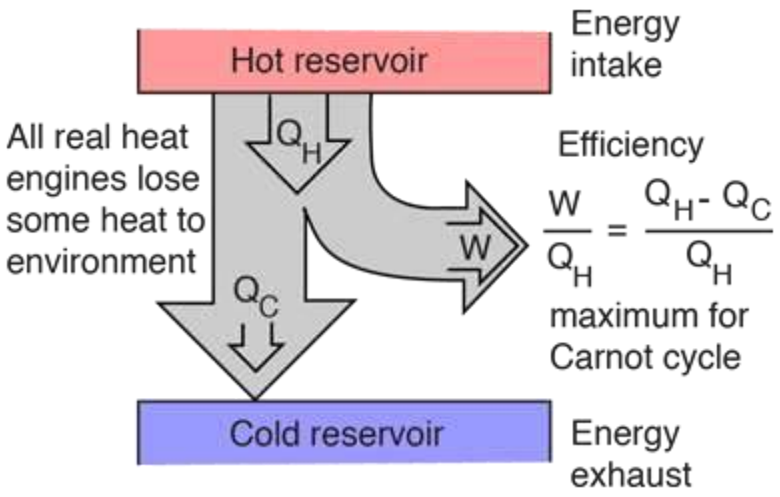
4. The total entropy of the universe ($S_{universe}$) will never decrease, it will either
   a. Remain unchanged (for a reversible process)
   b. Increase (for an irreversible process)
5. Entropy change is related to the amount of energy lost irretrievably by a thermodynamic process:

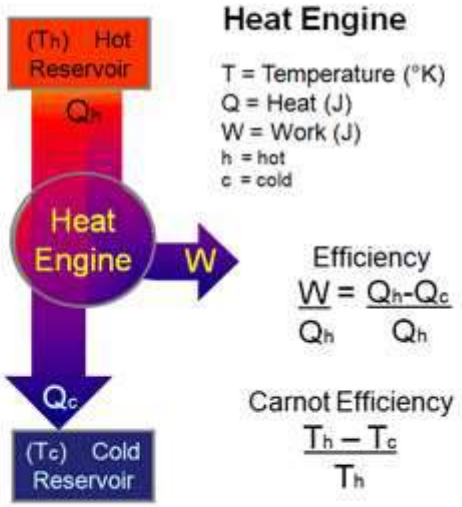
$$dW_{unavailable} = T_{cold} dS_{universe} \text{ or } W_{unavailable} = T_{cold} \Delta S_{universe}$$

What is Heat Engine?

- Heat Engine is the device which converts **chemical** energy of fuel into **heat** energy & this heat energy is utilized converting it to **mechanical** work.
- A **heat engine** is a system that performs the conversion of heat to mechanical energy which can then be used to do mechanical work.







Carnot Engine

- A theoretical engine developed by Sadi Carnot
- A heat engine operating in an ideal, reversible cycle (now called a *Carnot Cycle*) between two reservoirs is the most efficient engine possible
- *Carnot's Theorem*: No real engine operating between two energy reservoirs can be more efficient than a Carnot engine operating between the same two reservoirs

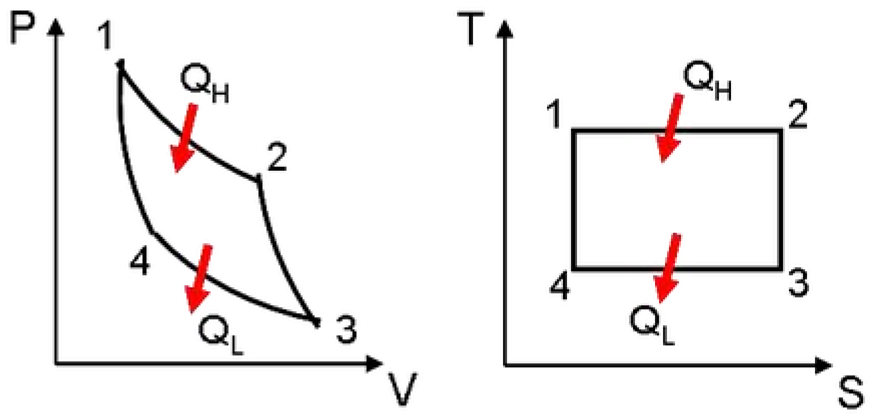
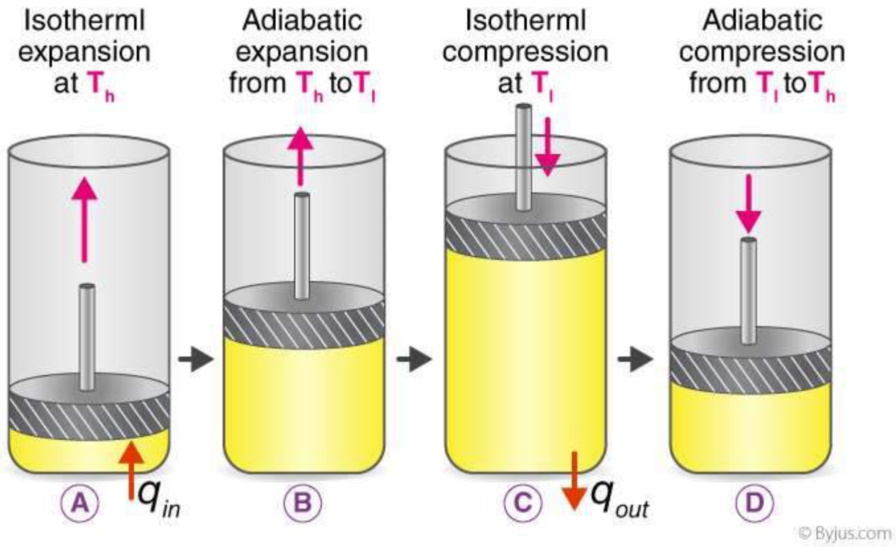
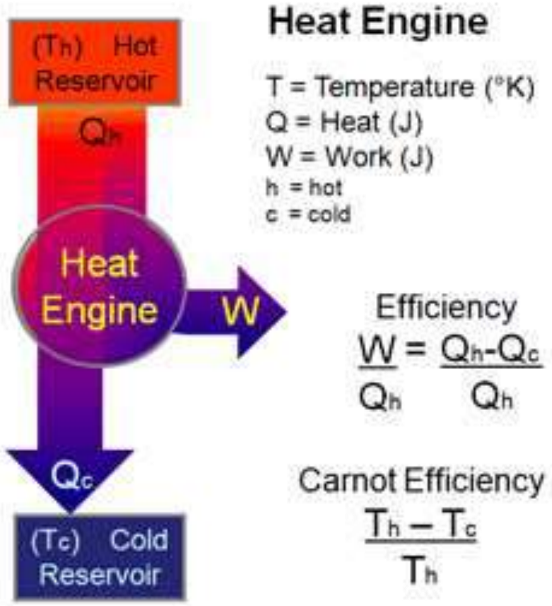


Fig.1. P-V and T-S diagrams of Carnot Cycle





Stirling Cycle

- The Stirling cycle consists of two isothermal and two isochoric processes.
- The p-V and T-s diagrams of Stirling cycle has been given below:

Idealised Stirling Cycle

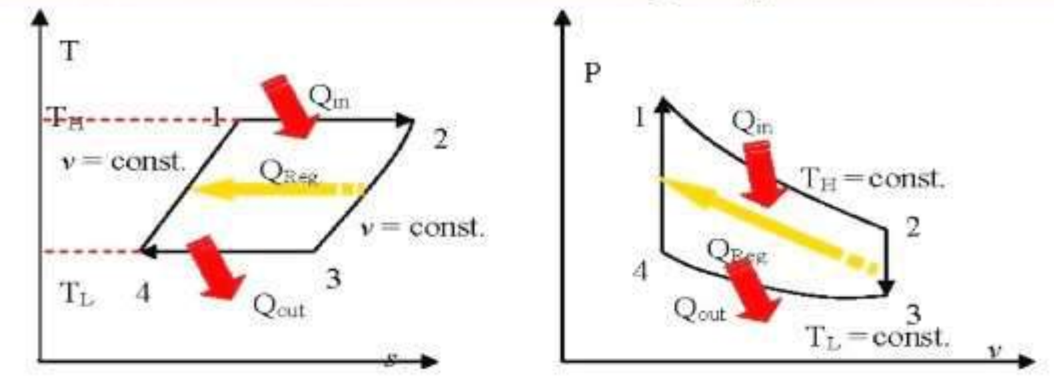


Fig. 3-2: T-s and P-v diagrams for Stirling cycle.

- 1-2 isothermal expansion heat addition from external source
- 2-3 const. vol. heat transfer internal heat transfer from the gas to the regenerator
- 3-4 isothermal compression heat rejection to the external sink
- 4-1 const. vol. heat transfer internal heat transfer from the regenerator to the gas

What is a **Phase Change**?

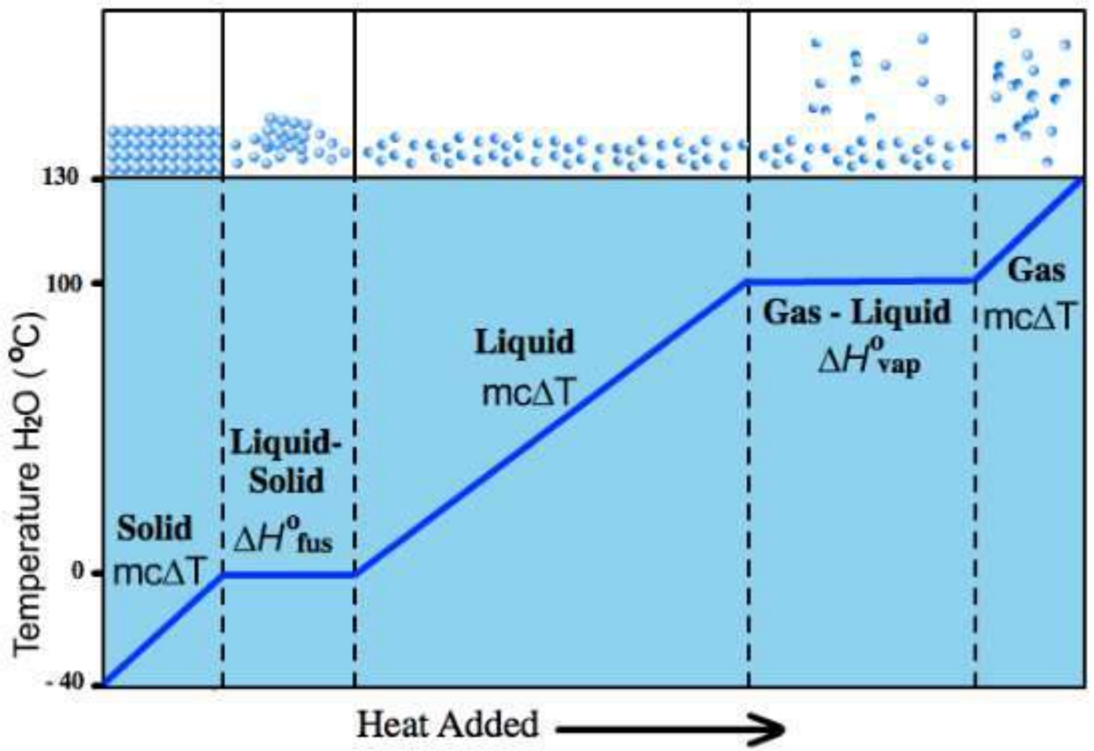
- Is a change from one state of matter (solid, liquid, gas) to another.

- Phase changes are **physical changes** because:
  - It only affects physical appearance, not chemical make-up.
  - Reversible

PHASE CHANGES

Description of Phase Change	Term for Phase Change	Heat Movement During Phase Change
Solid to liquid	**Melting**	**Heat goes into the solid as it melts.**
Liquid to solid	**Freezing**	**Heat leaves the liquid as it freezes.**

Phase Change Diagram for Water (H_2O)



What Is Power Plant?

- A **power plant** or a **power generating station**, is basically an industrial location that is utilized for the generation and distribution of electric power in mass scale, usually in the order of several 1000 Watts.
- A power plant can be of several types depending mainly on the type of fuel used.

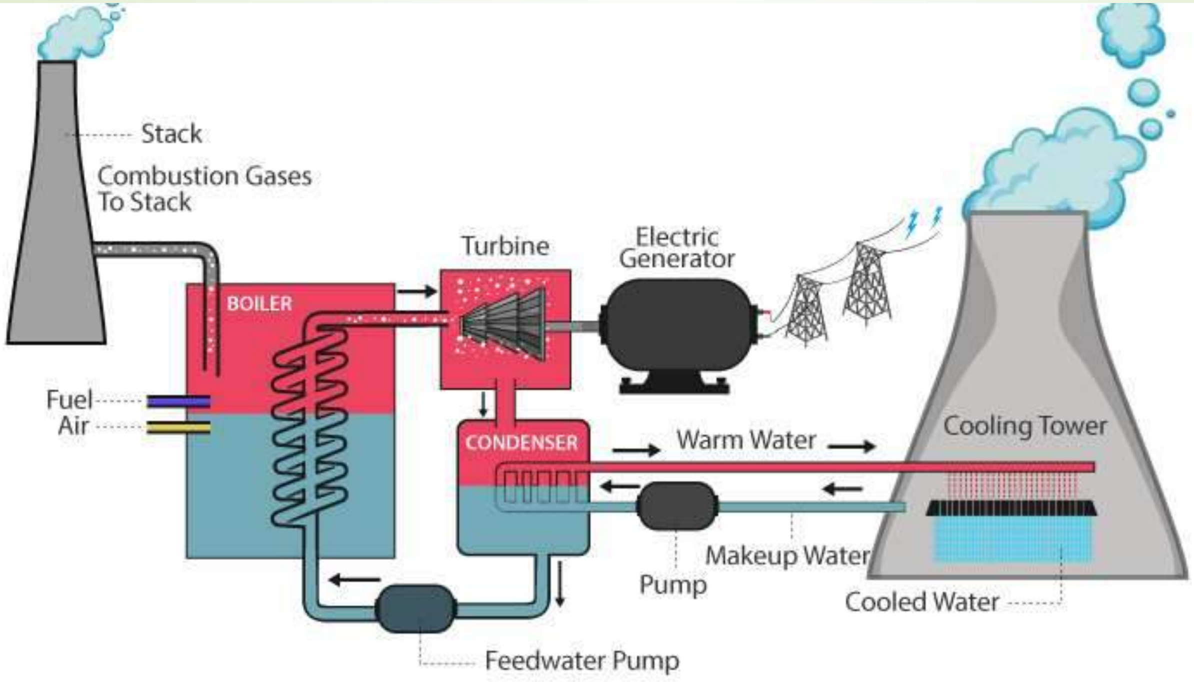
TYPES OF POWER PLANTS

1.BASED ON INPUT ENERGY /FUEL

(a.)COAL thermal Power Plants
(b.) HYDRAULIC Power Plants
(c.) NUCLEAR Power Plants
(d.) GEOTHERMAL Power Plants
(e.) SOLAR Power Plants
(f.)WIND power plants
(g.)BIOMASS power plant

Thermal power plant

A thermal power station or a coal fired thermal power plant is by far, the most conventional method of generating electric power with reasonably high efficiency. It uses coal as the primary fuel to boil the water available to superheated steam for driving the steam turbine. The steam turbine is then mechanically coupled to an alternator rotor, the rotation of which results in the generation of electric power. Generally in India, bituminous coal or brown coal are used as fuel of boiler which has volatile content ranging from 8 to 33% and ash content 5 to 16 %. To enhance the thermal efficiency of the plant, the coal is used in the boiler in its pulverized form.



The Rankine Cycle

The **Rankine cycle** is a cycle that converts heat into work. The heat is supplied externally to a closed loop. This cycle generates about 90% of all electric power used throughout the world The Rankine cycle is the fundamental thermodynamic underpinning of the steam engine and thermal power plant

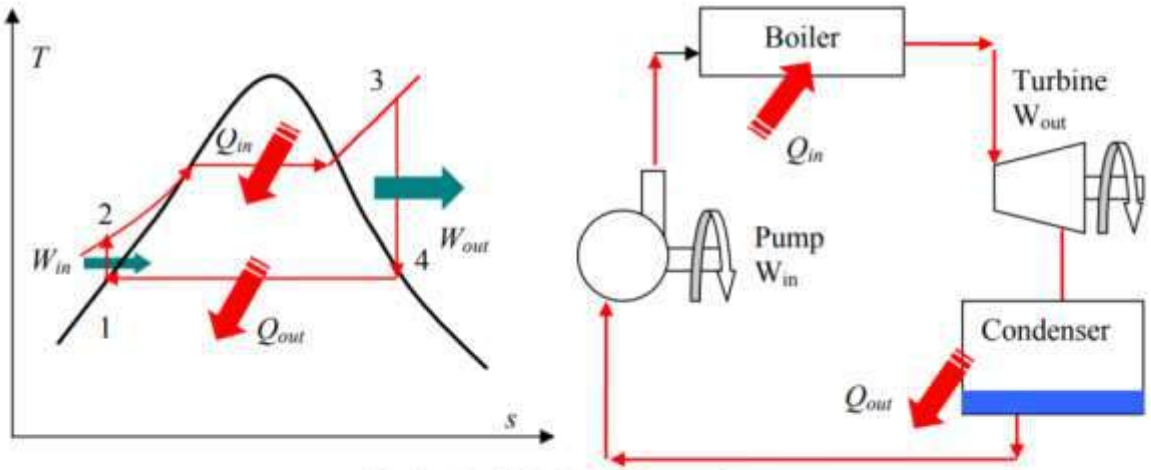


Fig. 2: The ideal Rankine cycle.

Energy Analysis for the Cycle

All four components of the Rankine cycle are steady-state steady-flow devices. The potential and kinetic energy effects can be neglected. The first law per unit mass of steam can be written as:

Pump	$q = 0$	$w_{pump,in} = h_2 - h_1$
Boiler	$w = 0$	$q_{in} = h_3 - h_2$
Turbine	$q = 0$	$w_{turbine,out} = h_3 - h_4$
Condenser	$w = 0$	$q_{out} = h_4 - h_1$

The thermal efficiency of the cycle is determined from:

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

where

$$w_{net} = q_{in} - q_{out} = w_{turbine,out} - w_{pump,in}$$

If we consider the fluid to be incompressible, the work input to the pump will be:

$$(h_2 - h_1) = v(P_2 - P_1)$$

where $h_1 = h_{f@P1}$ & $v = v_1 = v_{f@P1}$

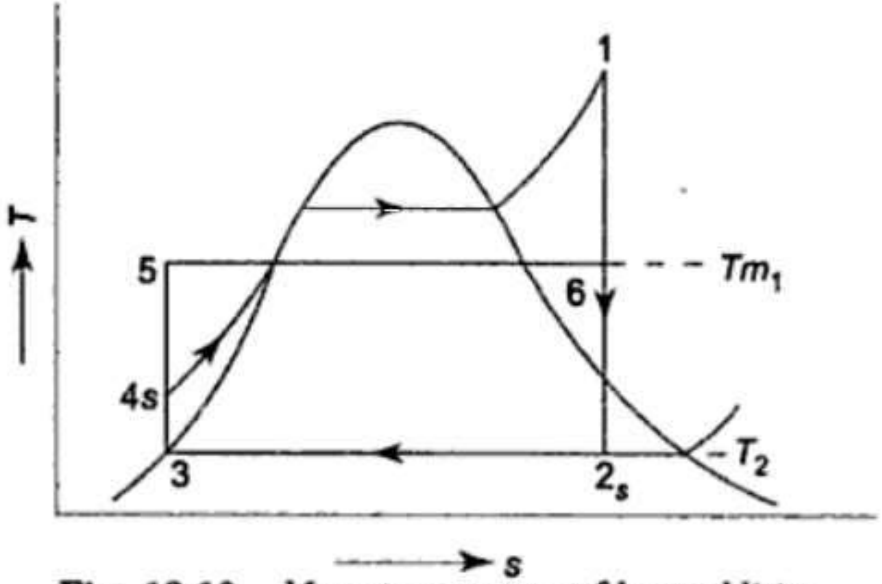


Fig. 12.10 *Mean temperature of heat addition*

$\eta_{rankine} = 1 - T_2/ Tm$ ➡ Lowering the condenser pressure, Higher will be the efficiency of Rankine cycle.

Rankine cycles in other applications

- **Solar thermal energy conversion**
- **Ocean thermal energy conversion**

  Using ammonia or other fluid with appropriate thermodynamics
- **Low temperature organic Rankine cycles (ORC)**

  Utilize low energy density sources like

  Biomass, low intensity solar, low temperature geothermal

  Using organic fluids (eg. pentane) with appropriate thermodynamics

So
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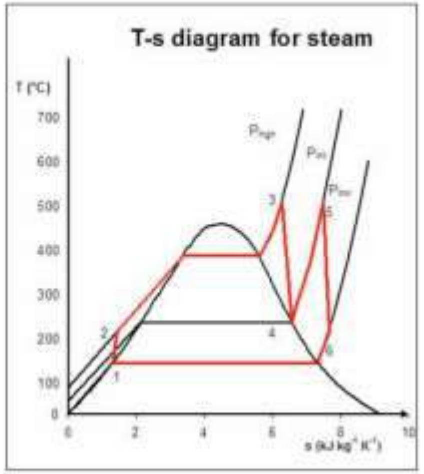
More complex Rankine cycles



Rankine with reheating:

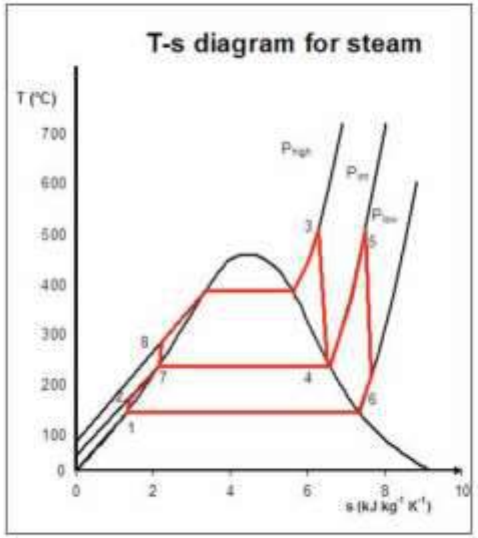
- **Two turbines in series**

  Output from one at ④

  Re-enters boiler without recompression

  Hence no decrease in entropy before reheating

  And then to second turbine



Rankine with regeneration:

- **Commonly used in actual power plants**
- **Two turbines in series**

  Condensed subcooled liquid at ②

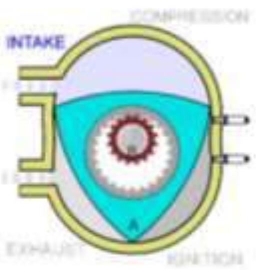
  Mixed with steam tapped at ④

  To preheat to saturated liquid at ⑦

Internal Combustion Engine

The **Internal combustion engine** is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber.

2 – Stroke Engine

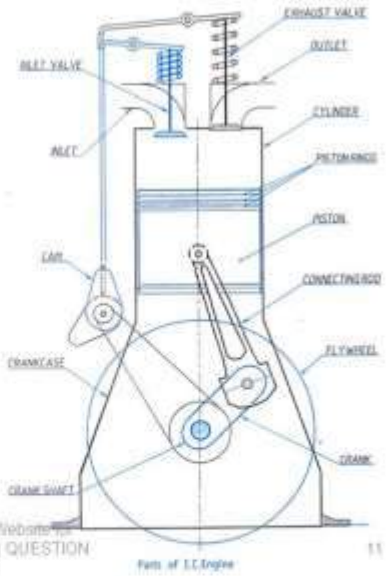


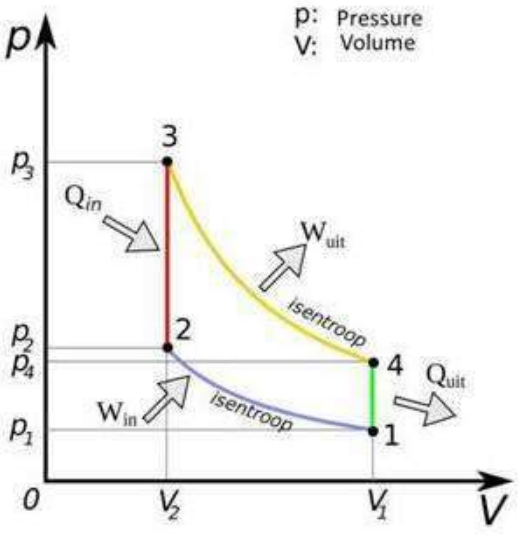
Rotay Engine

4 – Stroke Engine

Parts of I.C Engine

- *Cylinder*
- *Piston*
- *Piston rings*
- *Connecting rod*
- *Crank and crankshaft*
- *Valves*
- *Flywheel*
- *Crankcase*





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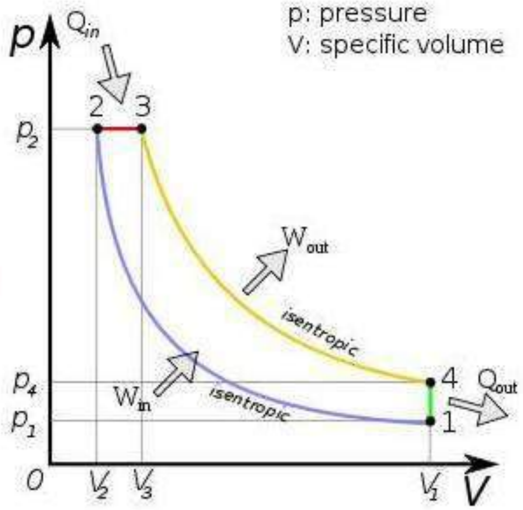


Otto Cycle **Diesel Cycle**

	Otto Cycle	Diesel Cycle
1	Heat is addition in system at constant volume.	Heat is addition in system at constant pressure.
2	Compression ration varies from 6 to 10.	Compression ration varies from 14 to 22.
3	High Efficiency at same compression ratio.	Low efficiency at same compression ratio.
4	Petrol engine work on Otto cycle.	Diesel engine is work on diesel cycle.
5	Spark plug required.	Fuel injector required.
6	Air Fuel mixture inserted from inlet valve.	Only Air is inserted from inlet valve.
7	After generating spark, combustion take place.	Combustion take place due to hot air and fuel receive from fuel injector.
8	In compression stroke, air fuel is compressed.	In compression stroke, only air is compressed.
9	Fuel is inserted during the suction stroke.	Fuel is inserted at the end of compression stroke.
10	No need of high pressure and temperature because spark starts the combustion.	High pressure and temperature is required to start combustion when fuel is injected.
11	Low compression ratio.	High compression ratio.

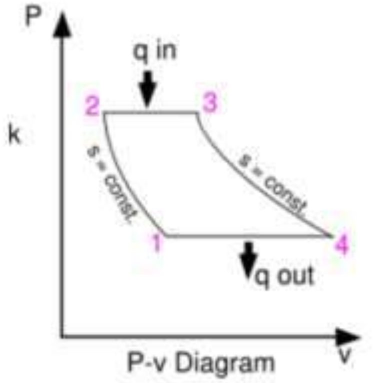
Brayton Gas Turbine Cycles

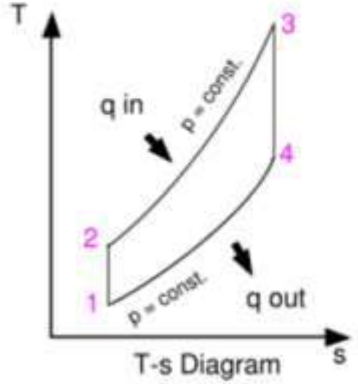
Open cycle gas fired turbine

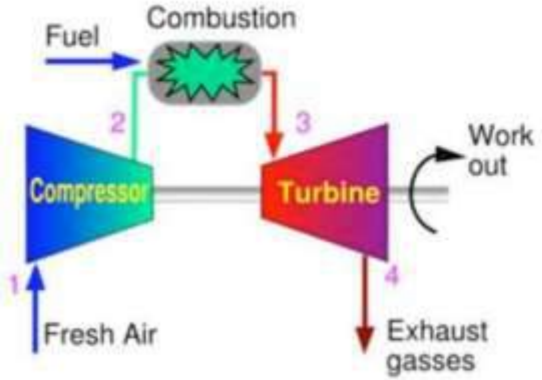
- ★ **What's the idea? Burn natural gas to produce high T and high P vapor**

  Directly powers turbine

- ★ **Very high temperatures $\sim 1200°\text{C}$ and efficiencies $\sim 35-42\%$.**





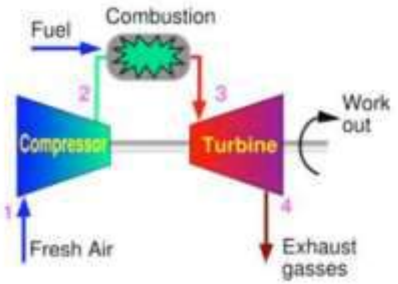


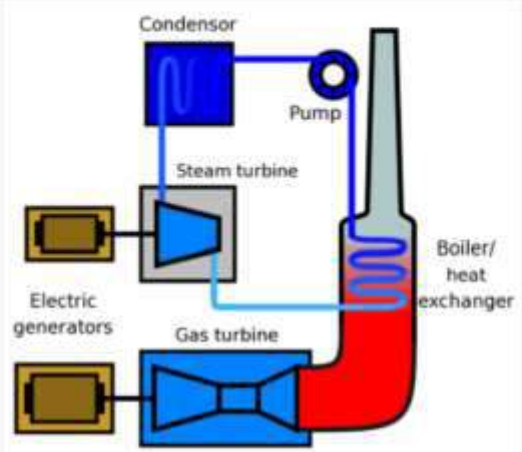
- ★ **Elements in cycle**
  - **[12] Fresh air enters compressor: Adiabatic compression**
  - **[23] Combustion: Isobaric heating**
  - **[34] Turbine: Adiabatic expansion**
  - **[41] Exhaust: Isobaric cooling**

Brayton Gas Turbine Cycles

Combine Brayton Gas Cycle with Rankine Steam Cycle

- ★ **Very high temperatures $\sim 1200°\text{C}$ and efficiencies $\sim 35-42\%$.**
- ★ **By-product gases from gas turbine are hot enough, $\sim 500°\text{C}$ to source a downstream Rankine cycle**
- ★ **Ideally combine with cogeneration for most greatest efficiency!**
- ★ **Efficiencies exceed 60 – 65 % compared to 30-40 % for separate Rankine or Brayton cycles (when using natural gas)**





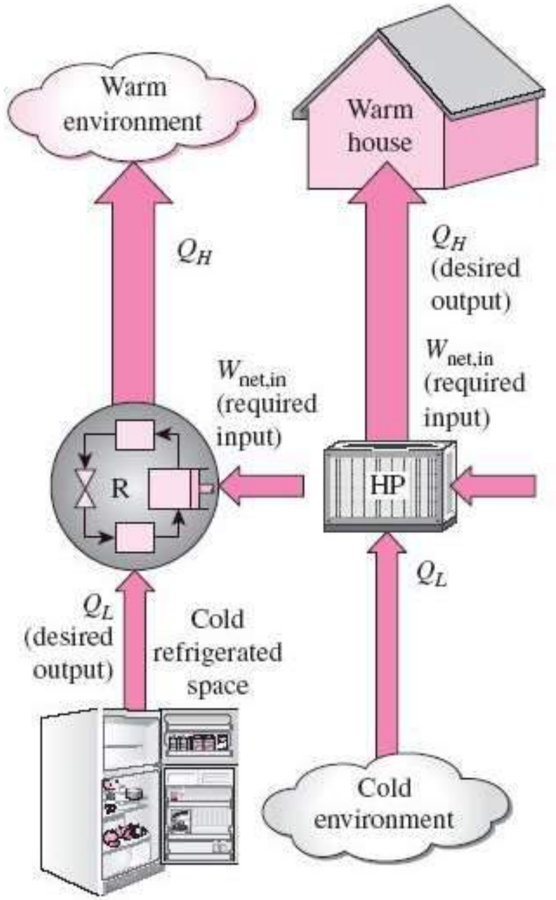
$$\eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

$$\eta = 1 - \frac{T_1\left[\left(\frac{T_4}{T_1}\right) - 1\right]}{T_2\left[\left(\frac{T_3}{T_2}\right) - 1\right]}$$

$$\eta_{th,Brayton} = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{P_1}{P_2}\right)^{(k-1)/k}$$

$$= 1 - \frac{1}{r_P^{(k-1)/k}}$$

REFRIGERATORS AND HEAT PUMPS



(*a*) Refrigerator (*b*) Heat pump

- The transfer of heat from a low-temperature region to a high-temperature one requires special devices called **refrigerators**.
- Another device that transfers heat from a low-temperature medium to a high-temperature one is the **heat pump**.
- Refrigerators and heat pumps are essentially the same devices; they differ in their objectives only.
- The objective of a refrigerator is to remove heat (Q_L) from the cold medium
- The objective of a heat pump is to supply heat (Q_H) to a warm medium.

$$\text{COP}_{\text{Heating}} = \frac{T_{\text{HOT}}}{T_{\text{HOT}} - T_{\text{COLD}}}$$

$$\text{COP}_{\text{COOLING}} = \frac{T_{\text{COLD}}}{T_{\text{HOT}} - T_{\text{COLD}}}$$

Semiconductors

A semiconductor material is one which conducts only when excited.

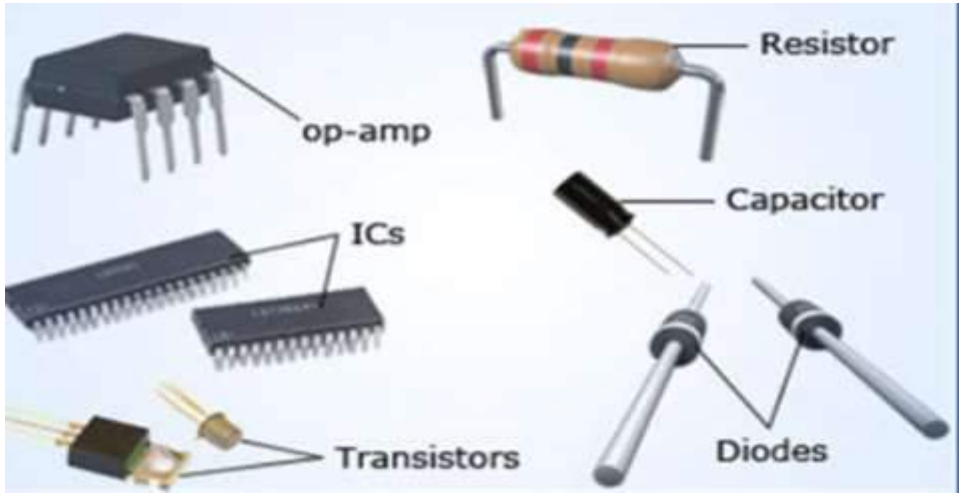
- It is neither an Insulator, nor a Conductor.
- A conductor has normally one carrier per atom, while a semiconductor has one carrier per 10^{12} at room temperature (Silicon).
- The devices are built by introducing an impurity into otherwise a pure matter, and the process is called "doping".

- **Semiconductor device,** electronic circuit component made from a material that is neither a good conductor nor a good insulator (hence semiconductor). Such devices have found wide applications because of their compactness, reliability, and low cost. As discrete components, they have found use in power devices, optical sensors, and light emitters, including solid-state lasers.
- Semiconductor device have high conductivities, typically from 10^4 to 10^6 Siemens per centimeter. The conductivities of semiconductors are between these extremes.

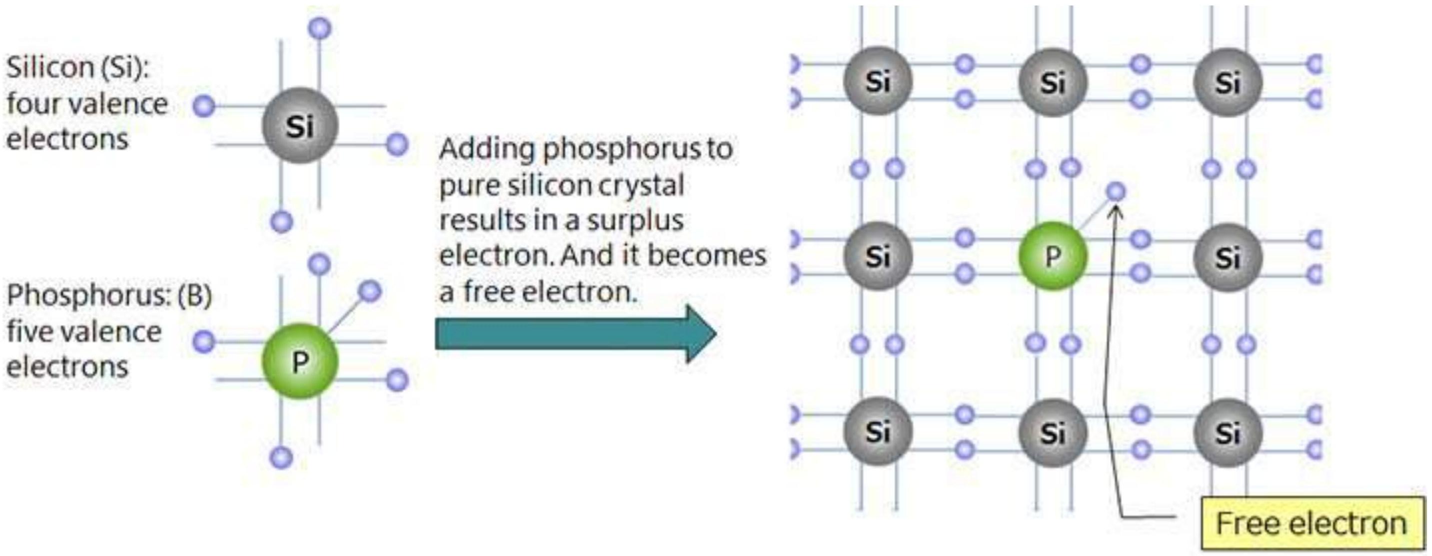
Applications of semiconductor devices

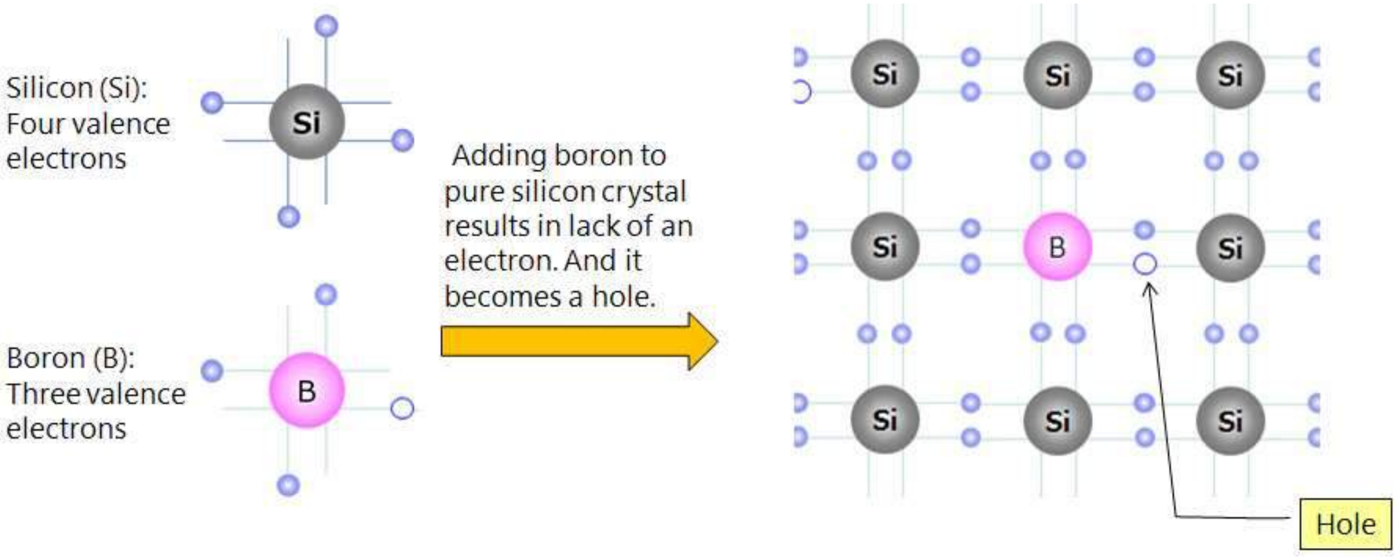
Semiconductor devices are all around us. . They can be found in just about every commercial product we touch, from the family car to the pocket calculator.

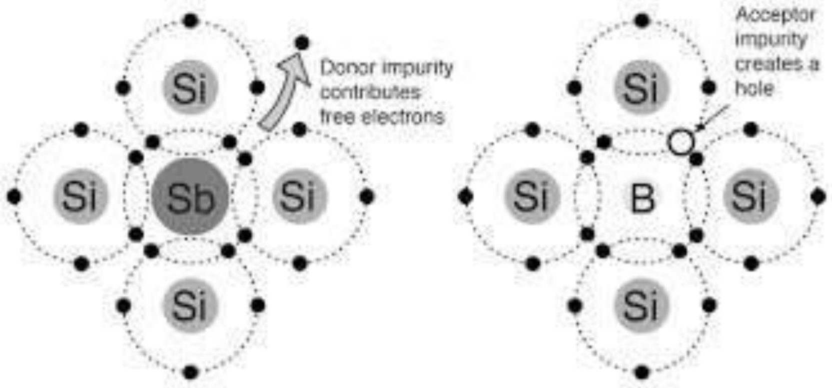
- Rectifiers which are used in d. c. power supplies.
- Wave shaping circuits such as clippers and clampers.
- Voltage regulator circuits.
- Portable Radios and TV receivers.
- Science and industry,
- solid-state devices, space systems, computers, and data processing equipment,
- military equipment,
- Data display systems, data processing units, computers, and aircraft guidance-control assemblies etc...



n and p type semiconductor



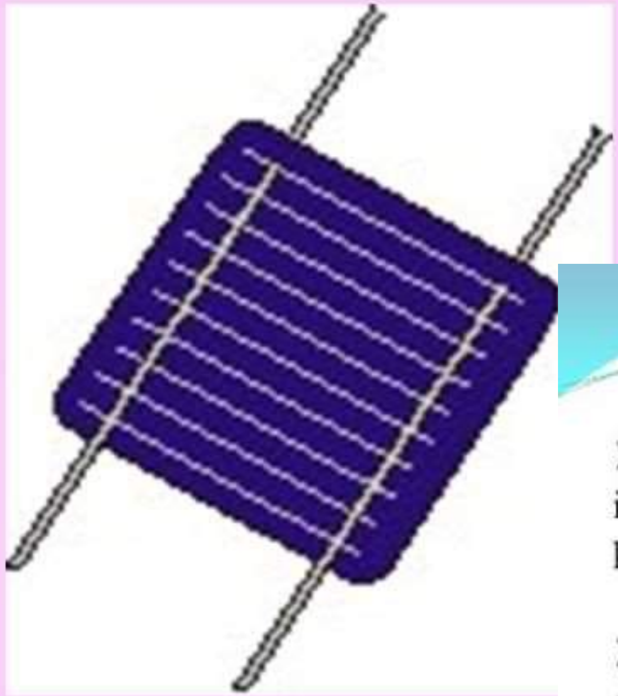




N-type semiconductor	P-type semiconductor
1. It is an extrinsic semi-conductor which is obtained by doping the impurity pentavalent impurity atoms such as antimony, phosphorous, arsenic etc. to the pure germanium or silicon semiconductor.	1. It is an extrinsic semiconductor which is obtained by doping trivalent impurity atoms such as boron, gallium, indium etc. to the pure germanium or silicon semiconductor.
2. The impurity atoms added, provide extra electrons in the structure, and are called donor atoms.	2. The impurity atoms added, create vacancies of electrons (i.e., holes) in the structure and are called acceptor atoms.
3. The electrons are majority charge carriers and holes are minority charge carriers.	3. The holes are majority charge carriers and eletrons are minority carriers.

What is a Solar Cell?

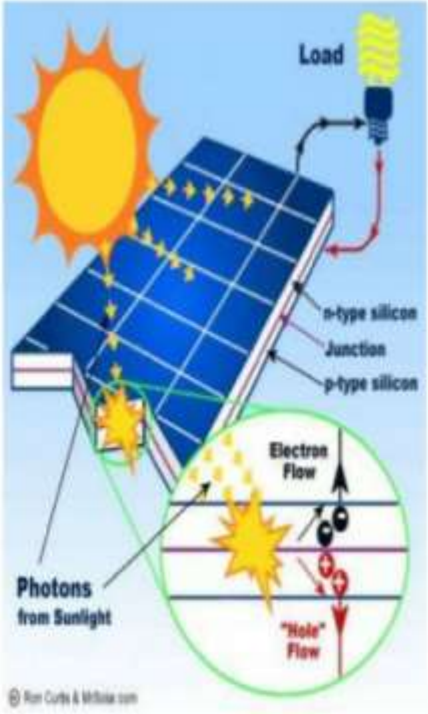
- A solar cell is a semiconductor device which converts electromagnetic radiation into electrical signals.
- It is a device which generates electricity directly from Sun's radiation by means of the photovoltaic effect so it is also called Photovoltaic cell.
- In order to generate useful power, it is necessary to connect a number of cells together to form a solar panel, also known as a photovoltaic module.
- The nominal output voltage of a solar panel is usually 12 Volts, and they may be used singly or wired together into an array.
- The number and size required is determined by the available light and the amount of energy required.



How Solar Panels Work?

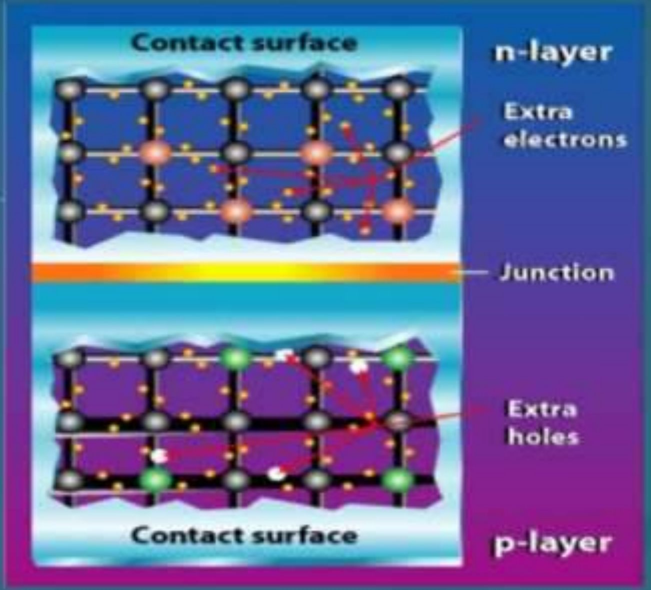
- Photovoltaic cell converts sunlight into electric energy and this effect is known as photovoltaic effect.
- Solar cells essentially create electricity by converting photons of light into electrons.
- Solar cell producing direct current, or DC, this DC current is converted to alternating current, or AC by using inverter.

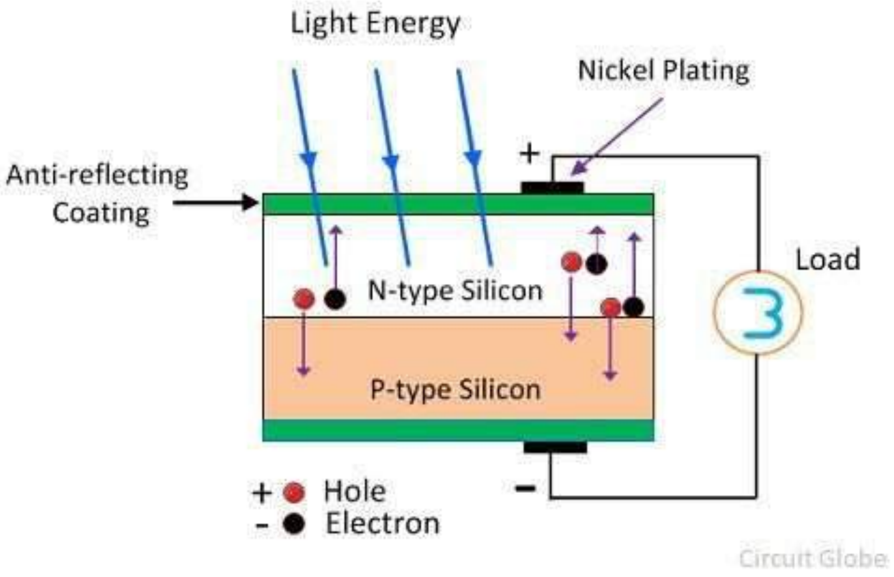
PROMSUN



Photovoltaic Effect

- Photovoltaic effect is generated photons hit a semi-conductor
- Material with a higher energy than the gap between its Valence andConduction bands.
- Free electrons move on one side
- (n-side) while holes move on the
- other side (p-side)
- A difference of potential is
- created
- between n-side and p-side
- allowing current through a load
- outside of the semi-conductor.





Unit-II Nuclear Energy: Fundamental forces in the universe, Quantum mechanics relevant for nuclear physics, Nuclear forces, energy scales and structure, Nuclear binding energy systematics, reactions and decays, Nuclear fusion, Nuclear fission and fission reactor physics, Nuclear fission reactor design, safety, operation and fuel cycles

Fundamental Forces

Watch me!

Physicists have identified four fundamental forces that account for the account all phenomena in the universe.*

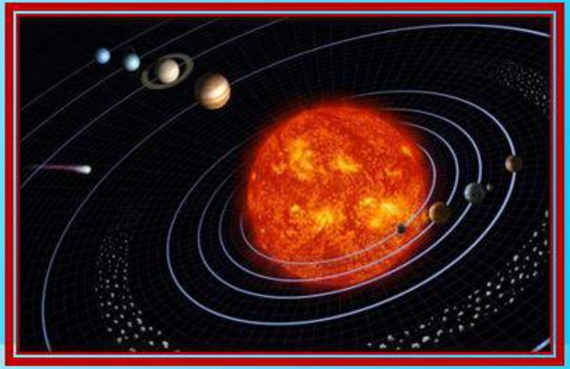
* Many scientists believe that these four forces are different aspects of ONE fundamental force – this is the search for the Unified Theory

Force	Strength	Distance of action	Description
Strong nuclear	Very strong!	Very, very Short	Holds the nucleus together
Weak nuclear	Very weak	Short	Arise during radioactive decay
Electromagnetic	Very weak	Infinite – but decreases with the square of distance	Attraction / repulsion of charged particles
Gravitational	Very, very, very weak	Infinite – but decreases with the square of distance	Attraction between matter

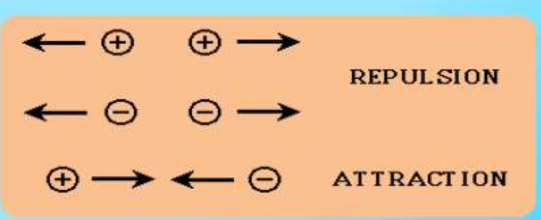
With the exception of gravity, ***all*** the forces we studied up to now are due, on a molecular level, to interactions between the electrons of objects – that is, they are caused by the electromagnetic force

1. Gravitational Force : The gravitational force is the force of mutual attraction between any two objects by virtue of their masses. It is a universal force. Every object experiences this force due to every other object in the universe.

All objects on the earth experience the force of gravity due to the earth. Gravity governs the motion of the moon and artificial satellites around the earth, motion of the earth and planets around the sun.



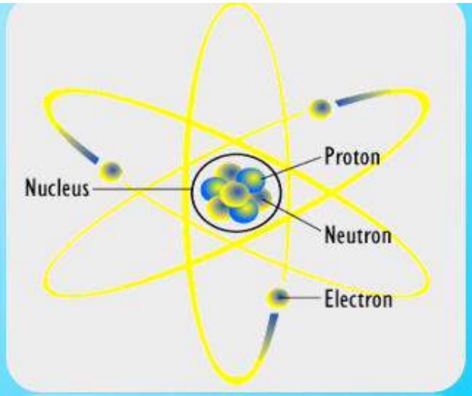
2.Electromagnetic Force: Electromagnetic force is the force between charged particles. When charges are at rest, the force is given by Coulomb's law : attractive for unlike charges and repulsive for like charges.



Charges in motion produce magnetic effects and a magnetic field gives rise to a force on a moving charge. Electromagnetic force acts over large distances and does not need any intervening medium.

Electromagnetic force can be attractive or repulsive.

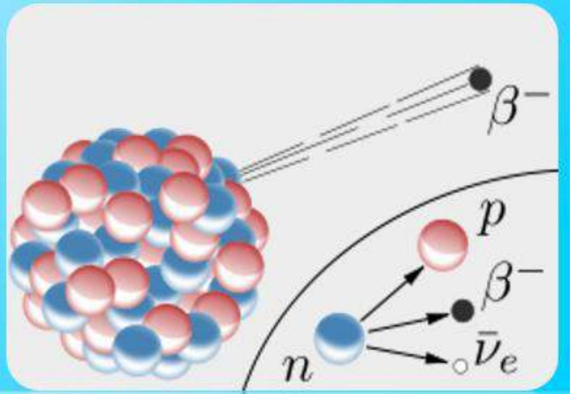
3. **Strong Nuclear Force:** The strong nuclear force binds protons and neutrons in a nucleus. The strong nuclear force is the strongest of all fundamental forces, about 100 times the electromagnetic force in strength.

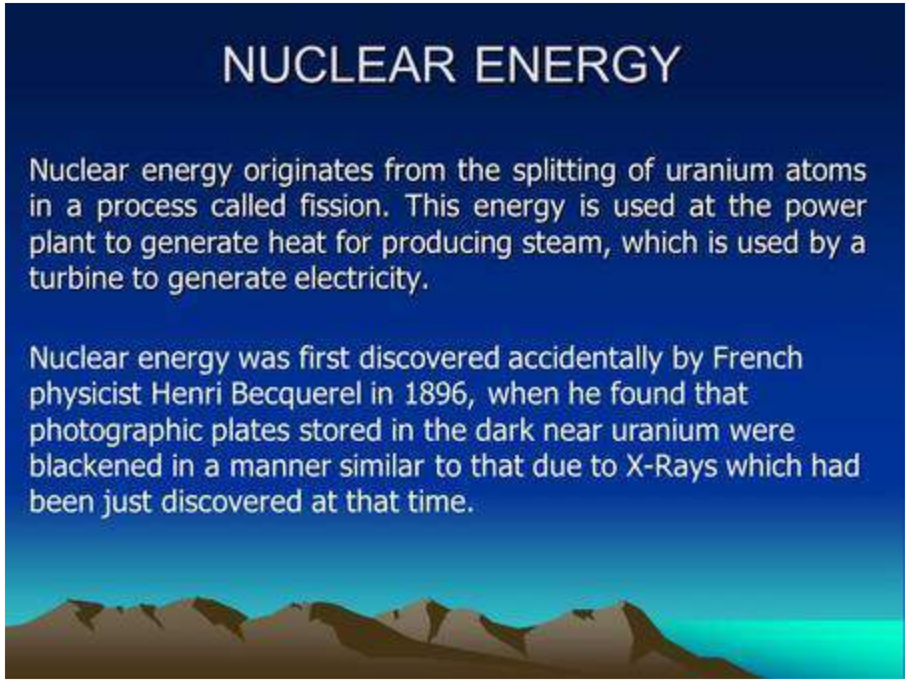


It is charge-independent and acts equally between a proton and a proton, a neutron and a neutron, and a proton and a neutron. Its range is, extremely small, of about nuclear dimensions (10^{-15}m). It is responsible for the stability of nuclei.

4.Weak Nuclear Force : The weak nuclear force appears only in certain nuclear processes such as the β-decay of a nucleus. In β-decay, the nucleus emits an electron and an uncharged particle called neutrino.

The weak nuclear force is not as weak as the gravitational force, but much weaker than the strong nuclear and electromagnetic forces. The range of weak nuclear force is exceedingly small, of the order of 10^{-16} m.





- **One major form of energy**
- **it is trapped inside each atom**
- **it makes up about 17 percent of the world's electricity.**
- **Some country depend on nuclear energy more than other energy**
- **There are now more than 400 nuclear power plants around the world.**

THE NUCLEAR FORCE

➢The force that binds together protons and neutrons inside the nucleus is called the **Nuclear Force.**

➢Some characteristics of the nuclear force are:

1.It does not depend on charge.

2.It is very short range.

3.It is much stronger than the electric force.

4.It is saturated force .

5.It favours formation of pairs of nucleons with opposite spins.

Nuclear power in India

- Nuclear Power is the fifth-largest source of generating electricity in India after coal, gas, wind power and hydroelectricity. At present, India has 22 operating nuclear reactors with an installed capacity of 6,780 MW in 7 nuclear power plants.

- Asia's first nuclear reactor is the Apsara Research Reactor situated in Mumbai. The domestic uranium reserve in India is small and the country is dependent on uranium imports from other countries to provide fuel to its nuclear power industry. Since the 1990s, Russia has been a major supplier of nuclear fuel to India.

Nuclear Power Plants in India 2021- Operational

Power Plant	Location	Operator	Type	Total Capacity (MW)
Kaiga	Karnataka	NPCIL	IPHWR-220	880
Kakrapar	Gujarat	NPCIL	IPHWR-220 IPHWR-700	1,140
Kudankulam	Tamil Nadu	NPCIL	VVER-1000	2,000
Madras (Kalpakkam)	Tamil Nadu	NPCIL	IPHWR-220	440
Narora	Uttar Pradesh	NPCIL	IPHWR-220	440
Rajasthan	Rajasthan	NPCIL	CANDU IPHWR-220	1,180
Tarapur	Maharashtra	NPCIL	BWR IPHWR-520	1,400
Total				**7,480**

Nuclear Power Plants in India 2021- Under Construction

Power Plant	Location	Operator	Type	Total Capacity (MW)
Madras (Kalpakkam)	Tamil Nadu	BHAVINI	PFBR	500
Kakrapar Unit 4	Gujarat	NPCIL	IPHWR-700	700
Gorakhpur	Haryana	NPCIL	IPHWR-700	1,400
Rajasthan Unit 7 & 8	Rajasthan	NPCIL	IPHWR-700	1,400
Kudankulam Unit 3 & 4	Tamil Nadu	NPCIL	VVER-1000	2,000
Total				**6,000**

Nuclear Power Plants in India 2021- Planned Projects

Power Plant	Location	Operator	Type	Total Capacity (MW)
Kaiga	Karnataka	NPCIL	IPHWR-700	1,400
Jaitapur	Maharashtra	NPCIL	EPR	9,900
Kovvada	Andhra Pradesh	NPCIL	AP1000	6,600
Kavali	Andhra Pradesh	NPCIL	VVER	6000
Gorakhpur	Haryana	NPCIL	IPHWR-700	2,800
Mahi Banswara	Rajasthan	NPCIL	IPHWR-700	2,800
Chutka	Madhya Pradesh	NPCIL	IPHWR-700	1,400
Kudankulam Unit 5 & 6	Tamil Nadu	NPCIL	VVER-1000	2,000
Madras	Tamil Nadu	BHAVINI	FBR	1,200
Tarapur	Maharashtra		AHWR	300
Total				**33,000**

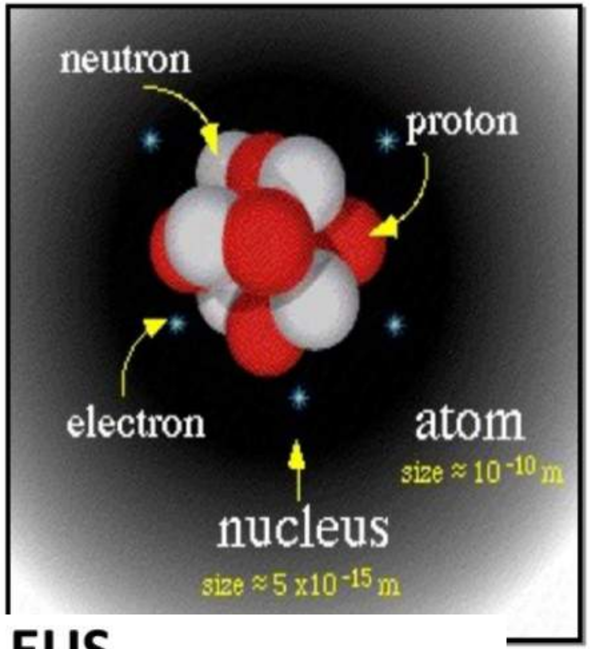
- India has a flourishing and largely indigenous nuclear power program and expects to have 20,000 MWe nuclear capacity on line by 2020. It aims to supply 25% of electricity from nuclear power by 2050.
- Because India is outside the Nuclear Non-Proliferation Treaty due to its weapons program, it has been for 34 years largely excluded from trade in nuclear plant or materials, which has hampered its development of civil nuclear energy until 2009.
- Due to these trade bans and lack of indigenous uranium, India has uniquely been developing a nuclear fuel cycle to exploit its reserves of thorium.
- From 2009, foreign technology and fuel are expected to boost India's nuclear power plans considerably.
- India has a vision of becoming a world leader in nuclear technology due to its expertise in fast reactors and thorium fuel cycle.

- Nuclear physics is the field of physics that studies the building blocks and interactions of atomic nuclei.
- It includes the study of,

1. The general properties of nucleus.
2. The particles contained in the nucleus.
3. The interaction between these particles.
4. Radio activity and nuclear reactions.
5. Practical applications of nuclear phenomena.

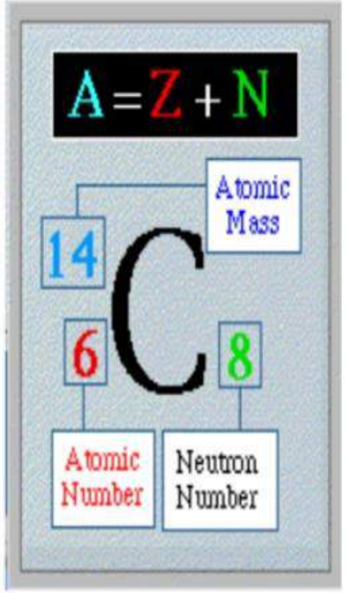
NUCLEUS

- Every atom contains a centre, an extremely dense, positively charged nucleus.
- The nucleus is made of protons and neutrons.
- Protons have positive electric charge.
- Neutrons have no electrical charge.



NUCLEUS

- <u>MASS NUMBER(**A**):</u> total number of nucleon.A=Z(protons)+N(neutrons).
- <u>ATOMIC NUMBER(**Z**):</u> number of protons.
- <u>NEUTRON NUMBER N</u>: number of neutrons.
- <u>RADIUS</u>: $\mathbf{r=r_0A^{1/3}}$, $r_0=1.25\times10^{-15}$ m.
- <u>MASS</u> **<u>M=AU</u>**,u=1.66×10^{-27}kg



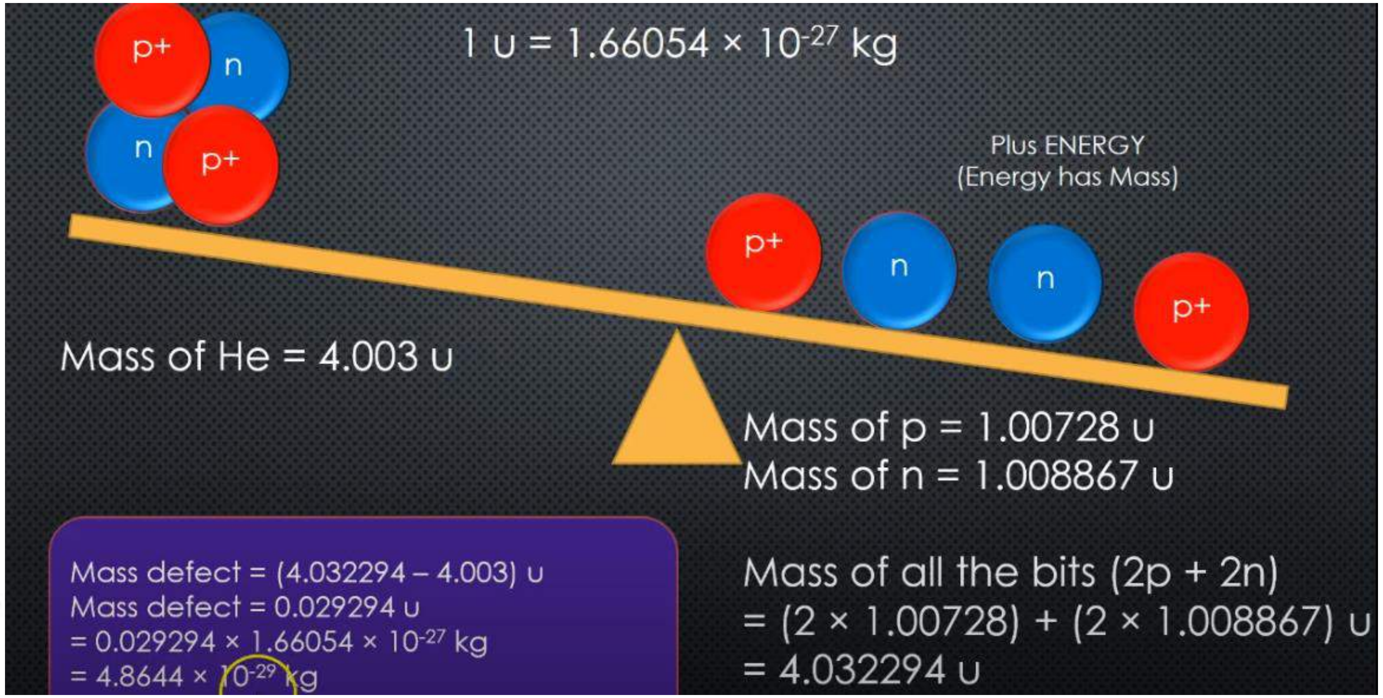
THE NUCLEAR FORCE

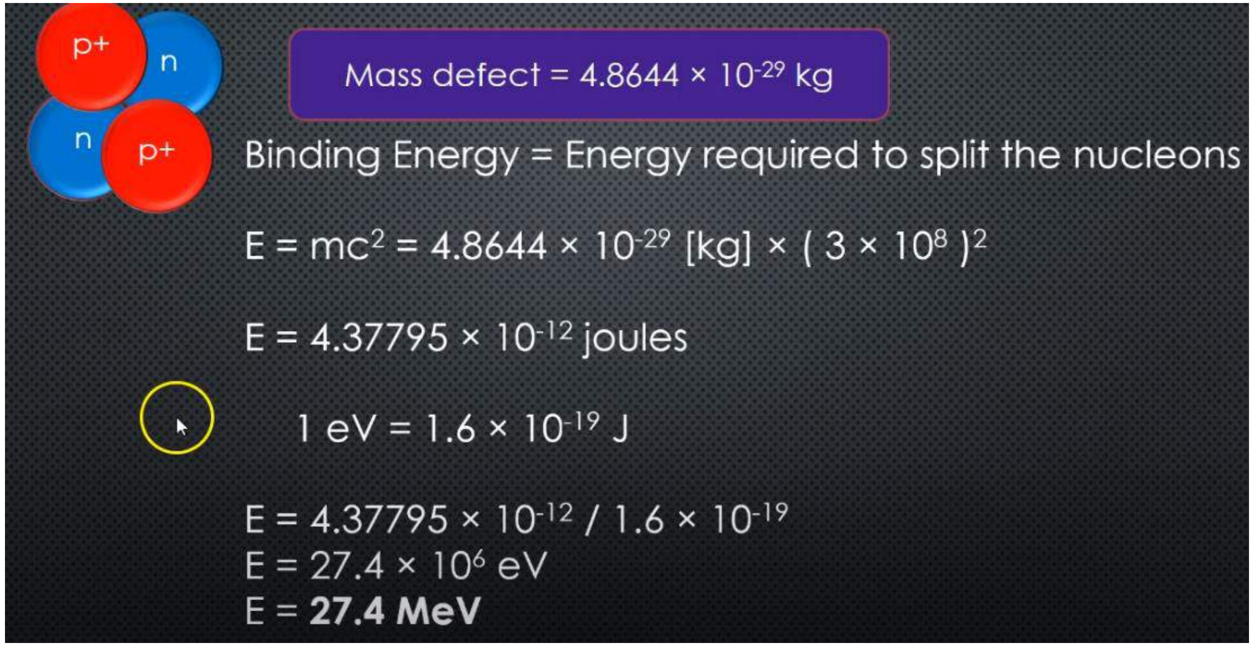
- The force that binds together protons and neutrons inside the nucleus is called the **Nuclear Force.**
- Some characteristics of the nuclear force are:

1. It does not depend on charge.
2. It is very short range.
3. It is much stronger than the electric force.
4. It is saturated force .
5. It favours formation of pairs of nucleons with opposite spins.

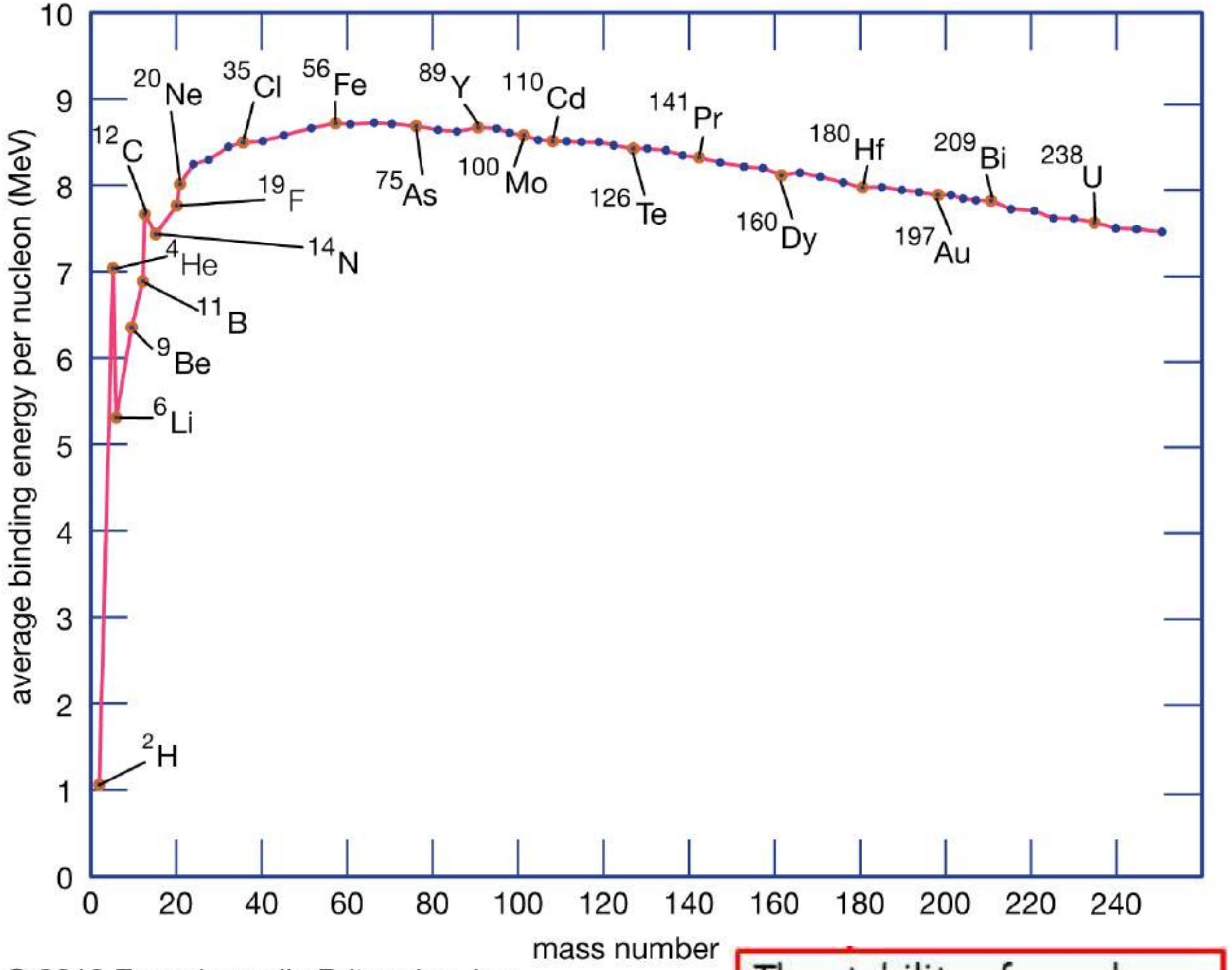
NUCLEAR BINDING ENERGY

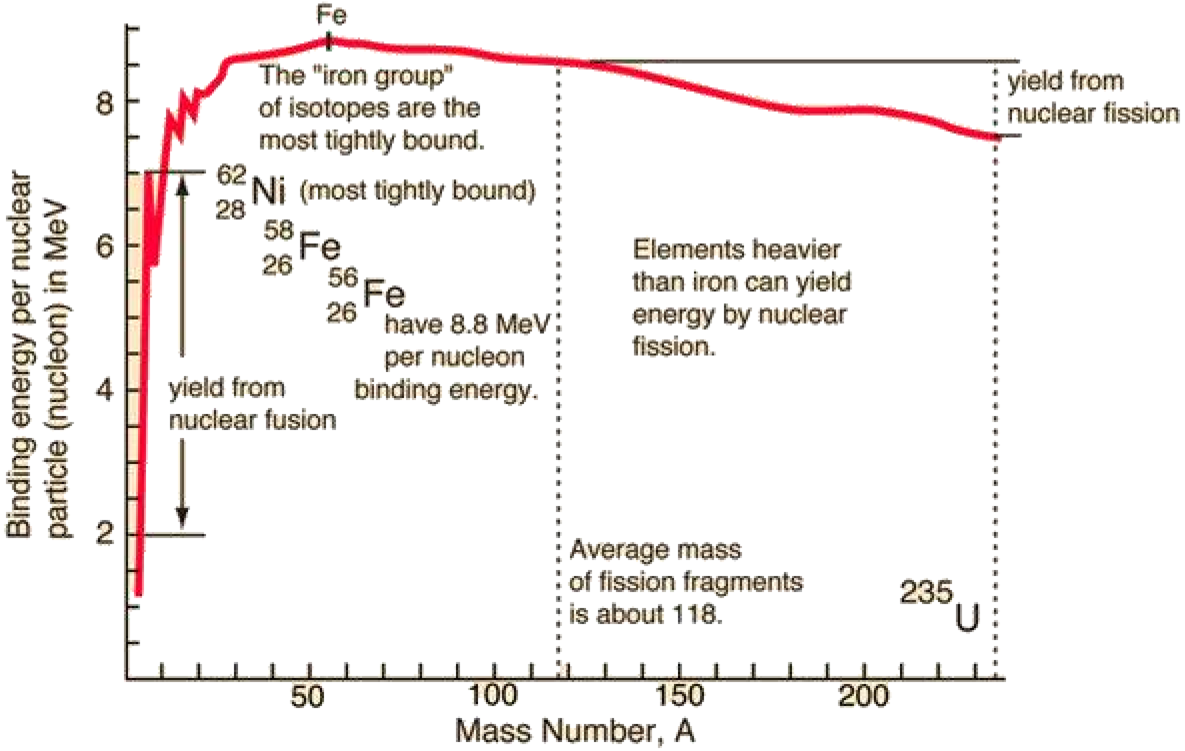
Nuclear binding energy is the energy required to split a nucleus of an atom into its component parts: protons and neutrons.



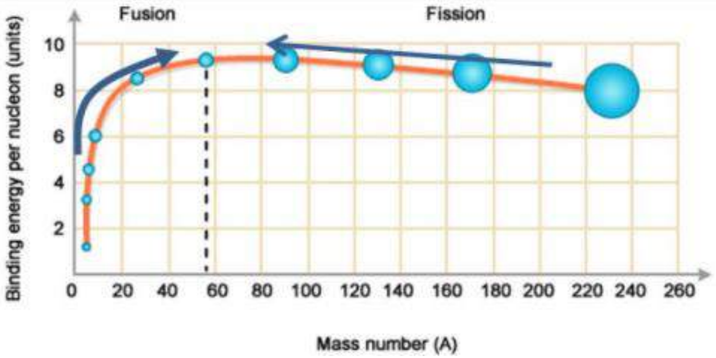


Binding energy per nucleon = 27.4 / 4 = 6.8 MeV



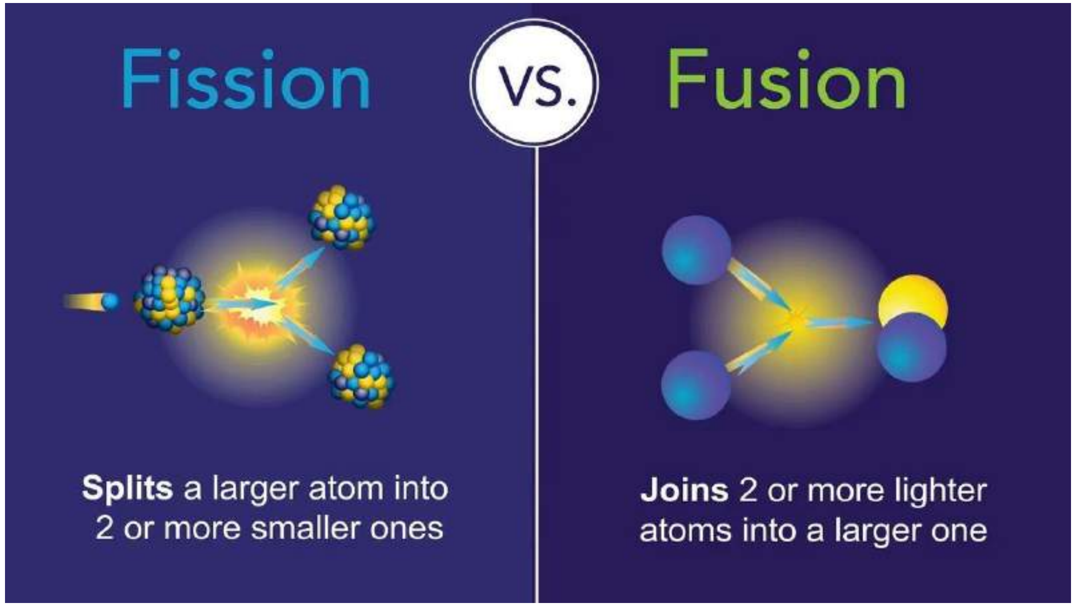


The stability of a nucleus depends on its binding energy per nucleon. **Iron** has the greatest stability because it has the largest binding energy per nucleon – lots of energy is required to separate its nucleons.



Nuclear fission and nuclear fusion both **release energy** because **both processes increase the binding energy per nucleon** of the particles involved.

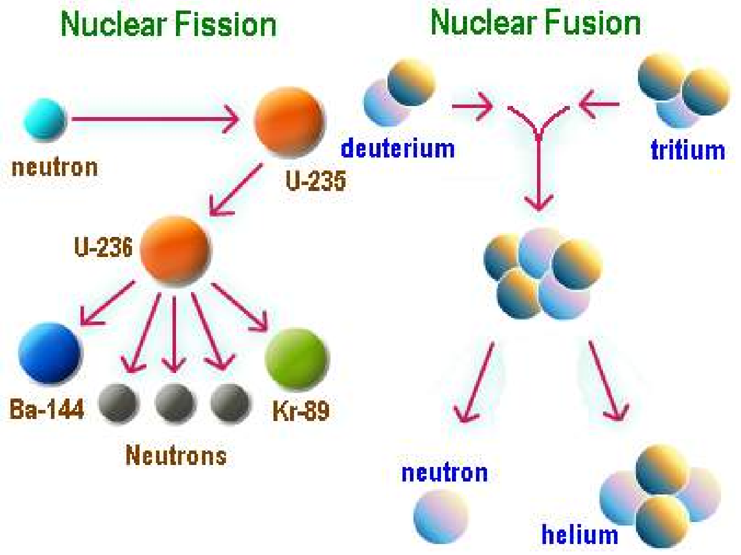
Nuclear reaction change in the identity or characteristics of an atomic nucleus, induced by bombarding it with an energetic particle.



Difference between nuclear fission and fusion

- Fission reaction does not occur naturaly.
- It produces many highly radioactive particles.
- Energy released is million times grater that that in chemical reactions, but lower that the energy released by nuclear fusion

- Fusion occurs in stars such as sun.
- Few radioactive particles are produced by fusion reaction, but requires fussion trigger
- Energy released is three to four times greater than the energy released by fission



Nuclear Fission and Fusion

Fission: Splitting a heavy nucleus into two nuclei with smaller mass numbers.

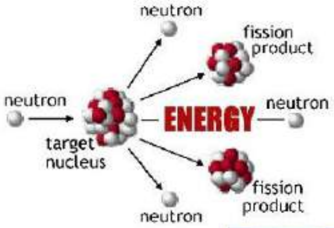
$$ {}^{1}_{0}n + {}^{235}_{92}\mathrm{U} \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n $$

Fusion: Combining two light nuclei to form a heavier, more stable nucleus.

$$ {}^{3}_{2}He + {}^{1}_{1}H \rightarrow {}^{4}_{2}He + {}^{0}_{1}e $$

What is Nuclear Fuel?

Nuclear fuel is an energy source that results from the splitting of atoms.



Advantages:
1)Helps generate electricity
2)Low fuel costs (Uranium – 235)
3)Water vapor is the only emission

Problems:
1) Cause thermal pollution of waterways.
2) Difficult to safely dispose of nuclear (radioactive) wastes .

SOURCE OF FUEL

- Uranium is the primary fuel for nuclear reactor.

- Uranium is a naturally-occurring element in the Earth's crust.

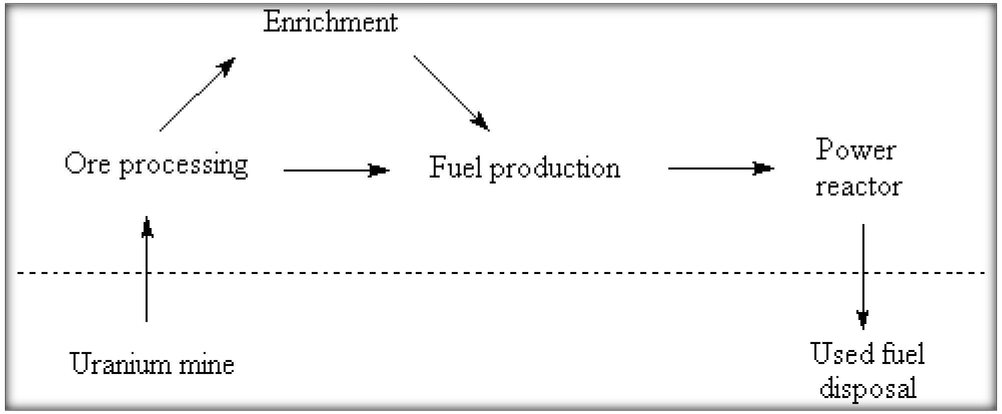
- Traces of it occur almost everywhere, although mining takes place in locations where it is naturally concentrated.

.

- Uranium mines operate in some twenty countries, though about half of world production comes from just ten mines in six countries, in Canada, Australia, Niger, Kazakhstan, Russia and Namibia.

Nuclear Fuel Cycle

- It is the progression of nuclear fuel through a series of stages.
- Nuclear fuel may be Uranium-235, Plutonium-239 etc.
- Front end : consists of mining of fuel, chemical purification, conversion to appropriate form and fuel rod fabrication.
- Back end : consists of steps to safely manage, contain, and either reprocess (closed cycle) or dispose(open cycle) spent nuclear fuel.



Uranium-235 is used as a fuel in different concentrations. Some reactors, such as the CANDU reactor, can use natural uranium with uranium-235 concentrations of only 0.7%, while other reactors require the uranium to be slightly enriched to levels of 3% to 5%.
Plutonium-239 is produced and used in reactors (specifically fast breeder reactors) that contain significant amounts of uranium-238. It can also be recycled and used as a fuel in thermal reactors. Current research is being done to investigate how thorium-232 can be used as a fuel.

Isotope Symbol Review

Mass number = number of protons + number of neutrons

$$^{A}_{Z}X$$

Element symbol

Atomic number = number of protons

A = number of protons + number of neutrons

Z = number of protons

A – Z = number of neutrons

*****Number of neutrons = Mass Number – Atomic Number*****

Fill in the chart for each isotope

$$^{235}_{92}U$$

A	235
Z	92
Number of protons	92
Number of neutrons	143

$$^{238}_{92}U$$

A	238
Z	92
Number of protons	92
Number of neutrons	146

Isotopes of any particular element contain the **same** number of protons, but **different** numbers of neutrons.

- Most of the isotopes which occur naturally are stable.
- A few naturally occurring isotopes and all of the man-made isotopes are unstable.
- Unstable isotopes can become stable by releasing different types of particles.
- This process is called radioactive decay and the elements which undergo this process are called radioisotopes.
- The products of this decay are called **daughter isotopes**

Radioactive Decay

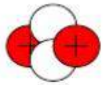
Radioactive decay results in the emission of either:

- an alpha particle (α),
- a negative beta particle (electron) (β^-),
- a positive beta particle (positron) (β^+),
- or a gamma ray (γ).

In a nuclear reaction the MASS and ATOMIC NUMBER must be the SAME on both sides of the equations

Alpha Decay

An alpha particle is identical to that of a helium nucleus.



It contains two protons and two neutrons.

$${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

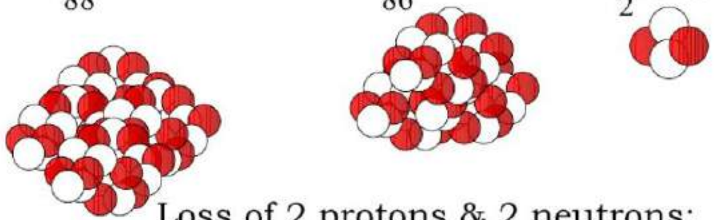
unstable atom

more stable atom

alpha particle

Alpha Decay

$${}^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

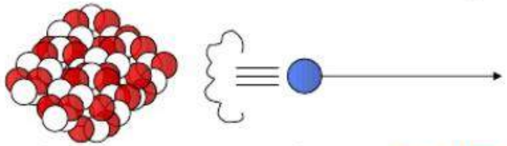


Loss of 2 protons & 2 neutrons:
Atomic # decreases by 2
Mass # decreases by 4

$${}^{234}_{92}U \longrightarrow {}^{230}_{90}Th + {}^{4}_{2}He$$

Beta Emission

A beta particle is a fast moving electron which is emitted from the nucleus of an atom undergoing radioactive decay.



Beta emission occurs when a **neutron changes into a proton and an electron**.

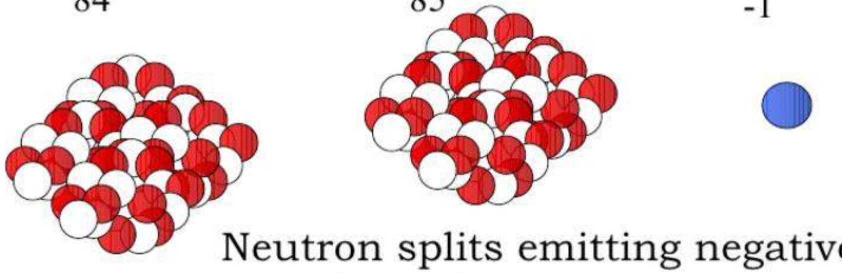
$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

proton stays in nucleus

beta particle (electron)

Beta Emission

$${}^{218}_{84}Po \longrightarrow {}^{218}_{85}At \quad {}^{0}_{-1}e$$



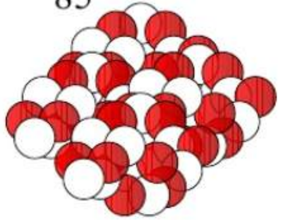
$${}^{234}_{90}Th \longrightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$$

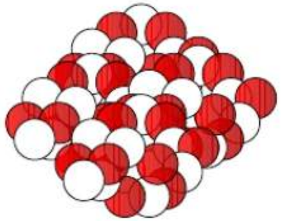
Neutron splits emitting negative particle leaving a proton.

- Atomic # increases by 1
- Mass # stays the same (electrons have no mass)

Electron Capture

$$^{218}_{85}At + ^{0}_{-1}e \longrightarrow ^{218}_{84}Po$$



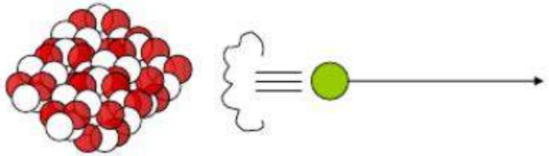


Capture negative particle,
forming a neutron from a proton

- Atomic # decreases by 1
- Mass # stays the same
  (electrons have no mass)

Positron Emission

A positron is like an electron but it has a positive charge.



During positron emission a **proton changes into a neutron** and the excess positive charge is emitted.

$$^{A}_{Z}X \longrightarrow ^{A}_{Z-1}Y + ^{0}_{+1}e$$

mass stays in nucleus

positron

Gamma Decay

- When atoms decay by emitting α or β particles to form a new atom, the nuclei of the new atom formed may still have too much energy to be completely stable. These atoms will emit gamma rays to release that energy.
- Gamma rays are high energy radiation
- Gamma rays are not charged particles like α and β particles.
- There is **no** change in mass or atomic number

$$^{A}_{Z}X \longrightarrow ^{A}_{Z}X + ^{0}_{0}\gamma$$

Summary

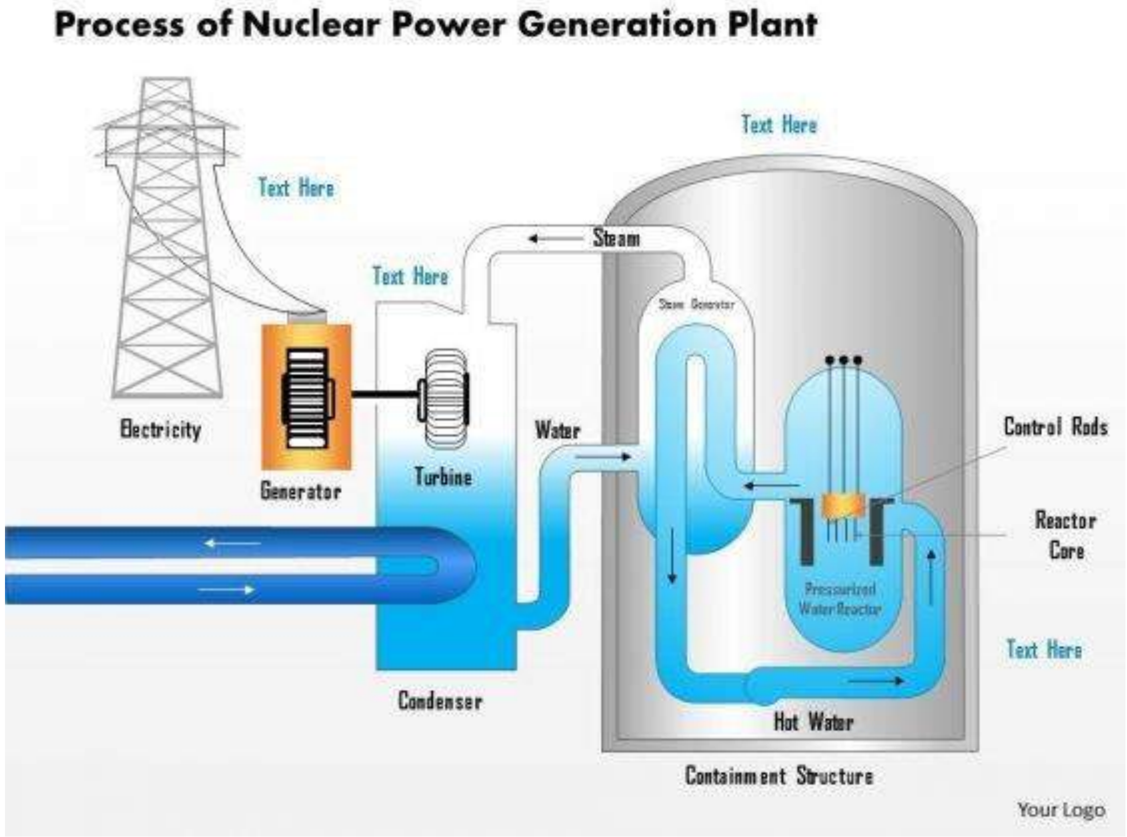
Reaction	What happens?	Mass #	Atomic #
Alpha Decay α	Lose Helium Nucleus	**-4**	**-2**
Beta Decay β^-	Lose electron from nucleus (neutron turns into proton)	**No change**	**+1**
Electron Capture	Gain electron in nucleus (proton turns into neutron)	**No change**	**-1**
Positron Emission β^+	Lose positron (proton turns into neutron)	**No change**	**-1**
Gammy Decay γ	Emit high energy gamma ray	**No change**	**No change**

Nuclear Stability

- The strong nuclear force holds all nuclei together
  - Otherwise protons would repel each other
  - Neutrons space out protons and make nucleus stable
- Not all isotopes are radioactive
- Only **unstable** nuclei decay
- In smaller atoms stable isotopes have **equal** numbers of protons and neutrons
- In larger atoms stable isotopes will have **more** neutrons than protons
- Too many or too few neutrons makes the nucleus unstable

Introduction to Nuclear Power

- It is the use of Nuclear Fission reactions to Generate Power
- Nuclear energy is the world's largest source of emission-free energy
- Most efficient Power Source per Unit Area
- Used in 31 Countries (approx 441 reactors)[1]
- Accounts for about 16% of all electricity generated world wide (approx 351 Gigawatts)

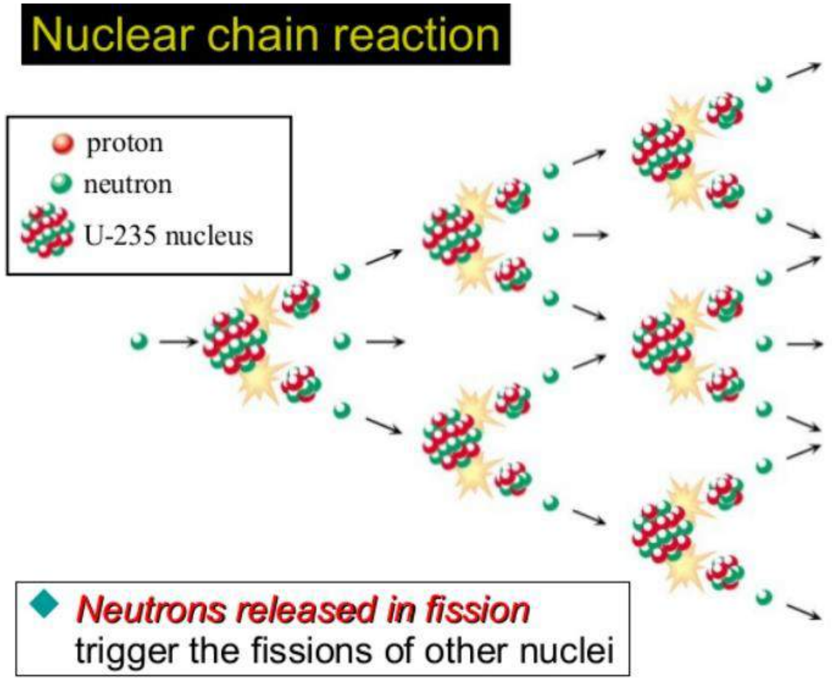


Benefits of Nuclear Power

- Reduce demand of Coal
- Stable fuel cost
- Improves the environment
- Less space is required
- Bigger capacity gives additional advantage
- Economic benefits – jobs & economy
- Waste product is controlled, stored, monitored, protected and regulated
- Proven, reliable, low-cost supplier of electricity

❑ Working principle :

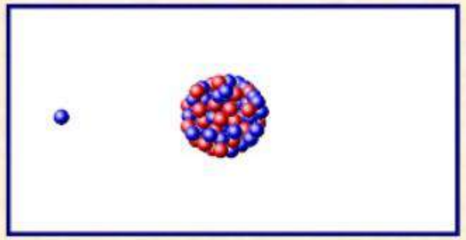
- ❖ A nuclear power plant works in a similar way as a thermal power plant. The difference between the two is in the fuel they use to heat the water in the boiler(steam generator).
- ❖ Inside a nuclear power station, energy is released by nuclear fission in the core of the reactor.
- ❖ 1 kg of Uranium U^{235} can produce as much energy as the burning of 4500 tonnes of high grade variety of coal or 2000 tonnes of oil.

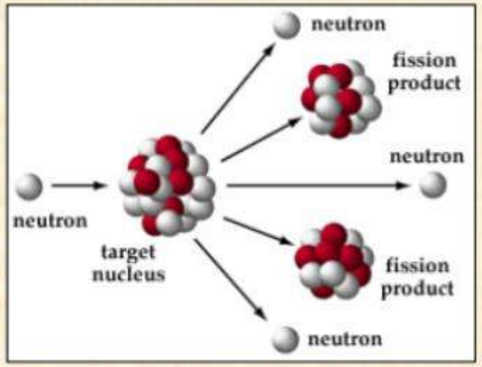


❑ Chain Reaction…

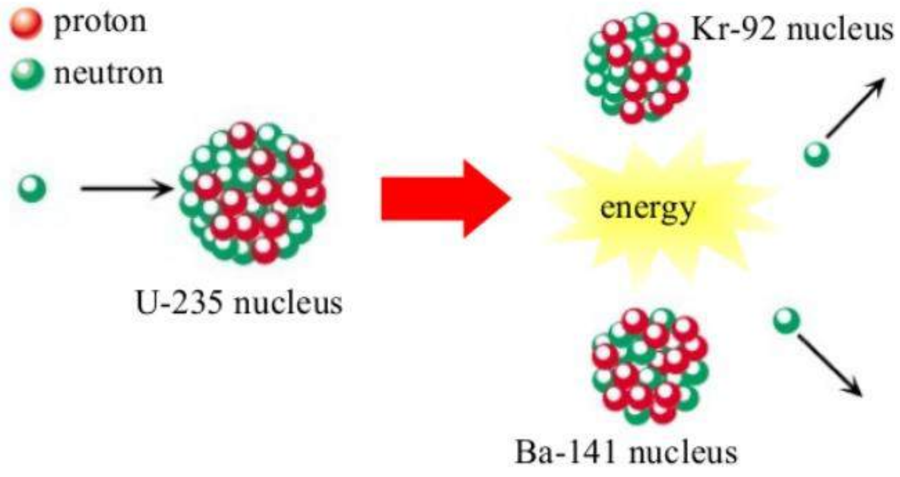
- ➢ Uranium exists as an isotope in the form of U^{235} which is unstable.
- ➢ When the nucleus of an atom of Uranium is split, the neutrons released hit other atoms and split them in turn. More energy is released each time another atom splits. This is called a chain reaction.

❑ Nuclear fission:





◆ Nuclear fission: **heavy nuclei split into two smaller parts** in order to become more stable



- It is a process of splitting up of nucleus of fissionable material like uranium into two or more fragments with release of enormous amount of energy.
- The nucleus of U^{235} is bombarded with high energy neutrons

$$U^{235} + {}_0n^1 \longrightarrow Ba^{141} + Kr^{92} + 2.5\,{}_0n^1 + 200\text{ MeV energy.}$$

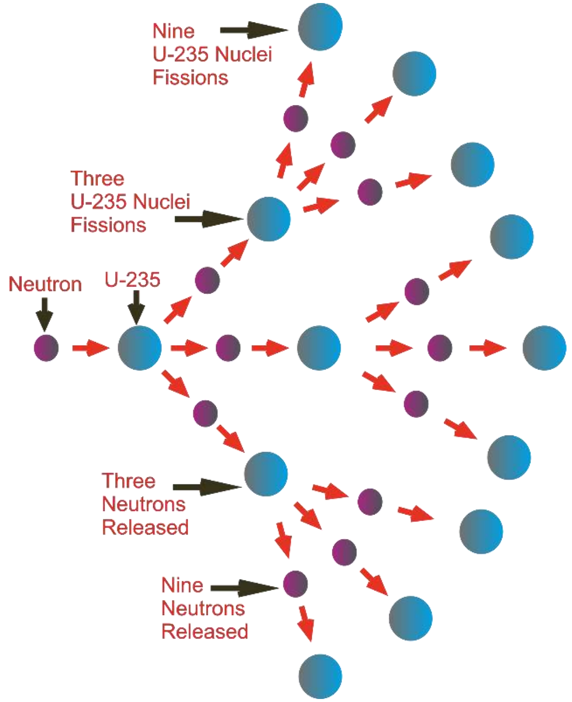
- The neutrons produced are very fast and can be made to fission other nuclei of U^{235}, thus setting up a chain reaction.
- Out of 2.5 neutrons released one neutron is used to sustain the chain reaction.

1 eV = 1.6×10^{-19} joule.
1 MeV = 10^6 eV

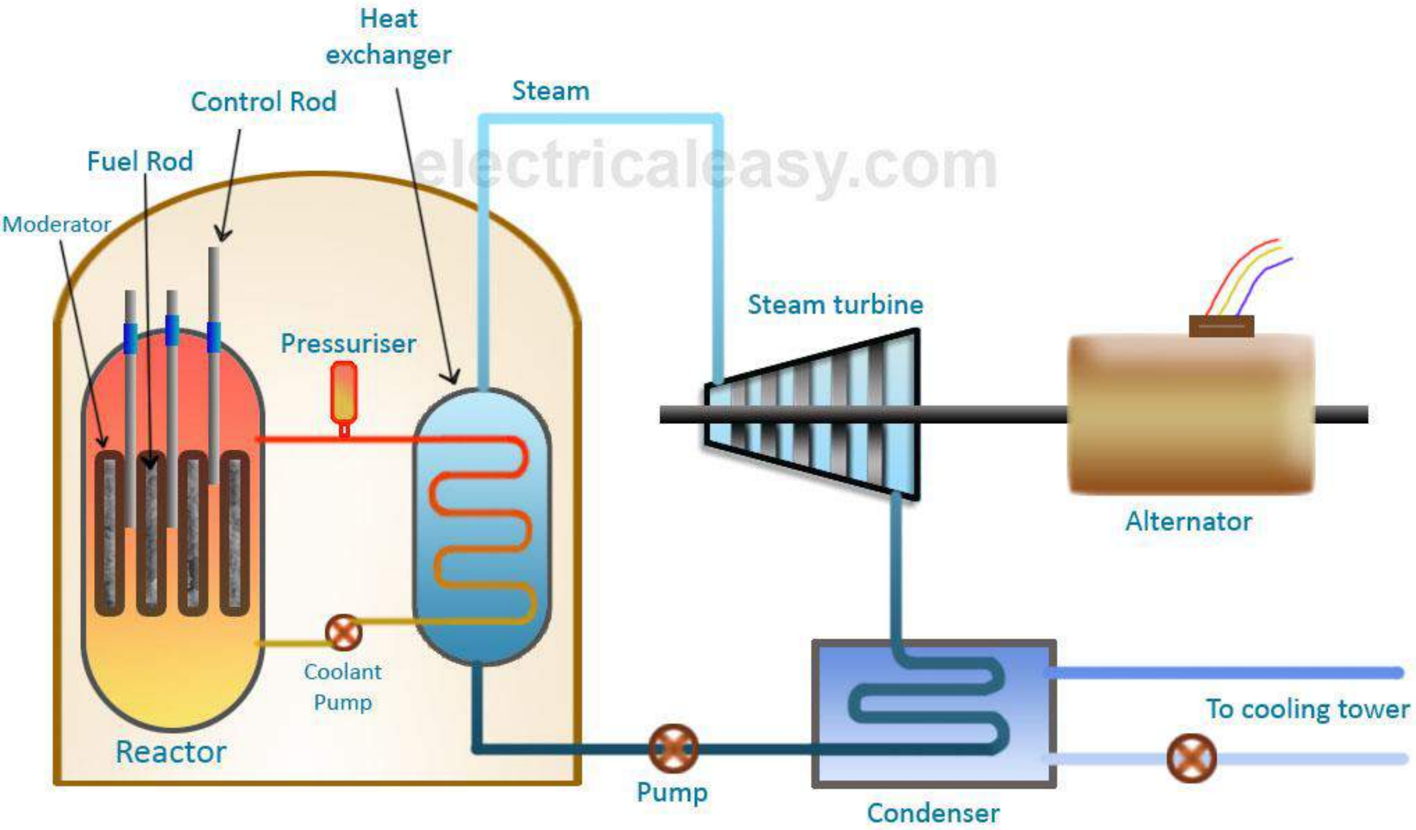
❑ Nuclear fission…

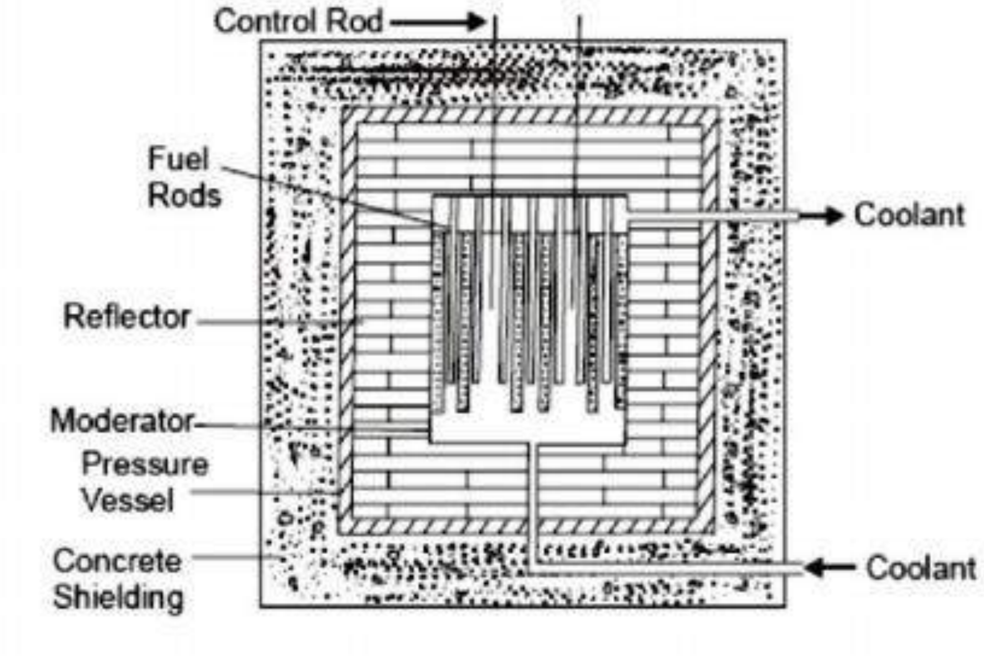
- ✓ U^{235} splits into two fragments (Ba^{141} & K^{92}) of approximately equal size.
- ✓ About 2.5 neutrons are released. 1 neutron is used to sustain the chain reaction. 0.9 neutrons is absorbed by U^{238} and becomes Pu^{239}. The remaining 0.6 neutrons escapes from the reactor.
- ✓ The neutrons produced move at a very high velocity of 1.5×10^7 m/sec and fission other nucleus of U^{235}. Thus fission process and release of neutrons take place continuously throughout the remaining material.
- ✓ A large amount of energy(200 Million electron volts, Mev) is produced.

➤ Note : Moderators are provided to slow down the neutrons from the high velocities but not to absorb them.



Parts of nuclear power plant





Nuclear reactor

1. Reactor Core

It consists of fuel elements, control rods, coolant, moderator and pressure vessels. Cores generally have shapes of right circular cylinders with diameters ranging from .5 to 15 metres. Fuel rods made of uranium rods clod in thin sheath of stainless steel, zirconium or aluminium.

2. Reflector-

It is placed round the core, to reflect back some of the neutrons that leak out from core surface.

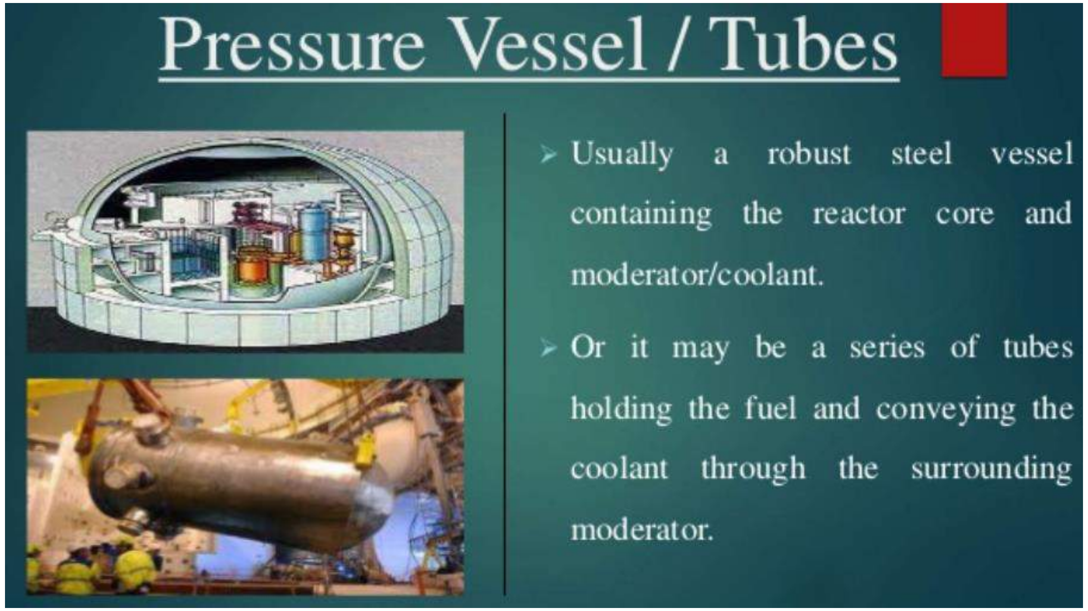
3. Control Rods

- It is made up of heavy mass element.It simply absorb the neutrons so that it can either maintain or stop a reaction.

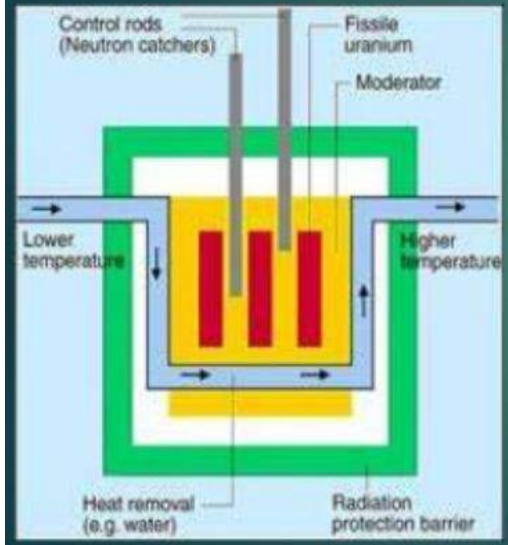
Examples-Cadmium,lead etc.

It has following purposes-

1. For starting the reactor.
2. For maintaining at that level.
3. For shutting the reactor down under normal or emergency conditions.



Moderator



- Function: -

  To slow down neutrons from high velocities and hence high energy level which they have on being released from fission process so that probability of neutron to hit the fuel rods increases.

- Main moderator used: -
  Water H_2O
  Heavy water D_2O
  Graphite
  Beryllium

Containment

- The structure around the reactor and associated steam generators which is designed to protect it from outside intrusion and to protect those outside from the effects of radiation in case of any serious malfunction inside.

- It is typically a meter-thick concrete and steel structure.

Coolant

- Function: -

  Coolant is used to remove intense heat produced in the reactor and that heat can be transferred to water in a separate vessel which is converted into steam and runs the turbine.

- Main coolant used: -
  Water H_2O, CO_2, Hg, He

For Starting Reactor

- To start a reactor, a neutron from a source is ejected through thermal means and the control rods are taken upwards so that the control rods can not disturb the reaction.

- Hence neutron hits the fuel rods, break it into lighter nuclei, energy is released, number of neutron keeps on increasing since K will be greater than 1 for this time period and hence reaction starts and its rate also increases.

- Hence reaction starts and its rate also increases.

For Maintaining the reaction at constant level

- When rate of reaction achieves a permissible value then control rods are inserted between the fuel rods in such away that K becomes equal to 1.
- Hence the rate of reaction achieves a finite constant value.

For Shutting Down Reactor

- To shut down the reactor either in normal or emergency conditions, the control rods are inserted in such away that K becomes less than 1.
- Hence the number of neutrons keeps on decreasing i.e. rate of reaction decreases, so the reaction stops after a certain interval of time.

1. Define Neutron Generation Time

A neutron generation is described as the absorption of a neutron which causes fission to the absorption of the neutrons from that fission. The time associated with this is known as the neutron generation time. By comparing the number of neutrons produced from fission in one generation to the number of neutrons produced from fission in the next generation, an indication of the rate of change in neutron population is obtained.

2. Define effective multiplication factor and discuss its relationship to the state of the reactor.

The effective neutron multiplication factor is defined as the factor by which the number of neutrons produced from fission in one generation must be multiplied to determine the number of neutrons produced from fission in the next generation. The effective neutron multiplication factor is represented by the symbol k_{eff} and can be mathematically expressed as:

$$k_{eff} = \frac{\text{\# of neutrons produced by fission in one generation}}{\text{\# of neutrons produced by fission in the previous generation}}$$

3. Define critical, subcritical and super critical with respect to the reactor and in terms of the effective neutron multiplication factor.

If the number of neutrons produced by fission in one generation equals the number of neutrons in the previous generation, $k_{eff} = 1$. This defines an exactly **critical** reactor. The reactor is at steady state with a constant power level.

If $k_{eff} > 1$, the number of neutrons produced by fission in one generation is greater than the number of neutrons produced in the previous generation. When neutron production is greater than neutron losses, reactor power is increasing and the reactor is said to be **supercritical**.

If $k_{eff} < 1$, the number of neutrons produced by fission in one generation is less than the number of neutrons produced in the previous generation. When neutron production is less than neutron losses, reactor power is decreasing and the reactor is said to be **subcritical**.

4. Describe the Neutron Life Cycle using the following terms:

4A: Fast Fission Factor - ()

Most fast neutrons in light water reactors are produced from thermal fission. However, an appreciable number of fast neutrons will be generated by fast fission of U-238. This occurs while the neutrons are still in the fast range. Probabilities for fission of U-238 drop significantly once the neutron energy falls below 1.1 MeV. Pu-239, which builds up over core life, has a small probability for fast fission but has large resonance peaks (probabilities) for fission at numerous lower neutron energy levels. The **fast fission factor** represents the change (increase) in the neutron population as a result of fast fission.

$$\varepsilon = \frac{\#\,of\ fast\ neutrons\ from\ ALL\ fission\ events}{\#\,of\ fast\ neutrons\ from\ THERMAL\ fission\ events}$$

4B: Fast Non-Leakage Probability Factor - (Lf)

Some of the fast neutrons produced from all fissions will leak out of the core while at fast energies. This will reduce the neutron population by a certain factor. The factor that remains is the fast non-leakage probability (L_f). The remaining neutrons are ones that "start to slow down".

$$L_f = \frac{\#\,of\ neutrons\ that\ do\ not\ leak\ while\ fast}{\#\,of\ fast\ neutrons\ from\ ALL\ fission\ events}$$

RESONANCE ESCAPE PROBABILITY (ρ)

- $\rho = \dfrac{\text{No: of neutrons that reach thermal energy}}{\text{No: of fast neutrons that starts to slow down}}$
- After fast fissions occur, neutrons continue to diffuse throughout reactor
- Collide with nuclei of fuel, non-fuel material, and moderator
  - Lose energy in each collision and slow down
- All nuclei within reactor core have some probability of absorbing neutrons
  - Microscopic cross-section for absorption (σ_a) for each material
- σ_a is not a constant value, dependent on energy level of incident neutron
- Absorption cross-sections increase as neutron energy level decreases

THERMAL UTILIZATION FACTOR (f)

- $f = \dfrac{\text{No:of thermal neutrons absorbed in the fuel}}{\text{No: of thermal neutrons absorbed in all reactor materials}}$
- After thermal non-leakage, thermalized neutrons still dispersed throughout the core where they are subject to absorption by either fuel or non-fuel material
- Thermal utilization factor describes how effectively thermal neutrons are being absorbed by fuel or underutilized by non-fuel materials
- Thermal utilization factor is always less than one
  - Not all thermal neutrons are absorbed in fuel
  - These neutrons are lost to the fission process
- A value range for thermal utilization factor is 0.70-0.80

REPRODUCTION FACTOR (η)

- η= No: of fast neutrons neutrons produced by thermal fission

  No: of thermal neutrons absorbed in the fuel

- Most neutrons absorbed in fuel cause fission, but some do not
- Reproduction factor represents net gain in neutron population
- Value range of 1.65-2.0

Formula:

$$\text{Mass per atom of } U^{235} = \frac{At.weight\ of\ U^{235}}{Avogadro\ number} = \frac{235}{6.02 \times 10^{26}}$$

Where Avogadro Number = 6.023×10^{23}

1 ev = $1.6 \text{ X } 10^{-12}$ erg

1 Mev = $1.6 \text{ X } 10^{-6}$ erg

1 Joule/sec = 10^{7} erg/sec

1 watt = Joule/sec

fission rate = P/E

Where, P = Power

E = Energy realeased

Example: 1

Calculate the number of fission in uranium per second required to produce 2 kw power if energy released per fission is 200 Mev.

Here ,

P= Power = 2 kw

E = Energy released per fission = 200 Mev = 200×10^{6}

= $200 \text{ X}10^{6}$ $\text{X}1.6 \text{ X}10^{-12}$ ergs

= 3.2×10^{-4} ergs

[1 ev =1×10^{-12} energy]

P = 2kw = 2000 watts = 2000 joules/sec

= 2000×10^{7} ergs/sec = 2×10^{10} ergs/sec

N = Number of fission per/ sec

= P/E

= $(2\times10^{10}) / 3.2 \text{ X}10^{-4}$

= $6.25 \text{ X } 10^{-3}$ (answer).

Example: 2

Calculate the fusion rate of U^{235} for producing power of one watt if 200 Mev if energy is released per fusion of U^{235}.

Solution: Here given that,

P = Power = 1watt

E = Energy released per fusion of U^{235} nucleus

= 200 Mev

= 200×10^{6} ev

= 200×10^{6} 1.6×10^{-12} ergs [1 ev = $1.6\ 10^{-12}$ ergs]

= 3.2×10^{-4} ergs

Fission rate of producing one watt of power = P/E

= $(1 \text{ X } 10^{7}) / (3.2 \text{ X } 10^{-4})$

= 3.1×10^{10} fusion/sec (answer)

Example: 3

A railway engine is driven by atomic power at an efficiency of 40% and develops an average power of 1600 kw during 8 hours run from one station to another. Determine how much U^{238} would be consumed on the run if each atom on fission releases 200 Mev.

Solution:

Output = 1600 kw

Efficiency η = 0.4

η = output / Input

input = 1600 /0.4

input = 4000 kw = $40 \text{ X } 10^{6}$ watts

E = Energy released per fission = 200 Mev = 200×10^{6} ev

= 200×10^{6} 1.6×10^{-12} ergs

[1 ev = $1.6\ 10^{-12}$ ergs]

= 3.2×10^{-4} ergs

t = Time = 8 hours = 8×3600 seconds

Input nuclear energy required for 8 hours = Input × t

= $4\times10^{6}\times8\times3600$ j

=115.2×10^{9}j

= 115.2×10^{16} ergs

Number of U^{235} atoms required for 8 hour run

= $115.2 \text{ X } 10^{9}/ E$

= $(115.2 \text{ X } 10^{9}) / (3.2 \text{ X } 10^{-11})$

= $36 \text{ X } 10^{20}$

e Weight of $6.023 \text{ X } 10^{23}$ Uranium = 235 gm

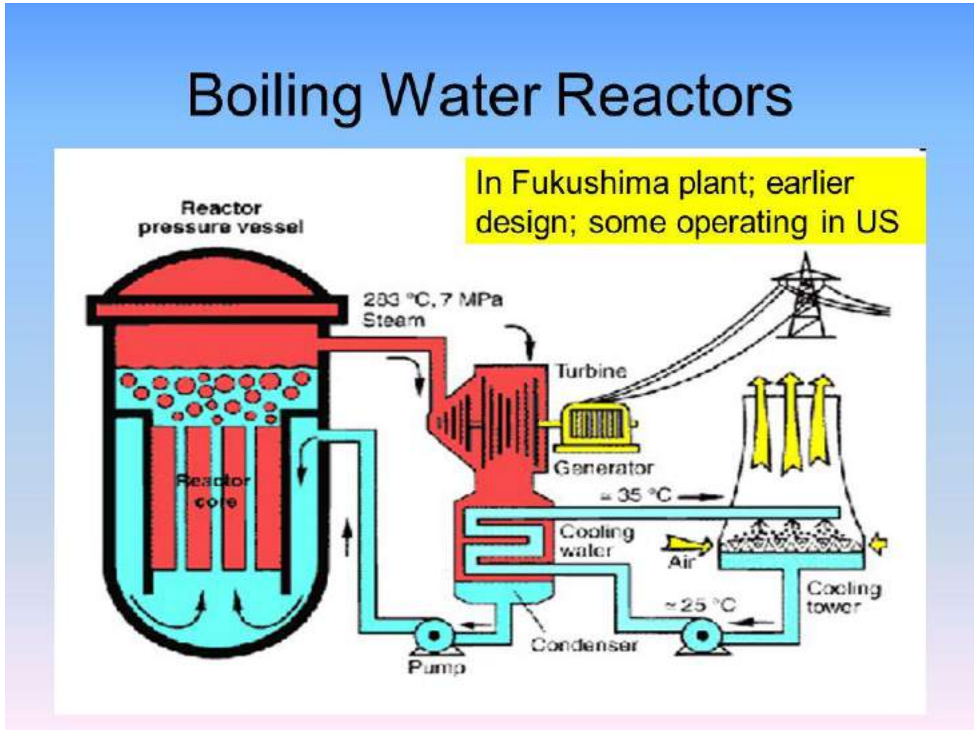
: Weight of 1 Uranium = $235/ 6.023 \text{ X } 10^{23}$

Weight of $36 \text{ X } 10^{20}$ Uranium = $\frac{235 \text{ X } 36 \text{ X } 10^{20}}{6.023 \text{ X}10^{23}}$

= 1.4 gm (Ans)

Types of Nuclear Reactors

1. BWR-Boiling Water Reactor
2. PWR-Pressurized Water Reactor
3. PHWR-Pressurised Heavy Water Reactor
4. GCR-Gas Cooled Reactor
5. AGR-Advanced Gas-Cooled Reactor
6. LGR-Light Water Cooled - Graphite Moderated Reactor



- ➢ The water is circulated through the reactor where it converts to water steam mixture.
- ➢ The steam gets collected above the steam separator.
- ➢ This steam is expanded in the turbine which turns the turbine shaft.
- ➢ The expanded steam coming out of the turbine is condensed and is pumped back as feed water by the feed water pump into the reactor core.
- ➢ Also the down coming recirculation water from the steam separator is fed back to the reactor core.

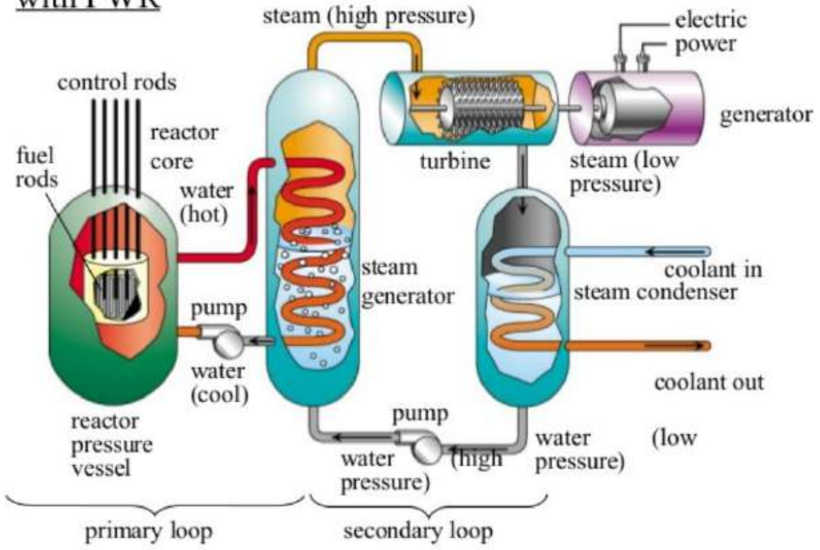
BWR Advantages:

- Direct cycle, no secondary loop
- Less mass flow rate since coolant water is permitted to absorb latent heat and sensible heat.
- Can operate at lower pressure ~ 900 psi
{not zero/ atmospheric pressure since
    1. high temp required to drive turbines
    2. high pressure prevents wall dryout}
- Lower pressure mean thinner pressure vessel and less expensive components.

BWR Disadvantages:

- Radioactive coolant throughout engine room
- Shielding and containment larger
- Lower power density – need larger core and PV then PWR

Schematic diagram of a nuclear power plant with PWR



❑ Pressurised Water Reactor (PWR)

✓ Heat is produced in the reactor due to nuclear fission and there is a chain reaction.

✓ The heat generated in the reactor is carried away by the coolant (water or heavy water) circulated through the core.

✓ The purpose of the pressure equalizer is to maintain a constant pressure of 14 MN/m^2. This enables water to carry more heat from the reactor.

✓ The purpose of the coolant pump is to pump coolant water under pressure into the reactor core.

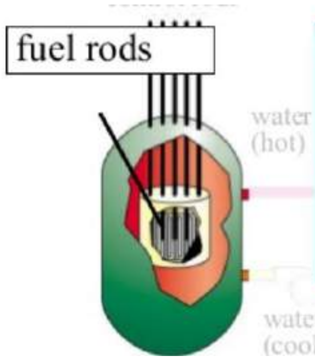
✓ The steam generator is a heat exchanger where the heat from the coolant is transferred on to the water that circulates through the steam generator. As the water passes through the steam generator it gets converted into steam.

✓ The steam produced in the steam generator is sent to the turbine. The turbine blades rotate.

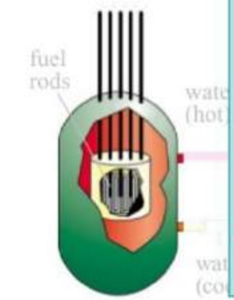
✓ The turbine shaft is coupled to a generator and electricity is produced.

✓ After the steam performing the work on the turbine blades by expansion, it comes out of the turbine as wet steam. This is converted back into water by circulating

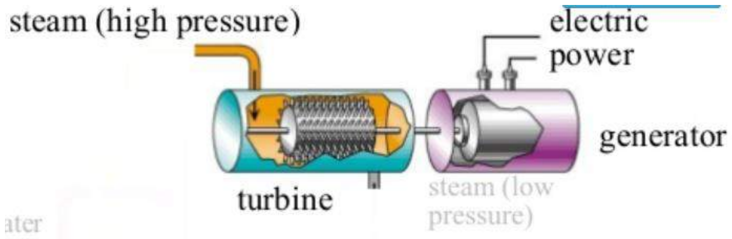
✓ The feed pump pumps back the condensed water into the steam generator.



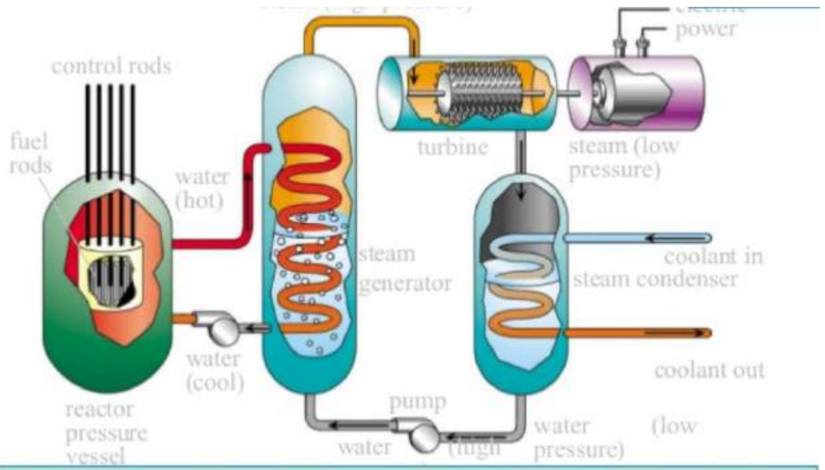
- They contain the nuclear fuel: uranium (U-235)
- They are surrounded by a moderator (water or graphite) to *slow down the neutrons released.*



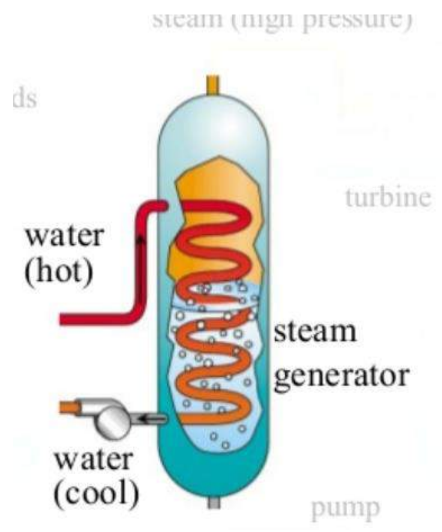
- They control the rate of reaction by moving in and out of the reactor.
  - Move in: rate of reaction ↓
  - Move out: rate of reaction ↑
  - All are moved in: the reactor is shut down
- They are made of boron or cadmium that can *absorb neutrons.*



- The steam drives a turbine, which turns the generator.
- Electricity is produced by the generator.



- *Two separate water systems* are used to avoid radioactive substances to reach the turbine.



- The energy released in fissions heats up the water around the reactor.
- The water in the secondary loop is boiled to steam.

Advantages

- Water used as coolant, moderator and reflector is cheap and available in plenty.
- The reactor is compact and high power density (65 KW/liter).
- Hardly 60 control rods are required in 1000 MW plant.
- Inspecting and maintaining of turbine, feed heaters and condenser during operation.
- Reducing fuel cost and extracting more energy.

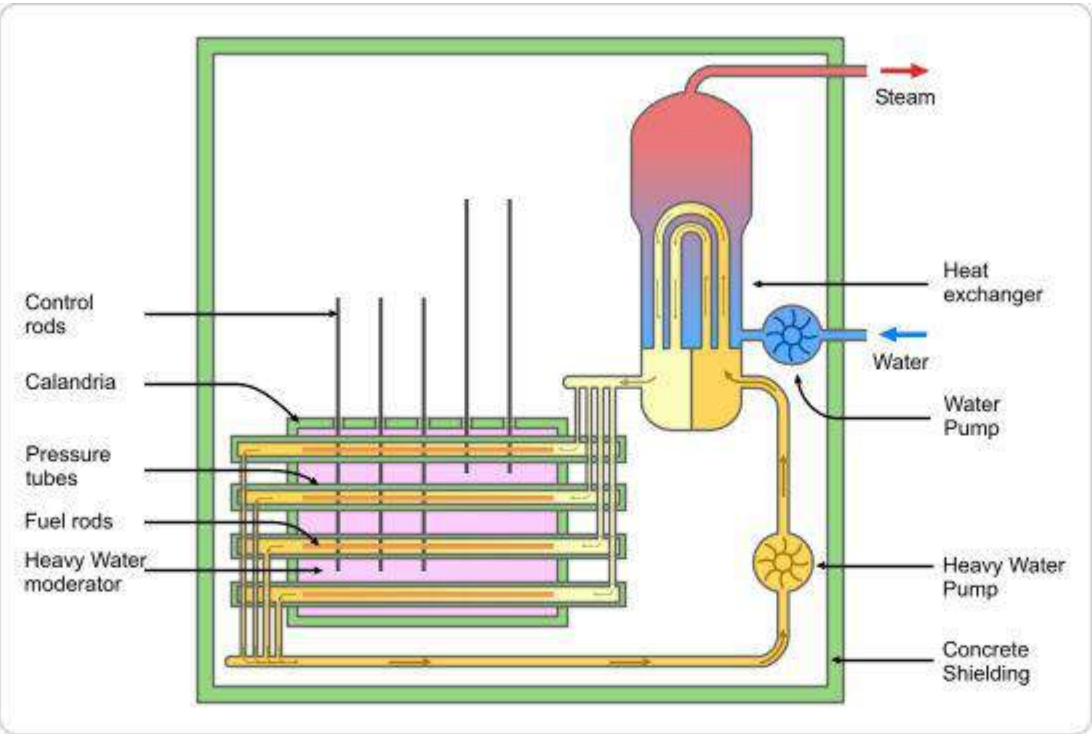
Disadvantages

- Requires high pressure vessel and high capital cost.
- Thermodynamic efficiency of plant is as low as 20% due t pressure.
- Corrosion problems are more severe. Use of stainless ste vessel is necessary.
- Fuel recharging requires a couple of months time.

Relative Advantages & Disadvantages of PWR vs. BWR

	BWR	PWR
Thermodynamic Cycle	Single loop (turbine steam directly from reactor) - lower capital cost	Two loops - higher capital cost
	Lower pressure (7 MPa) decreases capital cost	Higher pressure (15 MPa) increases capital cost
Power Density (kW/liter)	Low power density due to boiling moderator	High power density
	Better power distribution	Must use zone loading to flatten power distribution
Major Equipment	Larger pressure vessel (due to low power density)	Smaller pressure vessel
	Thinner vessel walls (lower pressure)	Thicker vessel walls (higher pressure)
	Steam separators	Steam generator, pressurizer
Control	Control by rods and burnable poison	Control by rods, burnable poison, and chemical shim
	Use jet pumps to load follow	Natural ability to load follow
Core Design	Larger fuel pins, smaller burnup	Smaller diameter fuel pins, larger burnup
Materials Problems	Lower temperatures	Higher temperatures
	Little control over coolant purity	Good control over coolant purity

Pressurized Heavy Water Reactor (PHWR) "CANDU"



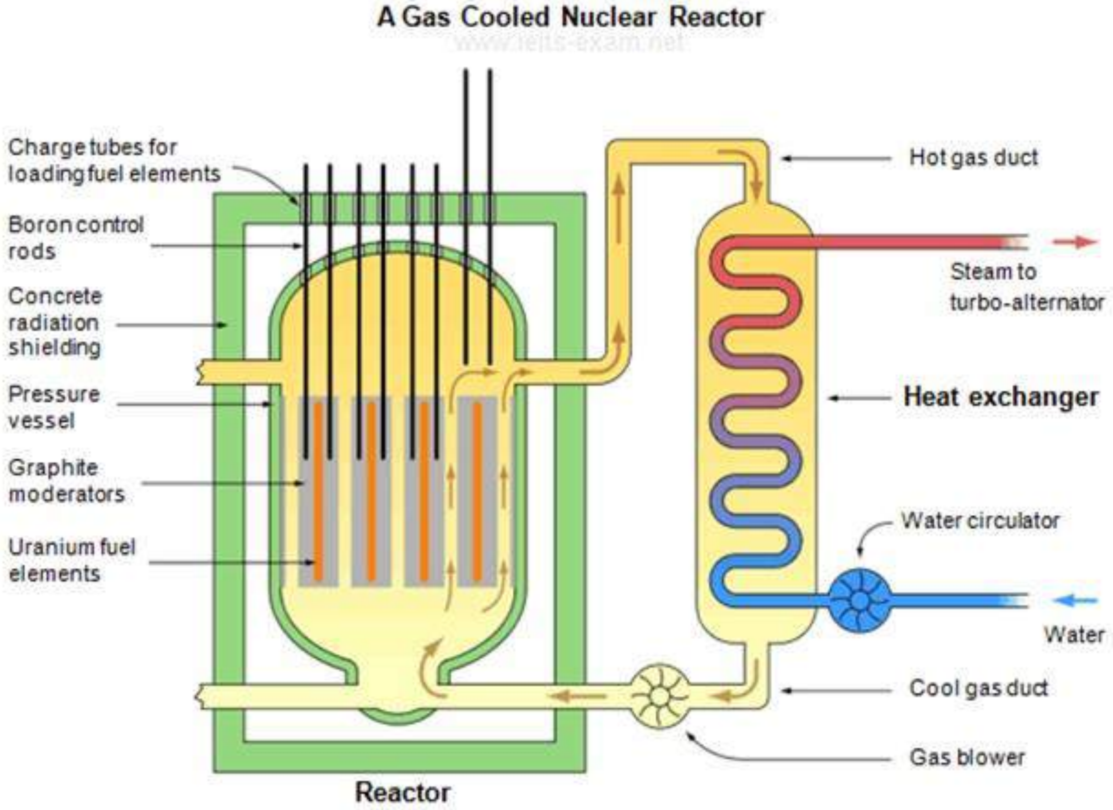
- Fuel used : Natural UO_2
- Moderator : Heavy Water
- Coolant : Heavy Water

- CANDU stands for "**CAN**ada **D**euterium **U**ranium".
- It's a Canadian-designed power reactor of PHWR type (Pressurized Heavy Water Reactor).
- CANDU is the most efficient of all reactors in using uranium: it uses about 15% less uranium than a pressurized water reactor for each megawatt of electricity produced

- In the reactor, neutrons emitted in the fission reaction are slowed down by the heavy water, which acts as a coolant carrying the heat energy produced in the nuclear reaction from the uranium rods to the heat exchanger and then to the turbines to produce electric power.

- The products of fission are hot because the smaller atoms produced when a large atom breaks up, it has a great deal of kinetic energy.

Gas cooled nuclear reactor



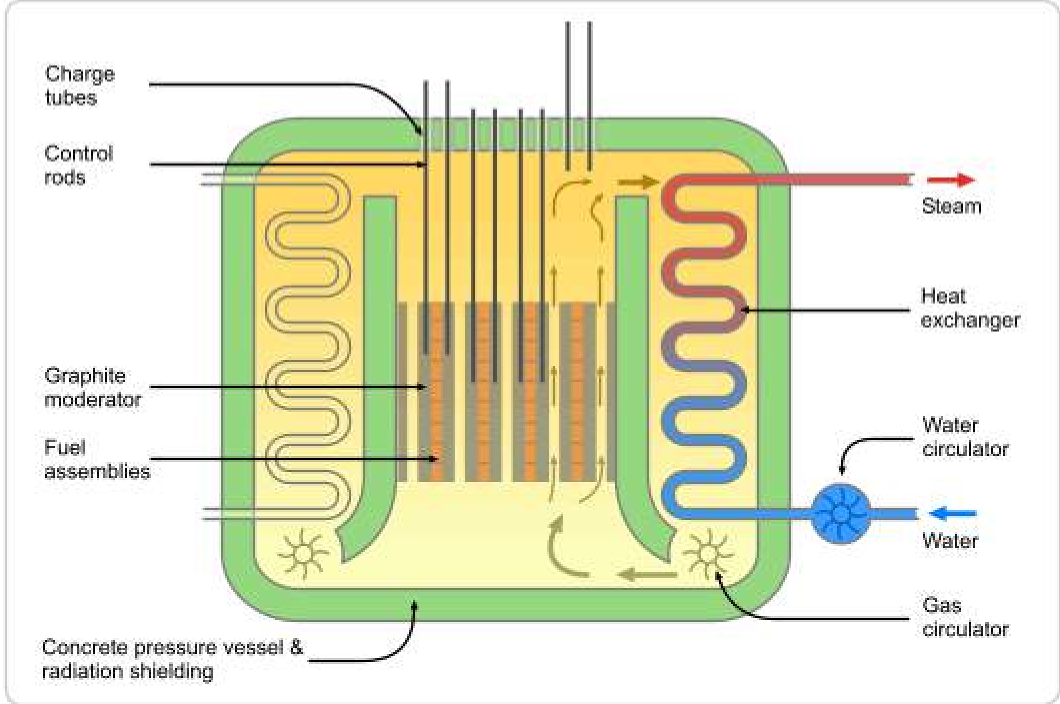
- Gas Cooled Reactor is also termed as Magnox reactor as the magnesium alloy is used to encase the fuel, natural uranium metal.

- These reactors are generally graphite moderated and CO_2 cooled. The whole assembly is cooled by blowing carbon dioxide gas past the fuel cans, which are specially designed to enhance heat transfer. The hot gas then converts water to steam in a steam generator.

- They can have a high thermal efficiency compared with PWRs due to higher operating temperatures.

AGR-Advanced Gas-Cooled Reactor

- To improve the cost effectiveness of the gas cooled reactor, it was necessary to go to higher temperatures to achieve higher thermal efficiencies and higher power densities to reduce capital costs.
- This entailed increases in cooling gas pressure and changing from Magnox to stainless steel cladding and from uranium metal to uranium dioxide fuel. This in turn led to the need for an increase in the proportion of U^{235} in the fuel.
- The resulting design is known as the AGR-Advanced Gas-Cooled Reactor

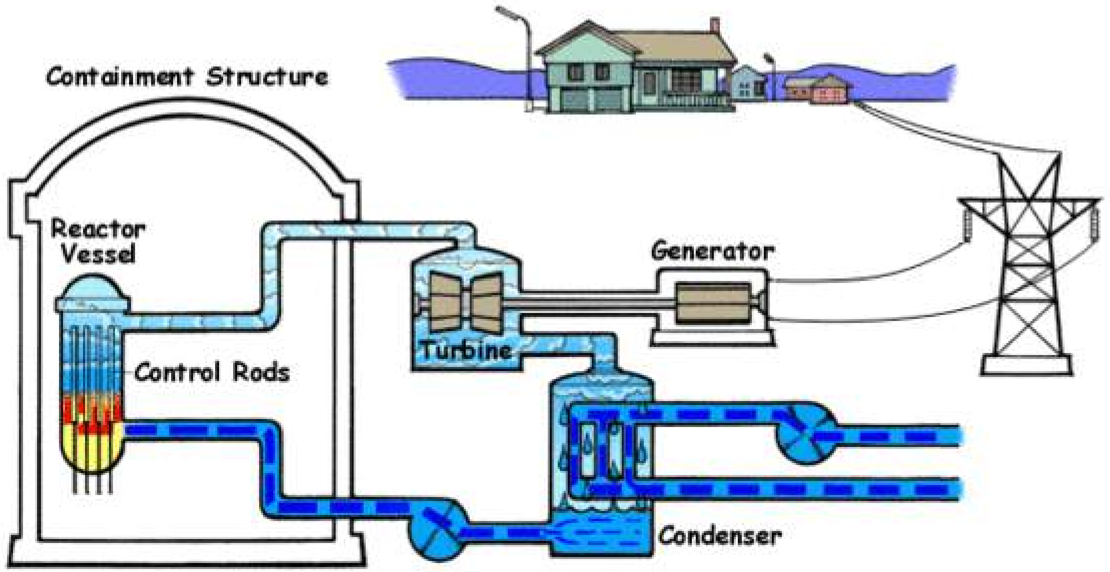


LGR-Light Water Cooled - Graphite Moderated Reactor

- In this type of reactor heat is removed from the fuel by pumping water under pressure up through the channels where it is allowed to boil, steam generated here drives electrical turbo-generators.

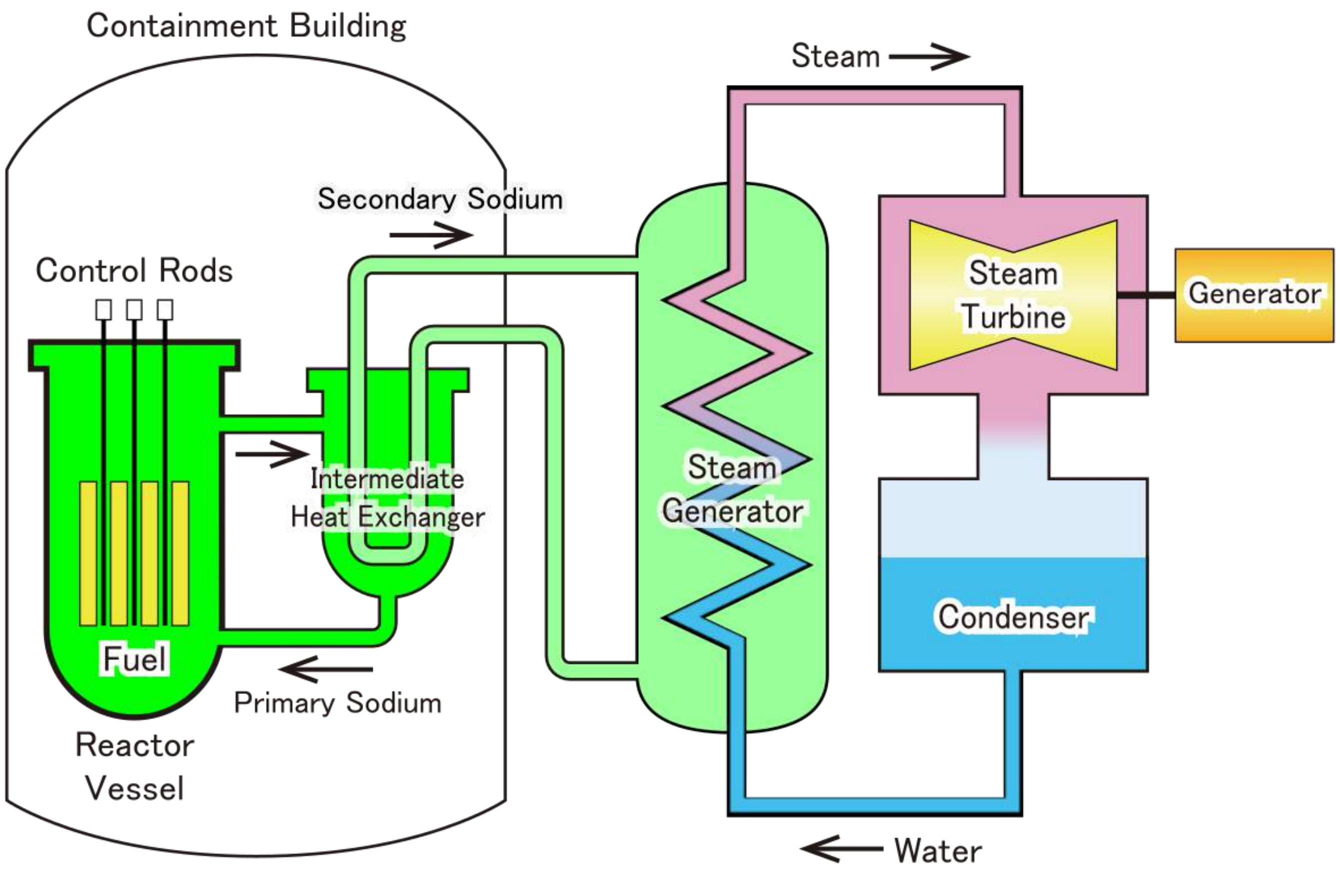
- Many of the major components, including pumps and steam drums, are located within a concrete shield to protect operators against the radioactivity of the steam.

- The design of this type of reactor is known as the RBMK Reactor.



Fast neutron reactor (FNR)/FBR

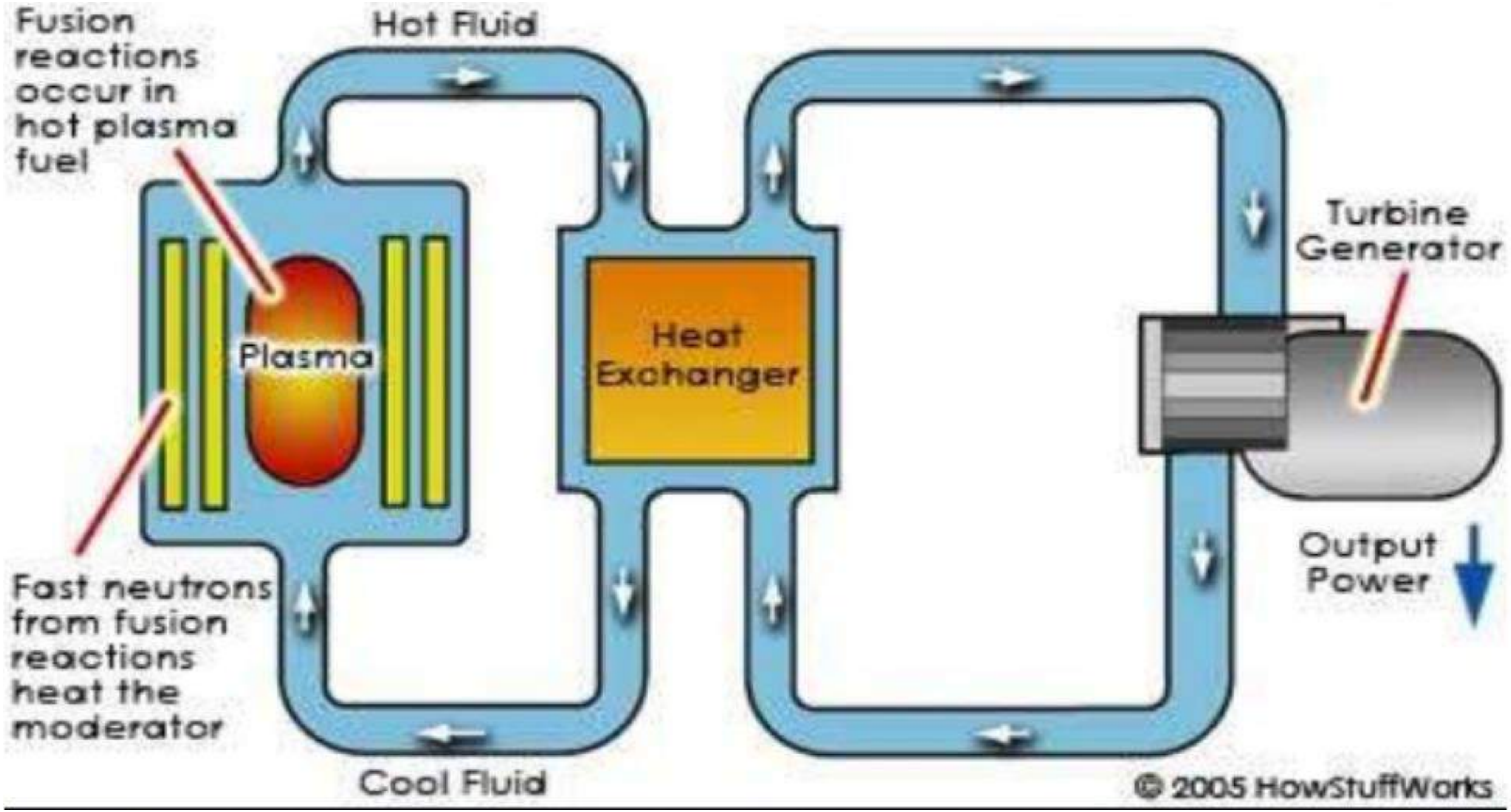
Some reactors do not have a moderator and utilise fast neutrons, generating power from plutonium while making more of it from the U-238 isotope in or around the fuel. While they get more than 60 times as much energy from the original uranium compared with normal reactors, they are expensive to build. Further development of them is likely in the next decade, and the main designs expected to be built in two decades are FNRs. If they are configured to produce more fissile material (plutonium) than they consume they are called fast breeder reactors (FBR).



Nuclear power plants in commercial operation or operable

Reactor type	Main countries	Number	GWe	Fuel	Coolant	Moderator
Pressurised water reactor (PWR)	USA, France, Japan, Russia, China, South Korea	302	287.0	enriched UO_2	water	water
Boiling water reactor (BWR)	USA, Japan, Sweden	63	64.1	enriched UO_2	water	water
Pressurised heavy water reactor (PHWR)	Canada, India	49	24.5	natural UO_2	heavy water	heavy water
Advanced gas-cooled reactor (AGR)	UK	14	7.7	natural U (metal), enriched UO_2	CO_2	graphite
Light water graphite reactor (LWGR)	Russia	12	8.4	enriched UO_2	water	graphite
Fast neutron reactor (FBR)	Russia	2	1.4	PuO_2 and UO_2	liquid sodium	none
TOTAL		442	393			

A Fusion Reactor



Working of a fusion reactor

- The fusion reactor will heat a stream of deuterium and tritium fuel to form high-temperature plasma. It will squeeze the plasma so that fusion can take place.
- The lithium blankets outside the plasma reaction chamber will absorb high-energy neutrons from the fusion reaction to make more tritium fuel. The blankets will also get heated by the neutrons.
- The heat will be transferred by a water-cooling loop to a heat exchanger to make steam.
- The steam will drive electrical turbines to produce electricity.
- The steam will be condensed back into water to absorb more heat from the reactor in the heat exchanger

Considerations

Any power plant using hot plasma, is going to have plasma facing walls. In even the simplest plasma approaches, the material will get blasted with matter and energy. This leads to a minimum list of considerations, including dealing with:

- A heating and cooling cycle, up to a 10 MW/m^2 thermal load.
- Neutron radiation, which over time leads to neutron activation.
- High energy ions leaving at tens to hundreds of electron volts.
- Alpha particles leaving at millions of electron volts.
- Electrons leaving at high energy.
- Light radiation (IR, visible, UV, X-ray).

Safety & the Environment

- Accident Potential: There is no possibility of a catastrophic accident in a fusion reactor resulting in major release of radioactivity to the environment or injury to non-staff, unlike modern fission reactors.
- Effluents during normal: The natural product of the fusion reaction is a small amount of helium, which is completely harmless to life.
- Waste management: There is very lesser amount of radioactivity produced when compared to a fission reaction and that too burns off within a very small time.

- As a sustainable energy source: It is a very sustainable source of energy as the reserves of deuterium are supposed to last for a very long time along with lithium, which is also supposed to last for about 3000 years.
- Reliable Power: Fusion power plants should provide a base load supply of large amounts of electricity, at costs that are estimated to be broadly similar to other energy sources.

Advantages

- Environment friendly as no greenhouse gases are produced.
- Virtually limitless fuel is available as the stocks are supposed to last for a really long time.
- No chain reaction. So no chances of major accidents as the reactions can be stopped anytime by just cutting off the supply of the fuel which is also quite low.
- The cost of the fuel is very low.
- Can be used for interstellar space where solar energy is not available.
- Some problems like fresh water shortages can also be solved because they exist mainly because of the power shortages.

Disadvantages

- Unproven till now at a commercial scale.
- Initial experiments have been very costly.
- The energy required to initiate is greater than what's generated.
- The material for setups has to be worked upon so that it can take the excessive temperatures produced during the process.

Main Sources of Radioactive Contamination

Three main sources of radioactive contamination are:

- **Fission** of nuclei or nuclear **fuels**
- The **effect** of **neutron fluxes** *(number of neutrons travelling through a unit area in unit time)* on the **heat** carried in the primary cooling system and on the ambient air.
- **Damage** of **shell** of fuel elements

All the above can cause health hazards to workers, communing and natural surroundings.

Nuclear Power: Clean & Green

What about Nuclear Reactor Accidents??

Nuclear disaster due to Great Tohoku Earthquake - 2011, Japan

Nuclear disaster at Chernobyl - 1986, Russia : 16000 People Died

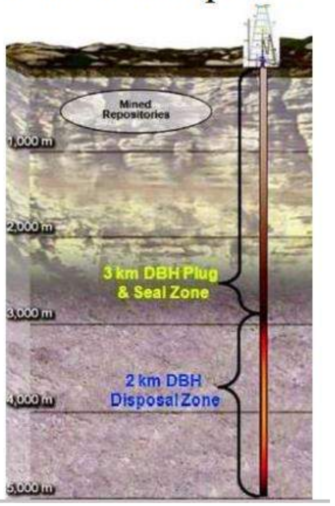
Safety Measures for Nuclear Power Plants

- A nuclear power plant should be constructed **away** from human habitation (exclusion zone of 160km radius)
- The materials used for construction should be of **required standards.**
- Waste **water** should be **purified**.
- Should have a proper safety system, **plant** could be **shut down** when required.
- Regular **periodic checks** to be performed to evaluate not to exceed the permissible radioactivity value
- While **disposing** off the **wastes** it should be ensured that it doesn't contaminate the **river or sea**.

Nuclear Waste Disposal

Geological Disposal

- The process of geological disposal centers on burrowing nuclear waste into the ground to the point where it is out of human reach.
- The waste needs to be properly protected to stop any material from leaking out. Seepage from the waste could contaminate the water table if the burial location is above or below the water level. Furthermore, the waste needs to be properly fastened to the burial site and also structurally supported in the event of a major seismic event, which could result in immediate contamination.



Reprocessing

- Reprocessing has also emerged as a viable long term method for dealing with waste. As the name implies, the process involves taking waste and **separating** the **useful components** from those that aren't as useful. Specifically, it involves taking the **fissionable material** out from the irradiated nuclear fuel.

Transmutation

- Transmutation also poses a solution for **long term disposal**. It specifically involves converting a **chemical element** into another **less harmful one**.
- Common conversions include going from **Chlorine to Argon or from Potassium to Argon.**
- The driving force behind transmutation is chemical reactions that are caused from an outside stimulus, such as a proton hitting the reaction materials.

Natural transmutation : can also occur **over a long period** of time. Natural transmutation also serves as the principle force behind **geological storage** on the assumption that giving the **waste enough isolated time** will allow it to become a non-fissionable material that poses little or no risk

Application of Nuclear Byproducts

Industrial Applications :

(1) **Position location** : **Buried pipelines** can be traced by using portable geiger Counters.

(2) Flow patterns in pipes can be detected by injecting radioactive isotopes into the flow. The radiation will be different for laminar and turbulent flows.

(3) Leakage detection can be done by injecting isotopes into fluid in pipes. The reactivity will be different at leakage points.

Byproduct of Nuclear Generation

- The Nuclear plants supply many by-products like isotopes which have many useful applications in our day-to-day life.
- The radioactive isotopes are widely used in **Biology**, **Medicine**, Agriculture and **Industries**.

Isotopes	%Yield	Half-life	Type of Radiation	
			Beta MeV	Gamma MeV
Cesium—137	6.22	33 years	0.5, 1.2	None
Barium—137	6.22	2.6 mins.	None	0.658
Strontium—90	5.3	28 years	0.605	None
Cerium—144	5.28	285 days	0.351	None
Praseodymium—144	5.28	17.3 minutes	3.02	0.2
Zirconium—95	6.39	65 days	0.391, 1.0	0.915
Niobium—95	6.39	35 days	0.15	0.76
Technetium—99	6.19	2.1 × 10 years	0.295	None
Promethium—147	2.61	2.5 years	0.219	None

(5) **Thickness gauges**.

(6) Liquid level gauges.

(7) Radiography (**Flaw detection**): X-rays, which are having a high penetrating power are made to pass through castings, welds etc. and on the other side, the photographic plate receives the radiation.

(8) **Density and content gauges:** The Through Gauge is used for this purpose. If the reactivity is a function of density of the material and thus the density of the content can be measured. This method is used in **cigarette packing line** and a relay arrangement is made to reject the faulty cigarettes.

(9) **Application in chemistry :** Substances **deteriorate** when exposed to radiation and the destroyed molecules are rejoined

(10) **Sterilization of foods and drugs :** Bacteria are produced in food-stuffs and vegetables and cause fermentation. Heating process can help in **sterilization** (complete destruction of Bacteria) and pasteurization (90% **destruction of Bacteria**).

But this **heating process cannot be done** for fruits, vegetables and drugs. Because the materials are kept in an **air-tight**

Future of nuclear power

- India has **hydro-power** potential, and some **coal reserves**; unfortunately these are **not very well distributed** throughout the country.
- Moreover, most of the economically feasible hydropower schemes have already been developed.
- The quality of **Indian coal** is not very **good**, and the reserves are concentrated in one or two parts of the country. These reserves are also being **depleted** at a **fast rate**, the railways consuming a large quantity in the past.

- On the other hand, India has **adequate deposits** of fissionable material-**thorium**, which can eventually be used for generation of power. Therefore, **development** of **nuclear power**, to supply the growing electricity demand of the country is quite logical and necessary. Thus the future of nuclear power is **quite bright**.

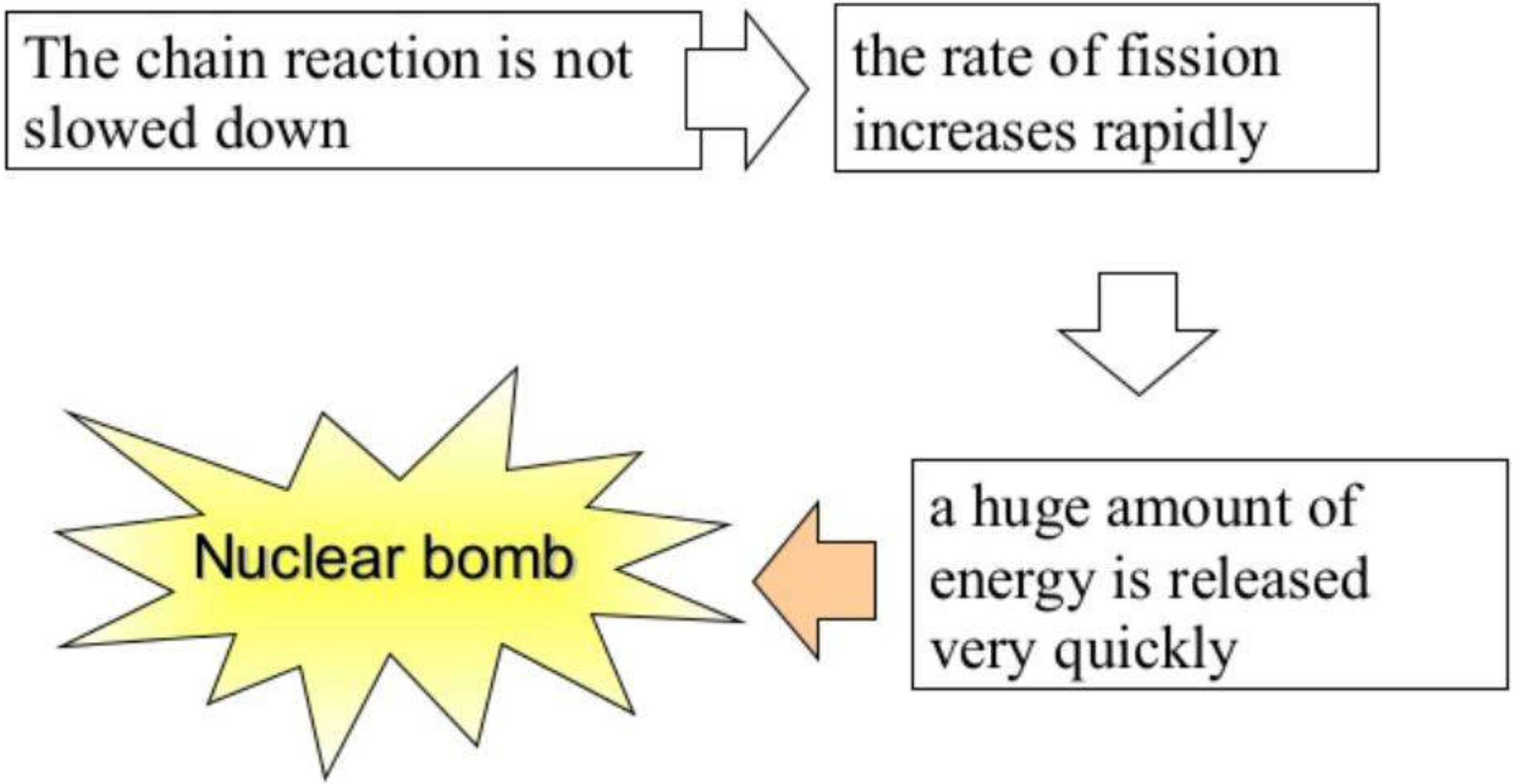
Following three factors need discussion

1. Cost of Power Generation
2. Availability of nuclear fuel, breeder reactor.
3. Safety of nuclear plants.

Safety Measures for Nuclear Power Plants

- A nuclear power plant should be constructed **away** from human habitation (exclusion zone of 160km radius)
- The materials used for construction should be of **required standards.**
- Waste **water** should be **purified**.
- Should have a proper safety system, **plant** could be **shut down** when required.
- Regular **periodic checks** to be performed to evaluate not to exceed the permissible radioactivity value
- While **disposing** off the **wastes** it should be ensured that it doesn’t contaminate the **river or sea**.

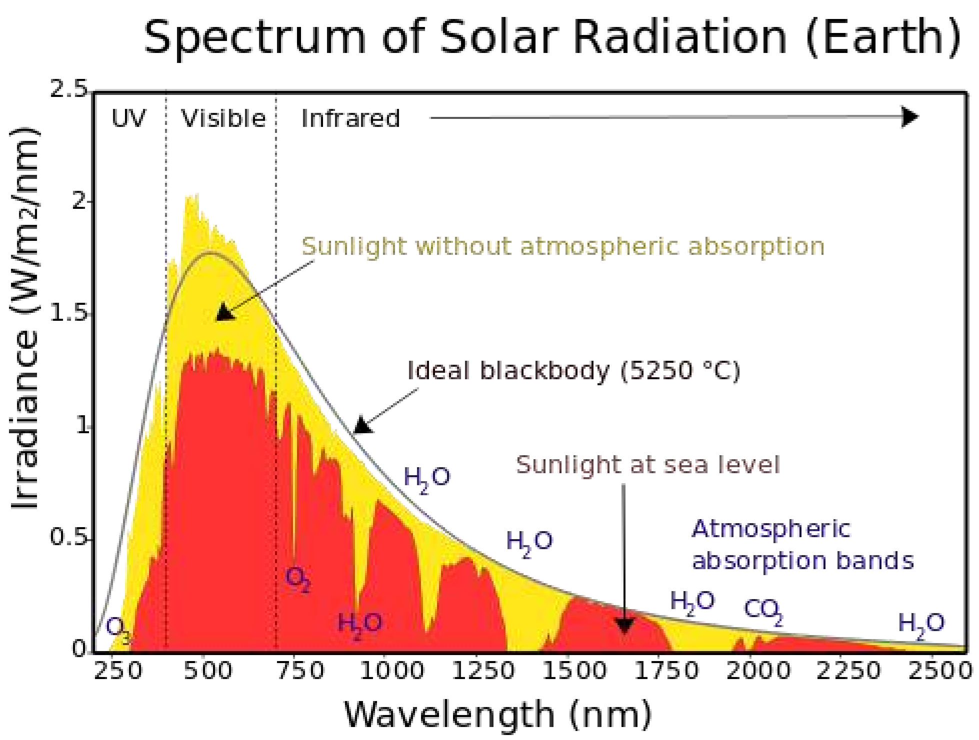
Uncontrolled nuclear reaction



Unit-III Solar Energy: Introduction to solar energy, fundamentals of solar radiation and its measurement aspects, Basic physics of semiconductors, Carrier transport, generation and recombination in semiconductors, Semiconductor junctions: metal-semiconductor junction & p-n junction, Essential characteristics of solar photovoltaic devices, First Generation Solar Cells, Second Generation Solar Cells, Third Generation Solar Cells

What's Solar Energy?

- Solar energy Originates with the thermonuclear fusion reactions occurring in the sun.
- Represents the entire electromagnetic radiation (visible light, infrared, ultraviolet, x-rays, and radio waves).
- This energy consists of radiant light and heat energy from the sun.
- Out of all energy emitted by sun only a small fraction of energy is absorbed by the earth.
- Just this tiny fraction of the sun's energy is enough to meet all our power needs.

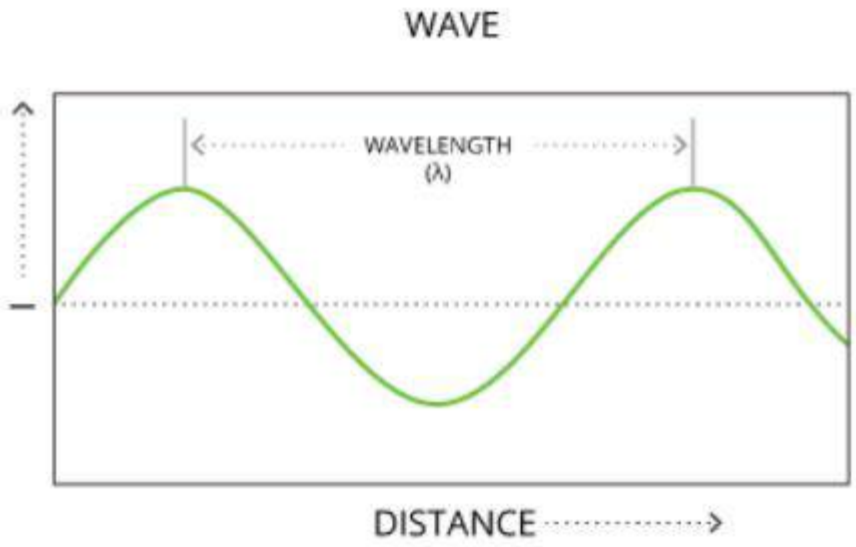


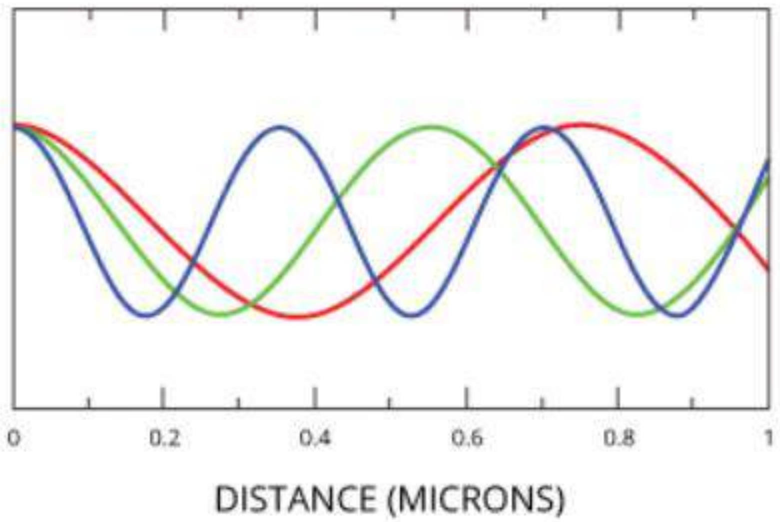
The three relevant bands, or ranges, along the solar radiation spectrum are ultraviolet, visible (PAR), and infrared. Of the light that reaches Earth's surface, infrared radiation makes up 49.4% of while visible light provides 42.3%. Ultraviolet radiation makes up just over 8% of the total solar radiation. Each of these bands has a different impact on the environment.

How is Solar Radiation Measured?

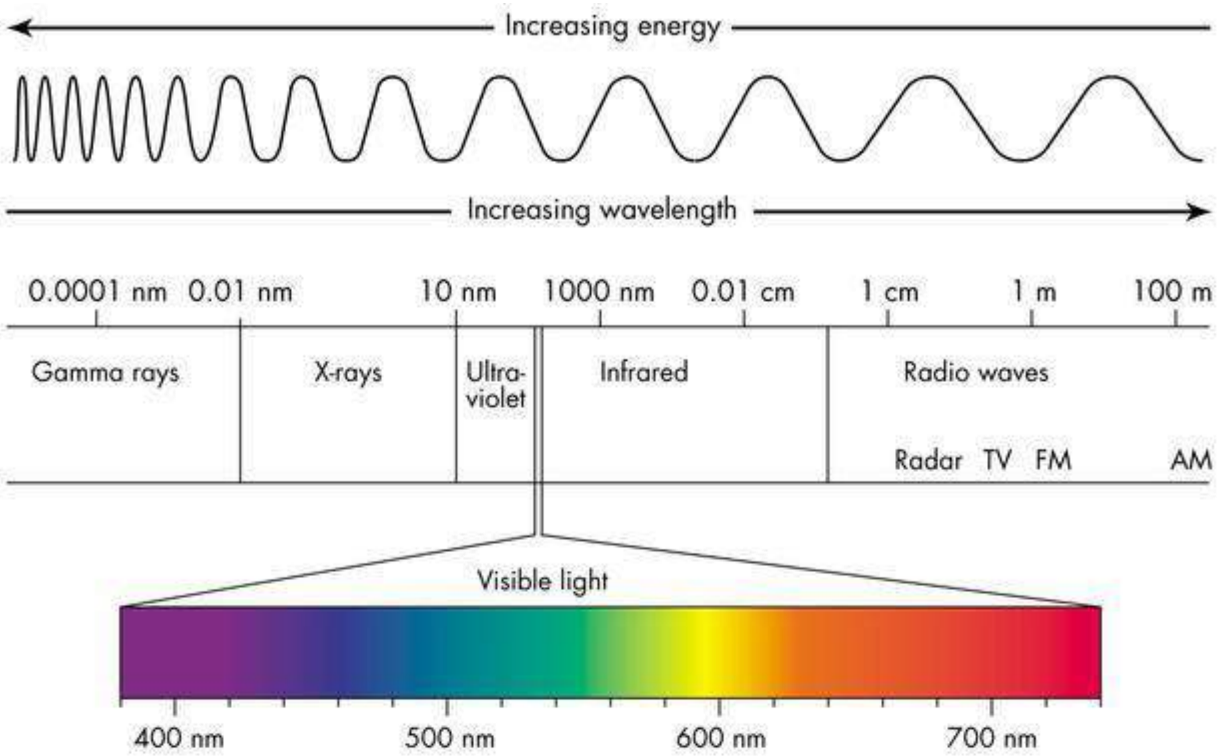
Solar radiation is measured in wavelengths or frequency. As light travels in a wave, a wavelength is defined as the distance from peak to peak and is measured in nanometers (nm). Frequency is defined as wavelength cycles per second and is expressed in hertz (Hz). Bands with shorter wavelengths produce higher frequencies. Likewise, the longer the wavelength, the longer it will take to complete a cycle, which produces a lower frequency [1].

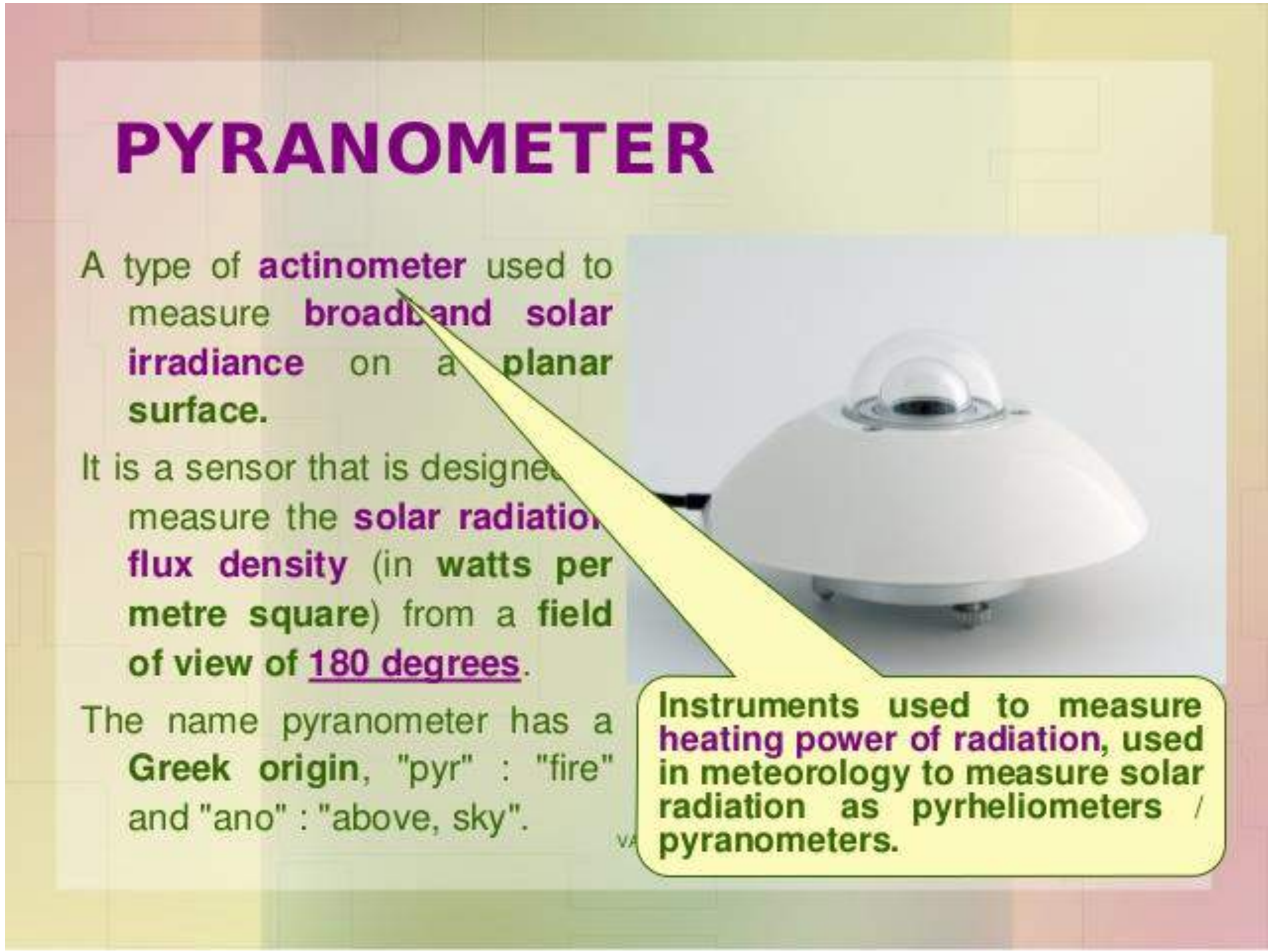
The energy of the wavelength increases with the frequency and decreases with the size of the wavelength [16]. In other words, shorter wavelengths are more energetic than longer ones. This means that ultraviolet radiation is more energetic than infrared radiation. Due to this extra energy, shorter wavelengths tend to cause more harm than longer wavelengths [16]. The more energy a wavelength has, the easier it is to disrupt the molecule that absorbs it. Ultraviolet light (which has the highest energy) can cause damage to DNA and other important cellular structures [16].





Wavelengths cycles are measured in nanometers (nm) from peak to peak. The shorter the wavelength, the more energy it has. Blue light has more energy than red light.


Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
Radio waves
Radar
TV
FM
AM
Visible light
400 nm
500 nm
600 nm
700 nm


PYRANOMETER
A type of actinometer used to measure broadband solar irradiance on a planar surface.
It is a sensor that is designe measure the solar radiatio flux density (in watts per metre square) from a field of view of 180 degrees.
The name pyranometer has a Greek origin, "pyr" : "fire" and "ano" : "above, sky".
Instruments used to measure heating power of radiation, used in meteorology to measure solar radiation as pyrheliometers / pyranometers.

PYRANOMETER (contd.)

Solar radiation spectrum : ~ 300 to 2,800 nm.

Pyranometers have a spectral sensitivity that is as "flat" as possible.

For Irradiance measurement : by definition – response to "beam" radiation varies with the cosine of angle of incidence.

Thus, Pyranometer needs to have a so-called "directional response" or "cosine response" that is close to the ideal cosine characteristic.

Full response when solar radiation hits the sensor perpendicularly – normal to surface, sun at zenith

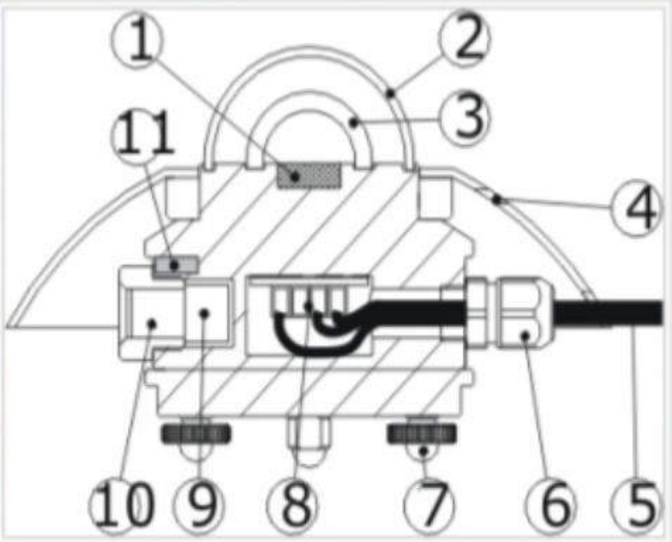
Zero response when sun is at the horizon (angle of incidence = zenith angle = 90°)

0.5 response at 60° angle of incidence.

PYRANOMETER (contd.)

MAIN COMPONENTS :

1. Thermopile Sensor with a Black Coating :
   1. absorbs all solar radiation,
   2. has a flat spectrum covering the 300 to 50,000 nanometer range,
   3. has a near-perfect cosine response.
2. Glass dome.
   1. limits the spectral response from 300 to 2,800 nanometers (cutting off the part above 2,800 nm), while preserving the 180 degrees field of view.
   2. shields the thermopile sensor from convection.



(1) sensor, (2, 3) glass domes, (5) cable, standard length 5 m, (9) desiccant.

VANITA N. THAKKAR - BIT, VARNAMA 4

3. Black coating on the thermopile sensor :
   1. absorbs solar radiation, which is converted to heat.
   2. The heat flows through the sensor to the pyranometer housing.
   3. The thermopile sensor generates a voltage output signal that is proportional to the solar radiation.

APPLICATIONS :

Pyranometers are frequently used in

1. **Meteorology** : They can be seen in many meteorological stations - typically installed horizontally and next to solar panels - typically mounted with the sensor surface in the plane of the panel.
2. **Climatology**
3. **Solar Energy Studies**
4. **Building Physics**

STANDARDIZATION :

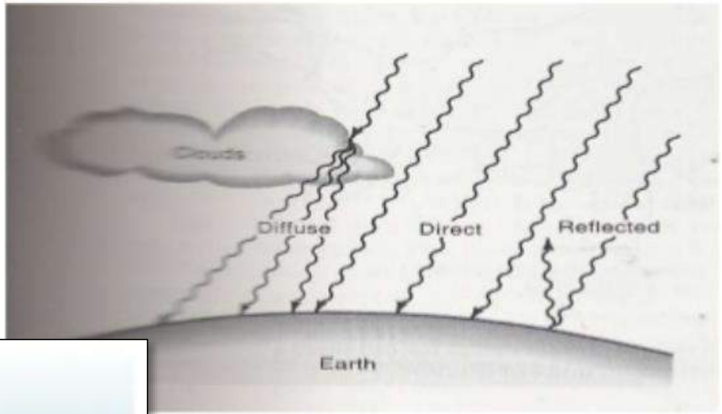
- Pyranometers are standardized according to the ISO 9060 standard, that is also adopted by the **World Meteorological Organization (WMO)**.
- This standard discriminates **three classes**. The best is (confusingly) called **"secondary standard"** the second best **"first class"** and the last one **"second class"**
- Calibration is typically done relative to **World Radiometric Reference (WRR)**. This reference is maintained by in **Davos, Switzerland.**

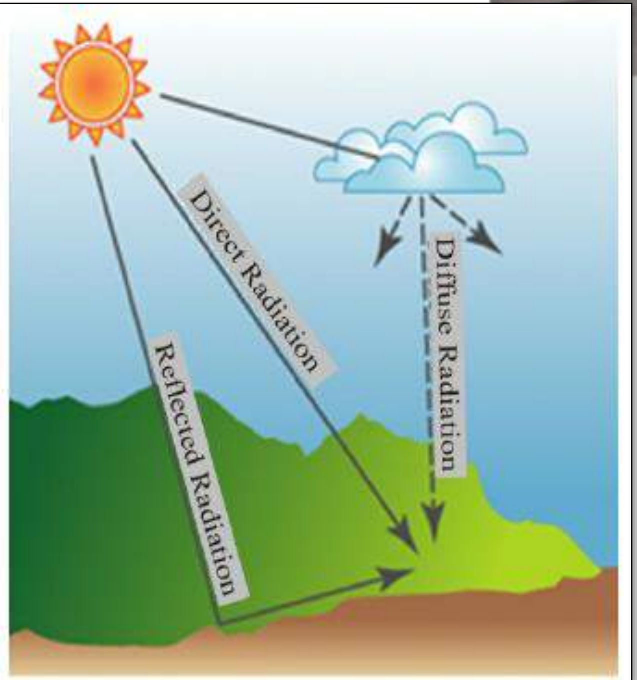
6

components of solar radiation

Insolation

- Insolation is the amount of solar radiation reaching the earth. Also called Incident Solar Radiation.
- Maximum value is 1000 kW/m².
- Components of Solar Radiation:
  - Direct radiation
  - Diffuse radiation
  - Reflect radiation





DIRECT AND DIFFUSE RADIATION

Direct / Beam Radiation : Solar radiation that **does not get absorbed or scattered**, but **reaches the ground directly** from the Sun. It **produces shadow** when interrupted by an opaque object.

Diffuse Radiation : Solar radiation received after its **direction** has been **changed** by **reflection and scattering** in the atmosphere.

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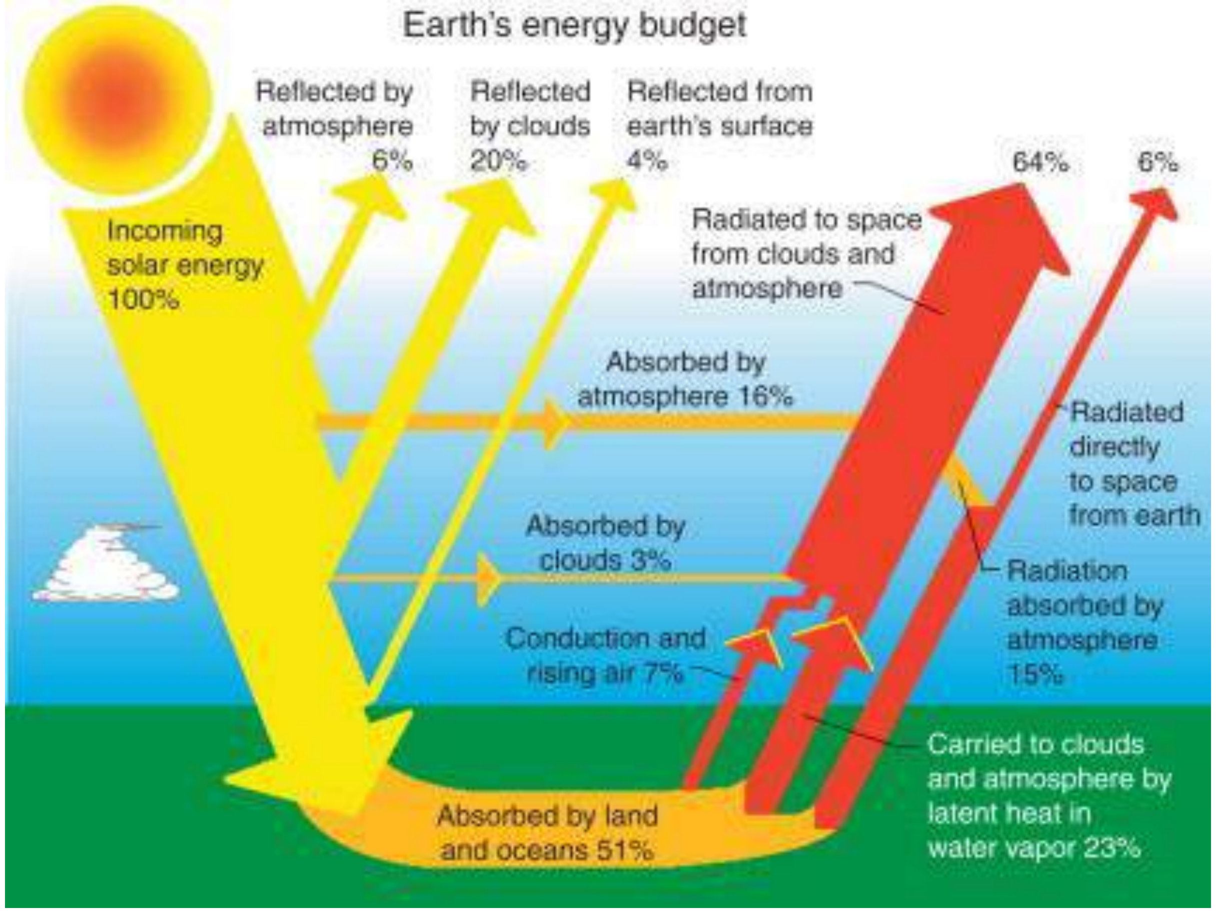
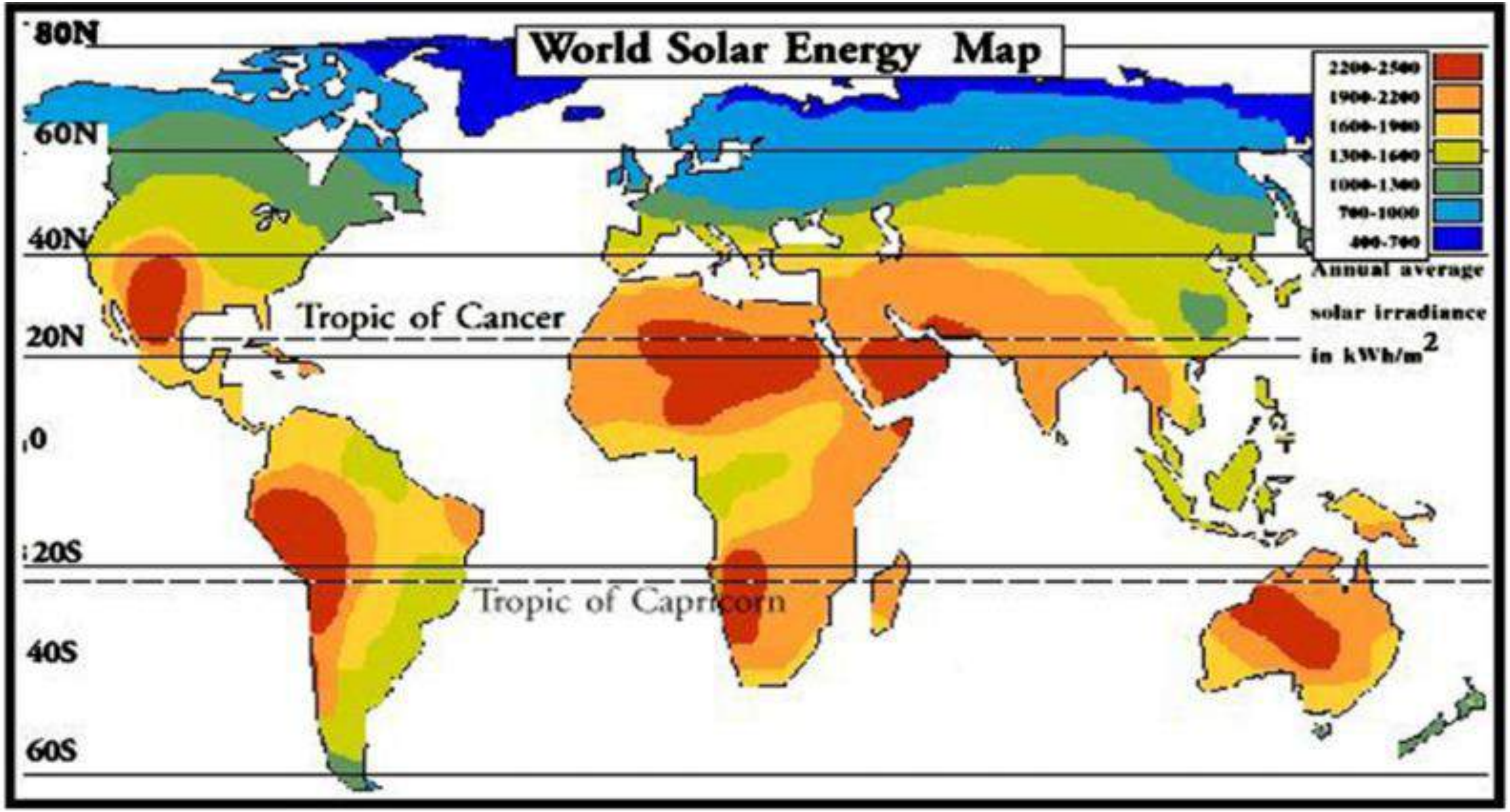
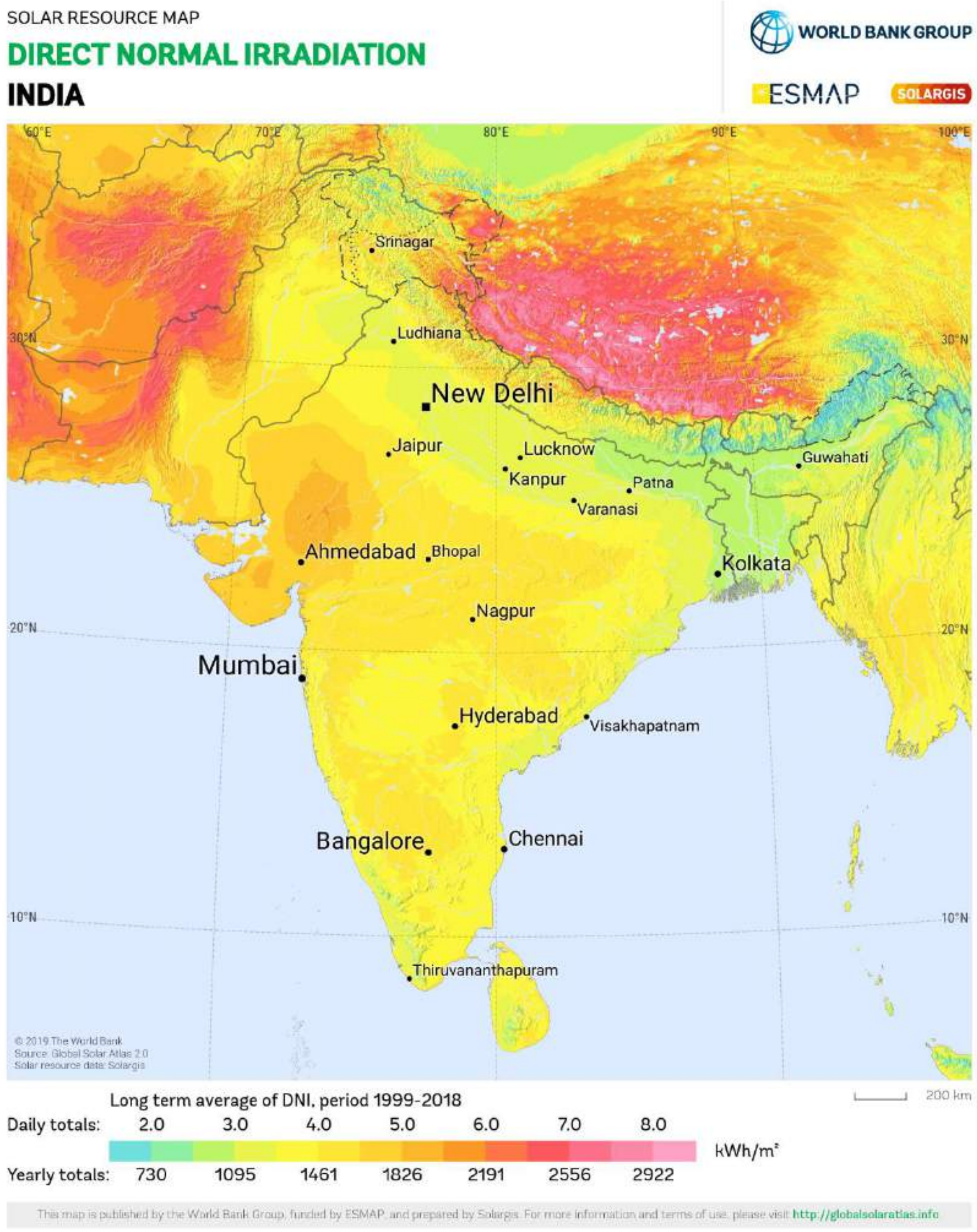
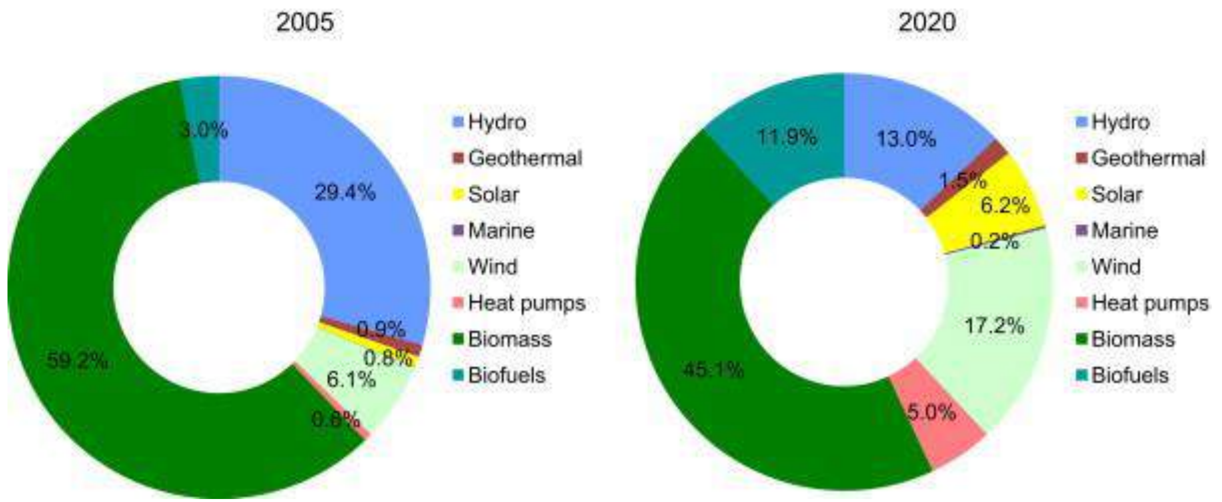
Attenuation of solar radiation



- Using present solar techniques some of the solar energy reaching the earth is utilized for generating heat, electricity etc....
- Even then the energy demand met by using solar energy is very less.


World Solar Energy Map
80N
60N
40N
20N
0
20S
40S
60S
Tropic of Cancer
Tropic of Capricorn
2200-2500
1900-2200
1600-1900
1300-1600
1000-1300
700-1000
400-700
Annual average solar irradiance in kWh/m2





Why Solar Energy?

- The fossil fuels are non renewable sources so we can not depend on them forever.
- Though nuclear energy is a clean and green energy ,as said by Dr.A.P.J Abdul Kalam, there are always some problems associated with it.
- So the only option we have is solar energy because it is a nonpolluting and silent source of electricity and also low maintenance and long lasting energy.

How solar energy is used

- Solar Thermal Energy
- Solar Heating
- – Solar Water Heating
- – Solar Space Heating
- – Solar Space Cooling
- Electricity Generation Using Solar Concentrators
- Photovoltaic Cells

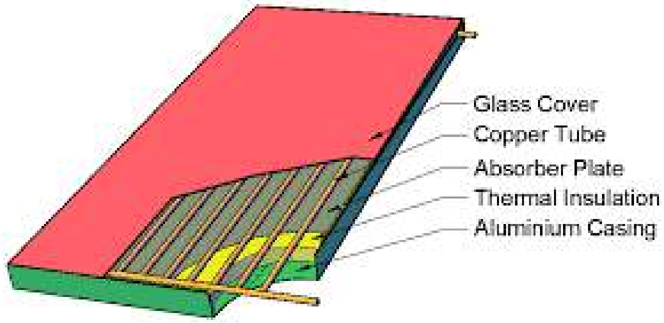
Solar Thermal Energy

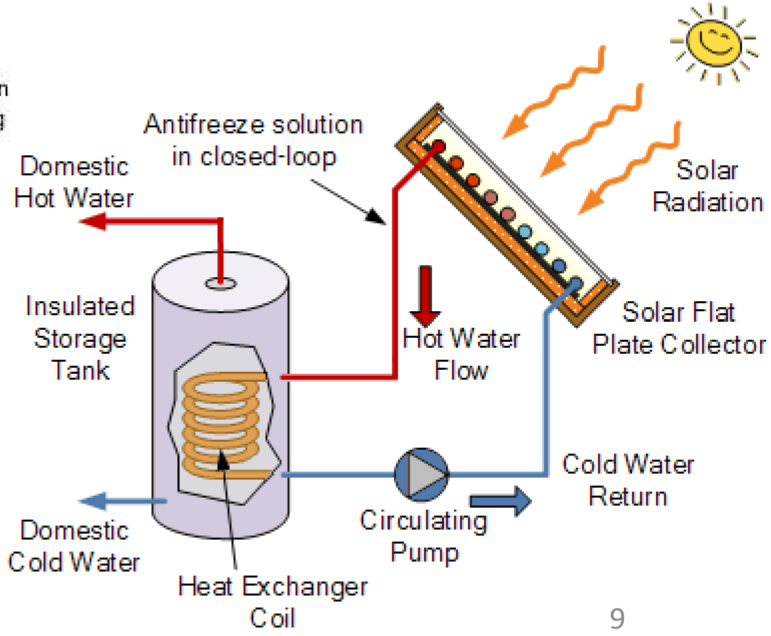
- Solar thermal technologies involve harvesting energy from the sun for heating water or producing electrical power.
- Solar collectors are used for this purpose.
- **Three Types:**
- Flat-plate collectors
- Evacuated-tube collectors
- Integral collector-storage systems(Batch or Bread Box)

FLAT PLATE SOLAR COLLECTOR

❖Flat-plate collectors, developed by Hottel and Whillier in the 1950s, are the most common type of solar collector which are widely used for domestic household hot-water heating and space heating, where the demand temperature is low.

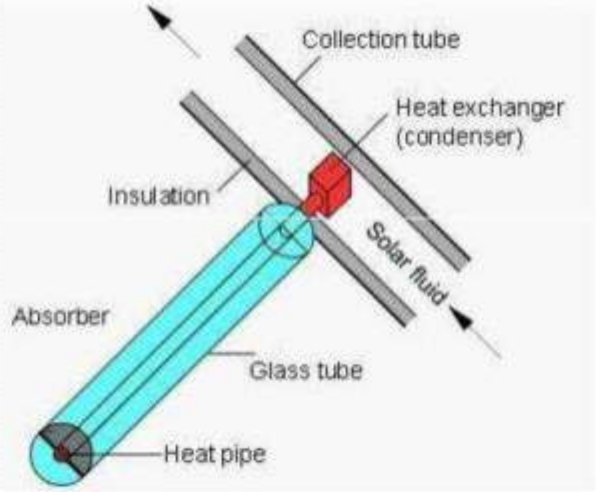
❖Flat plate collector is basically a black surface that is placed at a convenient path of a sun.

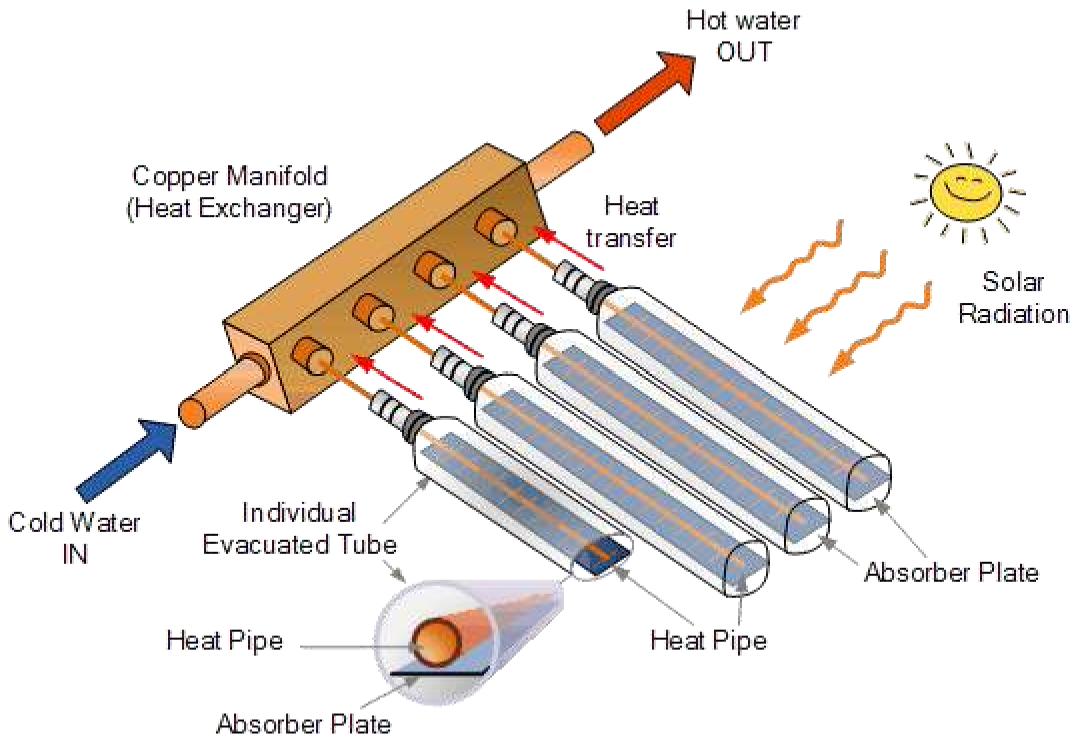




EVACUATED TUBE COLLECTOR:

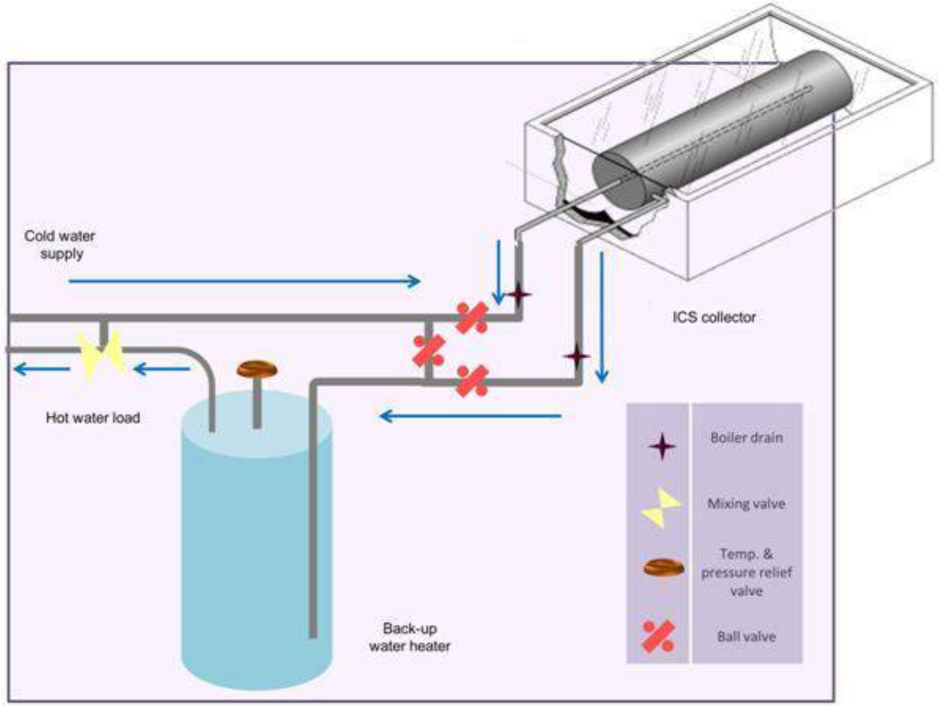
- ETC use rows of glass tube, each of which contains a heat pipe collector with a heat transfer fluid surrounded by a vacuum which greatly reduces heat losses.
- It provides temperatures up to 120°c
- More suitable for use in cold climates.
- With the use of inert gas or ultra-high vacuum, temperature can be increased up to 150°c.





Integral Collector Storage Passive System

Integral Collector Storage systems, also known as **ICS**, “batch” or “bread box” water heating systems, are very similar in design and operation to the flat plate panel collector we looked at previously. This time however, the heat tubes inside the insulated glazed box are much, much bigger in diameter. As their name suggests, in an integral collector storage (ICS) system, the collector and tank are combined into one single unit so circulation pumps and electronic controls are not required as the household tap water is heated and stored within the combined heat storage and collection unit.



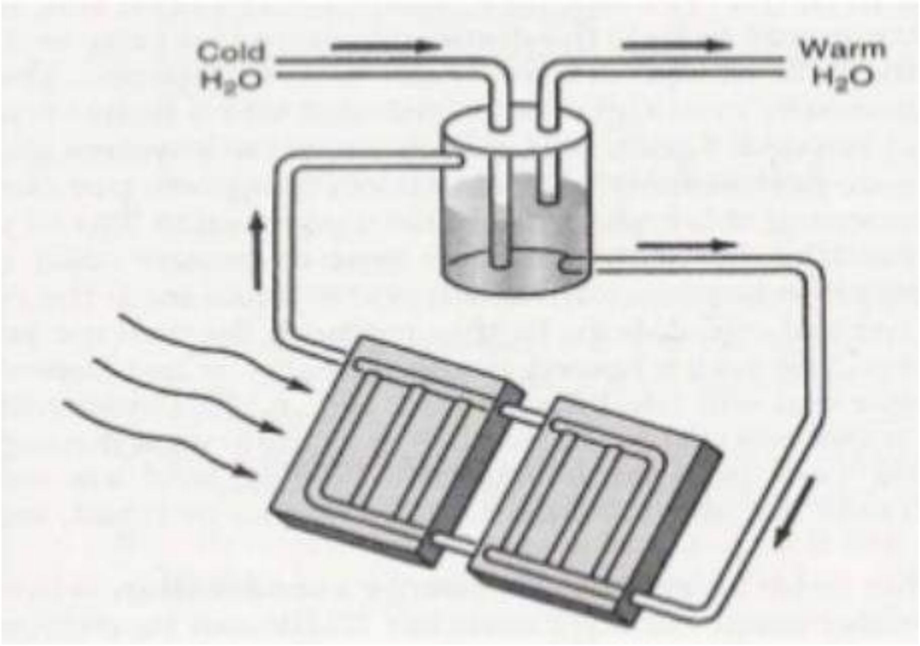
Integral collector storage units are one of the simplest solar hot water heating systems available and can be easily installed into any conventional water heating installation. ICS or “batch” systems, are made of a number of large diameter tubes of between 4 to 8 inches (100 – 200mm) in diameter with one or more black painted storage tanks included inside an insulated glazed weather tight box. Cold water flows under normal water pressure into the solar collector, which preheats and stores the water.

The transfer of the solar heat from the collector to the water is by natural convection, no outside energy is required making it a completely passive system. Whenever hot water is required, the solar heated water stored in the batch collector flows out buy the force of gravity or the pressure of the cold replacing it and continues into the conventional backup water heating system inside the house. This type of hot water installation is a direct system (open-loop) as the water being heated is the same water you drink.

Water Heating

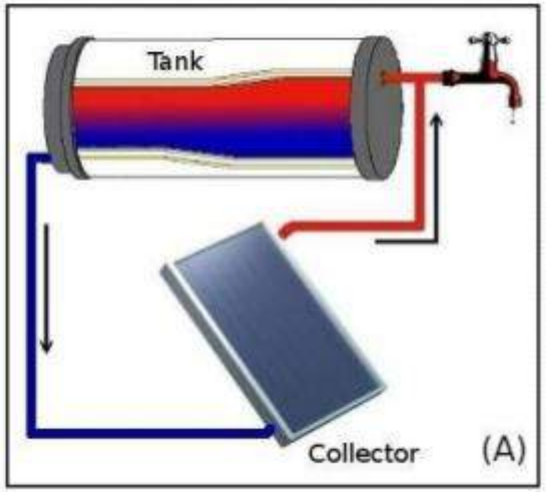
- **Passive systems**
  - Thermosyphon
  - Collector storage systems
- **Active systems**
  - Direct circulation systems
  - Indirect circulation systems
  - Hot air systems.

Thermosiphon is a method of passive heat exchange, based on natural convection, which circulates a fluid without the necessity of a mechanical pump. Thermosiphoning is used for circulation of liquids and volatile gases in heating and cooling applications such as heat pumps, water heaters, boilers and furnaces.



PASSIVE WATER HEATING:

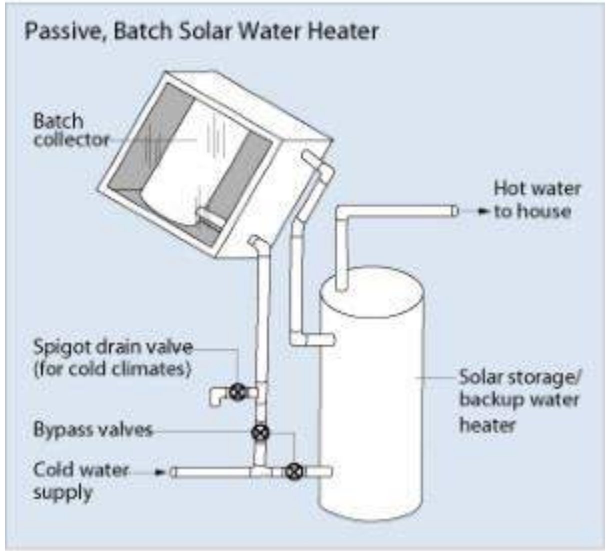
Passive water heating system involves no moving parts (no any external source required to circulate the water). Passive solar water heaters work on the principle of convection, in which hot water rises and cold water sinks within the tank in a continual process as long as there is sunlight available the process is also called Thermosiphon solar water heating.



Passive Integral Collector Storage System - Batch Water Heater

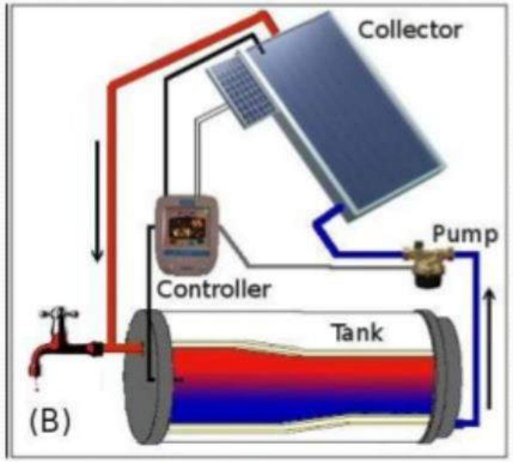
Integral Collector Storage systems are passive as they don't require pumps for the operation. They are also called batch water heaters, and they are the only solar heating systems that do not need the storage tank. They consist of the ICS collector and piping only.

The water storage tank is the solar collector at the same, has an inlet pipe connected to the bottom of the tank from the house plumbing and from the top of the collector hot water is usually connected to the backup storage heater. Whenever you open the hot tap, the pressure from the home plumbing moves the hot water from the top of the solar collector/tank as the cold water is pushed to the bottom.



ACTIVE WATER HEATING

solar water heating in this system the water is circulated forcedly through external source (pumps are used for circulation). The water is circulated through pump in the solar collector and then stored in the hot water storage tank.



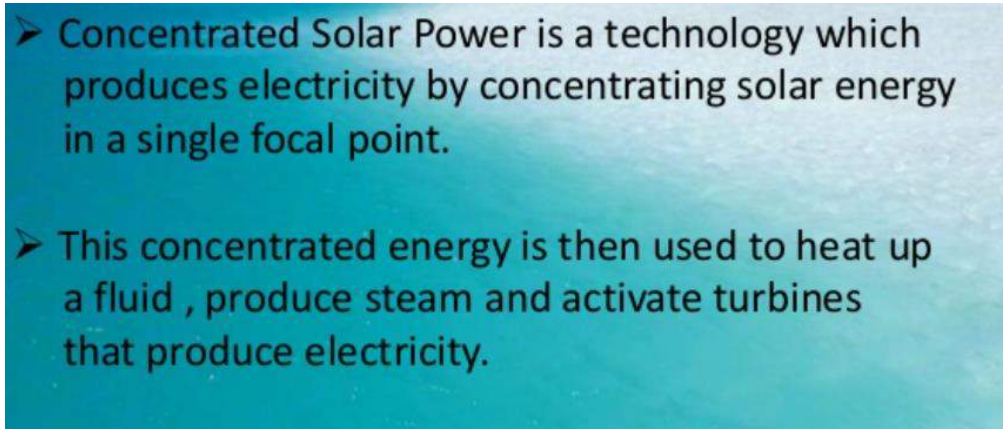
DIRECT V.S. INDIRECT HEATING SYSTEM

- Direct solar water heating systems pass potable water through the thermal collector that eventually flows directly to the desired application (No heat exchanger is required).
- Indirect Heating System works similarly to direct models but rather than 'directly' heating the water in the solar collectors, a special fluid with anti-freeze properties is heated. This fluid transfers the heat to the water by heat exchanger when it drains back into the tank.

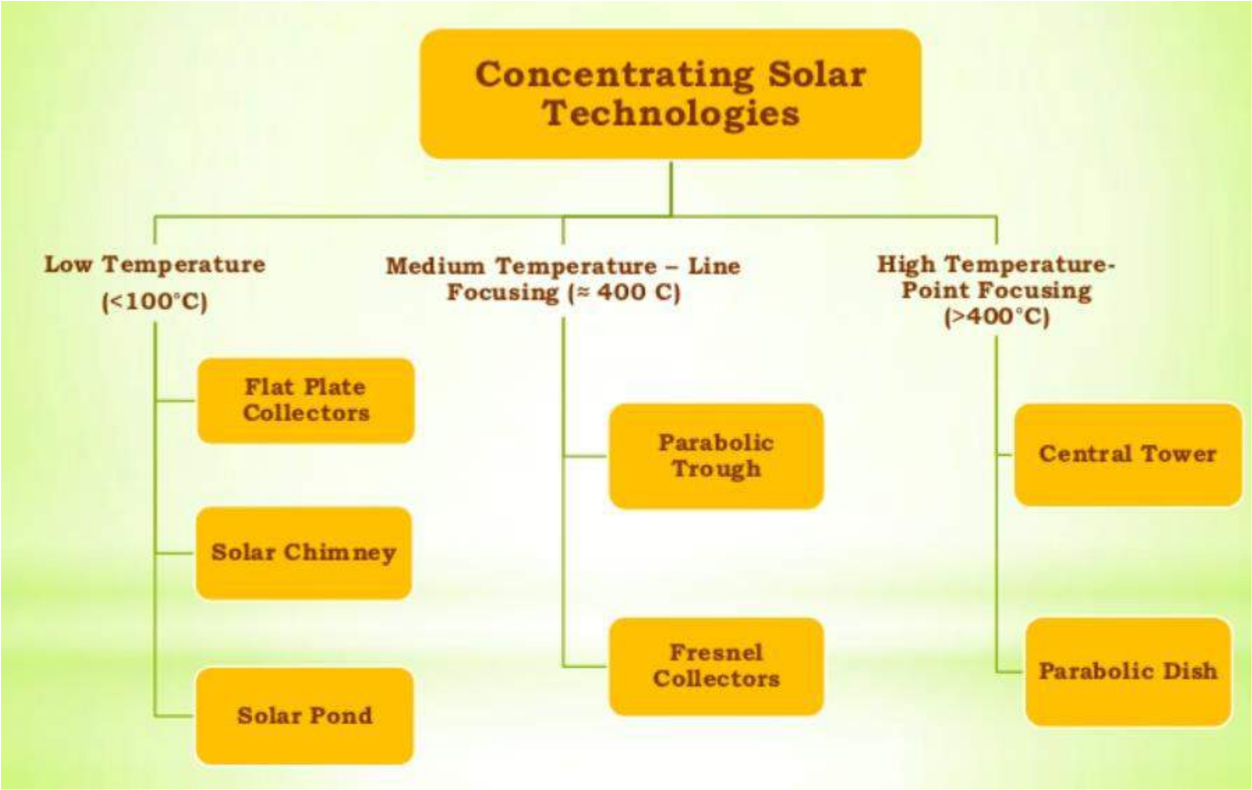
- **Space Heating**
- ***Active Solar Heating System***
  - A system that uses water or air that the sun has heated and is then circulated by a fan or pump.
- ***Passive Solar Heating System***
  - The house itself acts as the solar collector and storage facility.
  - No pumps or fans are used.
  - This system makes use of the materials of the house to store and absorb heat.

Electricity Generation

The ability to harness sunlight and use that energy to generate electricity is achieved mainly through solar thermal power plants (Concentrated solar power) and photovoltaic cells.

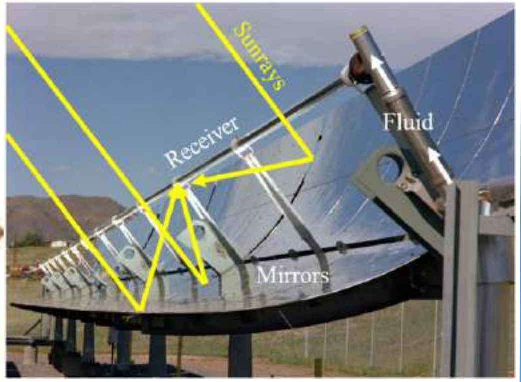


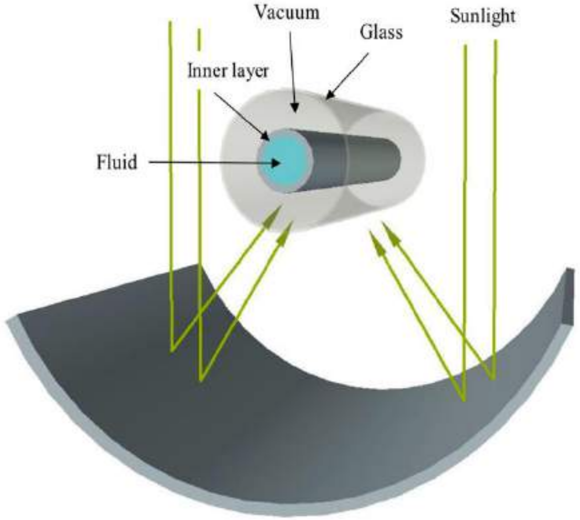
- Concentrated Solar Power is a technology which produces electricity by concentrating solar energy in a single focal point.
- This concentrated energy is then used to heat up a fluid , produce steam and activate turbines that produce electricity.



Parabolic Trough

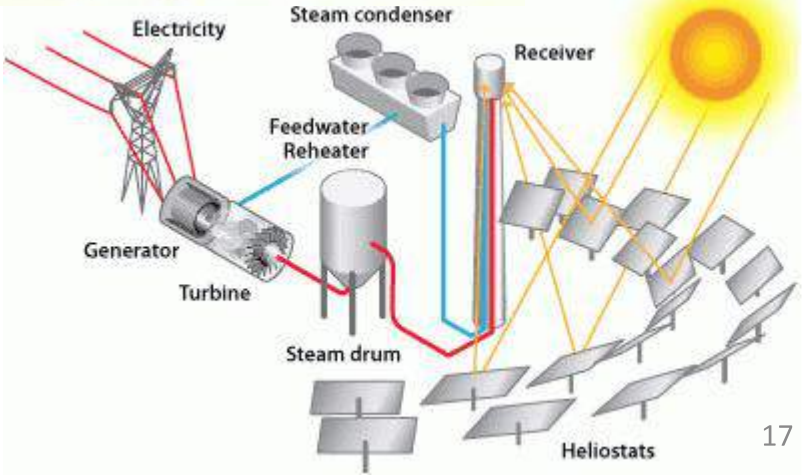
- Temp~400°C
- Line Focusing
- Linear Receiver tube
- Water consuming
- Conc.: Parabolic Mirrors
- Heat Storage feasible
- Most Commercialized
- Good for Hybrid option
- Requires flat land
- Good receiver η but low turbine η





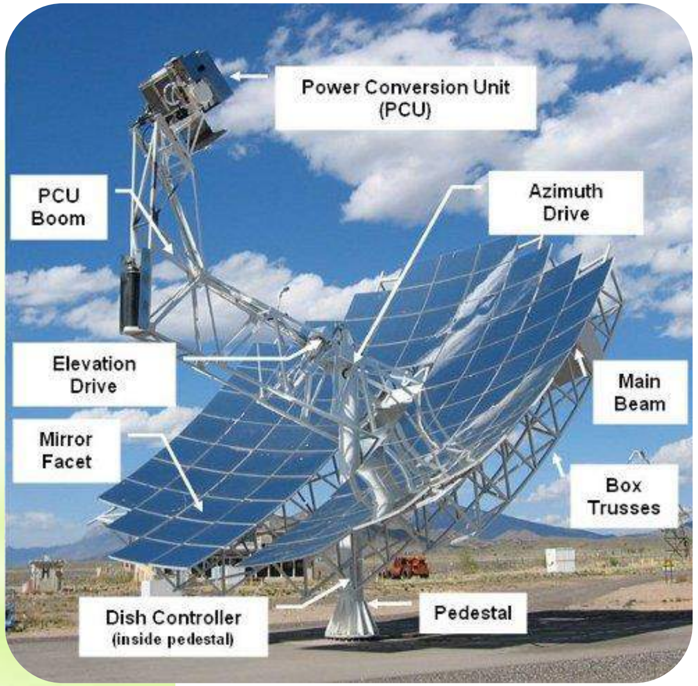
Central Tower

- Temp~600-800°C
- Point Focusing
- Flat Conc. Mirrors
- Commercially proven
- Central Receiver
- Water consuming
- Heat Storage capability
- Feasible on Non Flat sites
- Good performance for large capacity & temperatures
- Low receiver η but good turbine η



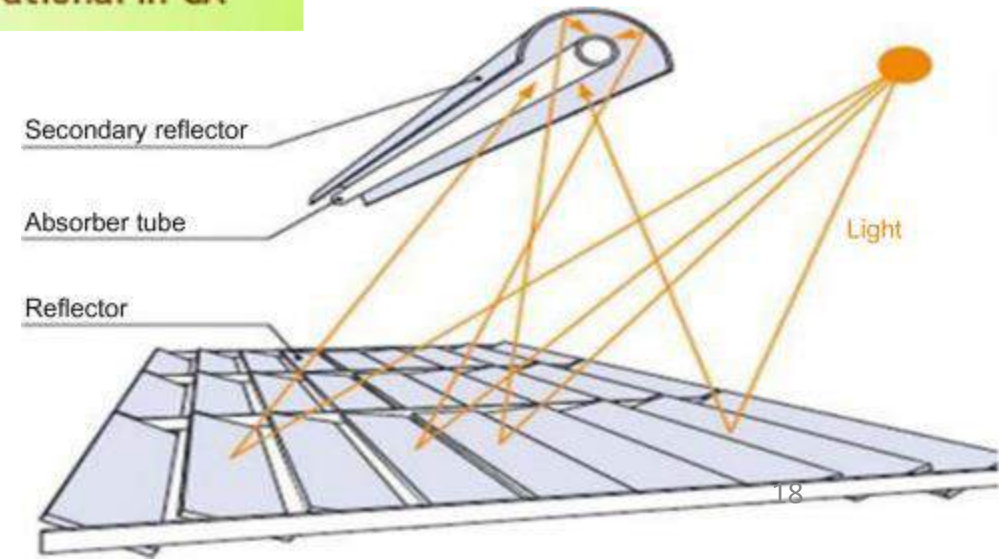
Dish Stirling

- Temp~700-800°C
- Point Focusing
- Uses Dish concentrator
- Stirling Engine
- Generally 25 kW units
- High Efficiency ~ 30%
- Dry cooling
- No water requirement
- Heat storage difficult
- Commercially under development
- Dual Axis Tracking



Fresnel Collector

- Temp~400°C
- Line Focusing type
- Linear receiver
- Fixed absorber row shared among mirrors
- Flat or curved conc. mirrors
- Commercially under development
- Less Structures
- 5 MW operational in CA



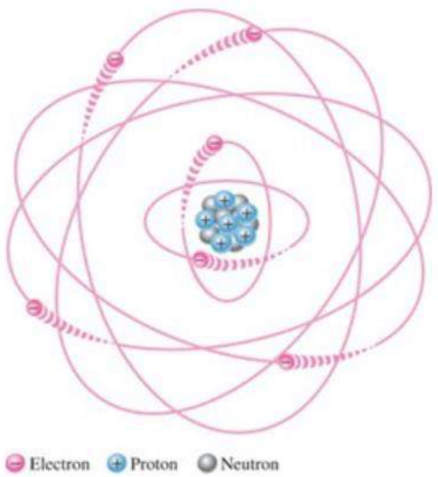
Feasible Applications

Utility / Commercial scale

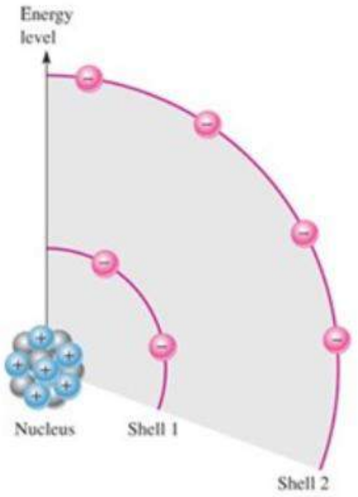
- Electricity Generation
  - Stand alone
  - Grid projects
  - Hybrid projects
- Industrial Process Heat
  - Boiling
  - Melting
  - Sterilizing
- Cooling systems
- Water Desalination

Domestic/small Scale

- Hot Water collectors
- Solar HVAC
- Solar steam Cooking
- Solar Ovens/cookers
- Solar Food dryers



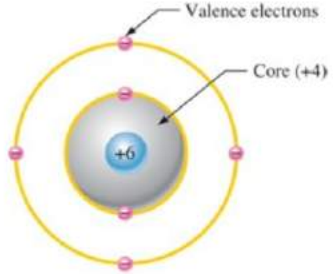
Atom is the smallest particle of an element. Nucleus consists of positively charged particles called protons and uncharged particles called neutrons. The negative charged particles are called electrons.



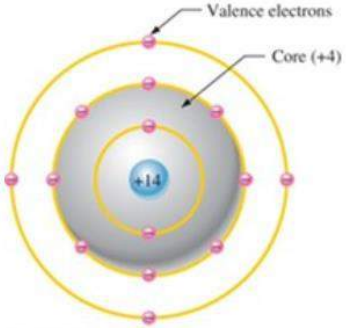
Electrons orbit the nucleus of an atom at certain distance from the nucleus. Electrons near the nucleus have less energy than those in more distant orbits

Valence Electrons

- Valence electrons: electrons in the outermost shell.
  - Electrons that are in orbits farther from the nucleus have higher energy and are less tightly bound to the atom than those close to the nucleus.
  - Electrons with the highest energy exist in the outermost shell of an atom and are relatively loosely bound to the atom.



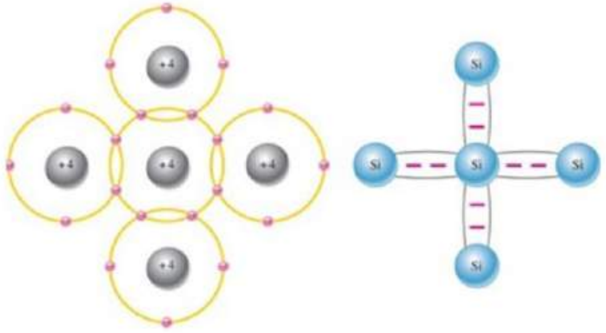
Silicon Atom



(a) Silicon atom

Silicon is the most popular material in microelectronics. It has four valence electrons.

Sharing of Electrons in Silicon

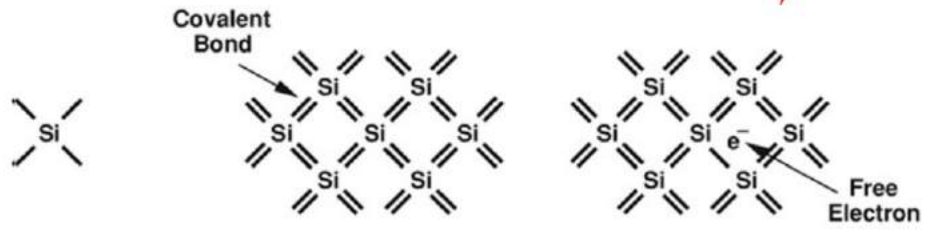


A silicon atom with its four valence electrons shares an electron with each of its four neighbors. This effectively creates eight shares valence electrons for each atom and produces a state of chemical stability.

The sharing of valence electrons produce the covalent bonds that hold the atoms together; each valence electron is attracted equally by the two adjacent atoms which share it.

An electron leave behind a void because the bond is now incomplete.

A void is called a hole. A hole can absorb an free electron if one becomes available.

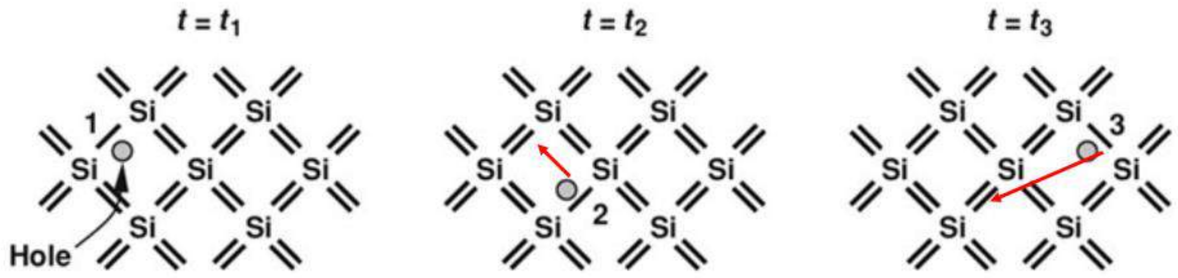


(a) (b) (c)

At T=0K

Electrons gain thermal energy and break away from the bonds. They begin to act as “free charge carriers”—free electron.

Movement of electrons and holes



One electron has traveled from right to left.
One hole has traveled from left to right.

Bandgap Energy

Q:Does any thermal energy create free electrons (and holes) in silicon?

A: No. A minimum energy—called the “bandgap energy” is required to dislodge an electron from a covalent bond. For silicon, the bandgap energy is 1.12 eV.

Note: eV represents the energy necessary to move one electron across A potential difference of 1V. 1 eV =1.6 x 10^{-19} J

Insulators display a higher E_g . (e.g. 2.5 eV for diamond)
Semiconductors usually have a moderate Eg between 1 eV and 1.5 eV.

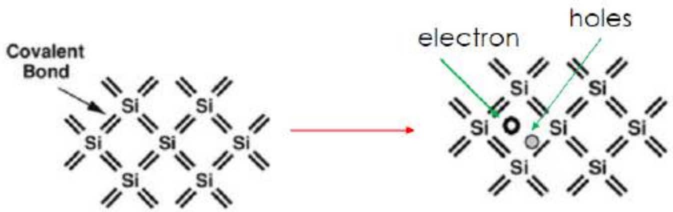
Intrinsic Semiconductor

The pure silicon has few electrons in comparison to the numbers of atoms. Therefore, it is somewhat resistive.

In an intrinsic semiconductors, the electron density(n or n_i) is equal to the hole density (p). (each electron is created by leaving behind a hole.)

So

$$np=n_i^2$$



III	IV	V
Boron (B)	Carbon (C)	
Aluminum (Al)	Silicon (Si)	Phosphorus (P)
Galium (Ga)	Germanium (Ge)	Arsenic (As)

Can we use something other than silicon?

Phosphorus has 5 valence electrons. The 5^{th} electron is "unattached". This electron is free to move and serves as a charge carrier.

Doping

The controlled addition of an impurity such as phosphorus to an intrinsic (pure) semiconductor is called "doping". And phosphorus itself is a dopant.

Providing many more free electrons than in the intrinsic state, the doped silicon crystal is now called "extrinsic," more specifically, an " n-type" semiconductor to emphasize the abundance of free electrons.

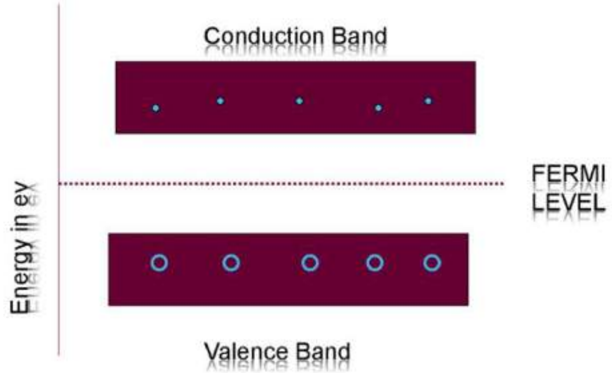
Conduction Band and Valence Band in Semiconductors

Valence Band:

The energy band involving the energy levels of valence electrons is known as the valence band. It is the highest occupied energy band. When compared with insulators, the bandgap in semiconductors is smaller. It allows the electrons in the valence band to jump into the conduction band on receiving any external energy.

Conduction Band:

It is the lowest unoccupied band that includes the energy levels of positive (holes) or negative (free electrons) charge carriers. It has conducting electrons resulting in the flow of current. The conduction band possess high energy level and are generally empty. The conduction band in semiconductors accepts the electrons from the valence band.

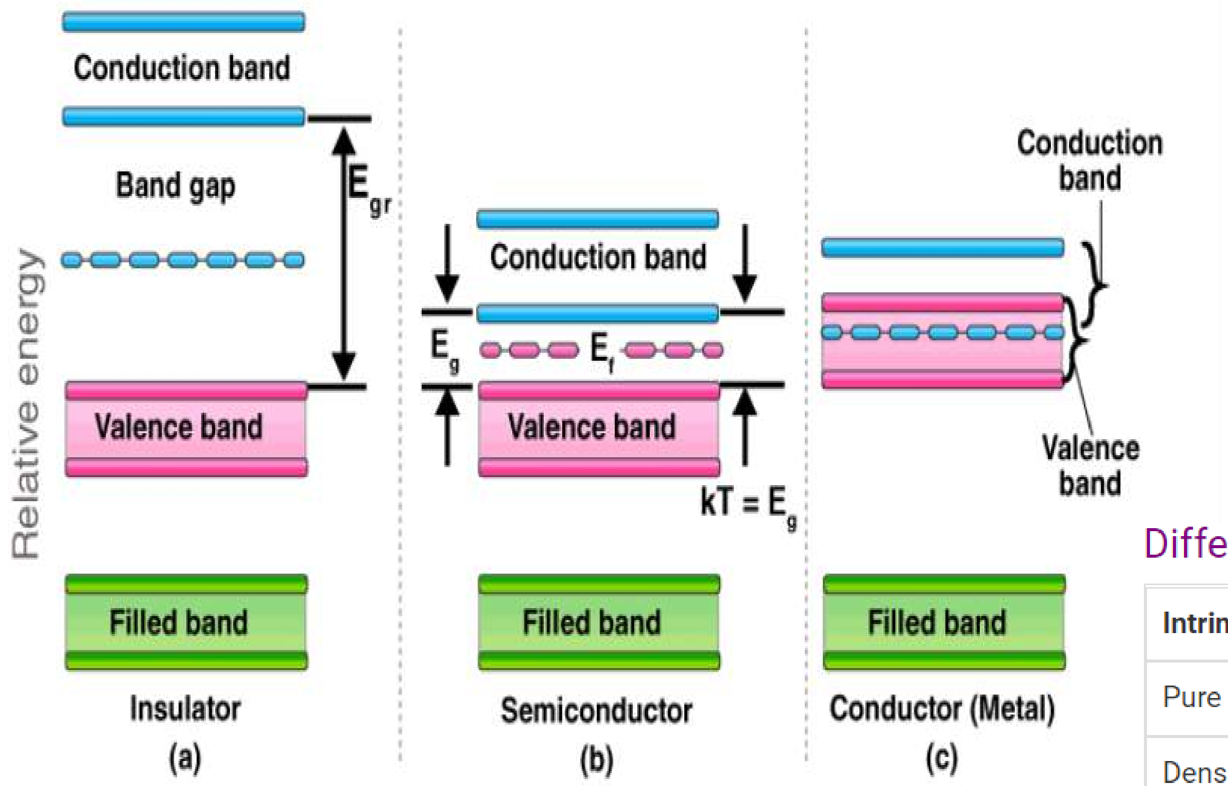


What is Fermi Level in Semiconductors?

Fermi level (denoted by EF) is present between the valence and conduction bands. It is the highest occupied molecular orbital at absolute zero. The charge carriers in this state have their own quantum states and generally do not interact with each other. When the temperature rises above absolute zero, these charge carriers will begin to occupy states above Fermi level.

In a p-type semiconductor, there is an increase in the density of unfilled states. Thus, accommodating more electrons at the lower energy levels. However, in an n-type semiconductor, the density of states increases, therefore, accommodating more electrons at higher energy levels.

ENERGY BAND GAPS IN MATERIALS



Difference Between Intrinsic and Extrinsic Semiconductors

Intrinsic Semiconductor	Extrinsic Semiconductor
Pure semiconductor	Impure semiconductor
Density of electrons is equal to the density of holes	Density of electrons is not equal to the density of holes
Electrical conductivity is low	Electrical conductivity is high
Dependence on temperature only	Dependence on temperature as well as on the amount of impurity
No impurities	Trivalent impurity, pentavalent impurity

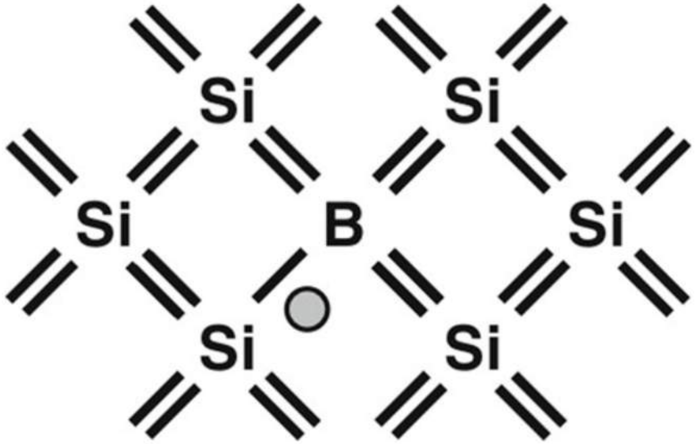
Hole density in an n-type semiconductor

Many of the new electrons donated by the dopant "recombine" with the holes that were created in the intrinsic material. As a consequence, in an n-type semiconductor. The hole density will drop below its intrinsic level.

$$np=n_i^2$$

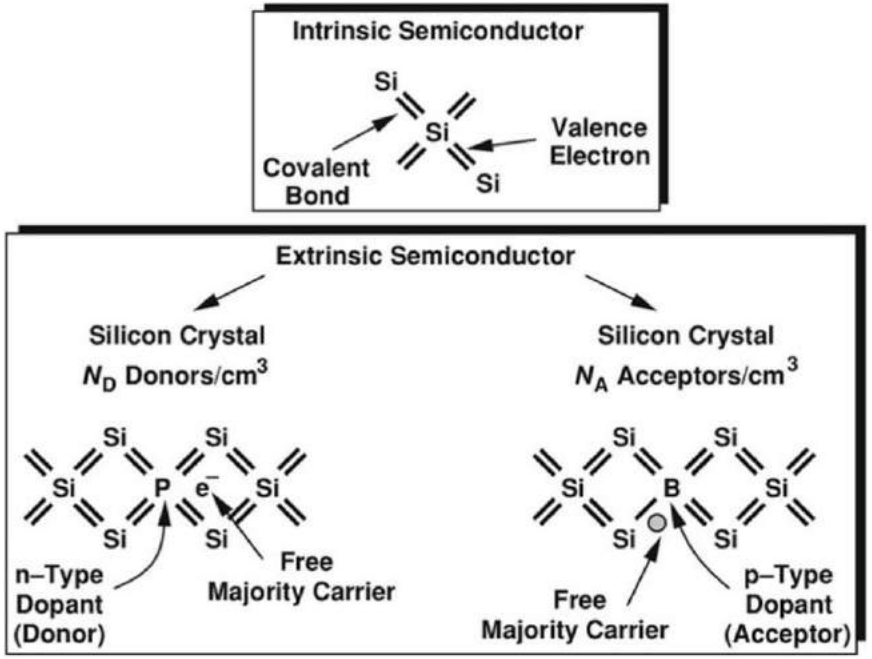
In an n-type semiconductor,
Electrons are the **majority** carriers.
Holes are the **minority** carriers.

If a voltage is applied across an n-type materials, the current consisting predominantly of electrons is produced!



if we dope silicon with an atom that provides an insufficient number of electrons, then we may obtain many incomplete covalent bonds.

A boron has only 3 valence electrons and can form only 3 covalent bonds. Therefore, it contains a hole and is ready to absorb a free electron.



Carrier Transport

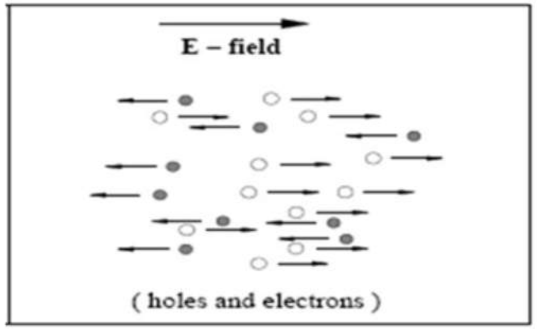
- The net flow of electrons and holes generate currents.
- The flow of "holes" within a solid–state material is, in all respects, equivalent to a flow of positive charge carriers.
- The process by which these charged particles move is called **Carrier Transport** .

There are 2 carrier transport mechanism in semiconductor

- **Diffusion** – the flow of charge due to density gradients.
- **Drift** – the movement of charge due to electric fields

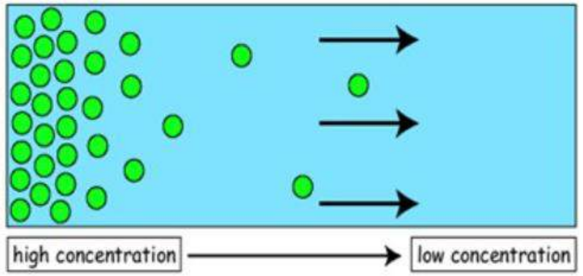
Carrier Transport: Drift

- An electric field applied to a semiconductor will produce a force on electrons and holes so that they will experience a *net acceleration* and *net movement.*
- This *net movement of charge due to an electric field is called* ***drift*** **.**
- The *net drift of charge gives rise to a* ***drift current*** .



Carrier Transport: Diffusion

- ***Diffusion*** is the process whereby particles flow from a region of high concentration toward a region of low concentration (**charge density gradients**).
- If the particles have charge, the net flow of charge would result in a **diffusion current** .



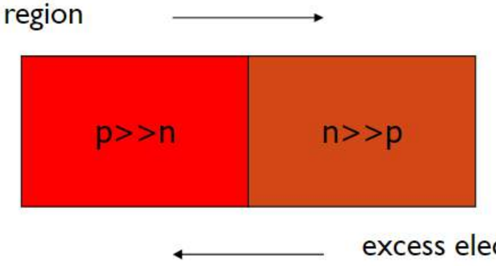
p-n Junction at Thermal Equilibrium

Before junction is formed:

- Uniform distribution of holes in p-type semiconductor
- Uniform distribution of electrons in n-type semiconductor.

After junction is formed:

excess holes diffuse
to the n-type region



excess electrons diffuse
to the p-type region

Hole Drift Velocity and Mobility

- The equation of motion of a positively charged hole in the presence of an electric field E is

$$F = m_p^* a = eE$$

a is the acceleration, m_p^* is the effective mass of hole, and e is the charge of a hole.

- For a constant electric field, we expect the velocity to increase linearly with time.
- However, charged particles in a semiconductor are involved in collisions with ionized atoms and with thermally vibrating lattice atoms.
- This accelerate, collide, accelerate, collide motion results in an average **drift velocity** $\boldsymbol{v_d}$.

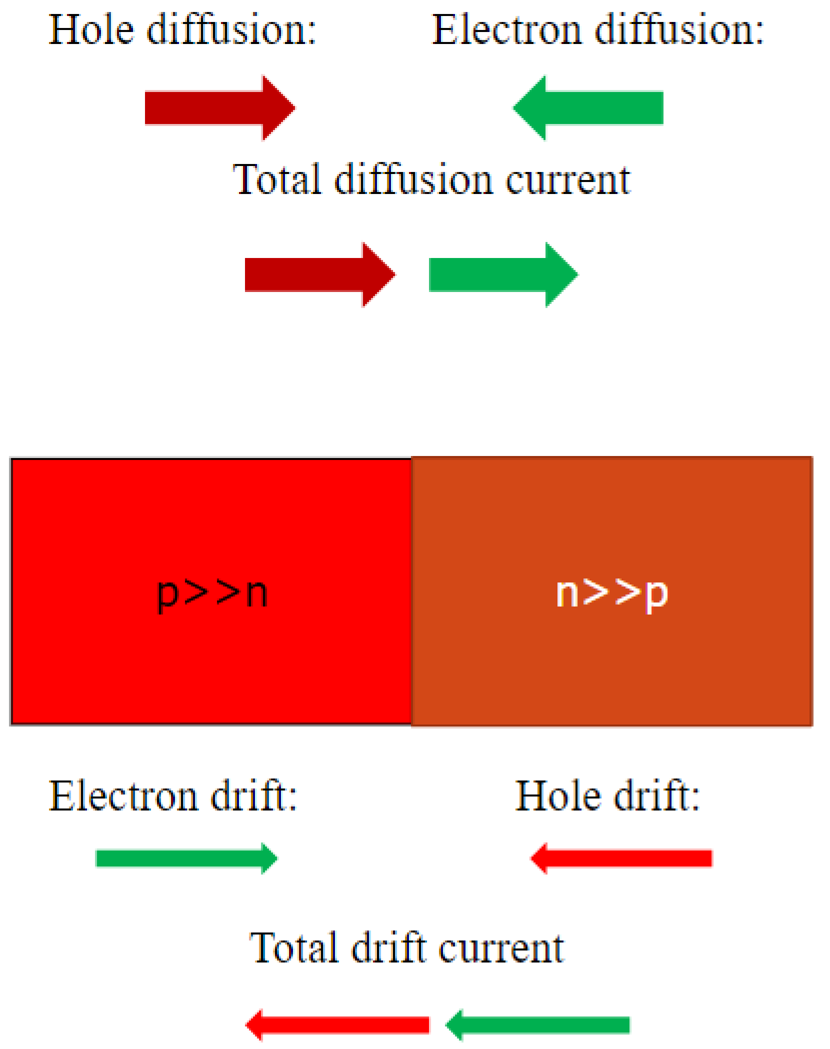
Hole Mobility

- At low electric fields, the drift velocit is directly proportional to the electric field.

$$v_{dp} = \mu_p E$$

where $\boldsymbol{v_{dp}}$ is the **hole drift velocity** and $\boldsymbol{\mu_p}$ is called the **hole mobility** (cm^2/V-sec).

Diffusion current & Drift current

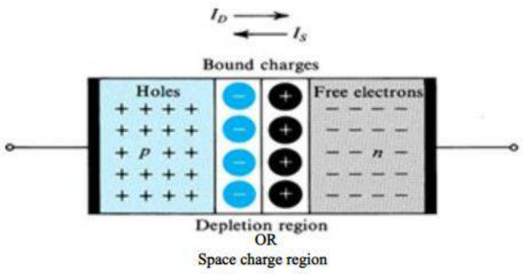


p-n Junction at Thermal Equilibrium

The Diffusion Current and the Space Charge Region

- Excess holes diffuse to the n-region and excess electrons diffuse to the p-region giving rise to **diffusion current**, I_D.

- The excess holes diffused recombine with the excess electrons in the n-region, thus uncovering **bound positively charged donor atoms** in the n-region near the junction.



- The excess electrons diffused to the p-region recombine with the excess holes thus uncovering **bound negatively charged acceptor atoms** in the p-region near the junction

- The charged region created at the junction is called the **depletion region** (depleted of free carriers) or the **space charge region.**

p-n Junction at Thermal Equilibrium

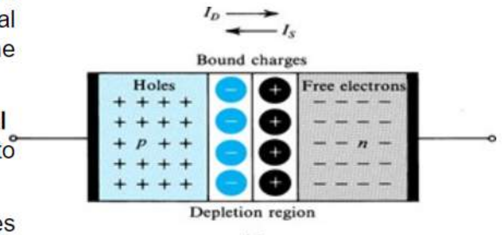
The Drift Current and the Barrier / Built-in / Contact Potential

<u>The Barrier Voltage</u>: The depletion region or the space charge region creates an electric field and establishes a potential barrier know as **barrier voltage** or the **built-in voltage**, V_0.

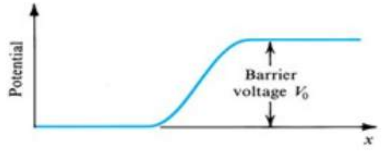
- It is also called the **contact potential** as the voltage is developed due to contact between p and n materials.

- The developed electric field opposes further diffusion of electrons and holes and hence the name barrier voltage.

- <u>Drift Current</u>: Further, the developed electric field will sweep minority carriers across the junction, i.e., holes from n to p and electrons from p to n, giving rise to minority carrier **drift current**, I_S.



(a)

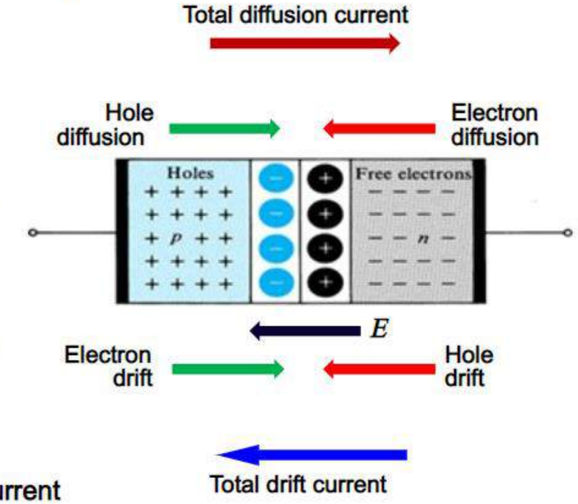


(b)

Diffusion and Drift Current Equilibrium

-The process of diffusion continues until the depletion region expands to a width such that the electric field in the depletion region is large enough so that the diffusion current due to majority carriers is exactly balanced by the drift current due to minority carrier.

- The *net flow of current through the junction is zero*. So for a p-n junction at *thermal equilibrium*,

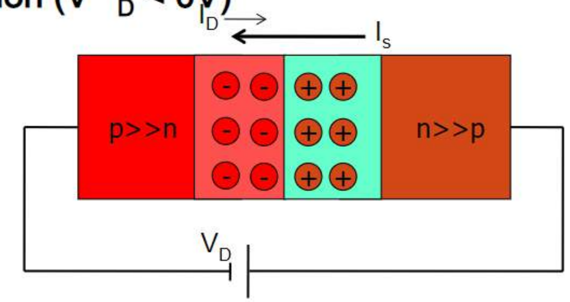


Total diffusion current = Total drift current

$$I_D = I_S$$

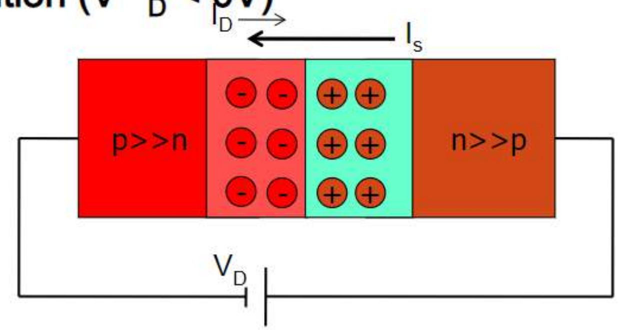
p-n Junction : Steady State Condition

Reverse-Bias Condition ($V_D < 0V$)



- The number of uncovered positive ions in the depletion region of n-type will increase due to large number of free electrons drawn to the positive potential
- Similarly, the number of uncovered negative ions will increase in p-type resulting in widening of depletion region
- The wider space charge region increases the barrier height by the reverse voltage, $V_B = V_0 + V_D$.
- The increased barrier height reduced the diffusion of majority carriers – resulting in a much reduced diffusion current I_D.

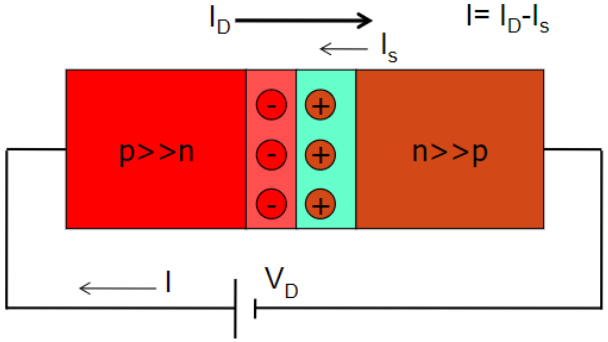
Reverse-Bias Condition ($V_D < 0V$)



- The drift current I_S due to minority carriers does not change as the number of minority carriers entering the depletion region remains same
- I_S depends only on the minority carrier concentration and is independent of the voltage applied.
- I_S is called the **reverse saturation current** as it keeps flowing under reverse biased condition
- Therefore, the diode current under reverse-biased condition,

$$I = I_D - I_s \approx - I_S$$

Forward-Bias Condition ($V_D > 0V$)

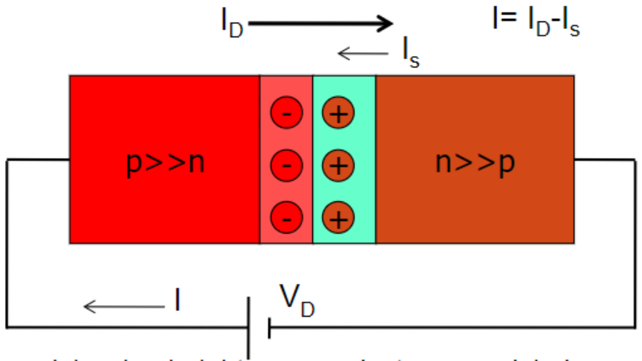


- In the forward-biased condition positive potential on the p-side and negative potential on n-side.

- The forward voltage will pressure the electrons in n-type and holes in p-type to neutralize some of the uncovered ions near the boundary and reduce the width of the depletion region

- The reduced depletion region will reduce the barrier voltage V_0 by the forward voltage V_D. The new barrier height, $\mathbf{V_B = V_0 - V_D}$.

Forward-Bias Condition ($V_D > 0V$)



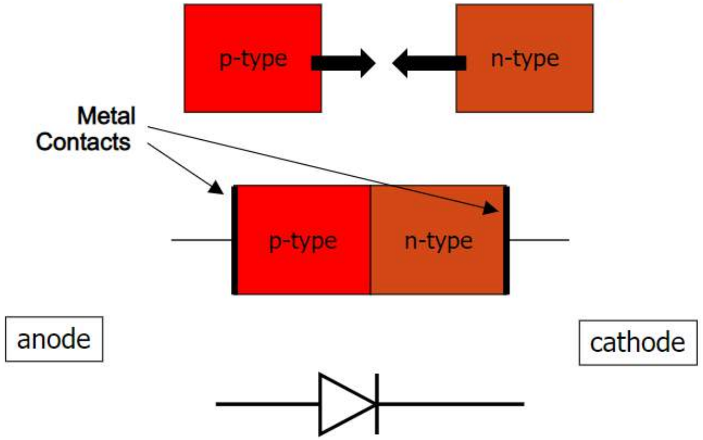
- Due to reduced barrier height, more electrons and holes can now diffuse across the junction, thus greatly increasing the diffusion current I_D.

- But the drift current I_S due to minority carriers remains unchanged, since the minority carrier concentration is same.

- Thus in the forward-biased condition, the diode current is almost equal to the diffusion current, $\mathbf{I = I_D - I_S \approx I_D}$

p-n Junction Diode: Structure and Symbol

p-n junction diode : A two terminal one way device.



Circuit Symbol
(Arrow head indicates the normal direction of current flow)

p-n Junction Diode Characteristics

Ideal Diode Characteristics

Forward-biased :

- On during forward bias
- Zero forward resistance (short-circuit)
- Zero forward voltage drop

Reversed-biased :

- Off during reverse bias
- Infinite resistance (open-circuit)
- Zero diode current

Semiconductors

A semiconductor material is one which conducts only when excited.

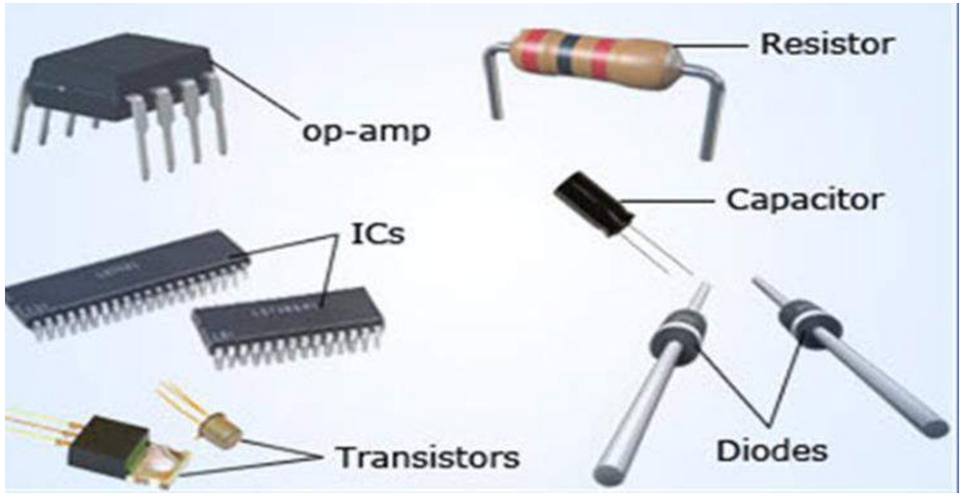
- It is neither an Insulator, nor a Conductor.
- A conductor has normally one carrier per atom, while a semiconductor has one carrier per 10^{12} at room temperature (Silicon).
- The devices are built by introducing an impurity into otherwise a pure matter, and the process is called "doping".

Applications of semiconductor devices

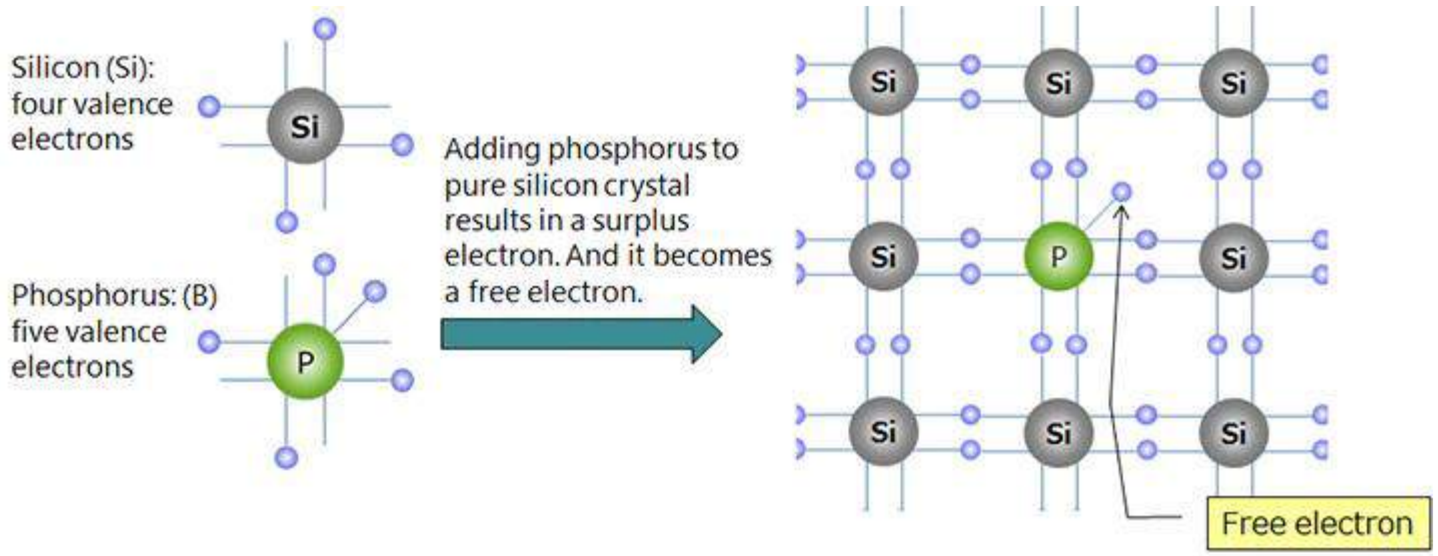
Semiconductor devices are all around us. . They can be found in just about every commercial product we touch, from the family car to the pocket calculator.

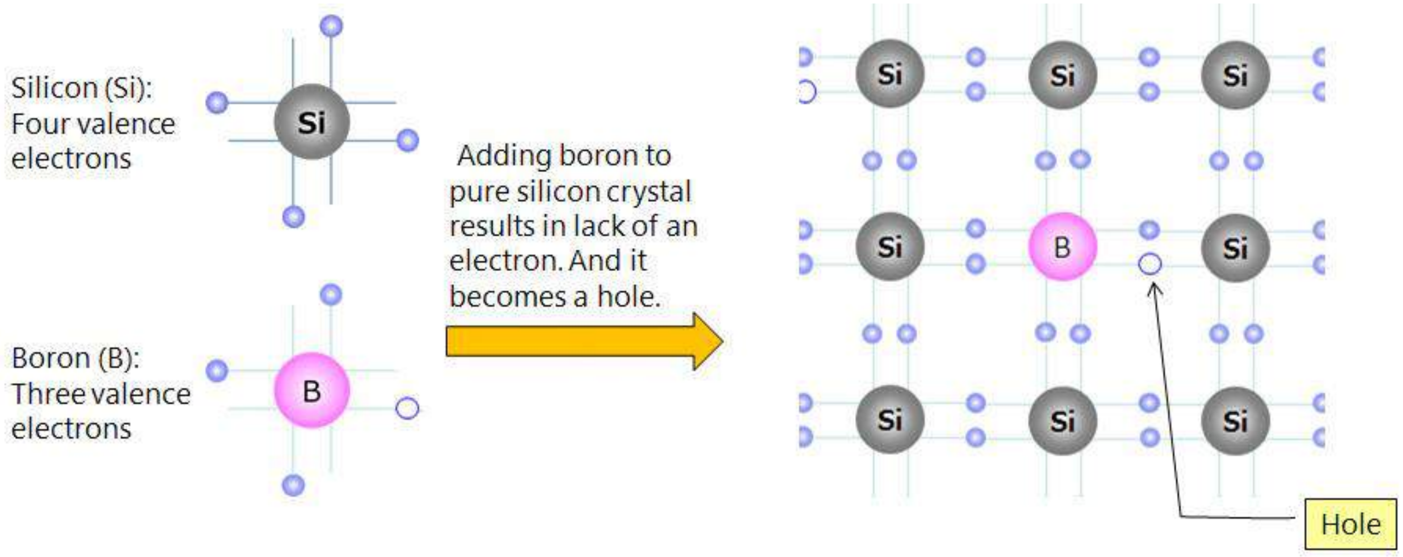
- Rectifiers which are used in d. c. power supplies.
- Wave shaping circuits such as clippers and clampers.
- Voltage regulator circuits.
- Portable Radios and TV receivers.
- Science and industry,
- solid-state devices, space systems, computers, and data processing equipment,
- military equipment,
- Data display systems, data processing units, computers, and aircraft guidance-control assemblies etc...

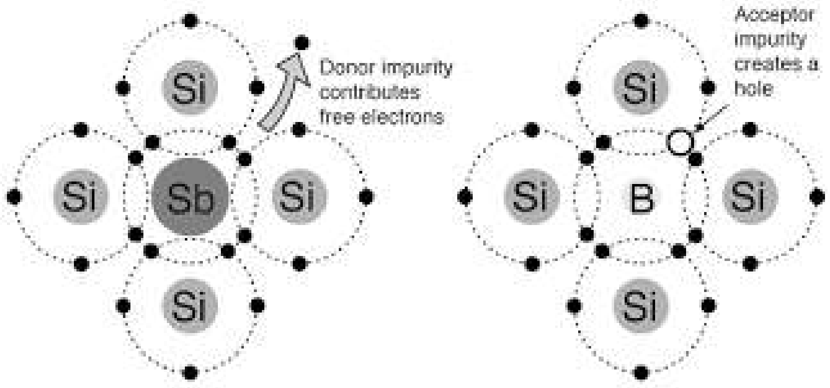
- **Semiconductor device,** electronic circuit component made from a material that is neither a good conductor nor a good insulator (hence semiconductor). Such devices have found wide applications because of their compactness, reliability, and low cost. As discrete components, they have found use in power devices, optical sensors, and light emitters, including solid-state lasers.
- Semiconductor device have high conductivities, typically from 10^4 to 10^6 Siemens per centimeter. The conductivities of semiconductors are between these extremes.



n and p type semiconductor







N-type semiconductor	P-type semiconductor
1. It is an extrinsic semi-conductor which is obtained by doping the impurity pentavalent impurity atoms such as antimony, phosphorous, arsenic etc. to the pure germanium or silicon semiconductor.	1. It is an extrinsic semiconductor which is obtained by doping trivalent impurity atoms such as boron, gallium, indium etc. to the pure germanium or silicon semiconductor.
2. The impurity atoms added, provide extra electrons in the structure, and are called donor atoms.	2. The impurity atoms added, create vacancies of electrons (i.e., holes) in the structure and are called acceptor atoms.
3. The electrons are majority charge carriers and holes are minority charge carriers.	3. The holes are majority charge carriers and eletrons are minority carriers.

Solar Cell

Photovoltaic (PV) Effect:

Electricity can be produced from sunlight through a process called the PV effect, where "photo" refers to light and "voltaic" to voltage.

Solar Cell

Solar cell is a device that converts the light energy into electrical energy based on the principles of photovoltaic effect.

Choice of material

- **Solar cell is composed of semiconductor material**
- **A typical silicon PV cell is composed of** a thin wafer consisting of **an ultra-thin** layer of phosphorus-doped (N-type) **silicon on top of a thicker layer** of boron-doped (P-type) **silicon.**

- Solar energy is primarily transmitted to the Earth by electromagnetic waves
- It can also be represented by particles (photons)
- Solar radiation consist of range of particles, classified based on wavelength (frequency)

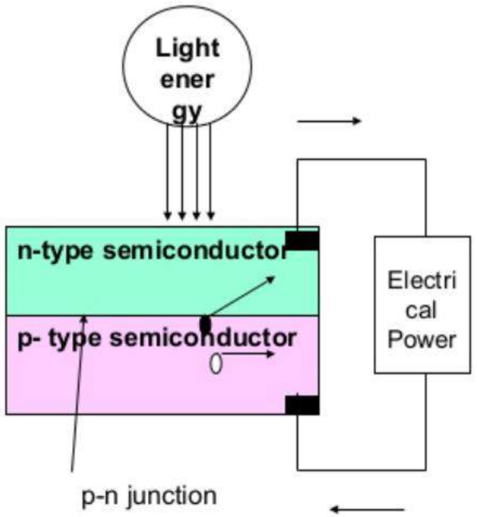
Region Of EM wave	Frequency	Energy
ultraviolet	100nm	1.2 keV
visible(blue)	400 nm	3.1 eV
visible(red)	700 nm	1.8 eV
infrared	10000 nm	0.12 eV

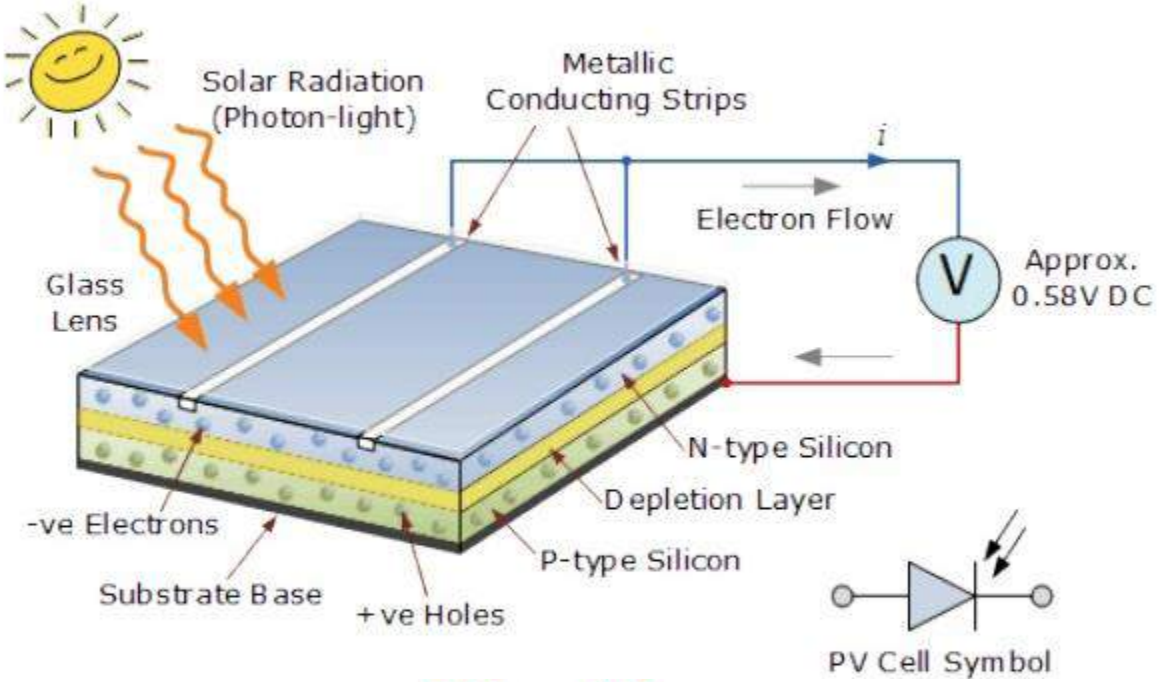
- Ultraviolet radiation is absorbed by ozone layer.
- So, solar radiation available to us have a photon energy in between 0.1 eV to 4.4 eV
- That's why semiconductor is used, whose band gap energy is in between the range
- Insulator require photon of above 4.4 eV energy, so solar radiation is not sufficient to knock electron from valence band to conduction band

Photovoltaic effect

Definition:

The generation of voltage across the PN junction in a semiconductor due to the absorption of light radiation is called photovoltaic effect. The Devices based on this effect is called photovoltaic device.





Construction

Solar cell (crystalline Silicon) consists of a n-type semiconductor (emitter) layer and p-type semiconductor layer (base). The two layers are sandwiched and hence there is formation of p-n junction.

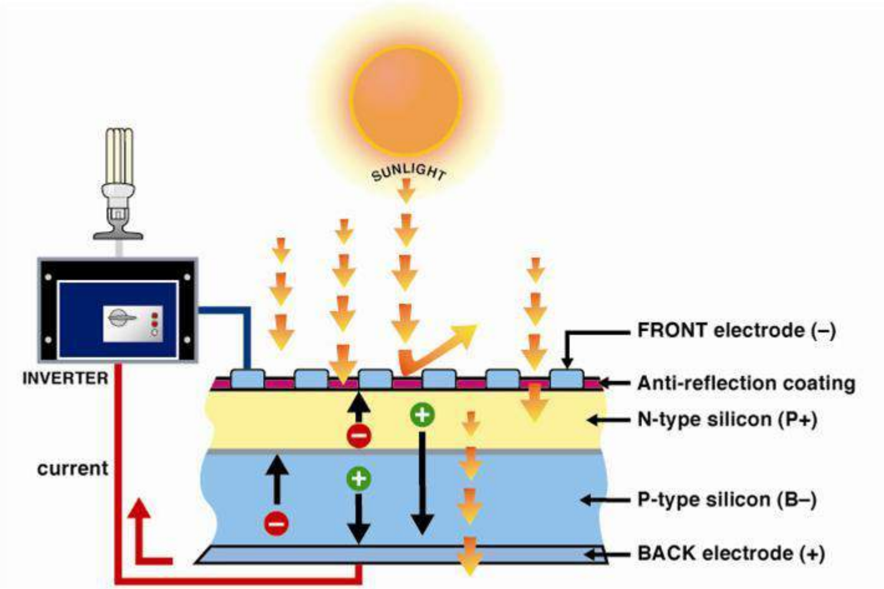
The surface is coated with anti-reflection coating to avoid the loss of incident light energy due to reflection.

Working

When a solar panel exposed to sunlight , the light energies are absorbed by a semi conduction materials.

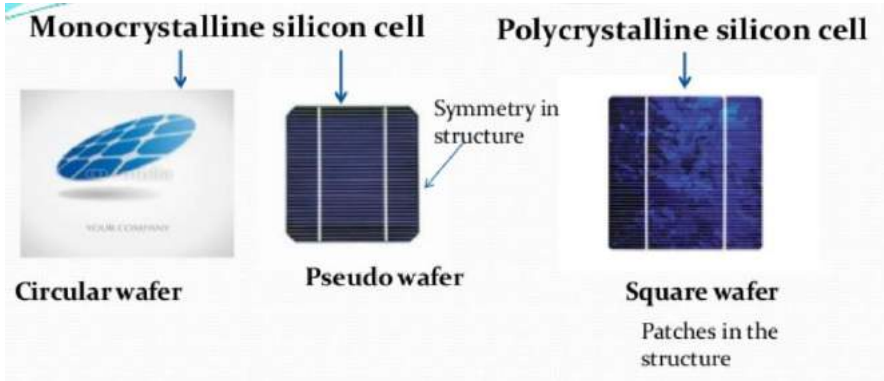
Due to this absorbed energy, the electrons are liberated and produce the external DC current.

The DC current is converted into 240-volt AC current using an inverter for different applications.



Thus when this p and n layers are connected to external circuit, electrons flow from n-layer to p-layer, an hence current is generated

The electrons that leave the solar cell as current give up their energy to whatever is connected to the solar cell, and then re-enter the solar cell. Once back in the solar cell, the process begins again.



Types of Solar cell

Based on the types of crystal used, soar cells can be classified as,

1. Monocrystalline silicon cells
2. Polycrystalline silicon cells
3. Amorphous silicon cells

1. The Monocrystalline silicon cell is produced from *pure silicon (single crystal).* Since the Monocrystalline silicon is pure and defect free, the efficiency of cell will be higher.

2. In polycrystalline solar cell, *liquid silicon* is used as raw material and polycrystalline silicon was obtained followed by *solidification process*. The materials contain various crystalline sizes. Hence, the efficiency of this type of cell is less than Monocrystalline cell.

Amorphous Silicon

Amorphous silicon is obtained by *depositing silicon film on the substrate like glass plate.*

• The layer thickness amounts to less than 1µm – the thickness of a human hair for comparison is 50-100 µm.

• The efficiency of amorphous cells is much lower than that of the other two cell types.

• As a result, they are used mainly in low power equipment, such as watches and pocket calculators, or as facade elements.

During choosing a particular solar cell for specific project it is essential to know the ratings of a solar panel. These parameters tell us how efficiently a solar cell can convert the light to electricity.

Solar cell characteristics:

Short Circuit Current of Solar Cell

- The maximum current that a solar cell can deliver without harming its own constriction. It is measured by short circuiting the terminals of the cell at most optimized condition of the cell for producing maximum output.

- Solar cell also depends upon the intensity of light and the angle at which the light falls on the cell. As the current production also depends upon the surface area of the cell exposed to light

  Maximum current density

$$J_{sc} = \frac{I_{sc}}{A}$$

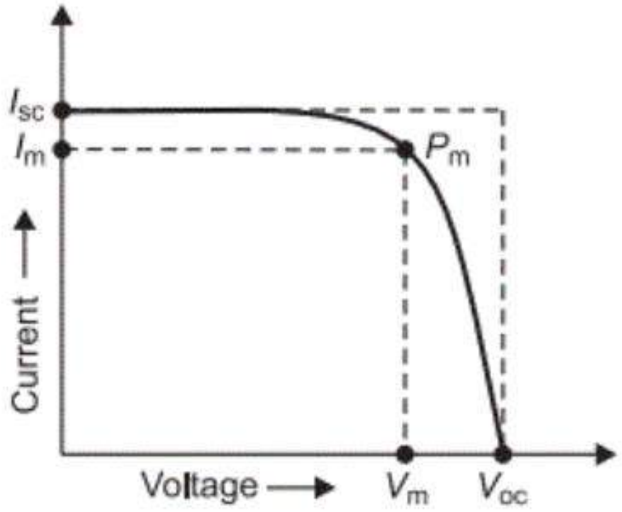
  I_{sc} is short circuit current, J_{sc} maximum current density and A is the area of solar cell.

Open Circuit Voltage of Solar Cell

It is measured by measuring voltage across the terminals of the cell when no load is connected to the cell. This voltage depends upon the techniques of manufacturing and temperature but not fairly on the intensity of light and area of exposed surface. Normally open circuit voltage of solar cell nearly equal to 0.5 to 0.6 volt. It is normally denoted by $V_{oc.}$

Maximum Power Point of Solar Cell

The maximum electrical power one solar cell can deliver at its standard test condition. If we draw the v-i characteristics of a solar cell maximum power will occur at the bend point of the characteristic curve. It is shown in the v-i characteristics of solar cell by Pm.



Current at Maximum Power Point

The current at which maximum power occurs. Current at Maximum Power Point is shown in the v-i characteristics of solar cell by I_m.

Voltage at Maximum Power Point

The voltage at which maximum power occurs. Voltage at Maximum Power Point is shown in the v-i characteristics of solar cell by V_m.

Fill Factor of Solar Cell

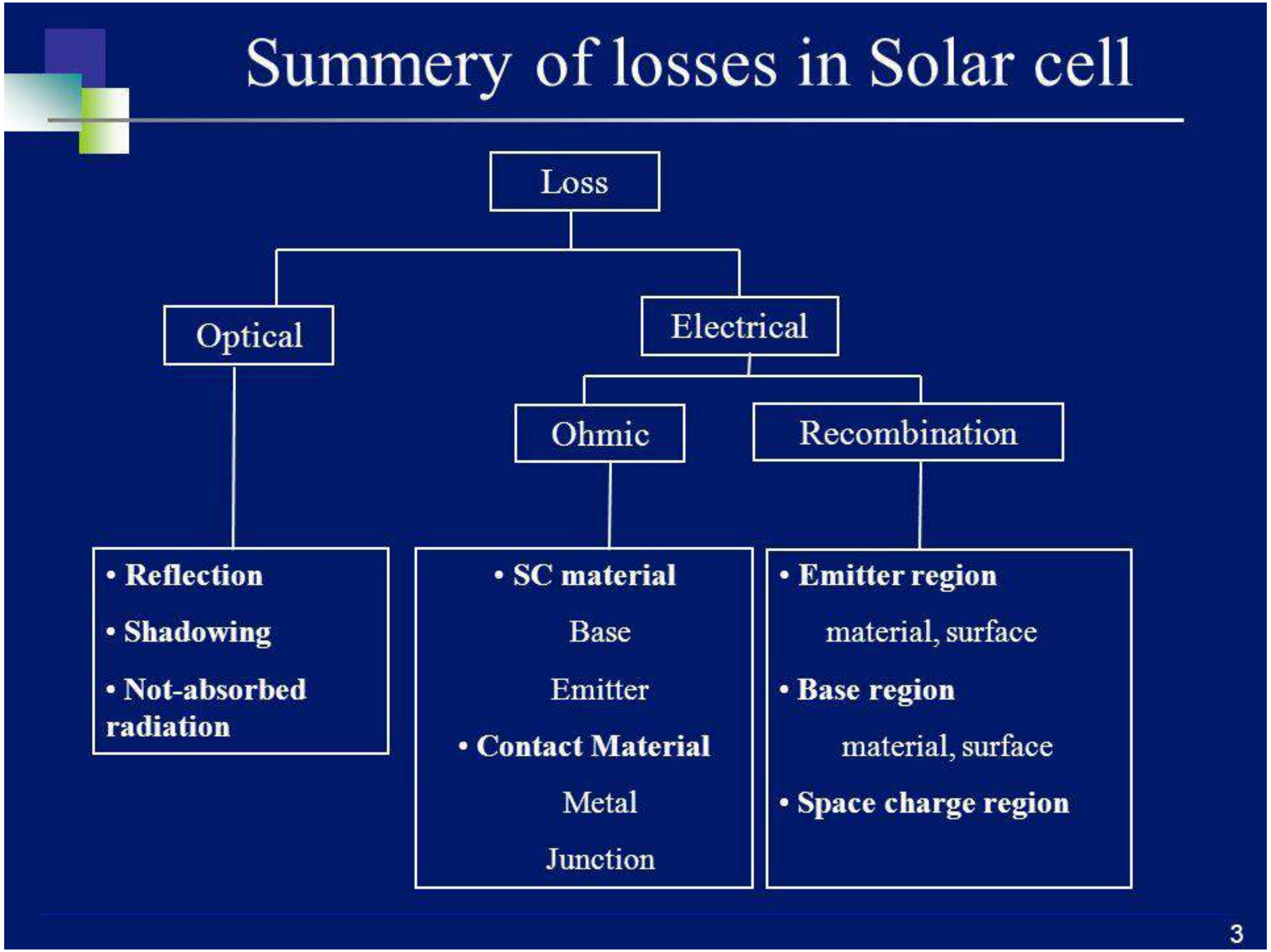
The ratio between product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage of the solar cell.

$$Fill\ Factor = \frac{P_m}{I_{sc} \times V_{oc}}$$

Efficiency of Solar Cell

It is defined as the ratio of maximum electrical power output to the radiation power input to the cell and it is expressed in percentage. It is considered that the radiation power on the earth is about 1000 watt/square metre hence if the exposed surface area of the cell is A then total radiation power on the cell will be 1000 A watts. Hence the efficiency of a solar cell may be expressed as

$$Efficiency(\eta) = \frac{P_m}{P_{in}} \approx \frac{P_m}{1000A}$$



1. Reflection Loss

- Typical solar cells operate at wavelengths from 400 to 1100 nm
- High refractive index (n~3.5) of silicon surface
- Reflectivity of a bare silicon wafer is ~**30%** of the incident light.

2. Spectral Loss

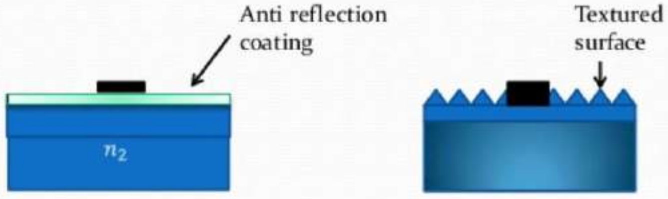
- Sunlight **below** $\mathbf{E_g}$ (i.e., λ>1100 nm) cannot be absorbed
- Accounting for **~19% solar energy loss**

3. Recombination Loss

- Instead of being collected by the junction and external electrical contacts, **charge carriers come back together resulting in light or heat**

Minimization of Optical Loss

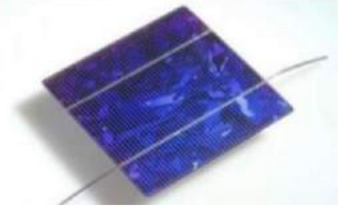
- Putting anti-reflection coating on the surface
- Texturing front surface
- Minimize the front metal contact coverage area
- Making solar cell thicker to increase absorption



Refractive index of ARC= $\sqrt{n_0 * n_2}$

Top metal coverage loss

- To collect current there is metal contact network on top
- Loss due to contact shadow is about 8%
- This loss is reduce by using transparent contact



Elementary material used in solar cell

Groups of periodic table				
2nd	3rd	4th	5th	6th
	B	C		
	Al	Si	P	S
Zn	Ga	Ge	As	Se
Cd	In		Sb	Te

Typical semiconductor used in PV cell		
Elemental	**Binary Compound**	**Ternary Compound**
• Germanium • Silicon	• Gallium arsenide • Indium arsenide • Cadmium sulfide • Cadmium telluride	• Aluminium gallium arsenide

Commercial Silicon solar cell

- Typical value

I_{sc} = 30-35 mA/cm^2
$V_{oc} = 0.55 - 0.57\ V$
Fill Factor (FF)= 75%

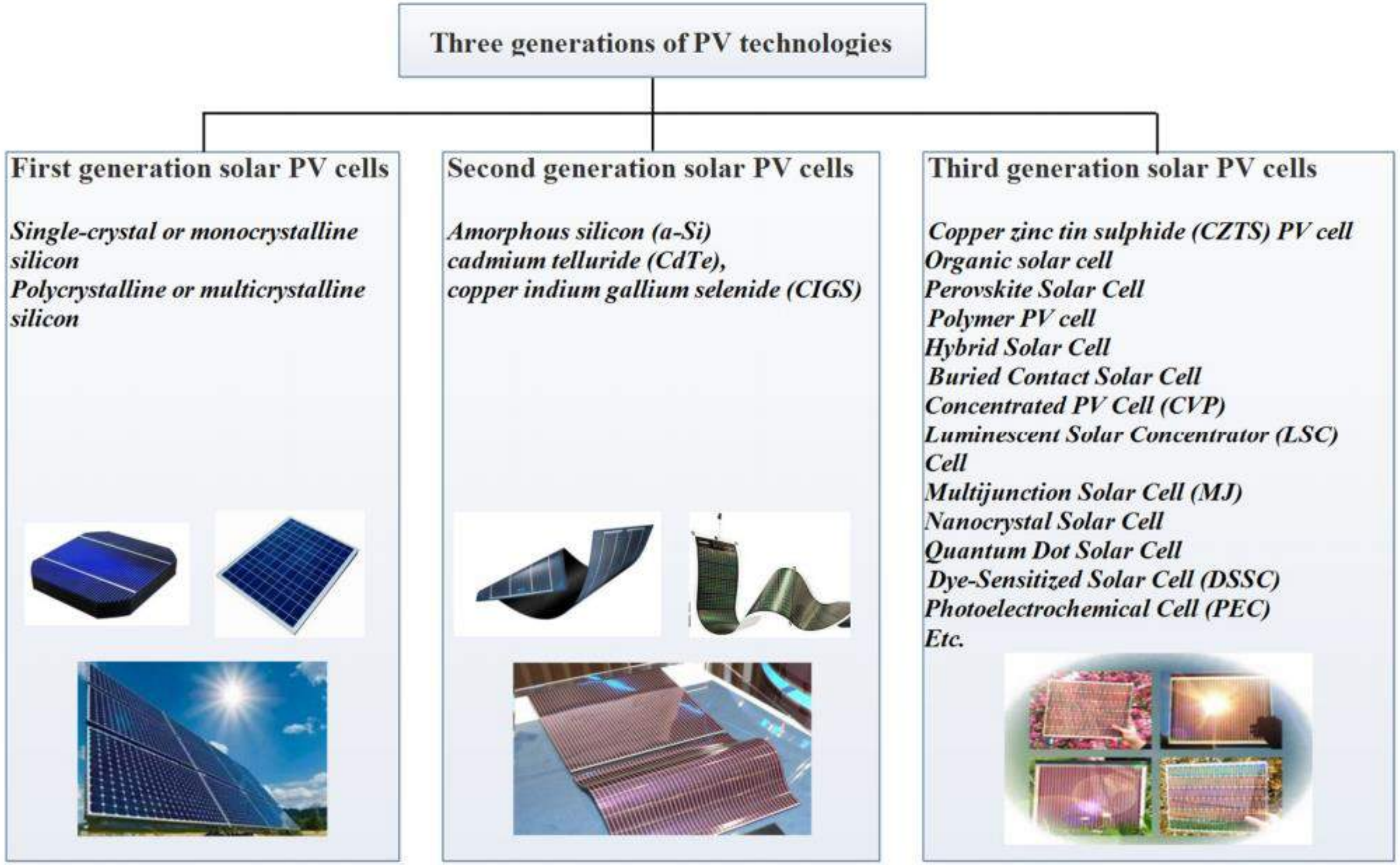
Typical area of cell= 12.5 * 12.5 cm^2

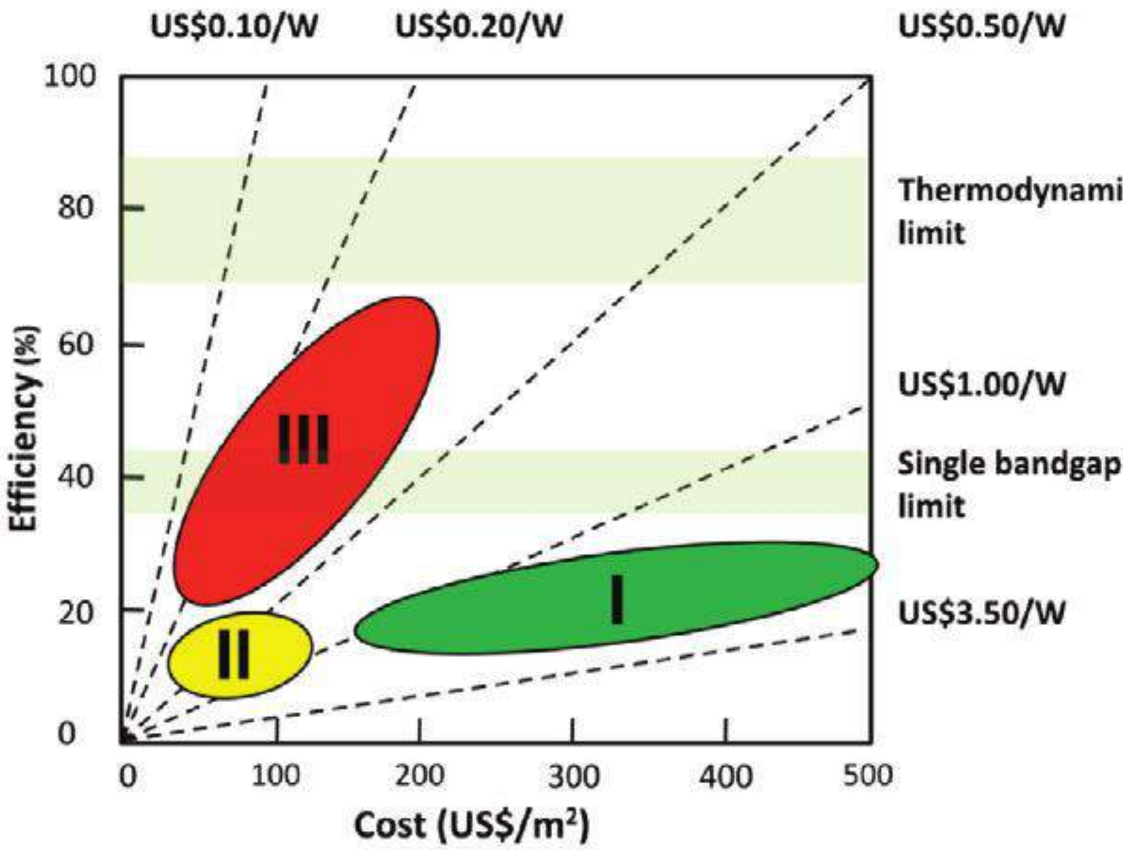
Approximate wattage of cell=area* I_{sc} * V_{oc} * FF
=12.5 * 12.5 *30 * 0.55* 0.75
=1.9 **W**

Photovoltaic generations

Solar cell divided into three main categories called generations:

- **1st generation:** Si wafer based technology
  High cost and efficient
- **2nd generation:** Amorphous silicon, CdTe etc.
  Low cost and less efficient
- **3rd generation:** Solar Paint, bio cells
  Low cost and very efficient





First Generation Solar Cells

- Single crystal silicon wafers
- Dominant in the commercial production of solar cells
- Consist of a large-area, single layer p-n junction
- Best crystalline Si solar cell efficiency: ~ 25%

- Advantages
  - Broad spectral absorption range
  - High carrier mobility

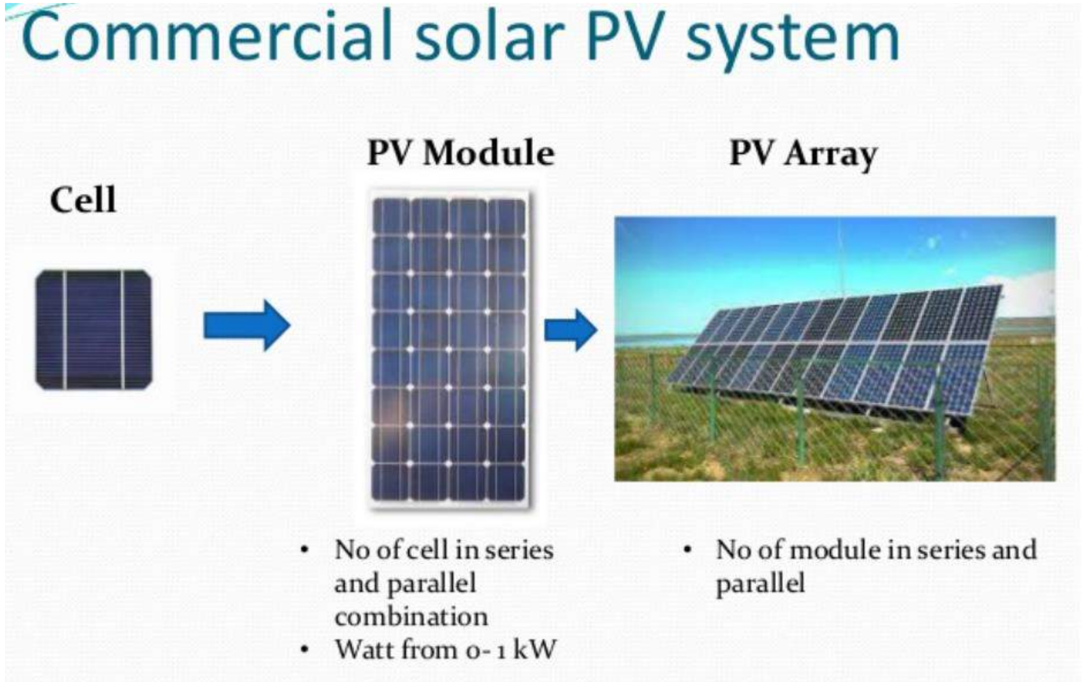
- Disadvantages
  - Most of photon energy is wasted as heat
  - Require expensive manufacturing technologies

Second Generation Solar Cells

- Thin-film Technologies
  - Amorphous silicon
  - Polycrystalline silicon
  - Cadmium Telluride (CdTe)
- Best large area Si-based solar cell efficiency: ~ 22%
- Advantages
  - Low material cost
  - Reduced mass
- Disadvantages
  - Toxic material (Cd),
  - Scarce material (Te)

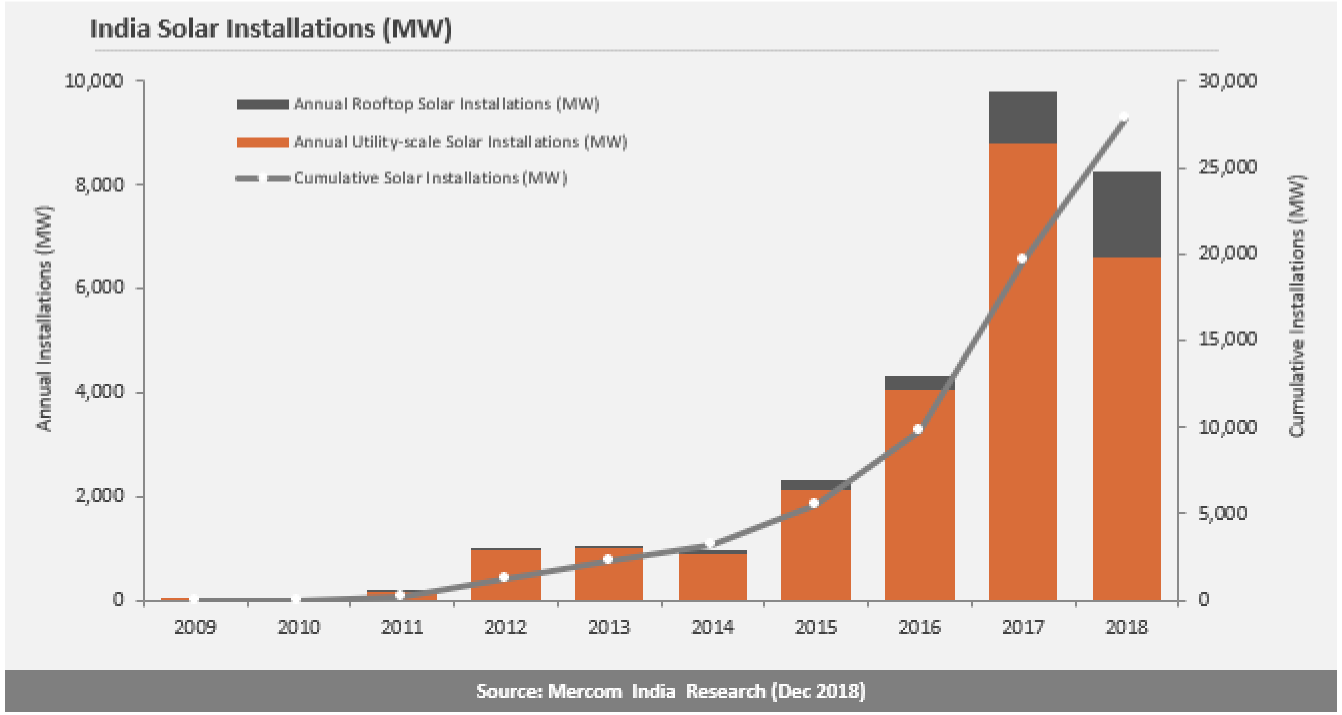
Third Generation Solar Cells

- Solar cells which use concepts that allow for a more efficient utilization of the sunlight than FG and SG solar cells
- The biggest challenge is reducing the cost/watt of delivered solar electricity
- Third generation solar cells pursue
  - More efficiency
  - More abundant materials
  - Non-toxic material
  - Durability



Parameter of PV module

- PV module is used to charge 12 V battery
- In a module there is 36 cell in series
- Open circuit voltage of silicon cell is 0.55 V at 25^0C
- 36 cell in series have a voltage of 20 V
- Due to rough weather temperature is around 40°C
- Approximate voltage at MPPT is 18 V
- There is drop in voltage of 2.3 mV/°C
- In operating condition output voltage in the range of 14 V- 16 V



Top five solar power plants in India
.NS Energy profiles the five largest solar power plants currently operating in India.
1. Bhadla Solar Park – 2,250MW
2. Shakti Sthala solar power project – 2,050MW
3. Ultra Mega Solar Park – 1,000MW
4.Rewa Solar Power Project – 750MW
5. Kamuthi solar power plant – 648MW

Unit-IV Conventional & non-conventional energy source: Biological energy sources and fossil fuels, Fluid dynamics and power in the wind, available resources, fluids, viscosity, types of fluid flow, lift, Wind turbine dynamics and design, wind farms, Geothermal power and ocean thermal energy conversion, Tidal/wave/hydro power

- Energy is an important input for development.
- It aims to the natural resources, energy resources are also renewable as well as non renewable.
- **Renewable energy resources :** Energy sources that are easily replaced after being consumed.
- **Non-renewable energy resources :** Energy sources that are not replaced or replenished after being used. (May take several years to replace).

3

Sources of energy

Conventional sources

Commercial

- Coal
- Oil & natural gas
- Thermal power

Non-commercial

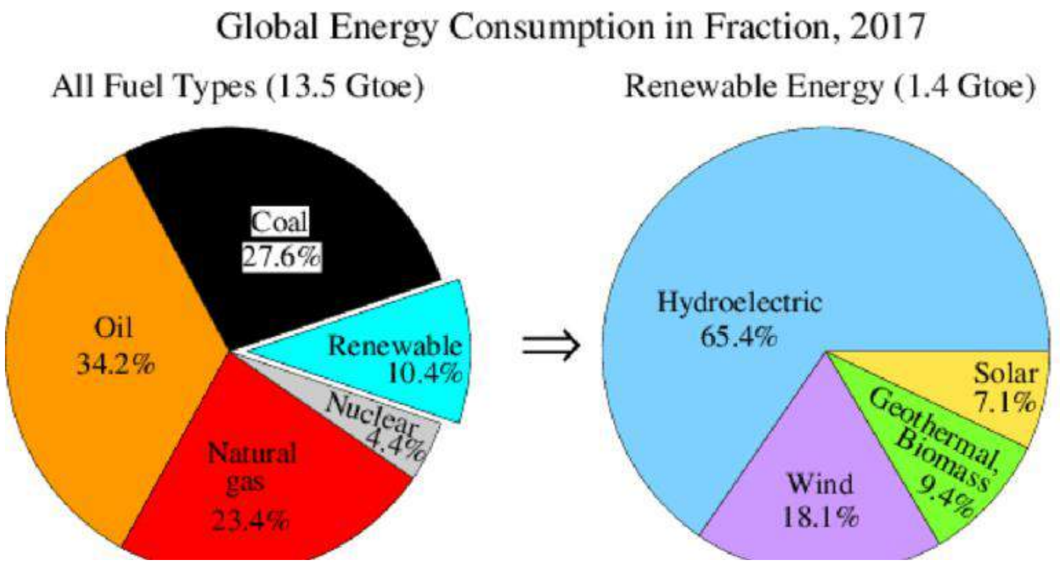
- Firewood (Fuel wood)
- Hydro power
- Nuclear power

Non-conventional sources

- Solar energy
- Wind energy
- Tidal energy
- Geothermal energy
- Biomass - based energy

CONVENTIONAL ENERGY SOURCES

- Energy that has been used from ancient times (natural resources) is known as conventional energy.
- A conventional resources are the ones that are commonly used. (like pen or a pencil).
- These are available in limited amount and develop over a longer period. As a result of unlimited use, they are likely to be exhausted one day.



- Conventional energy sources have two type of source like…
  1) Commercial energy sources
  2) Non-commercial energy sources

♣ **Commercial energy sources:** The sources of energy that are usually available in costly to the users are reffered to as Commercial energy sources.

♣ **Non-commercial energy sources :** The sources of energy that are usually availably free of cost to the users are reffered to as non-commercial energy sources.

Conventional Source of Energy	Non-Conventional Source of Energy
These are generally exhaustible and polluting.	These are usually inexhaustible and non-polluting.
They are non-renewable	They are renewable.
Their generation and use involve huge expenditure.	Their generation and use involve less expenditure.
Some Examples are: Firewood, Coal and Petroleum	Some Examples are: Solar, Wind, Tidal and Atomic Energy

What is Bioenergy?

- **Bioenergy** is energy contained in living or recently living biological organisms
- Organic material containing bioenergy is known as biomass
- Biofuels are renewable transport fuels including:
  - Bioethanol
  - Biodiesel
  - Biogas
  - Biobutanol

Biomass

- Biomass is the largest renewable energy source in use today

There are two main forms of biomass:

- Raw biomass consists of forestry products, grasses, crops, animal manure, and aquatic products, such as kelp and seaweed.
- Secondary biomass is material that comes from raw biomass, but has undergone significant changes. These would include items such as paper, cardboard, cotton, natural rubber products and used cooking oils.

Liquid Biofuels

- **Bioethanol**
  - Fuel ethanol is a form of alcohol, fermented and distilled from a wide range of plant life such as wheat, corn or woody material
- **Biodiesel**
  - produced by chemically upgrading oils obtained from the pressing of oil plants

Electricity generation from biomass

- **Electricity from sugarcane bagasse in Brazil**

Gas biofuels

- **Biogas**
- **Synthetic natural gas (SNG)**

Solid biofuels

- Wood
- Charcoal
- biomass pellets

Technology of Energy Conversion

- Conversion of biomass to energy requires some extraction if the fuel stream is contaminated with polluting substances
- Typical processes are the following:
  - Direct combustion
  - Anaerobic Digestion
  - Fermentation
  - Pyrolysis
  - Other less-used techniques

Enzymes can change cellulose into sugars, which can then be fermented into alcohol

Cane sugar, $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

Fermentation of corn or other biomass will produce ethanol.

- "INDIA" has enough land and agricultural networks to sustainably replace half of the nation's gasoline use or all of its nuclear energy.
- Millions of tons of unused agricultural waste, manure, and sawdust has the potential to generate energy.

Ethanol: a form of Biofuel

- Also known as ethyl alcohol or grain alcohol.
- Ethanol is made from the starch in certain grains, such as wheat, corn etc.
- Ethanol production usually begins with the grinding up of biomass such as wheat or corn.
- Once ground up, the starch or cellulose is converted into sugar.
- The sugar is then fed into microbes that use it for food, producing ethanol in the process.
- **Ethanol Uses** :--
- Most gasoline mixtures contain about 10 percent ethanol and 90 percent gasoline.
- All vehicles are equipped to handle this mixture.
- Such a mixture reduces greenhouse gases by up to 4 percent.

E85 Fuel

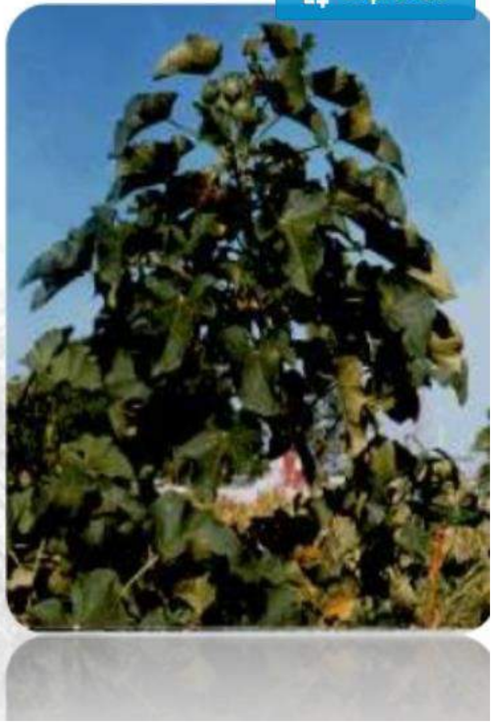
- Fuel containing 85 percent gasoline and 15 percent ethanol can be used in flexible fuel vehicles.
- The use of E85 fuel reduces the emission of greenhouse gases by up to 37 percent.
- E85 is considered an alternative fuel under the Energy Policy Act of 1992.
- Vehicles that run on E85 are called Flexible Fuel Vehicles (FFV).
- Many vehicle manufacturers offer FFVs. Ford, Mercedes, GM and Chrysler all offer FFVs.
- Reduces Petroleum Consumption- Using E85 reduces dependence on foreign oil markets.

Biodiesel

- Made by transforming animal fat or vegetable oil with alcohol .
- Fuel is made from rapeseed (canola) oil or soybean oil or recycled restaurant grease.
- It is directly used in place ofdiesel either as neat fuel or as an oxygenate additive

Jatropha Tree

- Biodiesel from Jatropha.
- Seeds of the Jatropha nut is crushed and oil is extracted
- The oil is processed and refined to form bio-diesel.



Biodiesel benefits:-

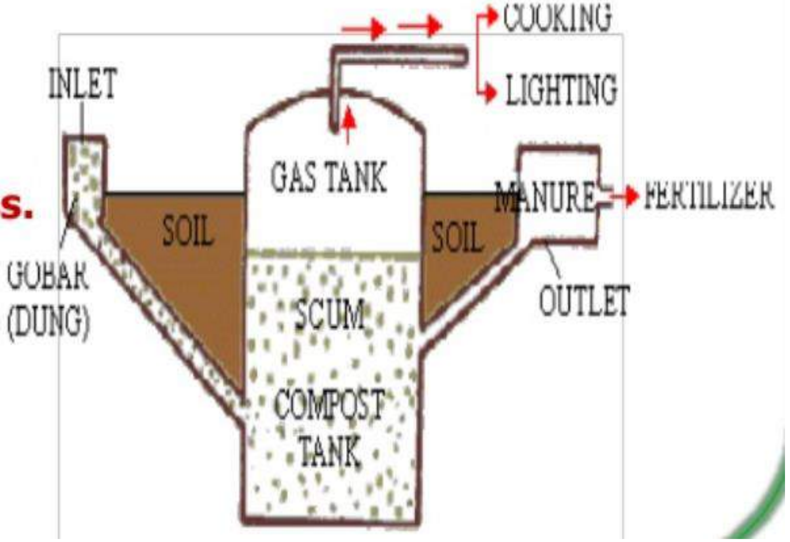
The roll of biodiesel is not to replace the petroleum diesel, but to help create a balanced energy policy. Biodiesel is one of several alternative fuels designed to extend the usefulness of petroleum and the longevity.

- ❑ Easy to use:-
  No vehicle modifications or special fuelling equipment is needed.
- ❑ Power, Performance and Economy:-
  Proven performance and economy make biodiesel a renewable winner.
- ❑ Emissions & Greenhouse Gas Reduction:-
  With lower exhaust emissions biodiesel is helping to reduce pollution and improve health. Lower CO2 emission help reduce the impact of Global warning.
- ❑ Energy balance & security:-
  Biodiesel helps reduce the need for foreign oil.
- ❑ Economical Development:-
  Biodiesel helps communities by keeping energy RUPEES at home.

BIO-GAS

- **Methane** is the primary biogas.
- Landfill gas is primarily methane but contains CO_2 and other gases from plastics, etc.
- **Gobar Gas :-**

Gobar gas production is an anaerobic process.



- **Methane, CH_4, is a likely future hydrogen gas source**
- **The four H atoms allow more hydrogen to be produced per molecule of methane**
- **Cracking or pyrolysis changes the molecules to yield hydrogen and CO, which is also combustible**
- **The combination of methane and CO_x is known as biogas and can be made from acetic acid, produced from glucose by microorganisms.**

What are fossil fuels?

Fossil fuels are fuels produced by natural resources like anaerobic decomposition of buried dead organisms.

How is coal formed?

Coal is made up of carbon, hydrogen, oxygen, nitrogen and sulphur. The three main types of coal are anthracite, bituminous and lignite. Anthracite coal is the hardest and has more carbon. Lignite is the softest and is low in carbon but high in hydrogen and oxygen content. Bituminous is in between anthracite and lignite.

What are different types of fossil Fuels?

Coal, oil and natural gas.

http://web.me.com/davgen1/ILS_12-22/Fossil_Fuels.html

- **Lignite** : A brownish-black coal of low quality with inherent moisture and volatile matter. Energy content is lower 4000 Btu/lb.
- **Subbituminous** : Black lignite is dull black and generally content is 8,300 Btu/lb.
- **Bituminous** : Most common coal is dense & black. It's moisture content usually is less than 20 %. Energy content about 10,500 Btu/lb.
- **Anthracite** : A hard, black, lustrous coal, often reffered to as hard coal. Energy content of about 14,000 Btu/lb.

ii) Oil & Natural gas :

- Sedimentary rocks containing plants, animals remains about 10 to 20 crore year old are the source of mineral oil.
- Mineral oil is very unevenly distributed over space like any other mineral.
- There are six regions in the world which are rich in mineral oil. USA, Mexico, former USSR and West Asian region are the major oil reproducing countries.

- Natural gas is really a mixture of gases that formed from the fossils remains of ancient plants and animals buried deep in the earth.
  - In india – gas is a natural gift.
- The main ingredient in natural gas is methane.
- Natural gas can be used both as energy source and also an industrial raw material in petrochemical industry. The gas is also used for fertiliser plants.

- Through pipe line, the gas from Bombay and Gujarat gas fields is now taken to M.P., Rajasthan and U.P.
- Hazira-Bijaipur-Jagdishpur (HBJ) gas pipe line is 1,730 km long carries 18 million cubic meters of gas everyday.
- It feeds six fertiliser and three power plants. There are already 12 refineries in India.
- The liquefied petroleum gas (LPG), also called the cooking gas is now a very common domestic fuel.

What is Wind?

Wind is the stabiliztion movement of air between areas of high and low atmospheric pressure, created by the uneven heating of the Earth's surfaces: land, water, and air.

The greater the pressure difference between these areas, the harder the wind blows. Wind also exists as the circulation of air around a high or low pressure area.

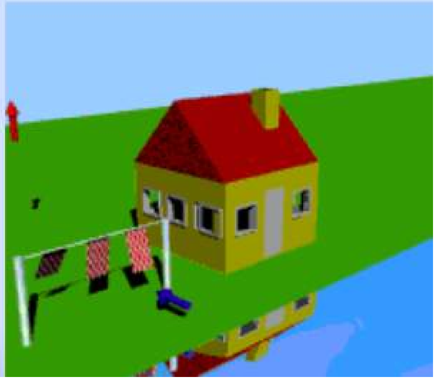
What is Wind Energy?

- Wind energy is the converting of wind power to electrical power through the use of windmills or turbines.
- electricity produced is sent to transformers where voltage is increased and sent to the power grid via transmission lines.

WIND ENERGY – WHERE IT COMES FROM?

- All renewable energy (except tidal and geothermal power), ultimately comes from the sun
- The earth receives 1.74 x 10^{17} watts of power (per hour) from the sun
- About one or 2 percent of this energy is converted to wind energy (which is about 50-100 times more than the energy converted to biomass by all plants on earth
- Differential heating of the earth's surface and atmosphere induces vertical and horizontal air currents that are affected by the earth's rotation and contours of the land → WIND.

  ~ e.g.: Land Sea Breeze Cycle



Historical overview

- Wind has been used by people for over 3000 years for grinding grain and pumping water
- Windmills were an important part of life for many communities beginning around 1200 BC.
- Wind was first used for electricity generation in the late 19th century.

Grandpa's Knob

- Smith Putnam Machine
- 1941
- Rutland, Vermont
- 1.25 MW
- 53 meters (largest turbine for 40 years)
- Structural steel
- Lost blade in 1945

WINDMILL DESIGN

- A Windmill captures wind energy and then uses a generator to convert it to electrical energy.
- The design of a windmill is an integral part of how efficient it will be.
- When designing a windmill, one must decide on the size of the turbine, and the size of the generator.

Wind Turbines: Number of Blades

❑ Most common design is the three-bladed turbine. The most important reason is the **stability** of the turbine. A rotor with an odd number of rotor blades (and at least three blades) can be considered.

❑ A rotor with an even number of blades will give stability problems for a machine with a stiff structure. The reason is that at the very moment when the uppermost blade bends backwards, because it gets the maximum power from the wind, the lowermost blade passes into the wind shade in front of the tower.

MATHEMATICAL MODEL

The following table shows the definition of various variables used in this model:

E	=	Kinetic Energy (J)	ρ	=	Density (kg/m^3)
m	=	Mass (kg)	A	=	Swept Area (m^2)
v	=	Wind Speed (m/s)	C_p	=	Power Coefficient
P	=	Power (W)	r	=	Radius (m)
$\frac{dm}{dt}$	=	Mass flow rate (kg/s)	x	=	distance (m)
$\frac{dE}{dt}$	=	Energy Flow Rate (J/s)	t	=	time (s)

Under constant acceleration, the kinetic energy of an object having mass m and velocity v is equal to the work done W in displacing that object from rest to a distance s under a force F, i.e.:

$$E = W = Fs$$

According to Newton's Law, we have:

$$F = ma$$

Hence,

$$E = mas \quad \ldots (1)$$

Using the third equation of motion:

$$v^2 = u^2 + 2as$$

we get:

$$a = \frac{(v^2 - u^2)}{2s}$$

Since the initial velocity of the object is zero, i.e. $u = 0$, we get:

$$a = \frac{v^2}{2s}$$

Substituting it in equation (1), we get that the kinetic energy of a mass in motions is:

$$E = \frac{1}{2} m v^2 \; \dots (2)$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \frac{1}{2} v^2 \frac{dm}{dt} \; \dots (3)$$

As mass flow rate is given by:

$$\frac{dm}{dt} = \rho A \frac{dx}{dt}$$

and the rate of change of distance is given by:

$$\frac{dx}{dt} = v$$

we get:

$$\frac{dm}{dt} = \rho A v$$

Hence, from equation (3), the power can be defined as:

$$P = \frac{1}{2} \rho A v^3 \; \dots (4)$$

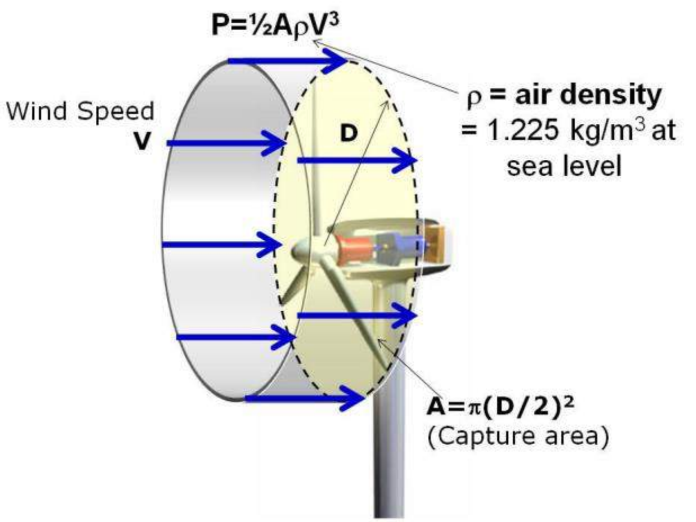
A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the **Betz Limit** or **Betz' Law.** The theoretical maximum **power efficiency** of *any* design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the "power coefficient" and is defined as:

$$C_{p_{max}} = 0.59$$

Also, wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular - the real world limit is well below the *Betz Limit* with values of 0.35-0.45 common even in the best designed wind turbines. By the time we take into account the other factors in a complete wind turbine system - e.g. the gearbox, bearings, generator and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity. Hence, the power coefficient needs to be factored in equation (4) and the extractable power from the wind is given by:

$$P_{avail} = \frac{1}{2}\rho A v^3 C_p \quad \ldots(5)$$

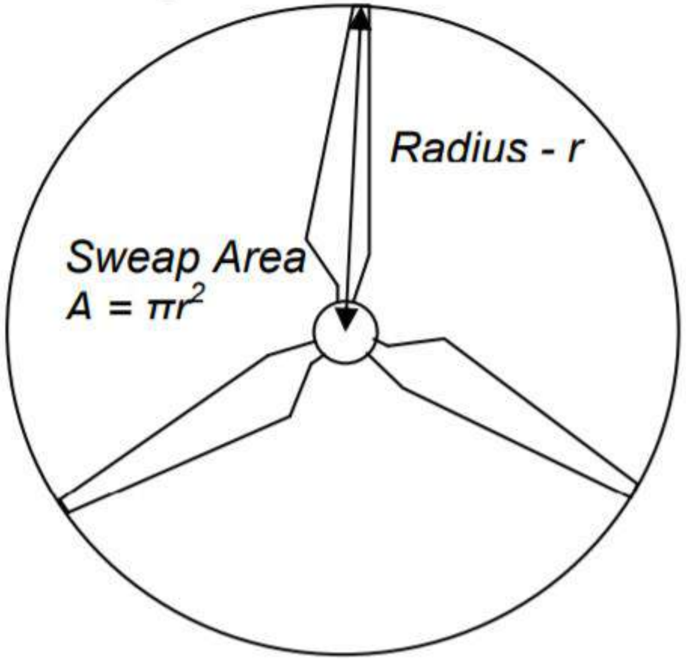
Figure 1: Power Available from the Wind



The swept area of the turbine can be calculated from the length of the turbine blades using the equation for the area of a circle:

$$A = \pi r^2 \quad \ldots(6)$$

where the radius is equal to the blade length as shown in the figure below:



CALCULATIONS WITH GIVEN DATA

We are given the following data:

Blade length, l = 52 m

Wind speed, v = 12 m/sec

Air density, ρ = 1.23 kg/m^3

Power Coefficient, C_p = 0.4

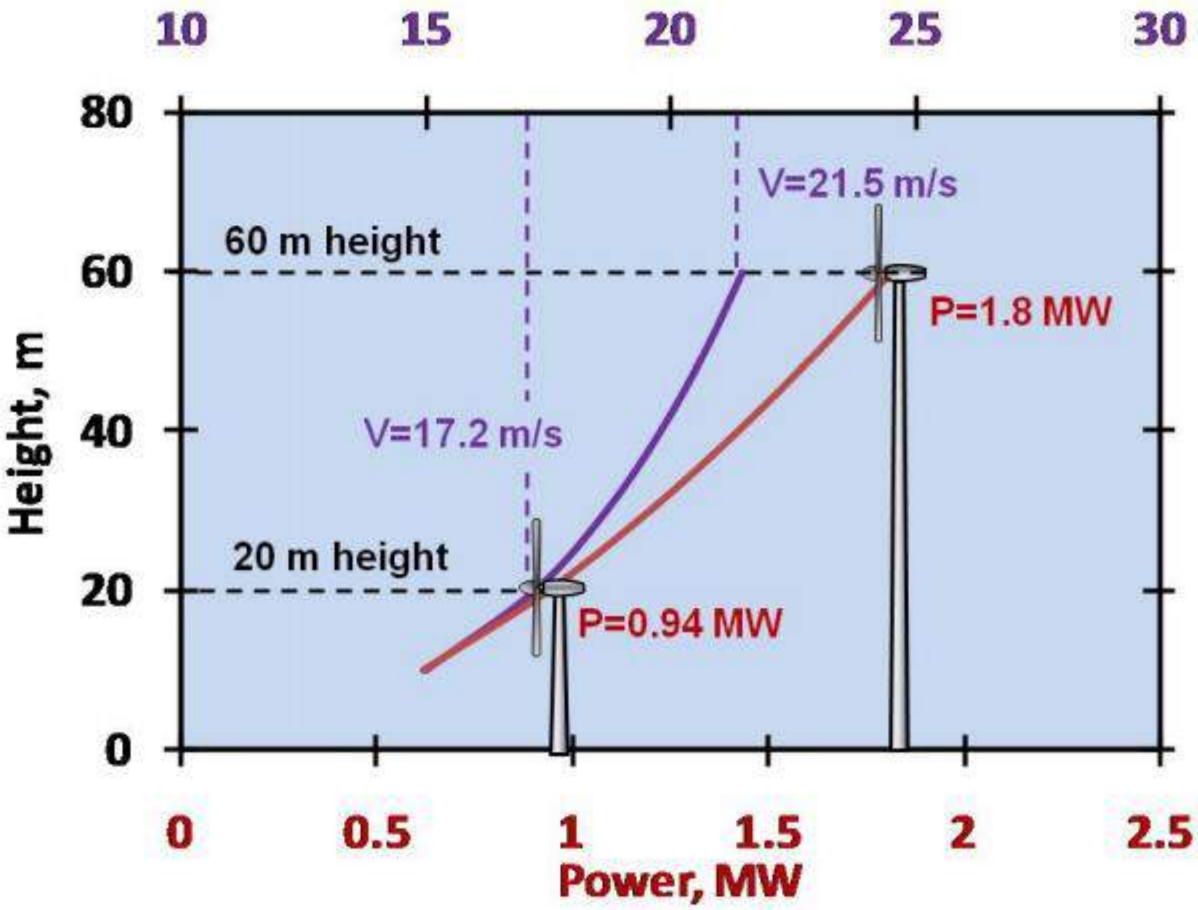
Inserting the value for blade length as the radius of the swept area into equation (8) we have:

$$l = r = 52m$$

$$A = \pi r^2$$
$$= \pi \times 52^2$$
$$= 8495m^2$$

We can then calculate the power converted from the wind into rotational energy in the turbine using equation (7):

$$P_{avail} = \frac{1}{2}\rho A v^3 C_p$$
$$= \frac{1}{2} \times 1.23 \times 8495 \times 12^3 \times 0.4$$
$$= 3.6MW$$



The Tip Speed Ratio (TSR) is an extremely important factor in wind turbine design. TSR refers to the ratio between the wind speed and the speed of the tips of the wind turbine blades.

$$\text{TSR } (\lambda) = \frac{\text{Tip Speed of Blade}}{\text{Wind Speed}}$$

- If the rotor of the wind turbine spins tooslowly, most of the wind will pass straight through the gap between the blades, therefore giving it no power!
- But if the rotor spins too fast, the blades will blur and act like a solid wall to the wind. Also, rotor blades create turbulence as they spin through the air. If the next blade arrives too quickly, it will hit that turbulent air.
- Sometimes it is actually better to slow down your blades!
- Wind turbines must be designed with optimal tip speed ratios to get the maximum amount of power from the wind.

How To Find The Tip Speed:

1. Measure the rotor radius (length of one blade)
2. Speed = distance divided by time. The distance travelled is the circumference ($2\Pi r$).
3. Speed:
   $$V = \frac{2\Pi r}{T \text{ (time)}}$$

The blades travel one circumference ($2\Pi r$) in a rotation time of T (seconds).

Now you see why we need to know how long it takes to make one full revolution!

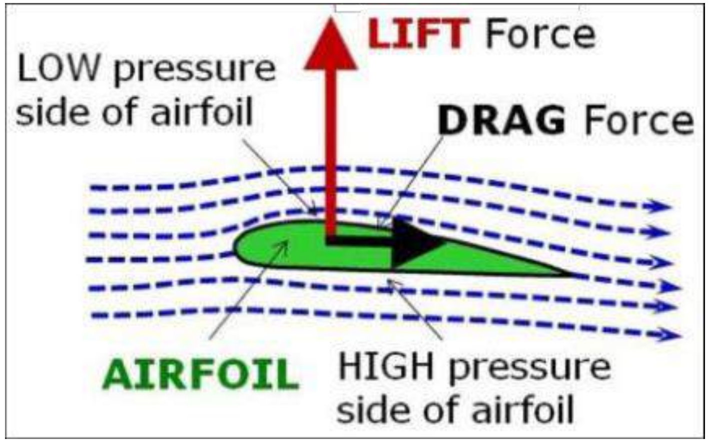
Capacity Factor (CF):

- The fraction of the year the turbine generator is operating at rated (peak) power

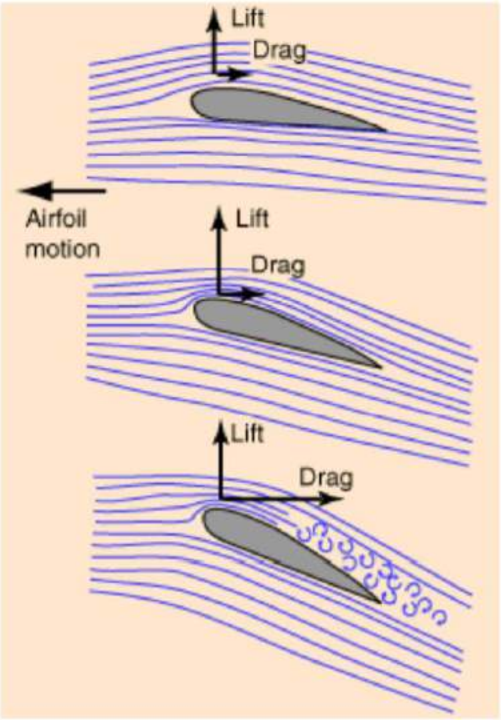
  Capacity Factor = Average Output / Peak Output ≈ 30%

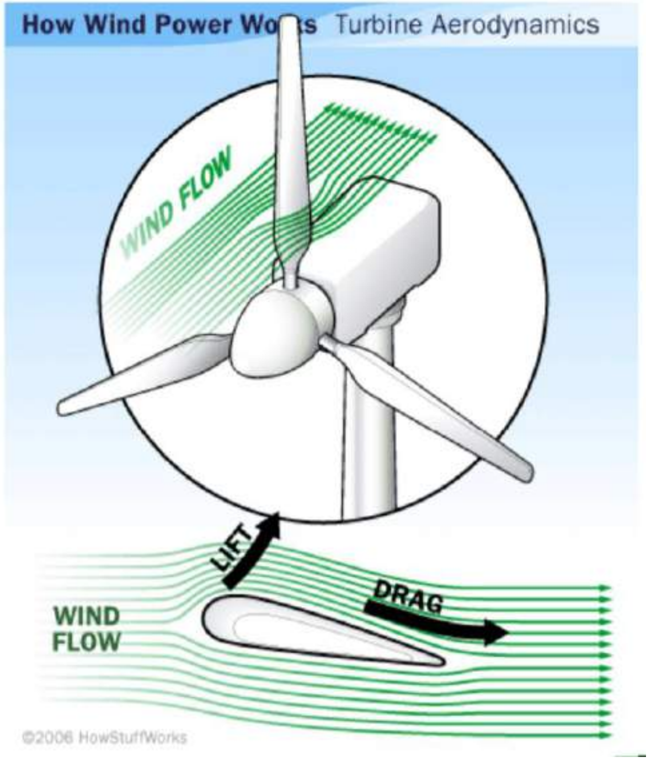
- CF is based on both the characteristics of the turbine and the site characteristics (typically 0.3 or above for a good site)

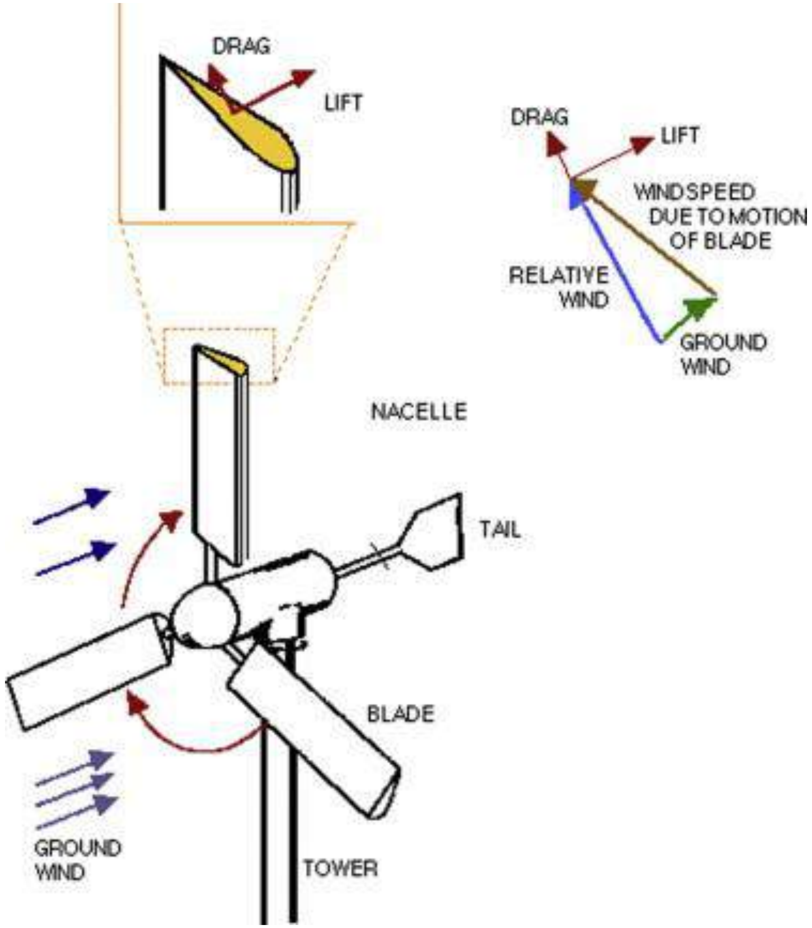
Airflow over any surface creates two types of aerodynamic forces— drag forces, in the direction of the airflow, and lift forces, perpendicular to the airflow. Either or both of these can be used to generate the forces needed to rotate the blades of a wind turbine.



Lift and Drag Forces





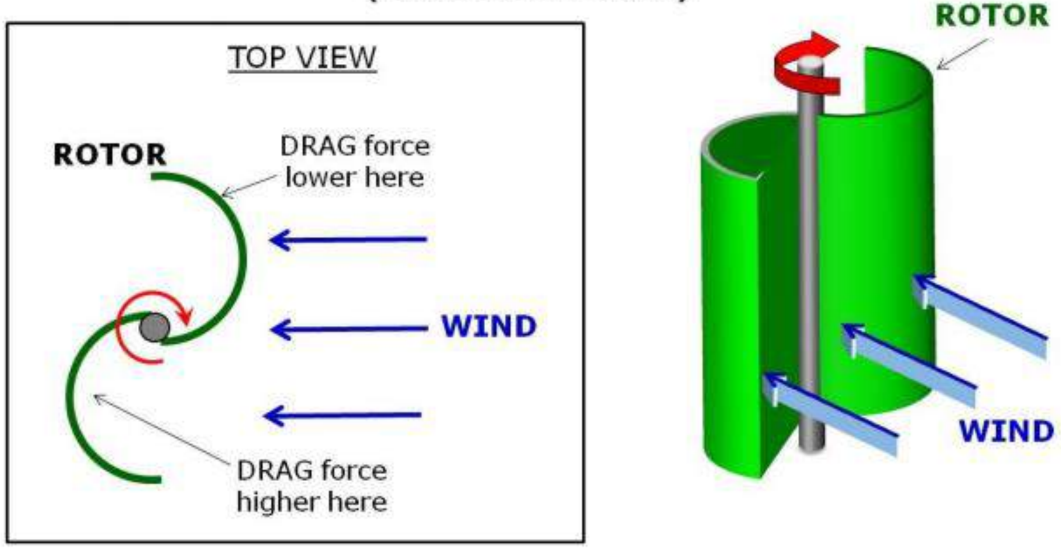


Drag-based wind turbine: In drag-based wind turbines, the force of the wind pushes against a surface, like an open sail. In fact, the earliest wind turbines, dating back to ancient Persia, used this approach. The Savonius rotor is a simple drag-based windmill. It works because the drag of the open, or concave, face of the cylinder is greater than the drag on the closed or convex section.

Lift-based Wind Turbines

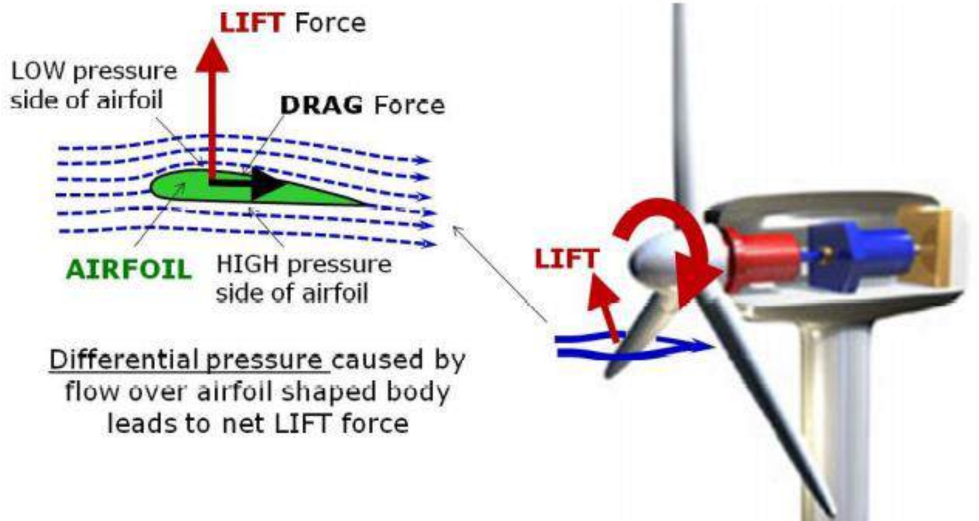
More energy can be extracted from wind using lift rather than drag, but this requires specially shaped airfoil surfaces, like those used on airplane wings (Figure2). The airfoil shape is designed to create a differential pressure between the upper and lower surfaces, leading to a net force in the direction perpendicular to the wind direction. Rotors of this type must be carefully oriented (the orientation is referred to as the rotor pitch), to maintain their ability to harness the power of the wind as wind speed changes.

Figure 1: Drag-based Wind Turbine Concept
(Savonius Rotor)



Rotation created by difference in DRAG forces on the convex and concave surfaces of the rotot

Figure 2: Lift-based Wind Turbine Concept



Wind Turbine Types

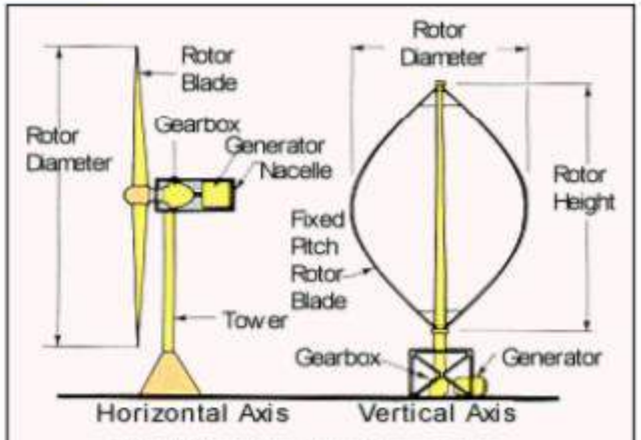
Horizontal-Axis – HAWT

- Single to many blades - 2, 3 most efficient
- Upwind, downwind facing
- Solidity / Aspect Ratio – speed and torque
- Shrouded / Ducted – Diffuser Augmented Wind Turbine (DAWT)

Vertical-Axis – VAWT

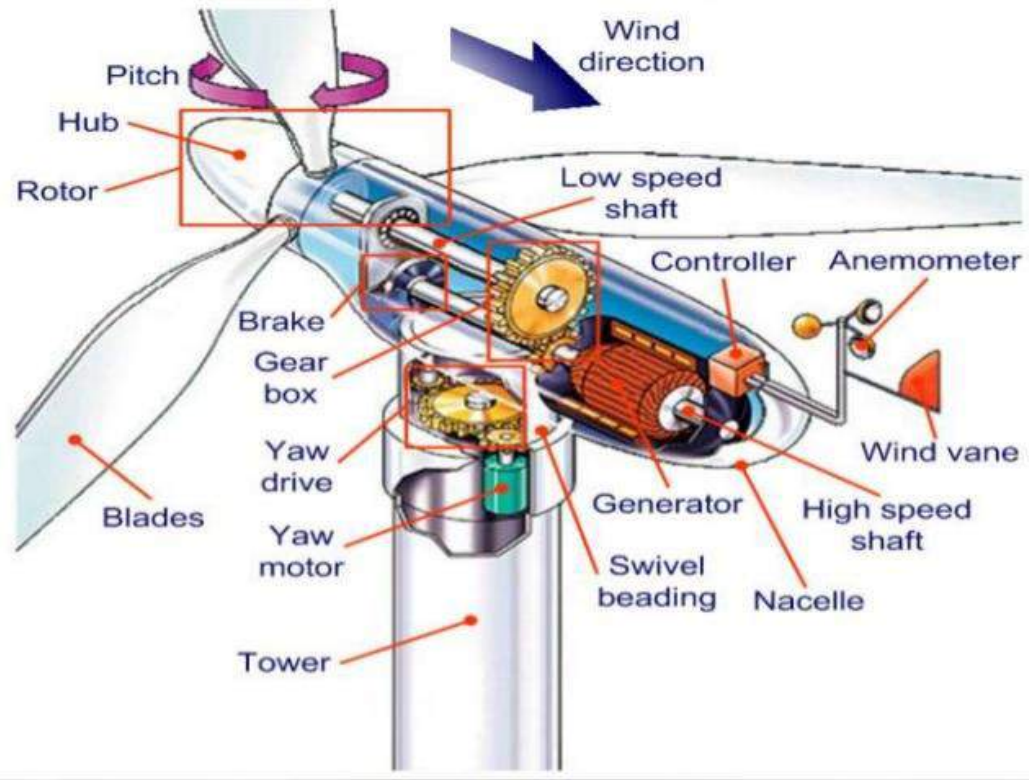
- Darrieus / Egg-Beater (lift force driven)
- Savonius (drag force driven)

Wind Turbine Subsystems



Wind Turbine Configurations

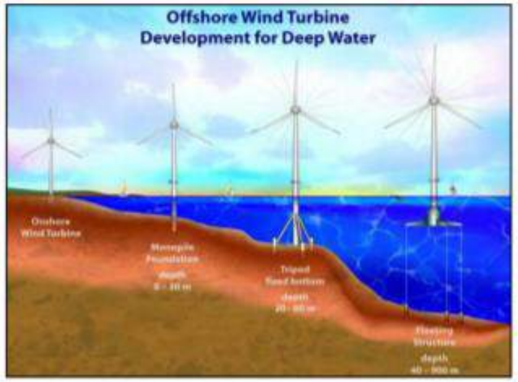
- Foundation
- Tower
- Nacelle
- Hub & Rotor
- Drivetrain
  - Gearbox
  - Generator
- Electronics & Controls
  - Yaw
  - Pitch
  - Braking
  - Power Electronics
  - Cooling
  - Diagnostics

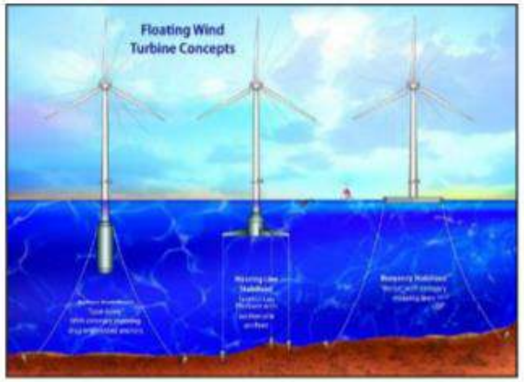


Foundations and Tower

- Evolution from truss (early 1970s) to monopole towers

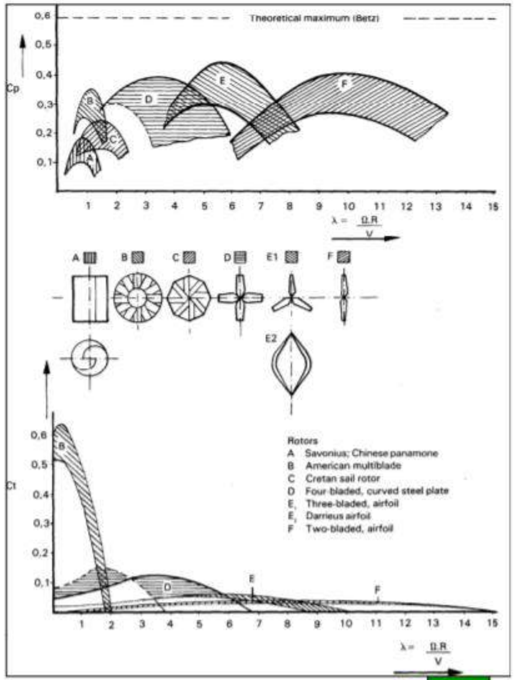
- Many different configurations proposed for offshore





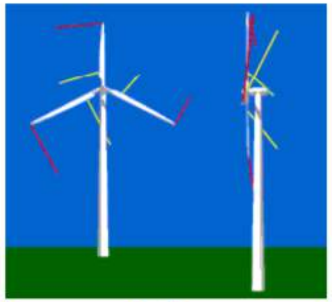
Nacelle, Rotor & Hub

- Main Rotor Design Method (ideal case):
  1. Determine basic configuration: orientation and blade number
  2. take site wind speed and desired power output
  3. Calculate rotor diameter (accounting for efficiency losses)
  4. Select tip-speed ratio (higher → more complex airfoils, noise) and blade number (higher efficiency with more blades)
  5. Design blade including angle of attack, lift and drag characteristics
  6. Combine with theory or empirical methods to determine optimum blade shape



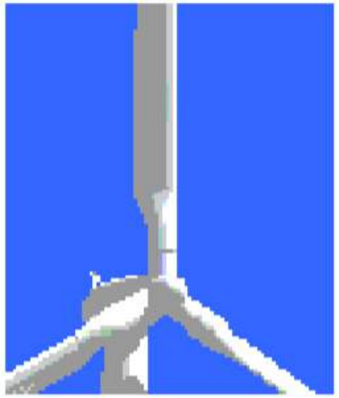
Wind Turbine Blades

- Blade tip speed:



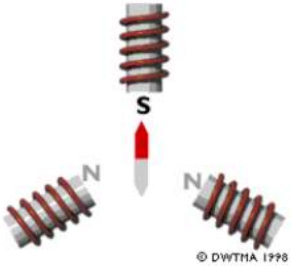
- 2-Blade Systems and Teetered Hubs:

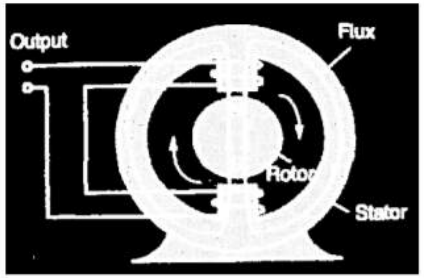
- Pitch control:

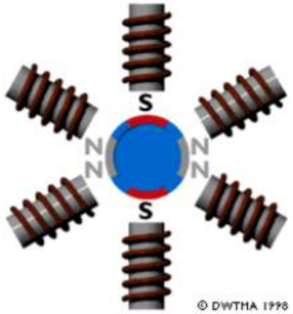


Electrical Generator

- Generator:
  - Rotating magnetic field induces current







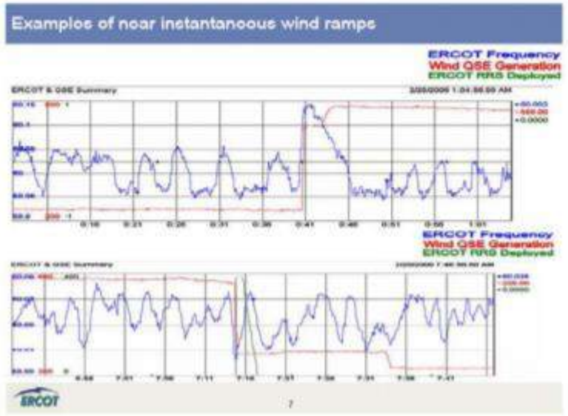
- Synchronous / Permanent Magnet Generator
  - Potential use without gearbox
  - Historically higher cost (use of rare-earth metals)
- Asynchronous / Induction Generator
  - Slip (operation above/below synchronous speed) possible
  - Reduces gearbox wear

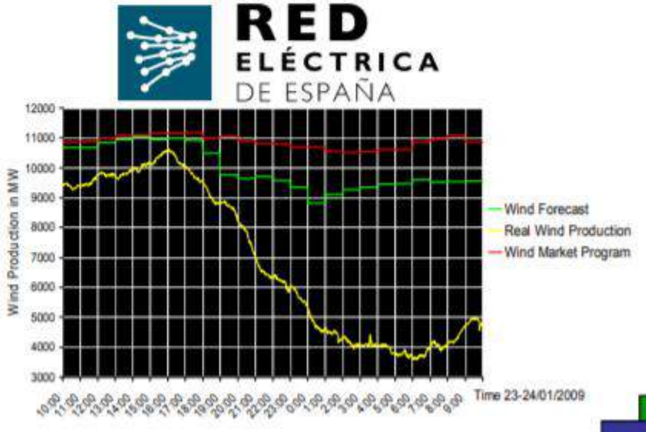
Control Systems & Electronics

- Control methods
  - Drivetrain Speed
    - Fixed (direct grid connection) and Variable (power electronics for indirect grid connection)
  - Blade Regulation
    - Stall – blade position fixed, angle of attack increases with wind speed until stall occurs behind blade
    - Pitch – blade position changes with wind speed to actively control low-speed shaft for a more clean power curve

Wind Grid Integration

- Short-term fluctuations and forecast error
- Potential solutions undergoing research:
  - Grid Integration: Transmission Infrastructure, Demand-Side Management and Advanced Controls
  - Storage: flywheels, compressed air, batteries, pumped-hydro, hydrogen, vehicle-2-grid (V2G)





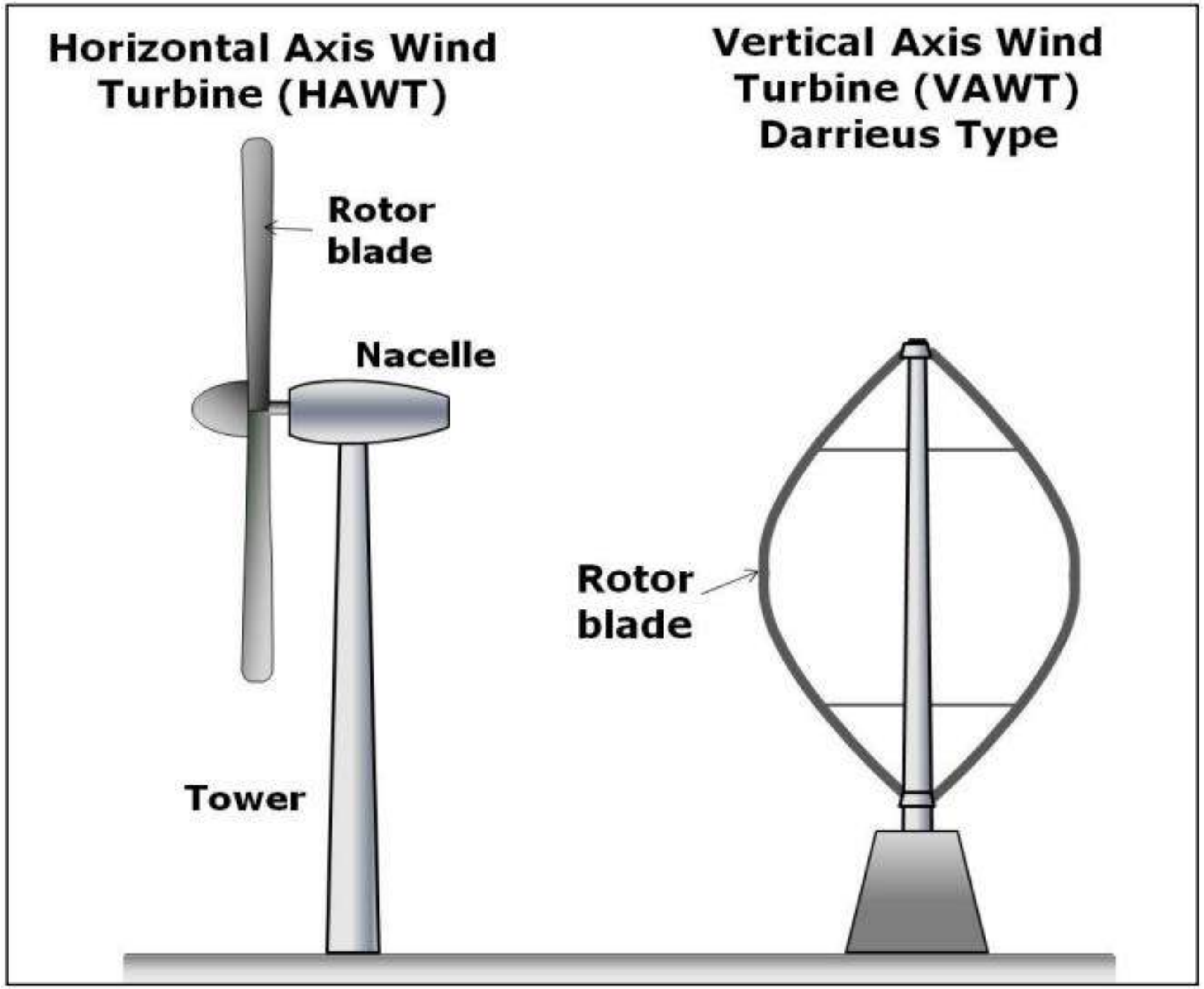
Future Technology Development

- Improving Performance:
  - Capacity: higher heights, larger blades, superconducting magnets
  - Capacity Factor: higher heights, advanced control methods (individual pitch, smart-blades), site-specific designs
- Reducing Costs:
  - Weight reduction: 2-blade designs, advanced materials, direct drive systems
  - Offshore wind: foundations, construction and maintenance

American Superconductor®

VERGNET GROUPE

Northern POWER SYSTEMS



HAWTS

Modern HAWTs usually feature rotors that resemble aircraft propellers, which operate on similar aerodynamic principles, i.e., the air flow over the airfoil shaped blades creates a lifting force that turns the rotor. The nacelle of a HAWT houses a gearbox and generator. HAWTS can be placed on towers to take advantage of higher winds farther from the ground.

The capture area of a HAWT, the area over which the sweeping blades can "capture" the wind, is given by

$$\mathbf{A=\pi(D/2)^2}$$

where **D** is the rotor diameter. However, this capture area must face directly into the wind, to maximize power generation, so HAWTS require a means for alignment (yawing mechanism) so that the entire nacelle can rotate into the wind. On smaller wind turbines (like the Lokata shown in Figure 1), a tail vane provides a "passive" yaw control. In large, grid-connected turbines, yaw control is active, with wind direction sensors and motors that rotate the nacelle.

VAWTS

There are two main types of VAWTs, the Savnoius and the Darrieus. The Savonius operates like a water wheel using drag forces, while the Darrieus uses blades similar to those used on HAWTS. VAWTs typically operate closer to the ground, which has the advantage of allowing placement of heavy equipment, like the generator and gearbox, near ground level rather than in the nacelle. However, winds are lower near ground level, so for the same wind and capture area, less power will be produced.

Another advantage of a VAWT over the HAWT is that it doesn't require a yaw mechanism, since it can harness wind from any direction. This advantage is outweighed by many other disadvantages, including: time varying power output due to variation of power during a single rotation of the blade, the need for guy wires to support the tower and the fact that Darrieus VAWTS are not self starting like HAWTS.

India averaged annual mean wind speed has decreased from 9.7 kmph in 1961 to 5.0 kmph in 2008 resulting i n a 49% decrease. All India averaged rate of decrease i n annual mean wind speed is -0.88 kmph/decade.

FACTS

•Wind Power potential in the country is over 695 GW at 120m Hub Height

•India Ranks 4th in Wind Energy Installation Globally

•Only country to have a dedicated Ministry for Renewable Energy

Target

•60 GW by 2022

•Balance 20 GW under implimentation

•About 5 Million Jobs to be created in next 20 yrs

•Better Land Reforms & Evacuation Facility

•Achieve NAPCC target of 15% from renewable by 2020

Wind power is one of the key renewable energy sources for electricity generation in India. With 37.5GW of capacity installed, the country currently ranks fourth in the world in wind power generation after China, the US and Germany

NS Energy profiles the top five wind farms in India.

1. Muppandal Wind Farm: 1,500MW
Situated in Kanyakumari district of the Indian state of Tamil Nadu

2. Jaisalmer Wind Park: 1,064MW
Developed by Suzlon Energy, the Jaisalmer wind park is the country’s second-largest onshore wind project.

3. Brahmanvel Wind Farm: 528MW
The 528MW Brahmanvel wind farm, located in Dhule district of Maharashtra, has been developed by Parakh Agro Industries.

4. Dhalgaon Wind Farm: 278MW
Gadre Marine Exports developed the 278MW Dhalgaon wind farm in Sangli, Maharashtra. The wind farm, commissioned in 2005, features turbines from Suzlon and Enercon.

5. Vankusawade Wind Park: 259MW
Maharashtra is also home to the 259MW Vankusawade wind park, which is one of India’s largest wind power production facilities.

- **Geothermal energy** is thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temerature of matter. Earth's geothermal energy originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%).

- A **geothermal power plant** uses its geothermal activity to generate power. This type of natural energy production is extremely environmentally friendly and used in many geothermal hot spots around the globe.

Why is geothermal energy a renewable resource?

Because its source is the almost unlimited amount of heat generated by the Earth's core.

How much does geothermal energy cost per kilowatt-hour (kWh)?

At The Geysers, power is sold at $0.03 to $0.035 per kWh.
A power plant built today would probably require about $0.05 per kWh.

Where is geothermal energy available?

Hydrothermal resources - reservoirs of steam or hot water - are available primarily in the western states, Alaska, and Hawaii. However, Earth energy can be tapped almost anywhere with geothermal heat pumps and direct-use applications. Other enormous and world-wide geothermal resources - hot dry rock and magma, for example - are awaiting further technology development.

What we all know about Geothermal power plant ?

Current worldwide installed capacity is 10,715 megawatts(MW), with the largest capacity in the United States (3,086 MW).

India has announced a plan to develop the country's first geothermal power facility in Chhattisgarh.

Economically Geothermal power requires no fuel, it is therefore immune to fuel cost fluctuations.

Geothermal power is considered to be renewable because any projected heat extraction is small compared to the Earth's heat content.
The Earth has an internal heat content of 10^{31} joules.

Further, due to its low emissions geothermal energy is considered to have excellent potential for mitigation of global warming.

Geothermal Reservoirs

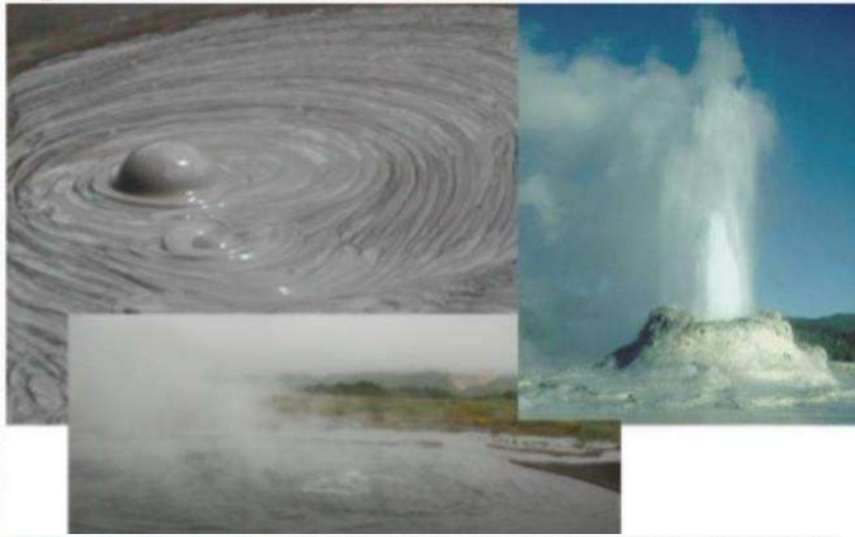
- Reservoirs can be suspected in the areas where we find :-

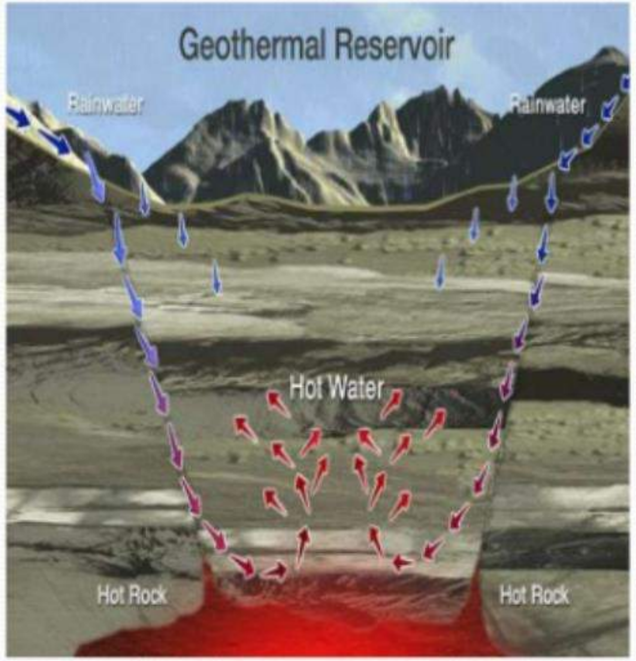
→Geyser

→Boiling mud pot

→Volcano

→Hot springs





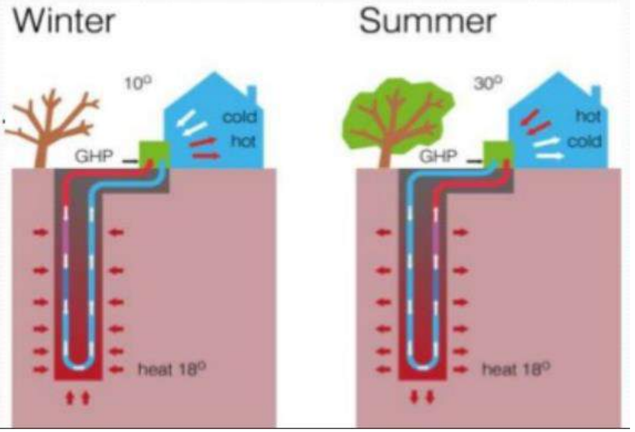
- The rising hot water & steam is trapped in permeable & porous rocks to form a geothermal reservoir.
- Reservoirs can be discovered by
  - → testing the soil
  - → analyzing underground temperature

Extraction & uses

- The heat energy can be brought to earth surface by following ways..
  - → directly from hot springs/ geysers
  - → geothermal heat pump
- Uses are broadly classified as:-
  - →direct use
  - →indirect use

Direct use of Geothermal Energy

- Hot springs, used as spas.
- Heating water at fish farms.
- Provide heat for buildings.
- Raising plants in greenhouses, drying crops.
- Provides heat to industrial processes.



Indirect use of Geothermal Energy

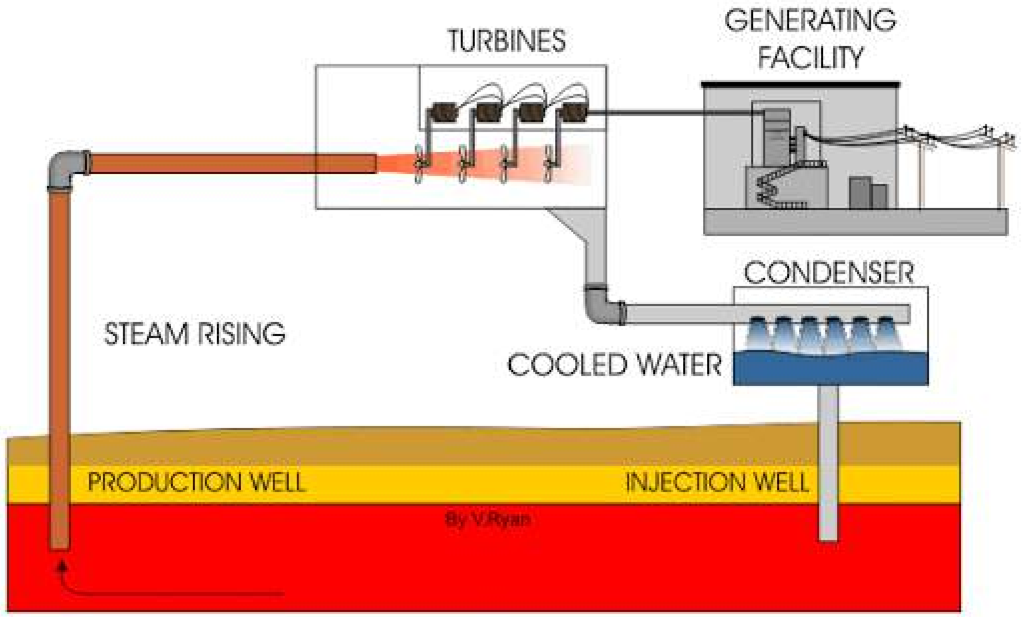
- Electricity Generation:

Electricity Generation (cont.)

There are 3 types of power plants:-

- → Dry steam power plant
- →Flash steam power plant
- →Binary cycle power plant

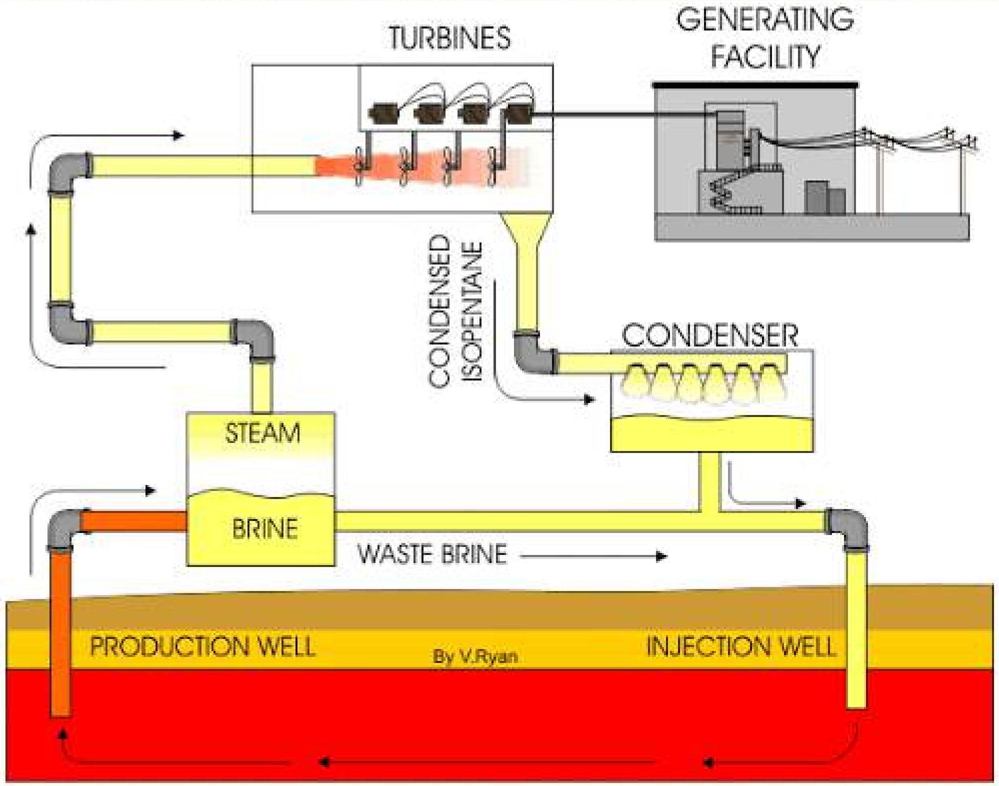
Dry Steam power plant



Dry Steam power plant (cont.)

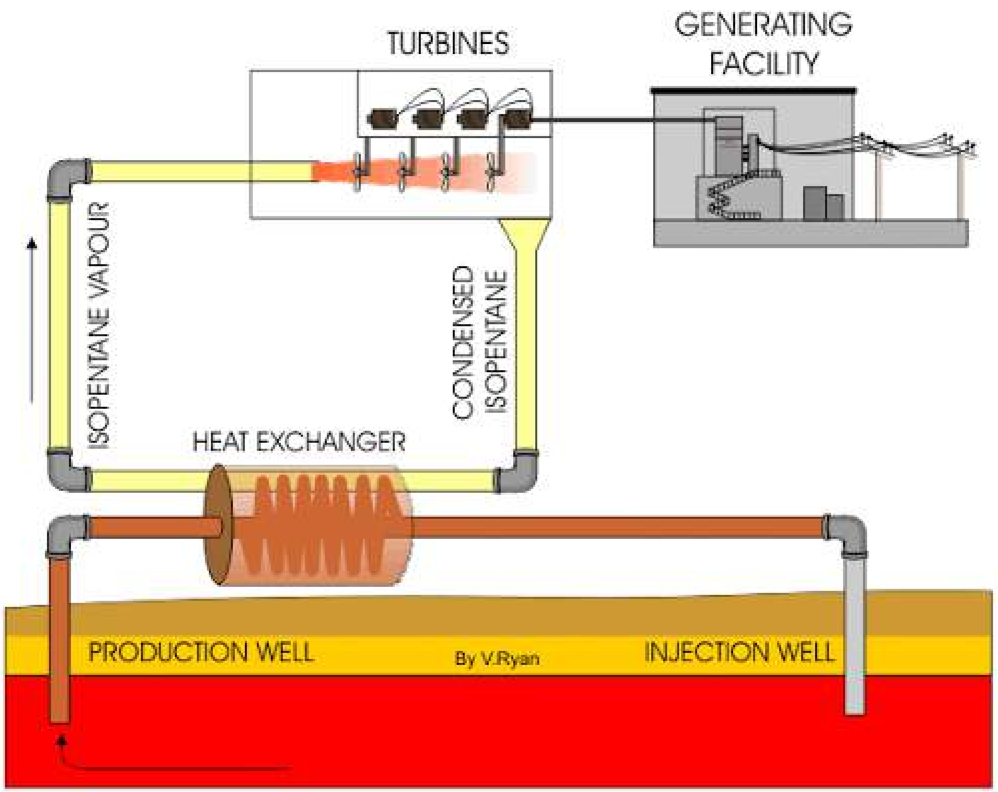
- The oldest type of Geothermal power plant used.
- Geothermal reservoir containing pure steam is required.
- Pure dry steam drives turbine.
- Very rare type of geothermal power plant.
- Operating at California, Italy, and Japan.

Flash steam power plant

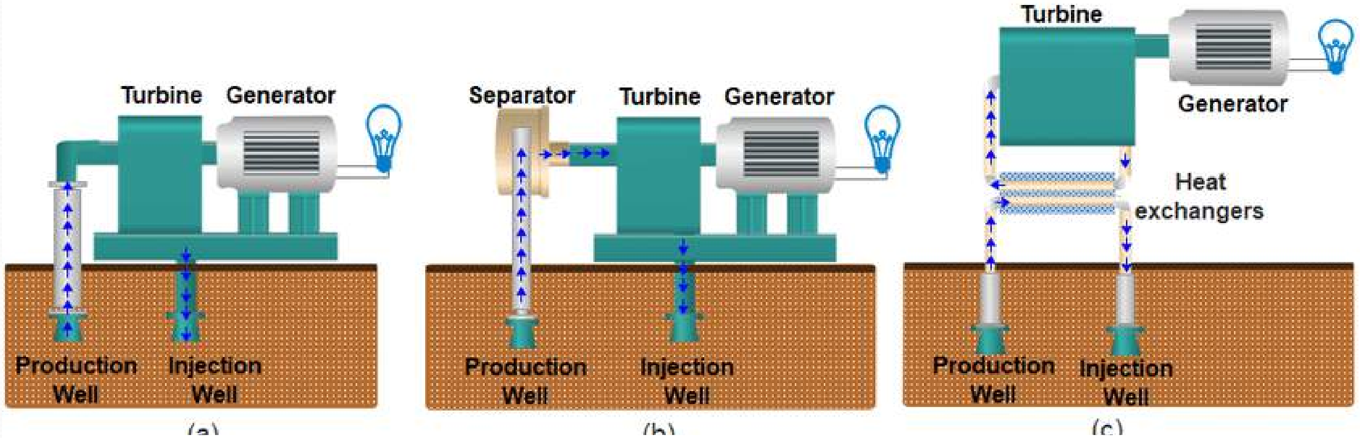


- Commonly used geothermal power plant.
- Geothermal reservoirs containing both hot water & steam is required.
- Pressure changing system is required.
- Operating at Hawaii, Nevada, Utah & some other places

Binary cycle power plant



- Does not use steam directly to spin turbines.
- Only the heat of the underground water is used.
- Vapourized hydrocarbons are used to spin the turbine.
- Hydrocarbons having lower boiling point such as isopentane, isobutane and propane can be used.
- No harmful gas is emitted to the atmosphere because the underground water is never disclosed to outside.
- This's the worldwide accepted power plant.



A) Dry steam plant b) Flash steam plant c) Binary cycle plant

Dry Steam Plants

- Use dry steam, that is naturally produced in the ground
- Oldest types of geothermal plants
- Can only be used where underground temperatures are extremely high

Flash Steam Plants

- Most common due to the lack of naturally occuring high-quality steam
- Water must be over 180 degrees Celsius
- Higher cost associated with construction and maintenance

Binary Steam Plants

- Expected to dominate geothermal plants
- Ability to utilize lower water temperatures
- Use a secondary loop, containing a fluid with lower boiling point

Advantages

- Available all the year around.
- Does not involve any combustion of fuel.
- Independent of weather
- Clean Resource – Very little emissions or overall environmental impact.
- Economically Sound Alternative – The fuel is free, rate / KWh likely to be competitive
- Overall, geothermal energy is a sustainable resource.

Disadvantages

- Not widespread source of energy
- High installation costs
- Can run out of steam
- May release harmful gases
- Transportation
- Earthquakes

In India, exploration and study of geothermal fields started in 1970. The GSI (Geological Survey of India) has identified 350 geothermal energy locations in the country. The most promising of these is in Puga valley of Ladakh. The estimated potential for geothermal energy in India is about 10000 MW.

Following are the six most promising geothermal energy sites in India –

- **Tattapani** in Chhattisgarh
- **Puga** in Jammu & Kashmir
- **Cambay Graben** in Gujarat
- **Manikaran** in Himachal Pradesh
- **Surajkund** in Jharkhand
- **Chhumathang** in Jammu & Kashmir

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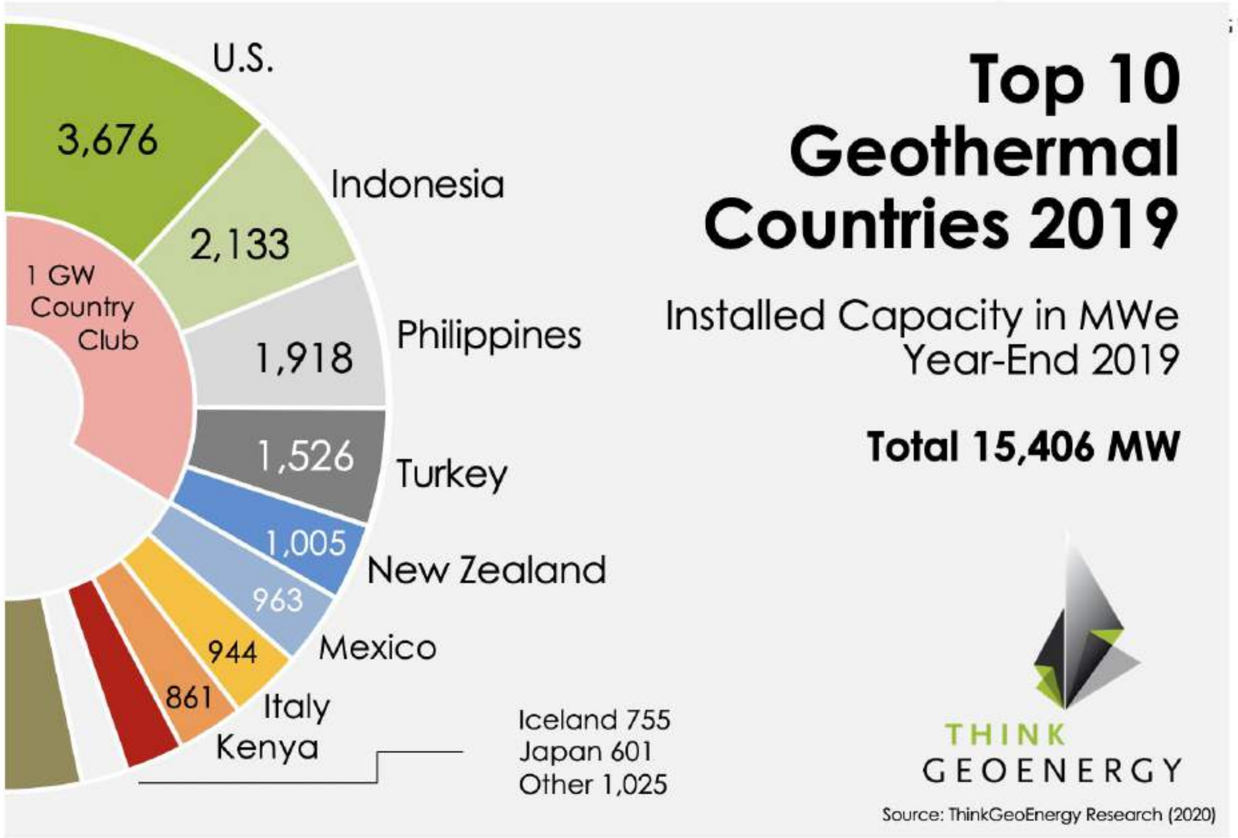
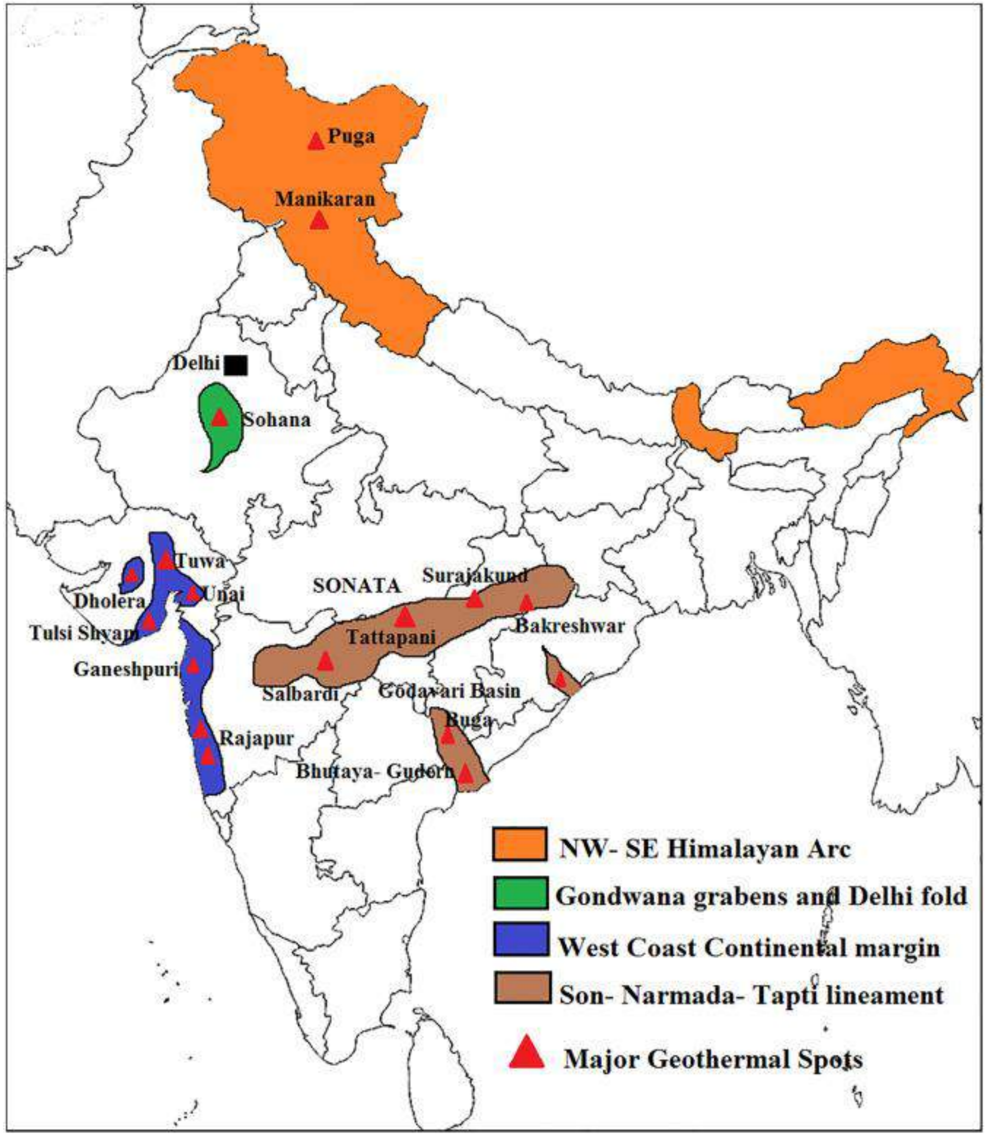




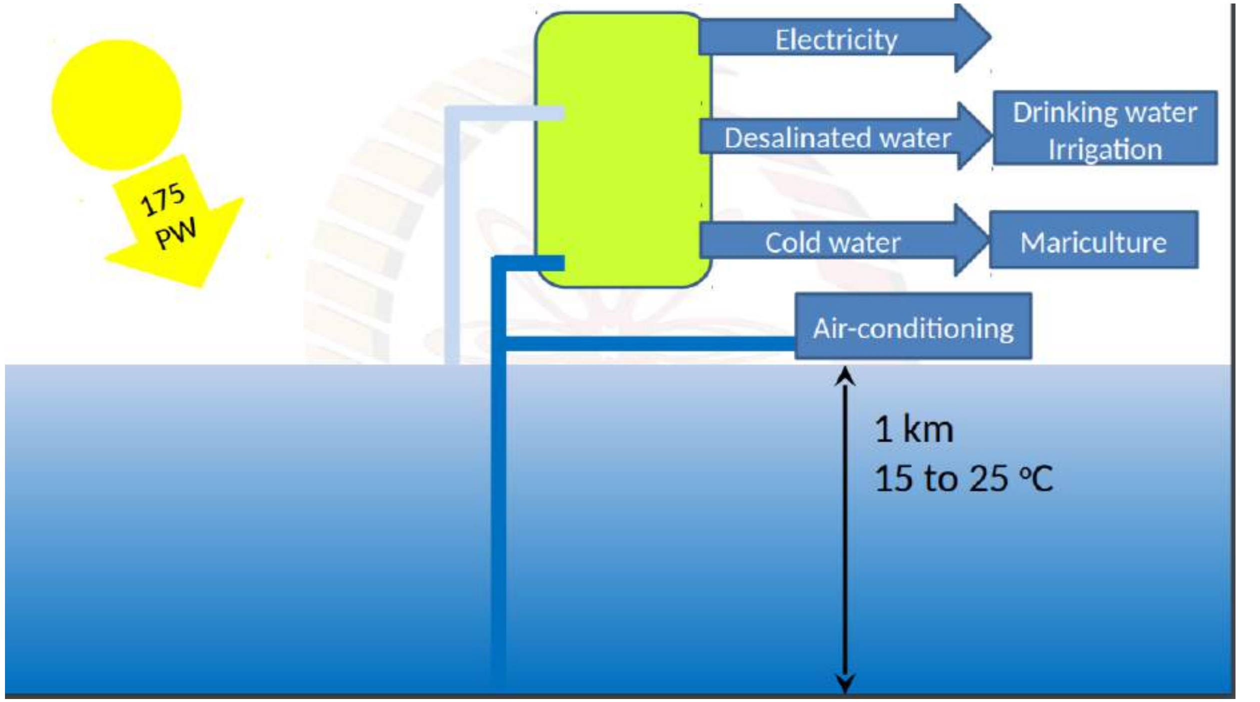
Ocean Thermal Energy: Conversion (OTEC)

Principle of OTEC:

- Temperature diference between warm water at the surface and colder water approximately 1km below the surface is used to run a heat engine and energy is extracted from the same.
- Temperature diference can be of the order of 15 oC to 25 oC

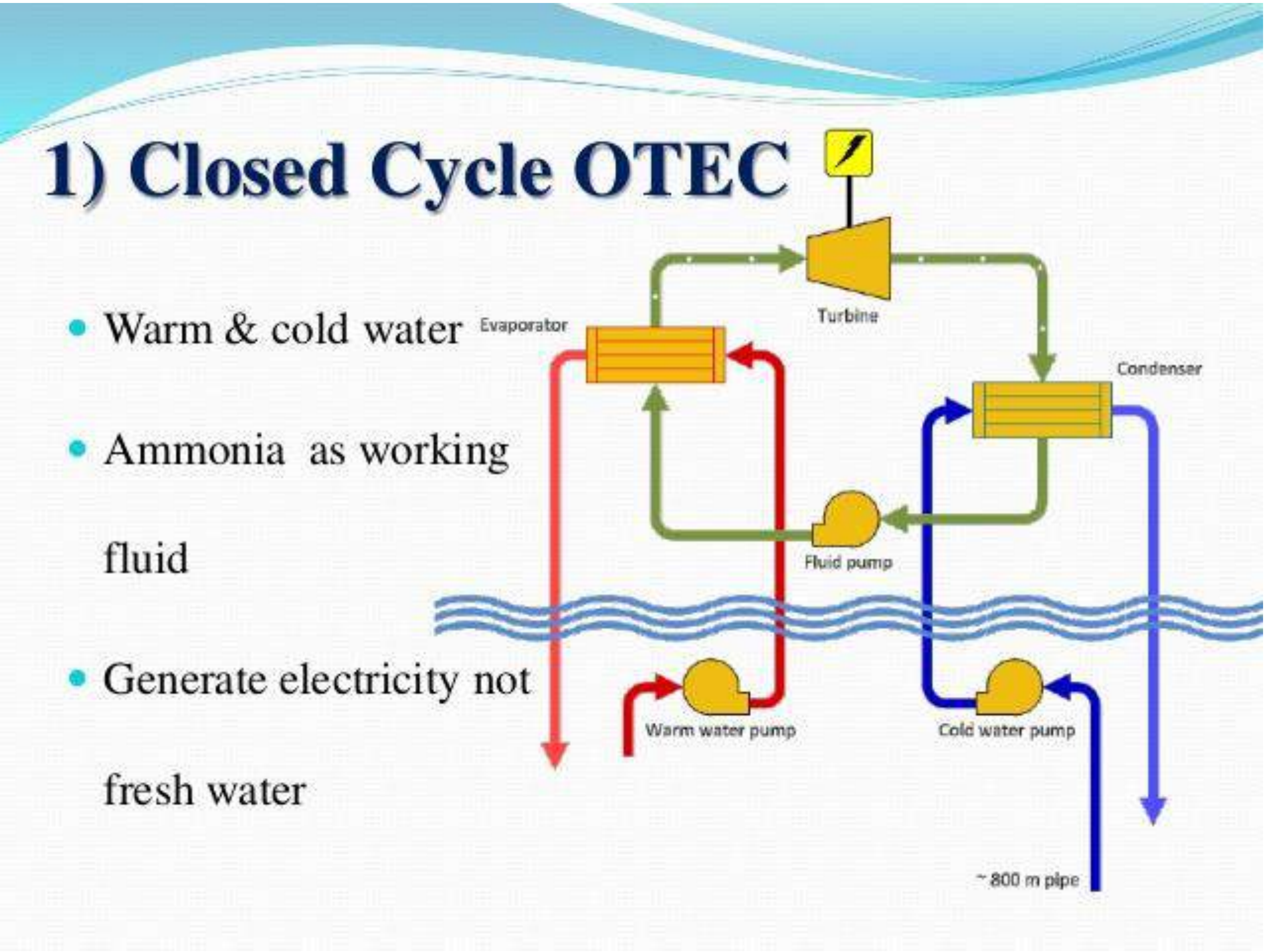
Thermal profle of sea water

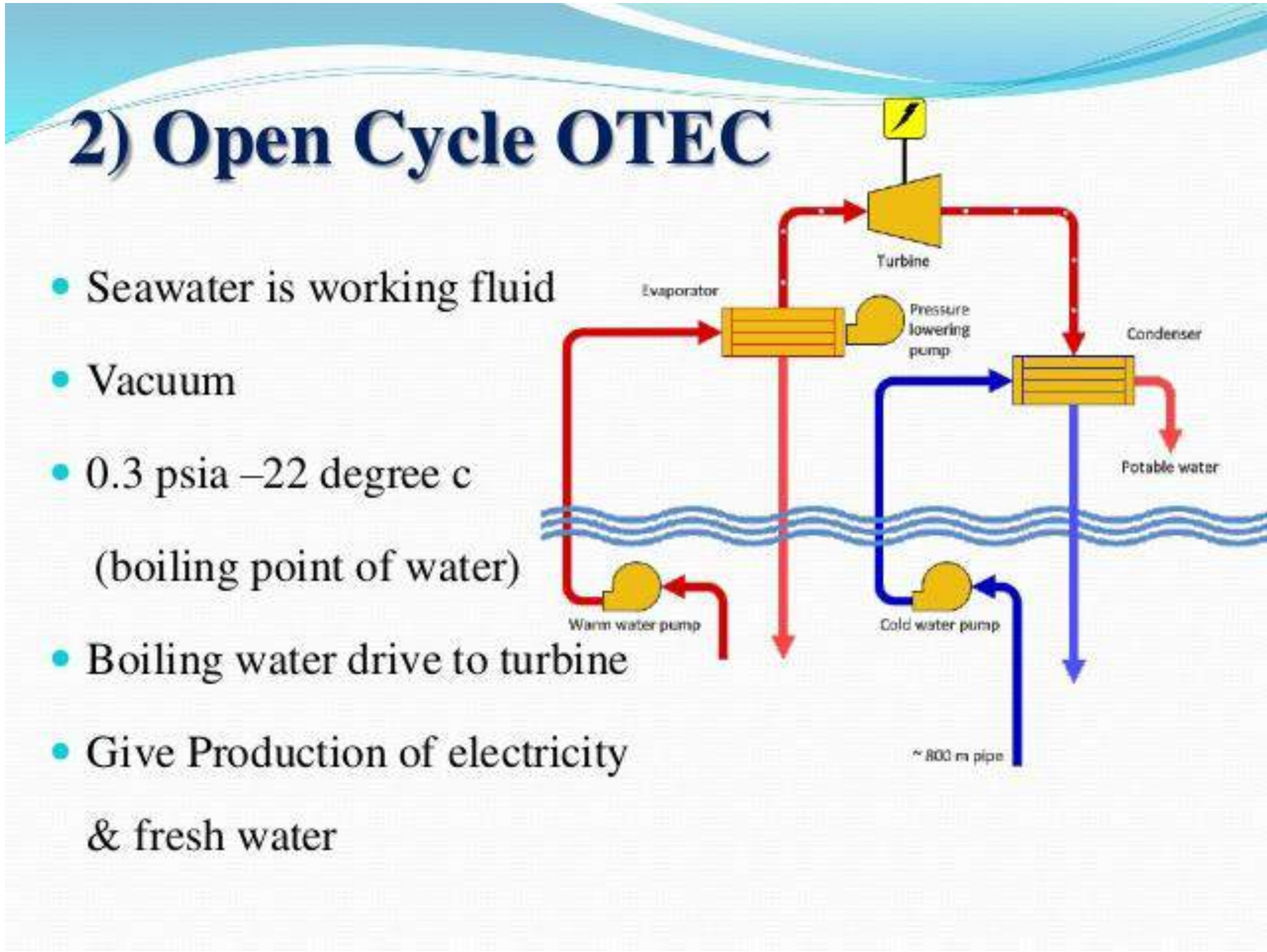
First 20 m absorbs sunlight. Surface freezing at poles to 36 oC in the Persian Gulf Water turbulent and mixed for a few hundred meters Boundary of a few hundred meters between mixed layer and undisturbed water below. Called Thermocline 90% of sea water below thermocline, temperature around 3 oC



Closed cycle: Low boiling point liquid, ammonia, -33oC. Warm water makes it evaporate and run turbine, cold water condenses it aferwards

Open Cycle: Warm sea water evaporates at low pressure, runs turbine, condensed by cold sea water. Desalinated water becomes available





Advantages and Disadvantages of Oceanic Thermal Energy

Advantages

- OTEC could prevent burning approximately 1.3 million barrels of oil per year.
- Large-scale OTEC is offshore and will not compete for land, food or freshwater.
- There are enough resources around the world to supply enough energy for 4 times humanity's electrical needs.
- 1 offshore commercial-scale plant could prevent over ½ a million tons of CO_2 emissions per year. (over 100k cars)

Disadvantages

- OTEC requires expensive, large-diameter pipes submerged nearly a mile below the ocean's surface. Many countries that are between the Tropic of Cancer and the Tropic of Capricorn (within viable geographic belt) can't economically afford to build this infrastructure.
- OTEC facilities are stationary surface platforms, are essentially considered artificial islands and, therefore, their exact location affects their legal status under the United Nations Convention on the Law of the Sea treaty.

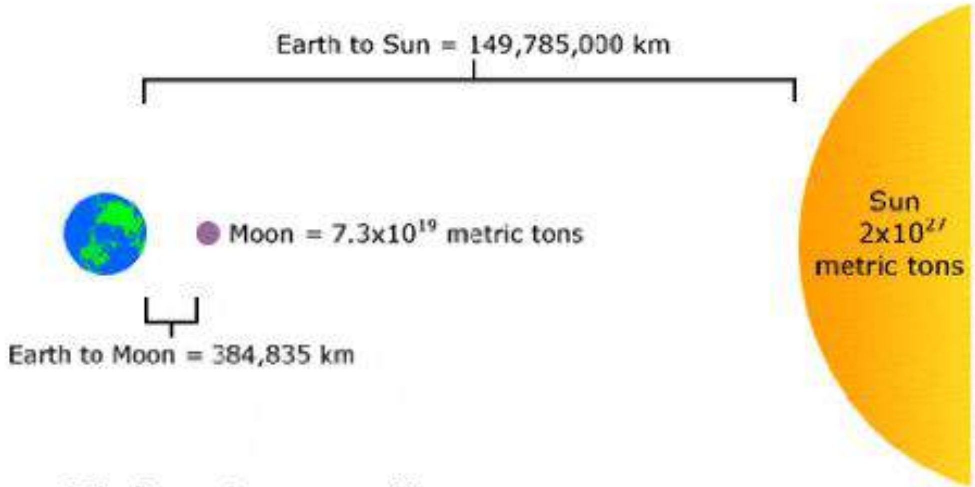
TIDAL ENERGY

- Tidal power, also called **TIDAL ENERGY**, is a form of **HYDROPOWER** which converts the energy of tides into the useful form of power, mainly in electricity.
- Tides are the waves caused due to gravitational pull of the moon and sun.
- Ocean tides are the periodic rise and fall of ocean water level occurs twice in each lunar day.
- During one lunar day the ocean water level rises twice and fall twice.

How is tide created

- Tide is created due the gravitational force between earth sun and moon

Tidal force



$$\text{Tide-Generating Force} = \propto \frac{\text{Mass}}{(\text{Distance})^3}$$

$$\text{Tide-Generating Force of the Sun} = \propto \frac{\text{Sun's Mass}}{(\text{Sun's Distance to Earth})^3}$$

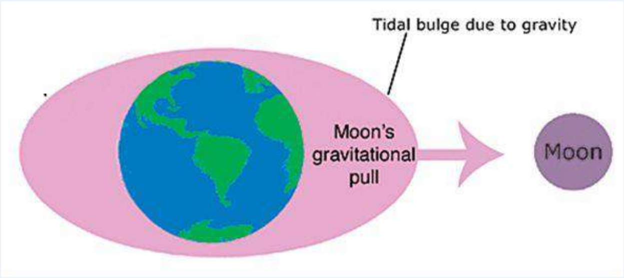
*NOTE: The sun has 27 million times more mass than the moon and is 390 times farther away from the earth than the moon.

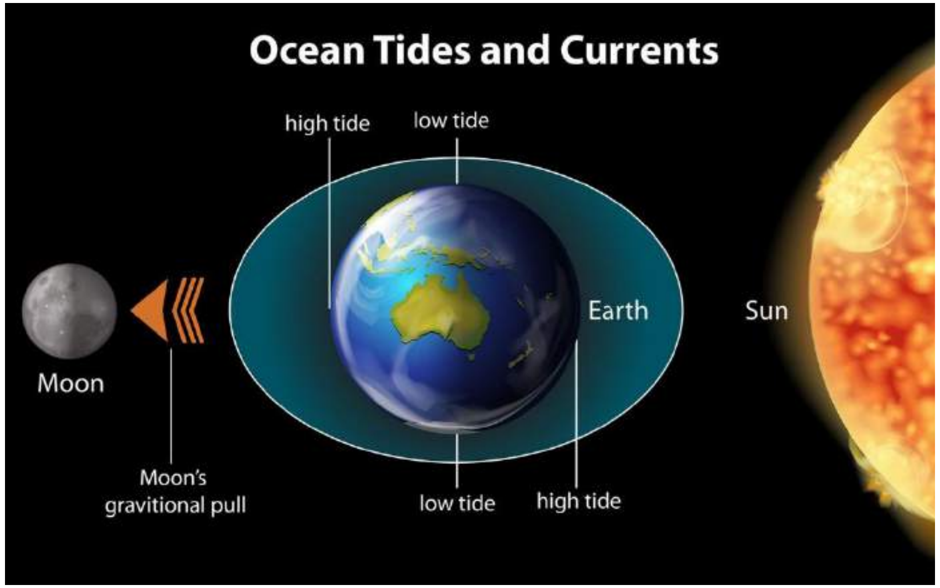
$(390)^3 = 59{,}000{,}000$ So... $\frac{27 \text{ million}}{59 \text{ million}} = 0.46$ or 46%

Therefore the Sun has 46% of the tide-generating force of the Moon.

Moon's Gravity – Tidal Bulges

- The Moon pulls on the water on the side **nearest** to it more **strongly** than it pulls on the **center** of the Earth.
- This **pull** creates a bulge of water, called a **tidal bulge**, on the side of Earth **facing** the Moon.





- ❖ Time interval between a consecutive low tide and high tide is 6.207 hrs.
- ❖ Tidal range is the difference between the consecutive high tide and low tide.
- ❖ During high tide, the water flow into the dam and during low tide water flow out which result in moving the turbine.
- ❖ Although not yet widely used, tidal power has potential for future electricity generation. Tides are more predictable than wind energy and solar power.

Main parts of TPP:-

- A tidal power plant consists of three main parts:
- The first being the barrage itself, holding the water back during high tide.
- The second part is the sluice gate that let water through the third part,
- The third part consist turbine and generator, resulting in electricity generation.

1. Tidal Barrage

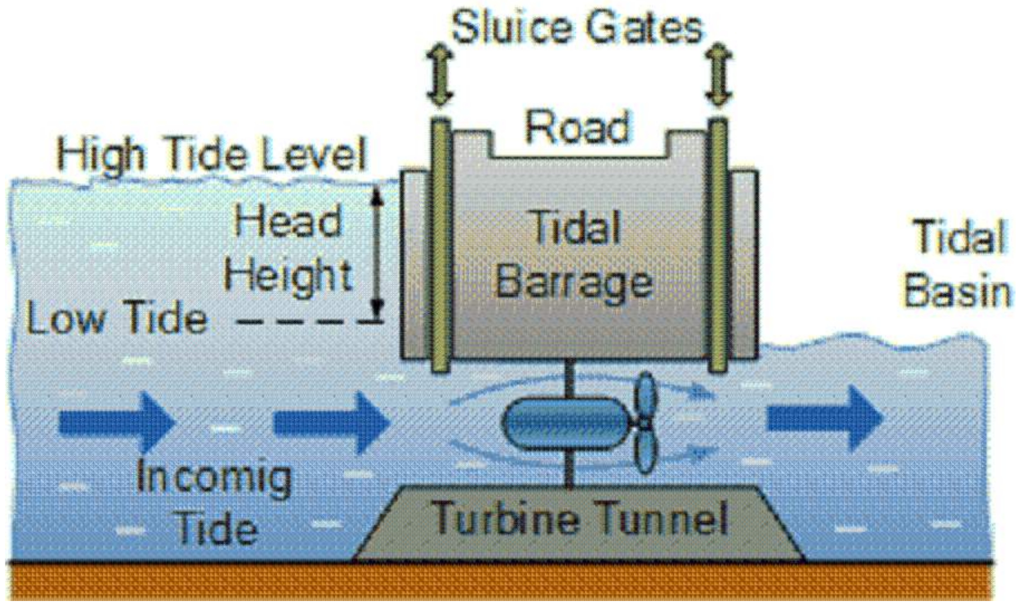
- A **tidal barrage** is a dam-like structure used to capture the energy from masses of water moving in and out of a bay or river due to tidal forces.

2. Sluice Gate

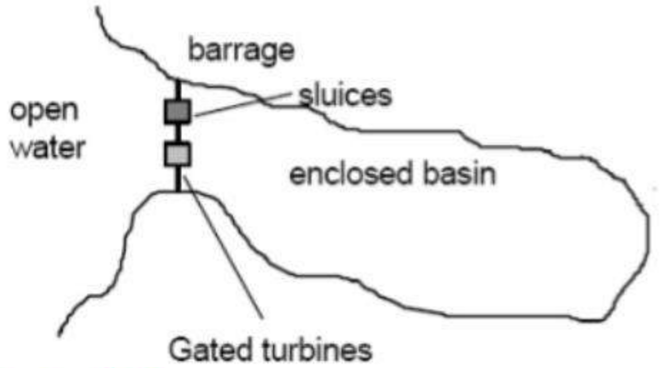
- The sluice gates are left open during high tide and closed during low tide to create a water level differential, creating a potential difference that powers the turbine when the water is released.

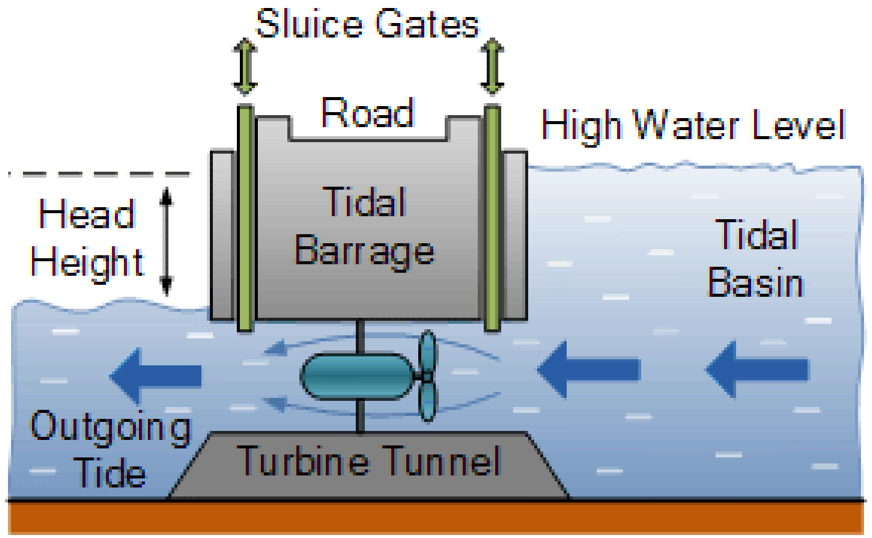
3. Tidal Stream Generator

- Tidal stream generators are very similar to wind turbines except their below the water surface instead of above or on land.
- The turbine and generator converts the movement of water coming from change in tide, the kinetic energy, into electricity.
- Water is 830 times denser than air and therefore can generate electricity at lower speeds than wind turbines.

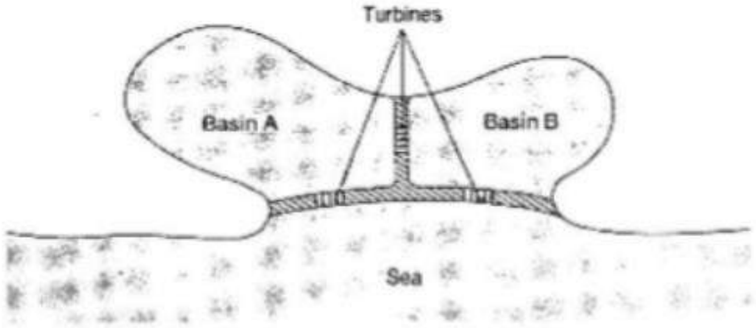


Single Basin Scheme: This scheme has one barrage and one water storage basin, one way system, the incoming tide is allowed to fill the basin through sluice ways during the tide and the impounded water is used to generate electricity by letting the water flow from basin to the sea through the turbines during single basin schemes is intermittent generation power.





Double Basin Scheme: In the double basin scheme, there are two basins on the landward side with the powerhouse located at the interconnecting waterway between the two basins



Advantages of Tidal Energy

❖ It is an inexhaustible source of energy.

❖ Tidal energy is environment friendly energy and doesn't produce greenhouse gases.

❖ As 71% of Earth's surface is covered by water, there is scope to generate this energy on large scale.

❖ Efficiency of tidal power is far greater as compared to coal, solar or wind energy. Its efficiency is around 80%.

❖ Tidal Energy doesn't require any kind of fuel to run.

❖ The life of tidal energy power plant is very long.

❖ The large density of water, almost 1000 times greater than in air, results in very large amounts of energy to get out of the tidal currents even if the speed is low.

Disadvantages of Tidal Energy

❖ Cost of construction of tidal power plant is high.

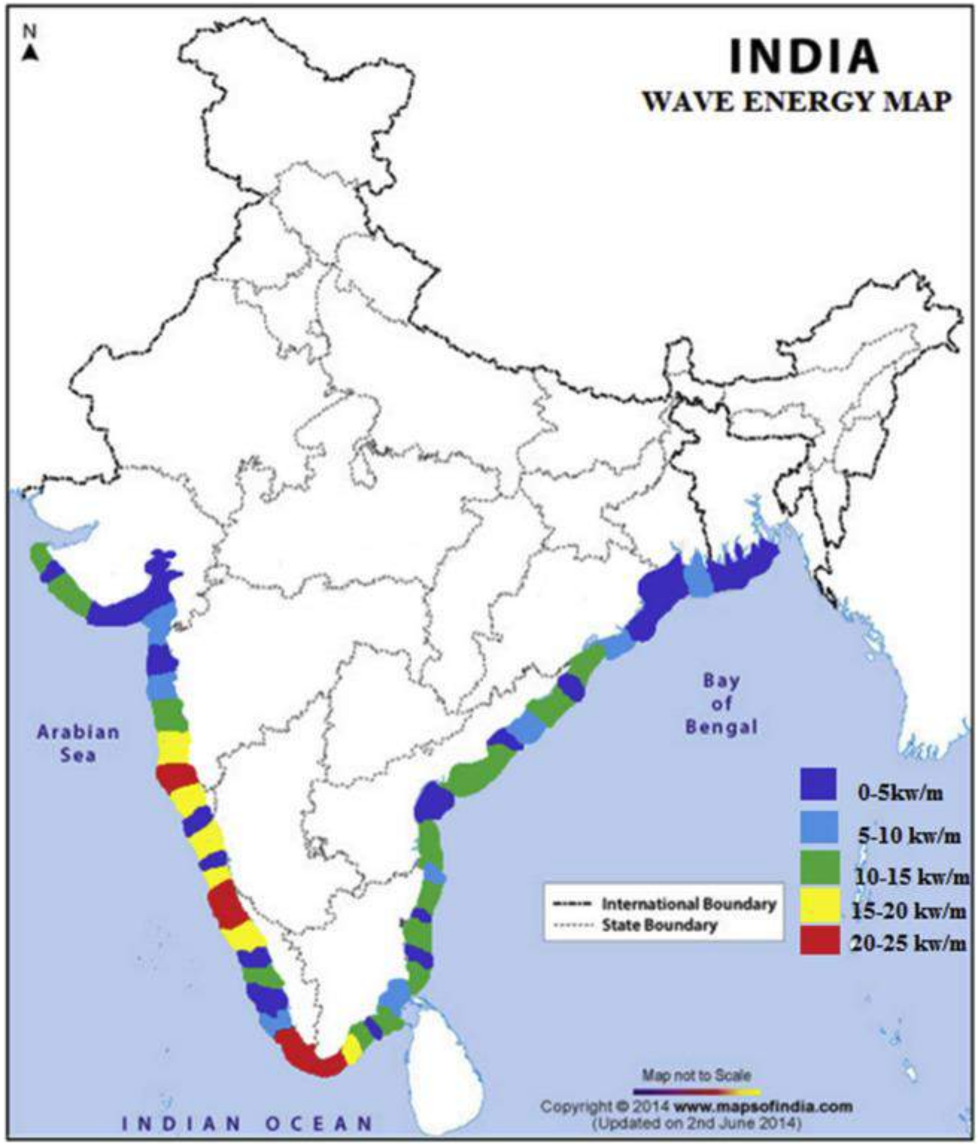
❖ There are very few ideal locations for construction of plant and they too are localized to coastal regions only.

❖ Intensity of sea waves is unpredictable and there can be damage to power generation units.

❖ Influences aquatic life adversely and can disrupt migration of fish.

❖ The actual generation is for a short period of time. The tides only happen twice a day so electricity can be produced only for that time.

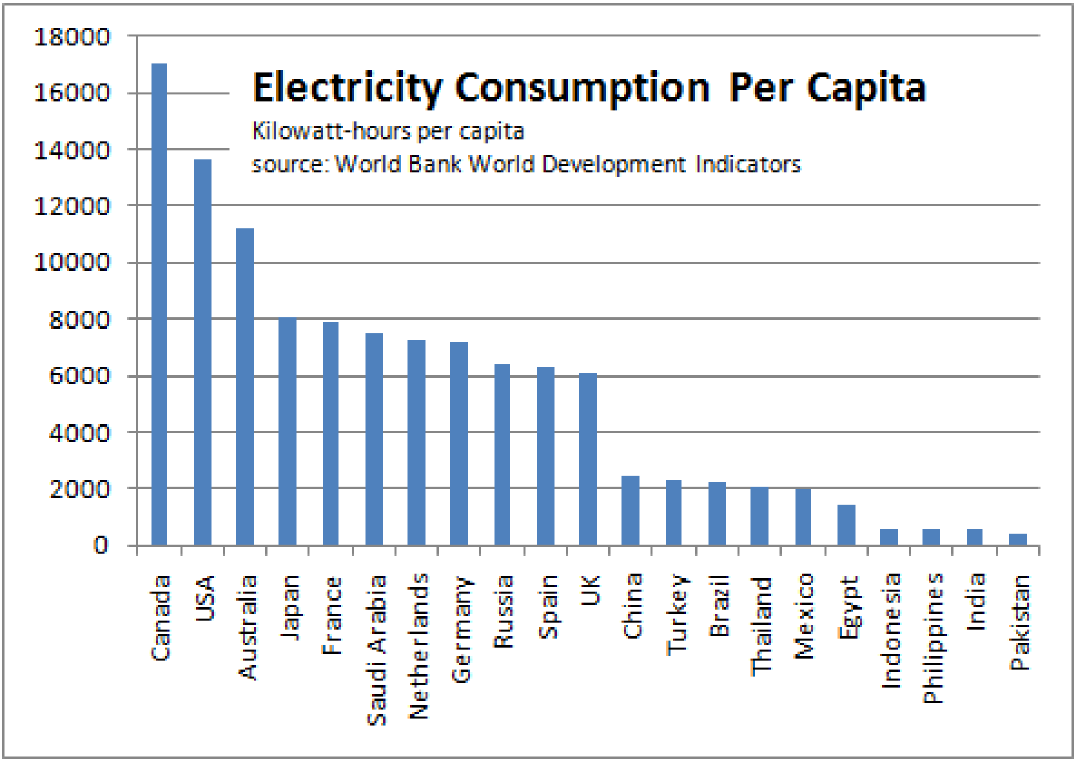
❖ Usually the places where tidal energy is produced are far away from the places where it is consumed. This transmission is expensive and difficult.

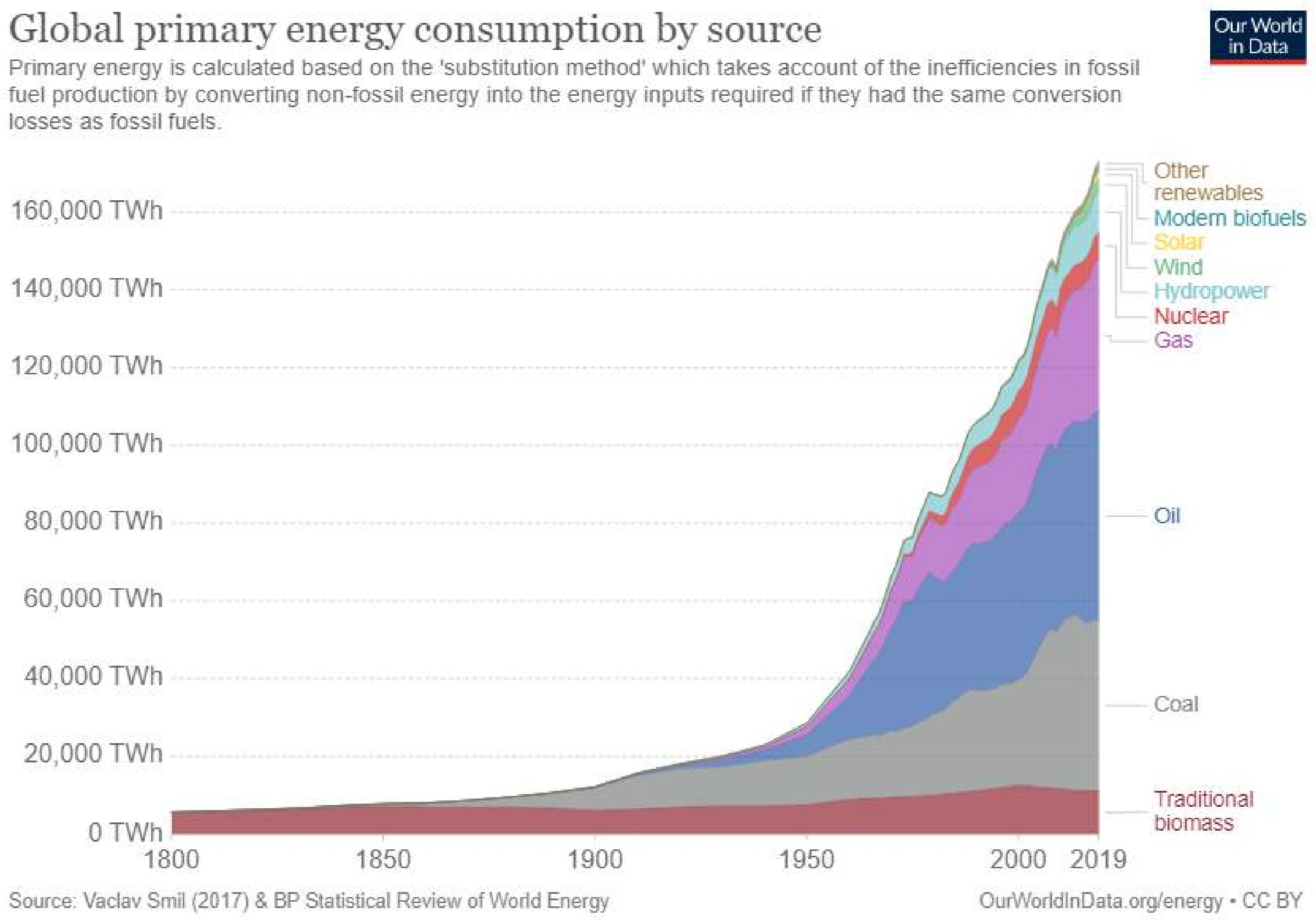


According to the estimates of the Indian government, the country has a potential of 8,000 MW of tidal energy. This includes about 7,000 MW in the Gulf of Cambay in Gujarat, 1,200 MW in the Gulf of Kutch and 100 MW in the Gangetic delta in the Sunderbans region of West Bengal.

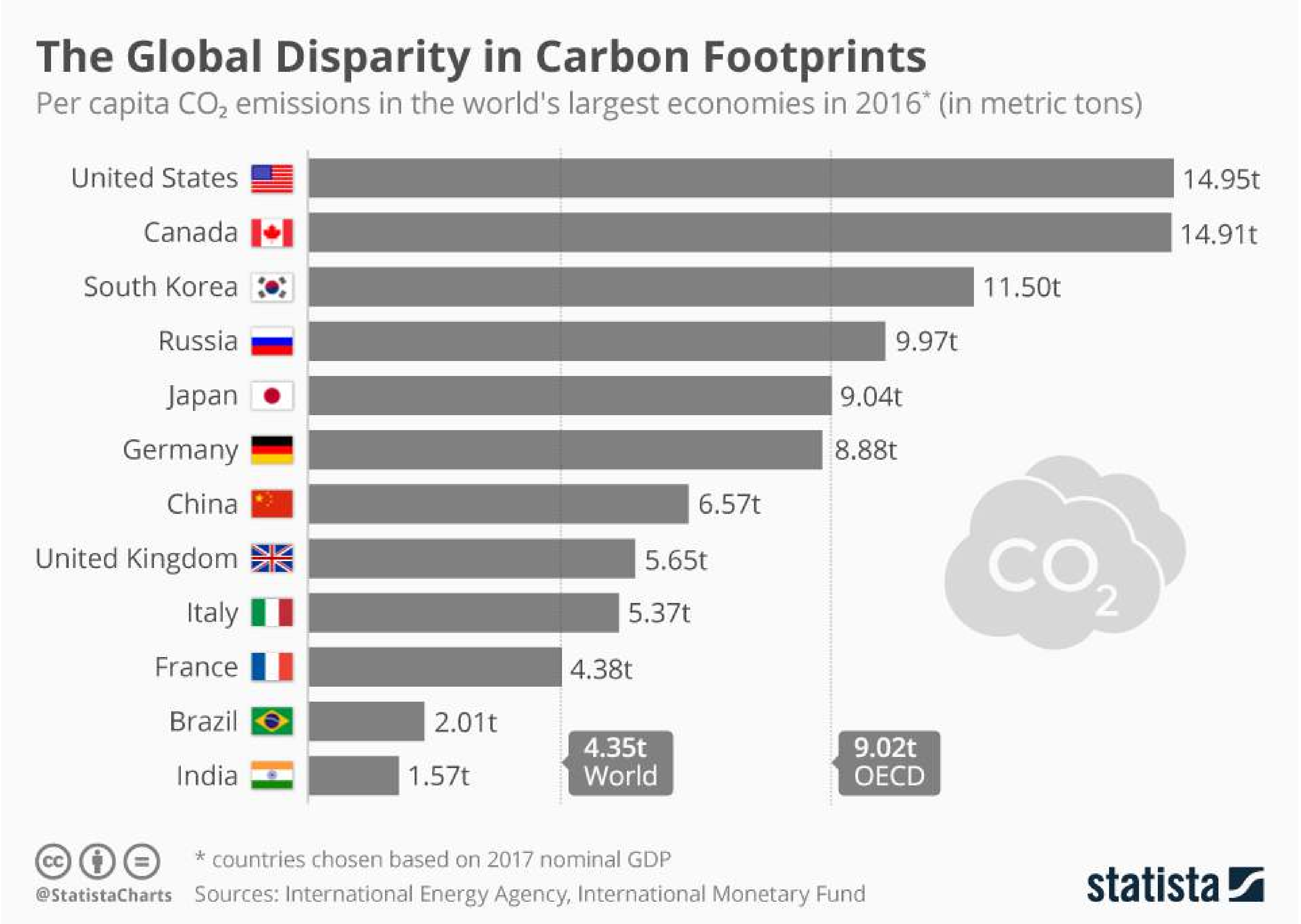
Unit-V Systems and Synthesis: Overview of World Energy Scenario, Nuclear radiation, fuel cycles, waste and proliferation, Climate change, Energy storage, Energy conservation. Engineering for Energy conservation: Concept of Green Building and Green Architecture; Green building concepts, LEED ratings; Identification of energy related enterprises that represent the breath of the industry and prioritizing these as candidates; Embodied energy analysis and use as a tool for measuring sustainability. Energy Audit of Facilities and optimization of energy consumption

Overview of World Energy Scenario

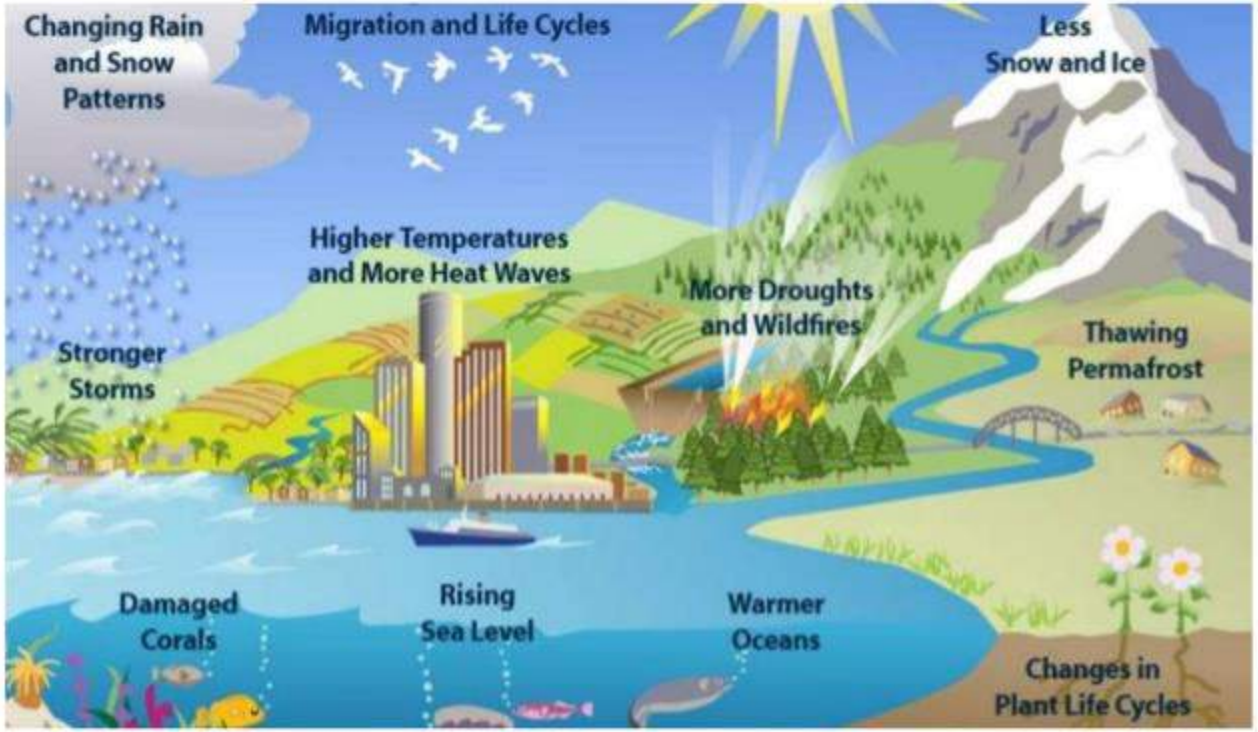




The energy system has transformed dramatically since the Industrial Revolution. We see this transformation of the global energy supply in the interactive chart shown here. It graphs global energy consumption from 1800 onwards.


The Global Disparity in Carbon Footprints
Per capita CO_2 emissions in the world's largest economies in 2016* (in metric tons)
United States
14.95t
Canada
14.91t
South Korea
11.50t
Russia
9.97t
Japan
9.04t
Germany
8.88t
China
6.57t
United Kingdom
5.65t
Italy
5.37t
France
4.38t
Brazil
2.01t
India
1.57t
4.35t World
9.02t OECD
CO_2
* countries chosen based on 2017 nominal GDP
Sources: International Energy Agency, International Monetary Fund
@StatistaCharts
statista

ENVIRONMENTAL IMPACT - FOSSIL FUELS

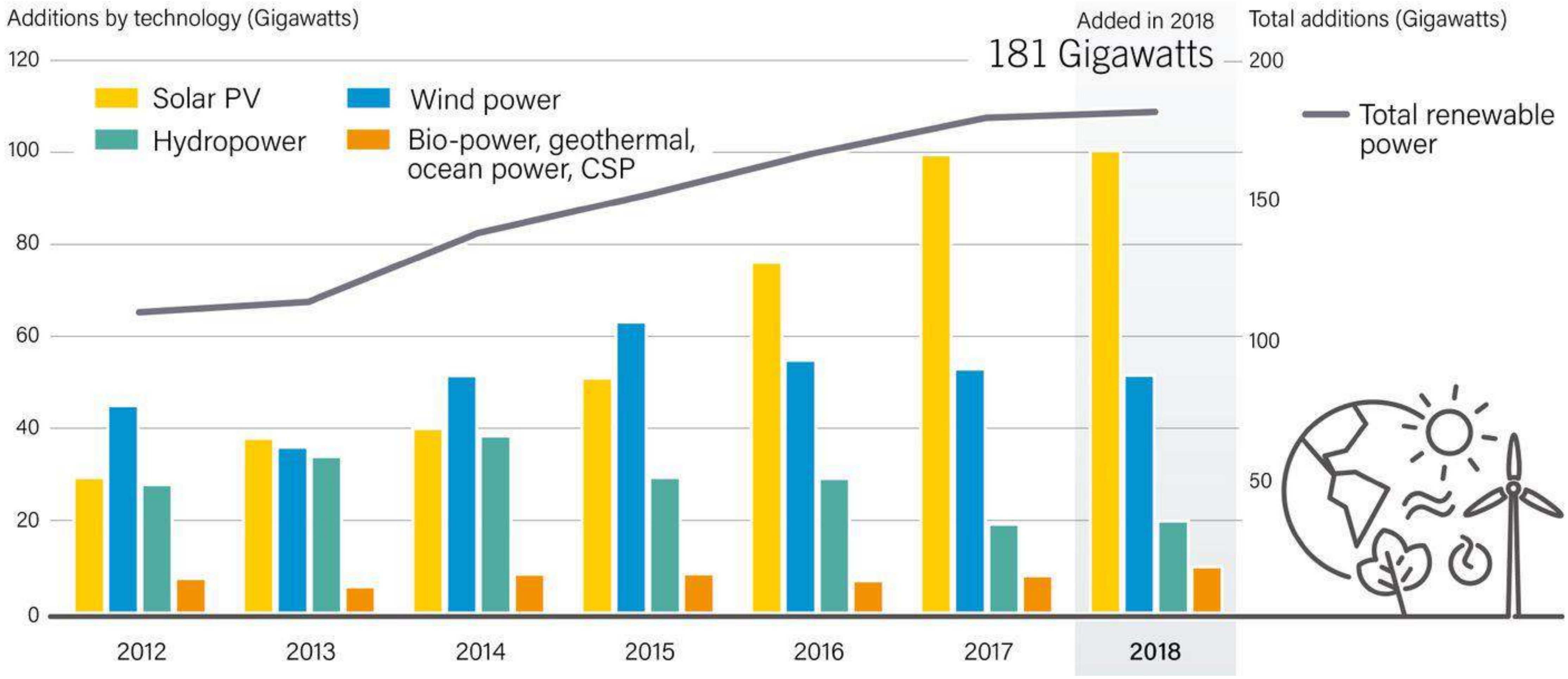


The impact of fossil fuels on human health

The air pollution from fossil fuels interconnects with:

- Headaches
- Nerve damage
- Fatigue
- Skin irritation
- Cardiovascular illness
- Cancer
- Respiratory illnesses
- Premature deaths

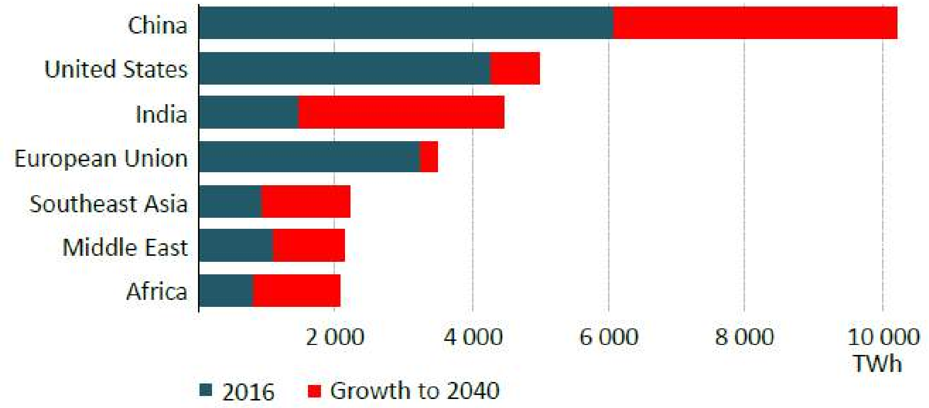
Annual Additions of Renewable Power Capacity, by Technology and Total, 2012-2018



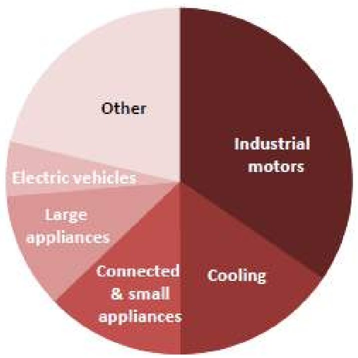
The future is electrifying

World Energy Outlook 2017

Electricity generation by selected region



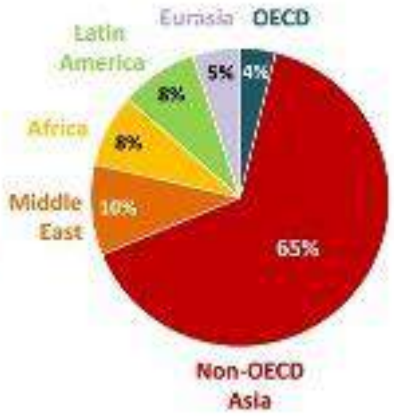
Sources of global electricity demand growth



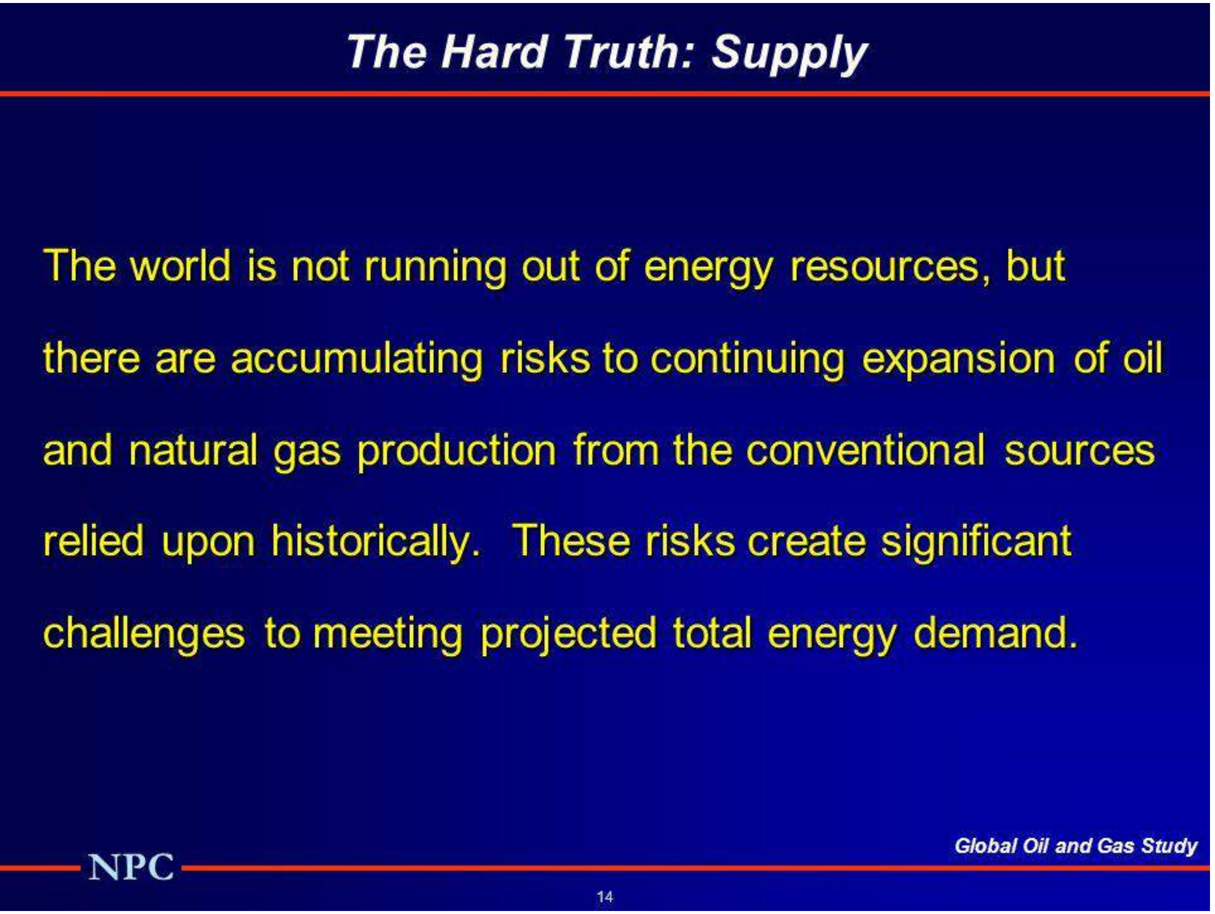
India adds the equivalent of today's European Union to its electricity generation by 2040, while China adds the equivalent of today's United States

Primary energy demand, 2035 (Mtoe)

Share of global growth 2012-2035



China is the main driver of increasing energy demand in the current decade, but India takes over in the 2020s as the principal source of growth



Climate change is a long-term change in the average weather patterns that have come to define Earth's local, regional and global climates. These changes have a broad range of observed effects that are synonymous with the term.

Causes and Effects of Climate Change

Causes

- Rapid industrialization
- Energy use
- Agricultural practices
- Deforestation
- Consumer practices
- Livestock
- Transport
- Resource extraction
- Pollution

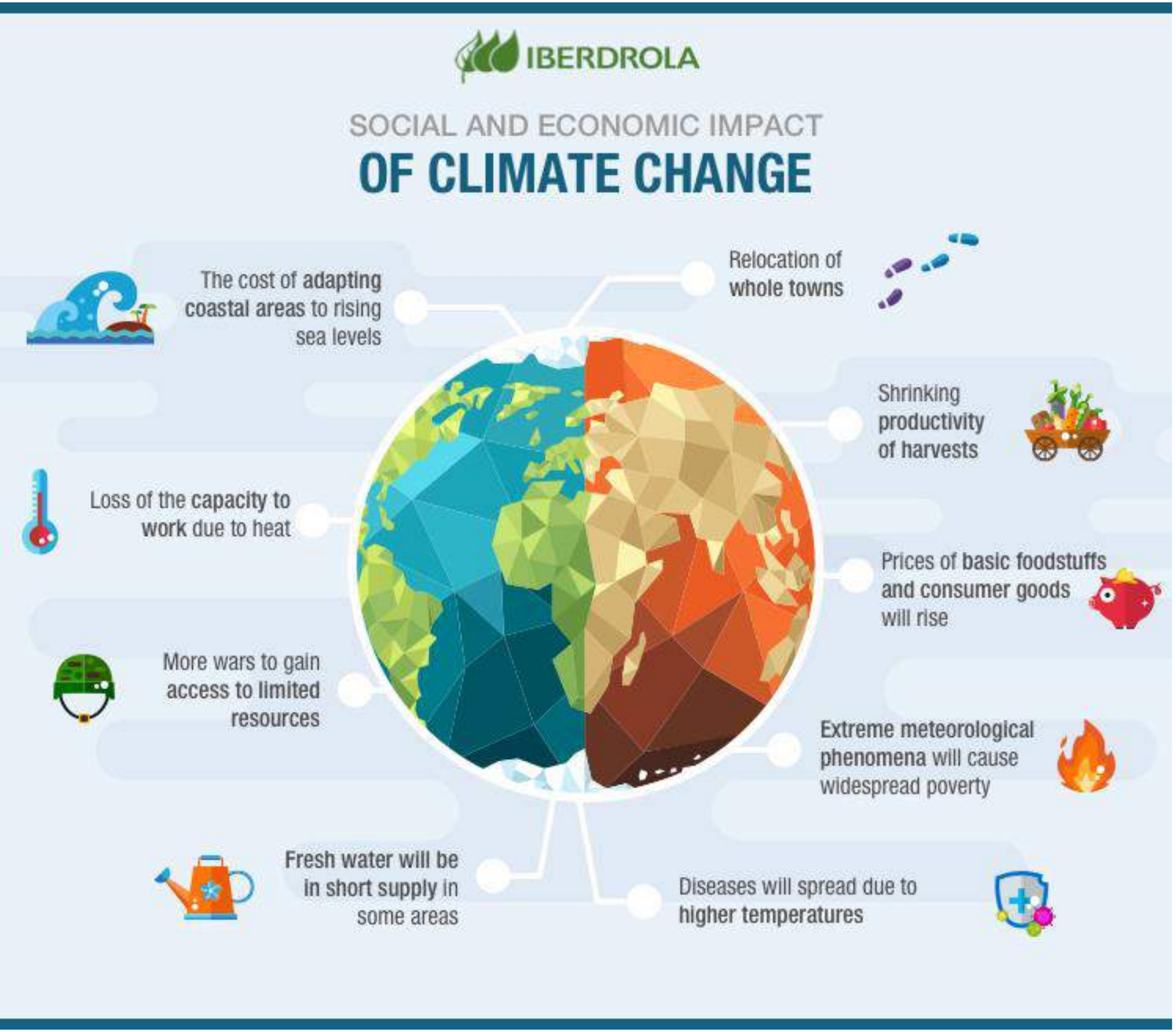
Effects

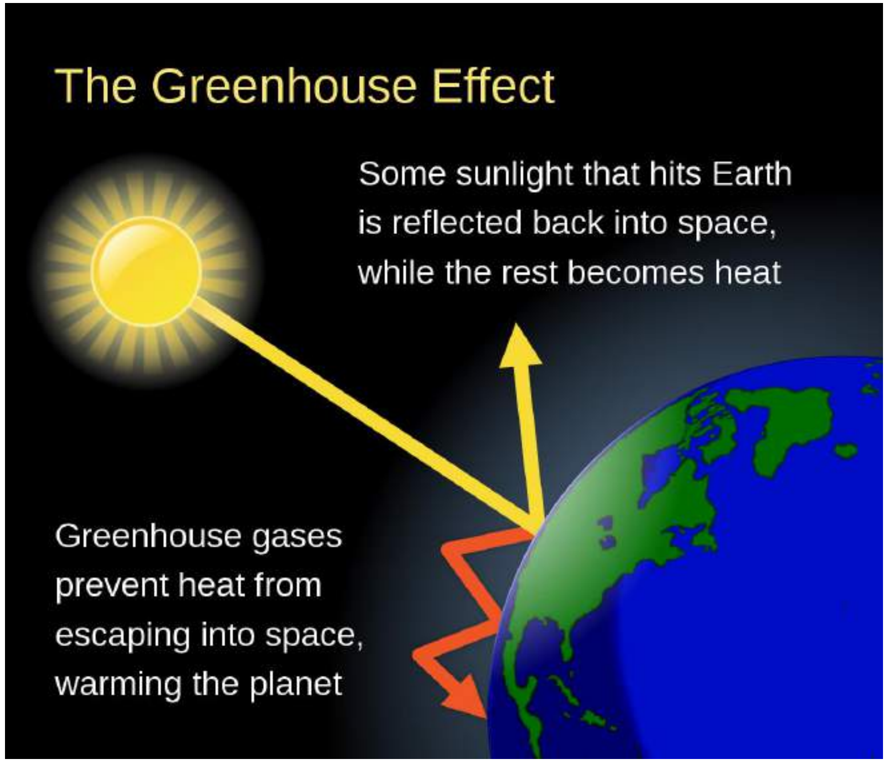
- Rising temperatures
- Rising sea levels
- Unpredictable weather patterns
- Increase in extreme weather events
- Land degradation
- Loss of wildlife and biodiversity

What are the social impacts of climate change?

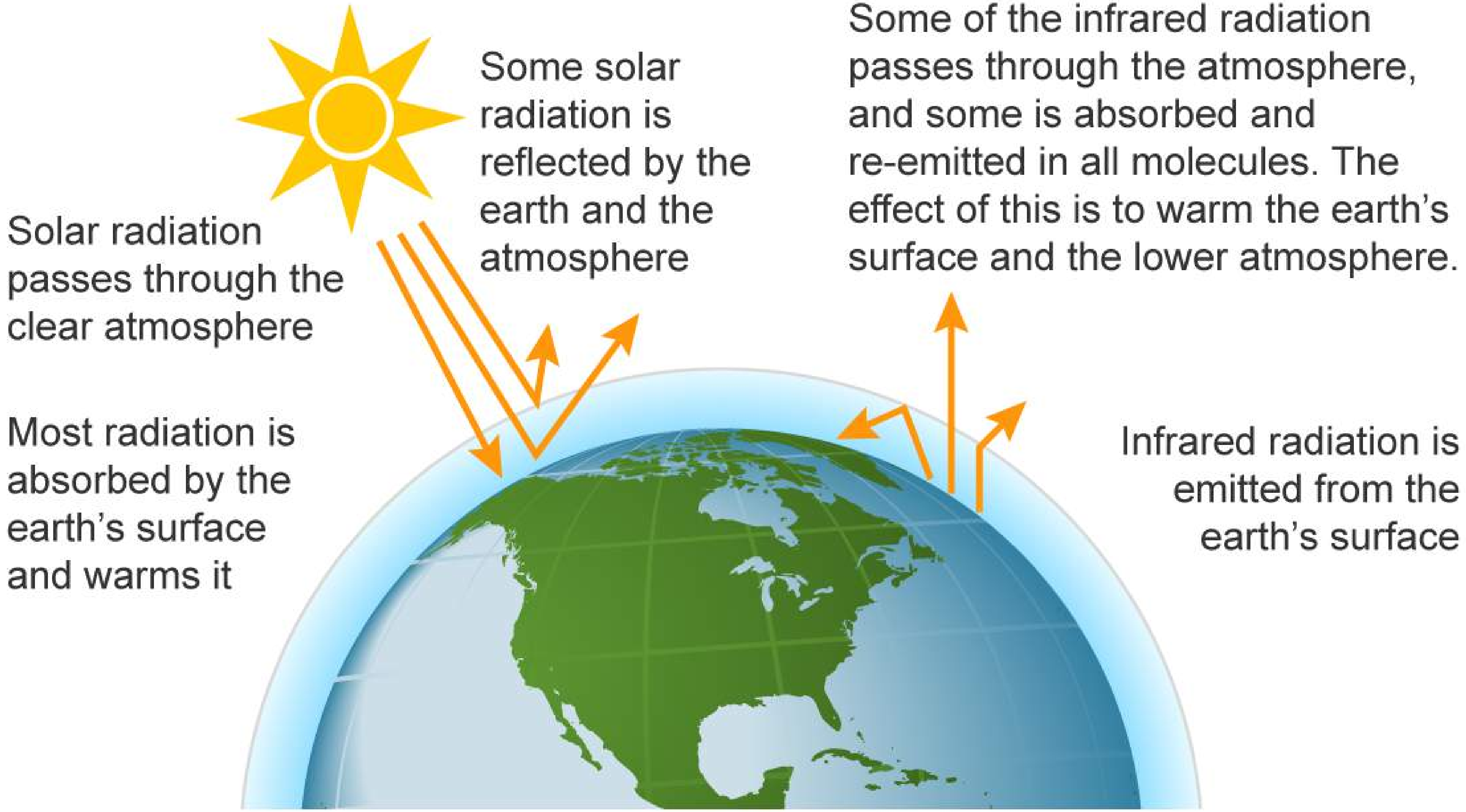
Displaced people. Poverty. Loss of livelihood. Hunger. Malnutrition. Increased risk of diseases. Global food and water shortages.

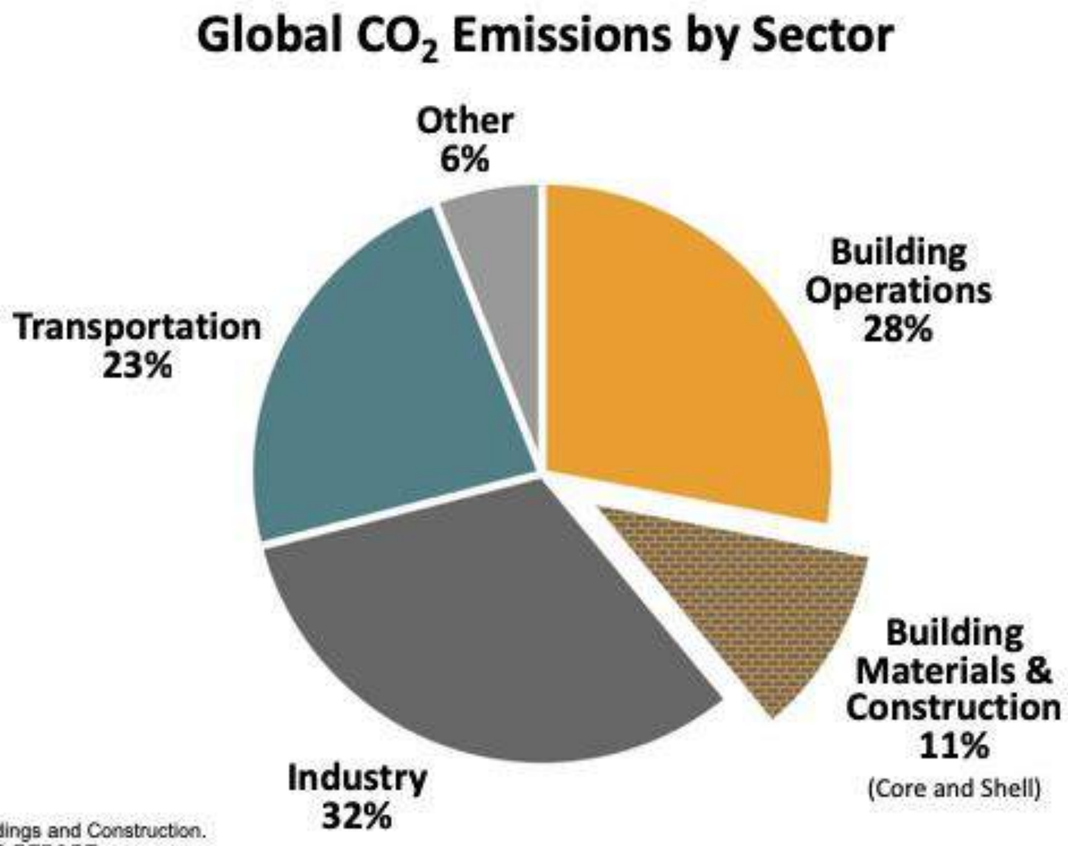
GlobalGiving


IBERDROLA
SOCIAL AND ECONOMIC IMPACT
OF CLIMATE CHANGE
The cost of adapting coastal areas to rising sea levels
Relocation of whole towns
Shrinking productivity of harvests
Loss of the capacity to work due to heat
Prices of basic foodstuffs and consumer goods will rise
More wars to gain access to limited resources
Extreme meteorological phenomena will cause widespread poverty
Fresh water will be in short supply in some areas
Diseases will spread due to higher temperatures

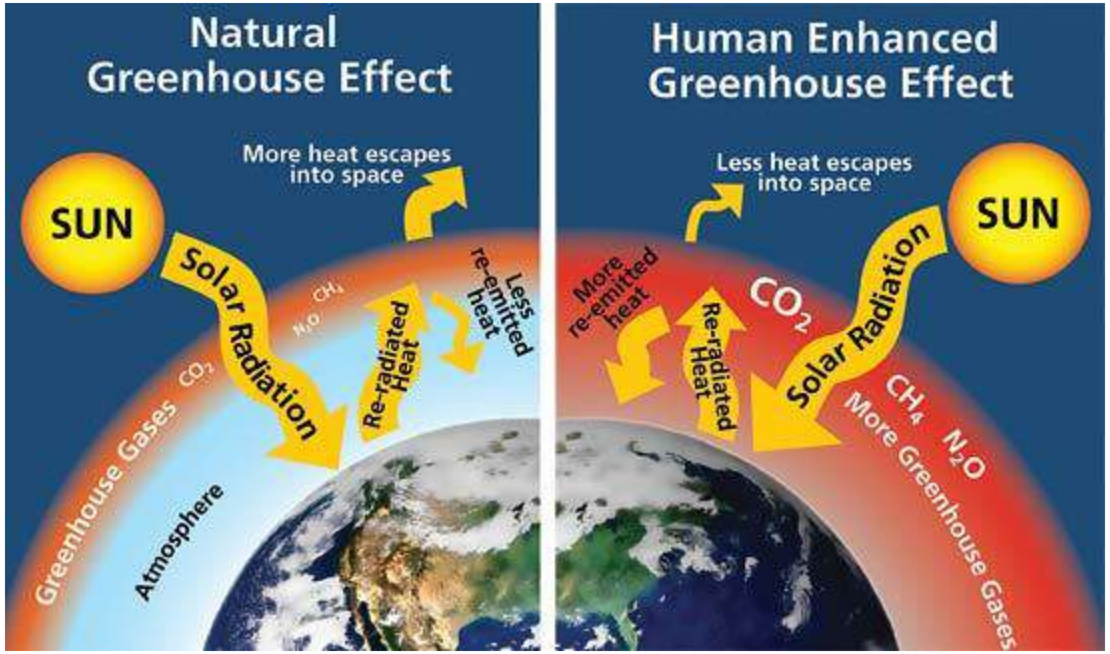

The Greenhouse Effect
Some sunlight that hits Earth is reflected back into space, while the rest becomes heat
Greenhouse gases prevent heat from escaping into space, warming the planet

The greenhouse effect





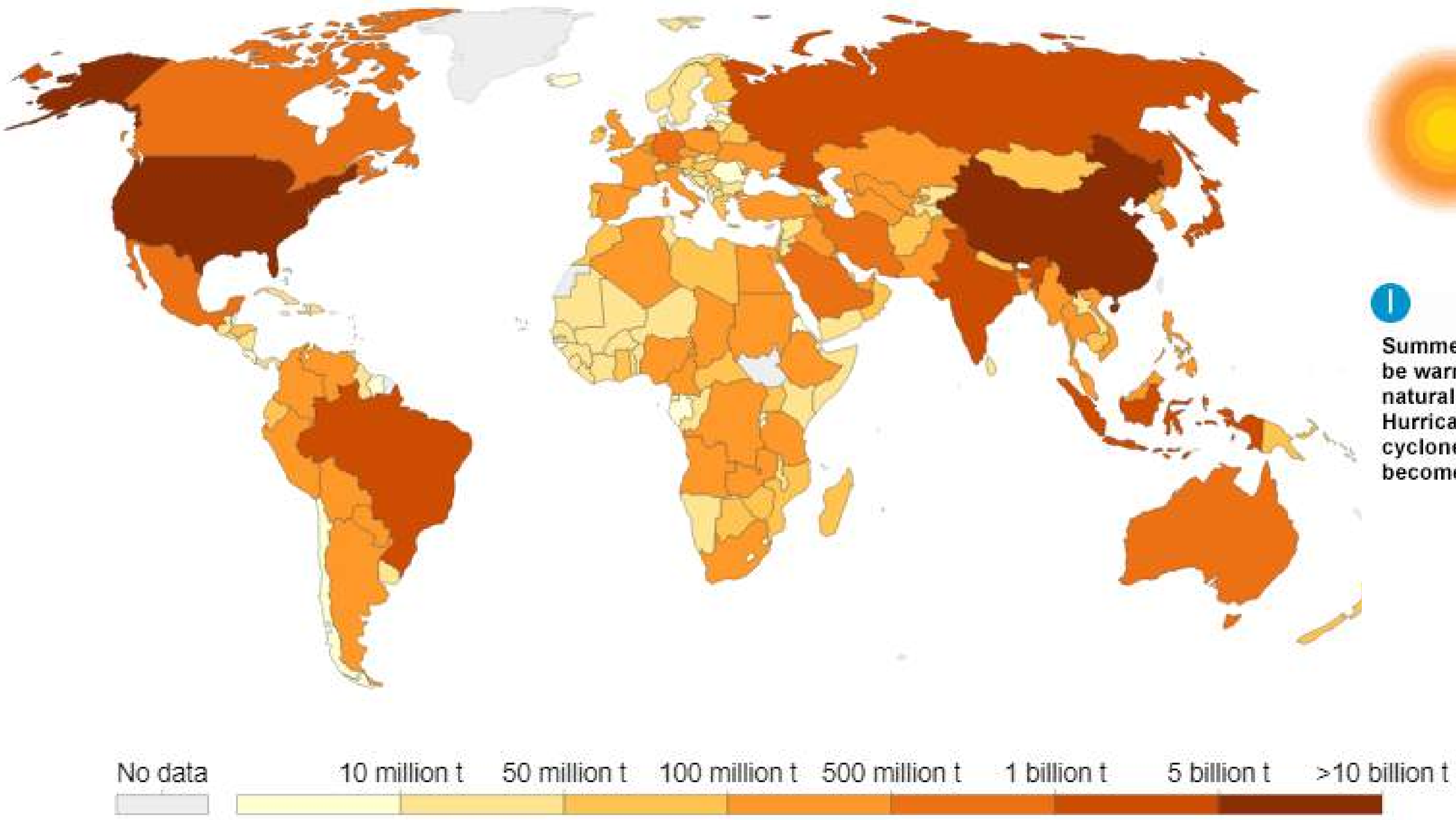
Source:
Global Alliance for Buildings and Construction.
2018 GLOBAL STATUS REPORT.



Total greenhouse gas emissions, 2016

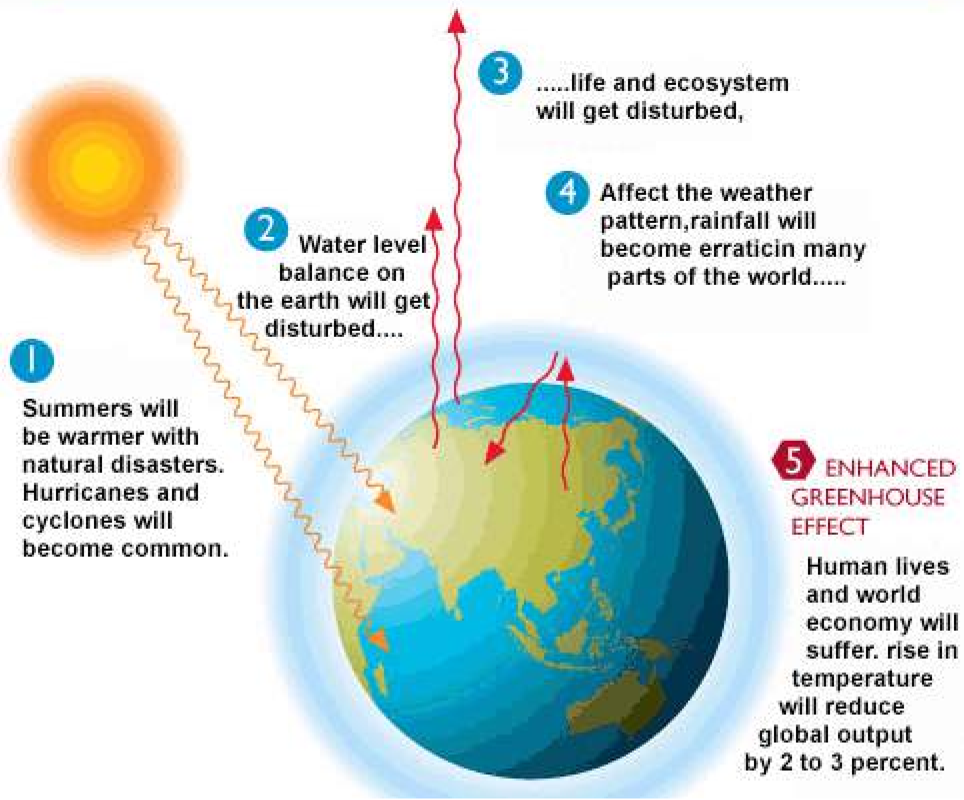
Our World in Data

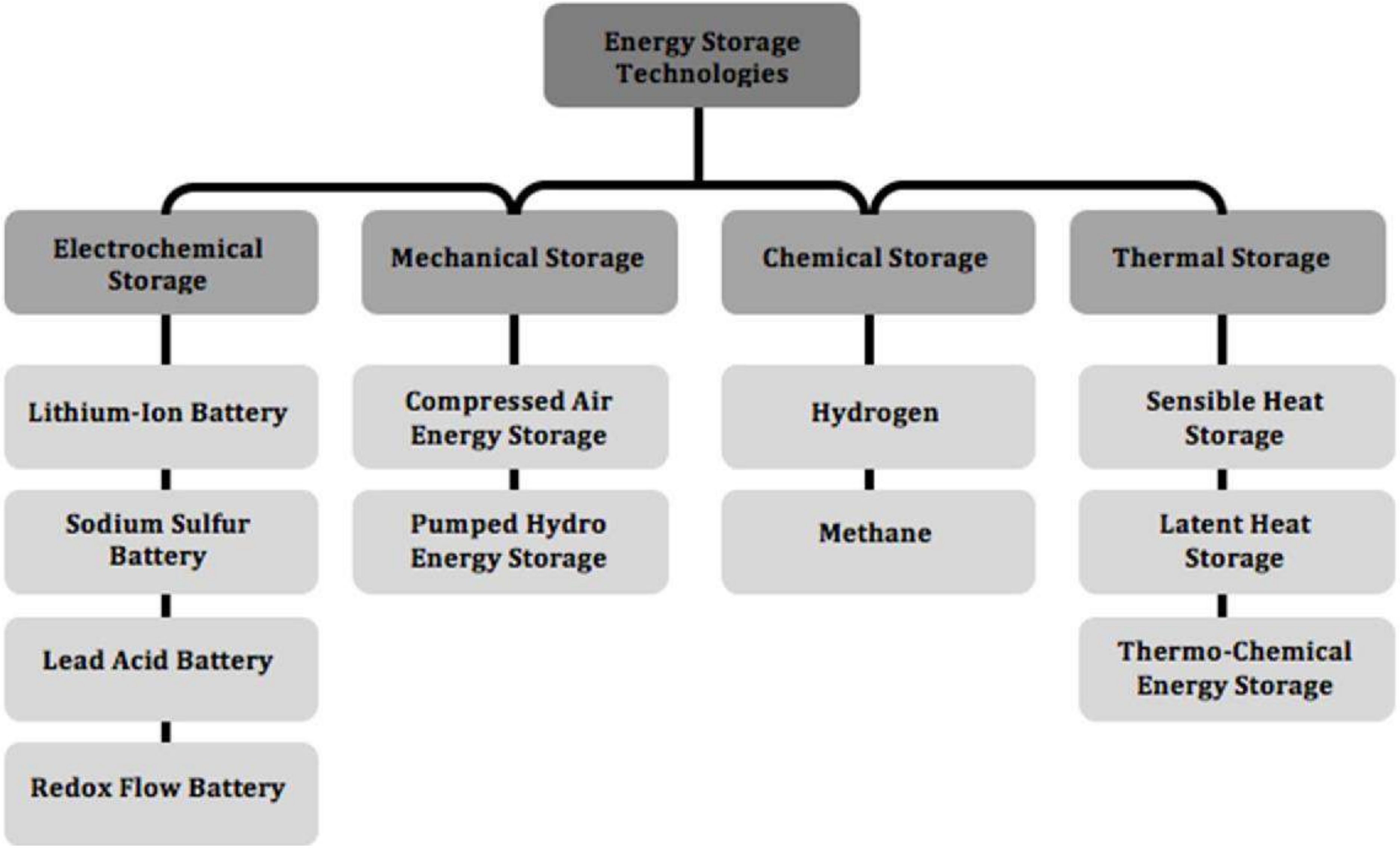
Greenhouse gas emissions – from carbon dioxide, methane, nitrous oxide, and F-gases – are summed up and measured in tonnes of carbon-dioxide equivalents (CO_2e), where “equivalent” means “having the same warming effect as CO_2 over a period of 100 years”. Emissions from land use change – which can be positive or negative – are taken into account.



Source: CAIT Climate Data Explorer via. Climate Watch

What are the Disadvantages of Greenhouse Effect?




Energy Storage Technologies
Electrochemical Storage
Mechanical Storage
Chemical Storage
Thermal Storage
Lithium-Ion Battery
Sodium Sulfur Battery
Lead Acid Battery
Redox Flow Battery
Compressed Air Energy Storage
Pumped Hydro Energy Storage
Hydrogen
Methane
Sensible Heat Storage
Latent Heat Storage
Thermo-Chemical Energy Storage

The 5 Most Promising Long-Duration Storage Technologies

1. Pumped hydro

This gravity-based concept physically moves water from a low to a high reservoir, from which the water descends, when needed, to generate electricity.

2. Stacked blocks

Instead of using batteries or pumping water, you stored surplus power by automating a six-armed robotic crane to stack thousands of purpose-built, 35-metric-ton monoliths into a Babel-like tower and drop them down again when you needed to release the power?

3. Liquid air

The company's mechanism cools down air and stores it in pressurized above-ground tanks. The compression equipment and power generators come from established supply chains in mature industries. The technological innovation here is using them for grid storage.

4. Underground compressed air

The basic concept is to use excess electricity to pump compressed air into a suitable underground formation that acts like a giant storage tank. Releasing the pressurized air allows the plant to re-generate electricity when needed.

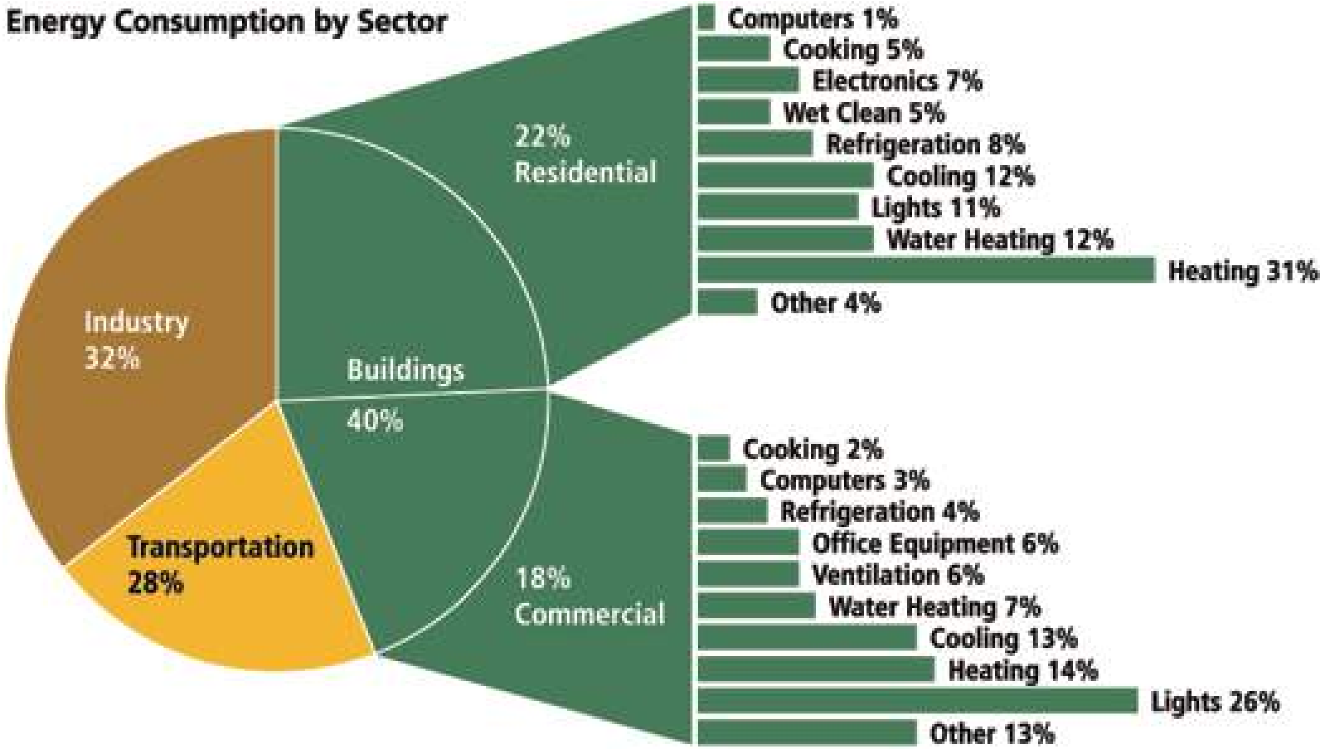
5. Flow batteries

A flow battery, or redox flow battery, is a type of electrochemical cell where chemical energy is provided by two chemical components dissolved in liquids that are pumped through the system on separate sides of a membrane.

Storage system	Life[cycles]	Efficiency [%]
Pumped Hydro	75 Years	70-80
Compressed air	40 Years	
Flow Batteries	1500-2500	75-85
Metal-Air	100-200	50
NAS	2000-3000	89
Other advanced batteries	500-1500	90-95
Lead-Acid	200-300	75
Supercapacitors	10'000-100'000	93-98

Improved energy storage technologies have several benefits:

1. **Security**: A more efficient grid that is more resistant to disruptions.
2. **Environment**: Decreased carbon dioxide emissions from a greater use of clean electricity.
3. **Economy**: Increase in the economic value of wind and solar power and strengthened U.S. competitiveness in the clean energy race.
4. **Jobs**: New income sources for rural landowners and tax revenues for wind and solar development areas. More jobs in supporting sectors such as manufacturing, engineering, construction, transportation and finance.



The buildings and buildings construction sectors combined are responsible for over one-third of global final energy consumption and nearly 40% of total direct and indirect CO2 emissions. Energy demand from buildings and buildings construction continues to rise, driven by improved access to energy in developing countries, greater ownership and use of energy-consuming devices, and rapid growth in global buildings floor area.

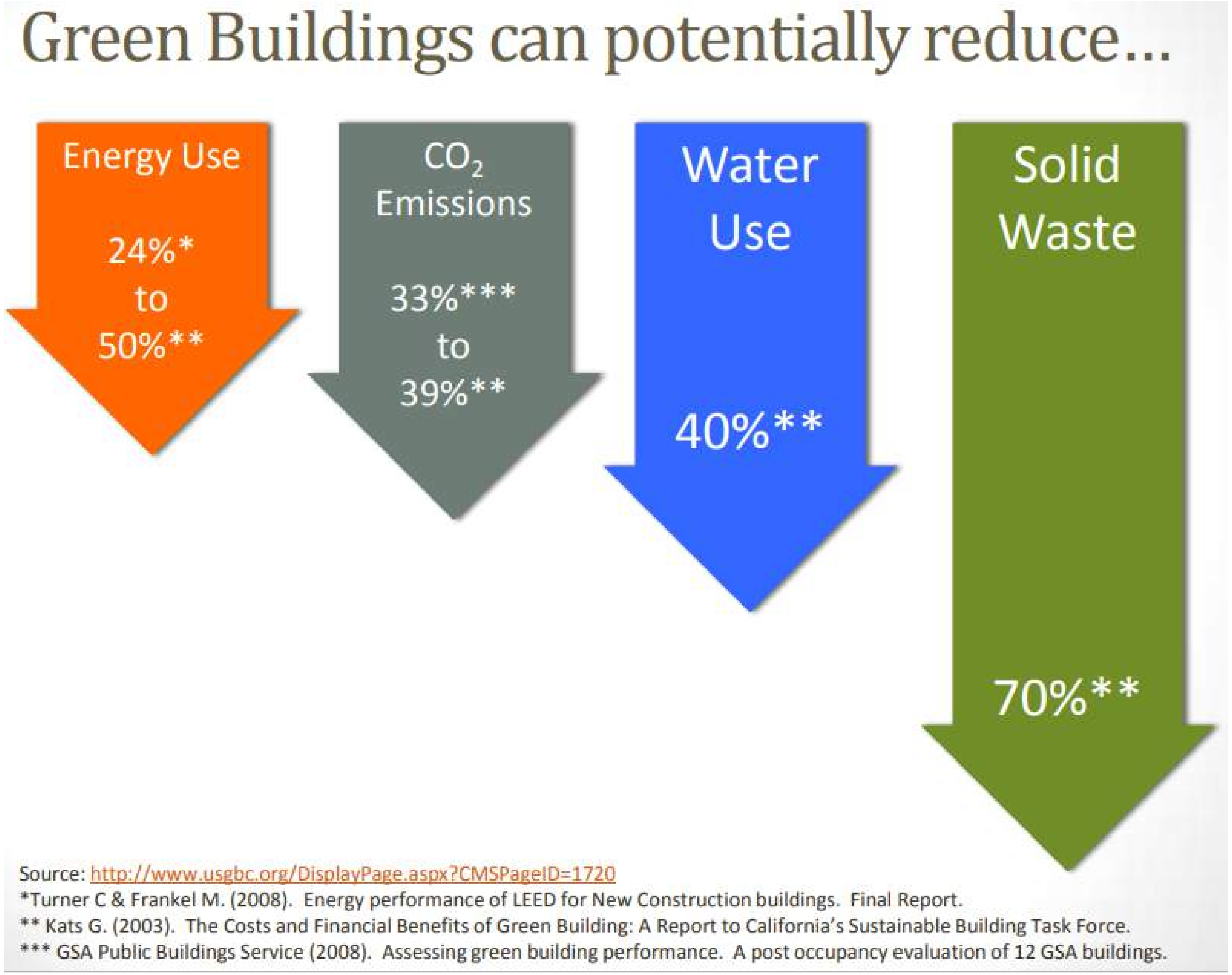
What are Green Buildings?
Green buildings are…
Buildings or homes that are more energy efficient, produce less waste and are healthier to be inside

Green buildings don’t literally mean…
Buildings that produce zero-emissions or totally green or totally environmentally friendly

Green building certification systems
Certification systems by different organizations/institutions that setup standards to quantify how ‘green’ a building is • Different standards world wide, but similar in concept.

Green Building Certifications

- Australia: Nabers / Green Star
- Brazil: AQUA / LEED Brasil
- Canada: LEED Canada / Green Globes / Built Green Canada
- China: GBAS
- Finland: PromisE
- France: HQE
- Germany: DGNB / CEPHEUS
- Hong Kong: HKBEAM
- India: Indian Green Building Council (IGBC) / GRIHA
- Indonesia: Green Building Council Indonesia (GBCI) / Greenship
- Italy: Protocollo Itaca / Green Building Council Italia
- Japan: CASBEE
- Korea: KGBC
- Malaysia: GBI Malaysia
- Mexico: LEED Mexico
- Netherlands: BREEAM Netherlands
- New Zealand: Green Star NZ
- Philippines: BERDE / Philippine Green Building Council
- Portugal: Lider A
- Qatar: QSAS
- Republic of China (Taiwan): Green Building Label
- Singapore: Green Mark
- South Africa: Green Star SA
- Spain: VERDE
- Switzerland: Minergie
- United States: LEED / Living Building Challenge / Green Globes / Build it Green / NAHB NGBS / International Green Construction Code (IGCC) / ENERGY STAR
- United Kingdom: BREEAM
- United Arab Emirates: Estidama
- IAPGSA Pakistan Institute of Architecture Pakistan Green Sustainable Architecture
- Jordan: EDAMA
- Czech Republic: SBToolCZ



Perceived Business Benefits to Going Green

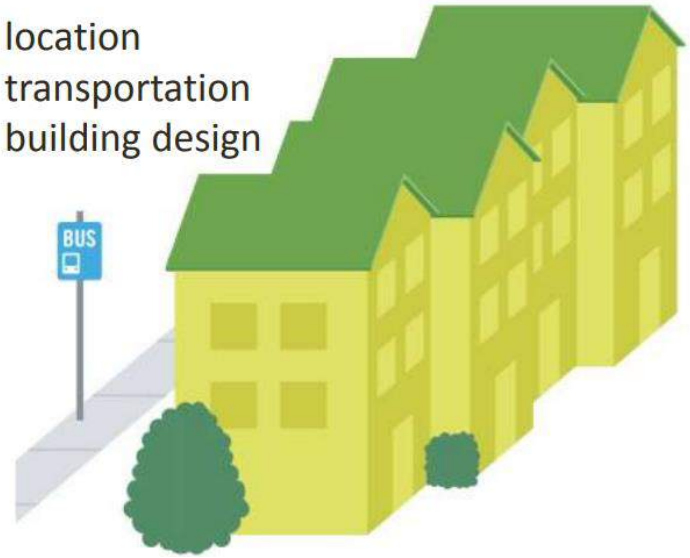
- Researches found…
- 8-9% operating cost decreases
- 7.5% building value increases
- 6.6% return on investment improves
- 3.5% occupancy rate increases
- 3% rent ratio increases

Other benefits

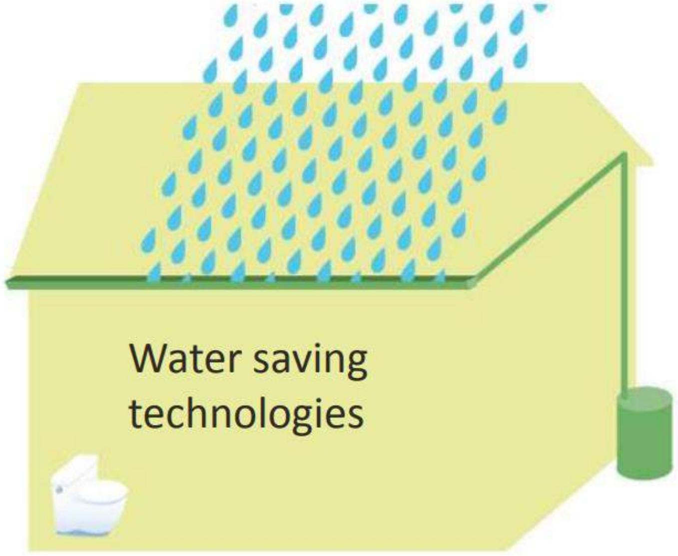
- Green building occupants are healthier and more productive
- In the U.S., people spend, on average, 90% or more of their time indoors
- Green buildings typically have better indoor air quality and lighting

Dimensions of being 'Green'

Sustainable Sites (SS) and Location & Linkages (LL)

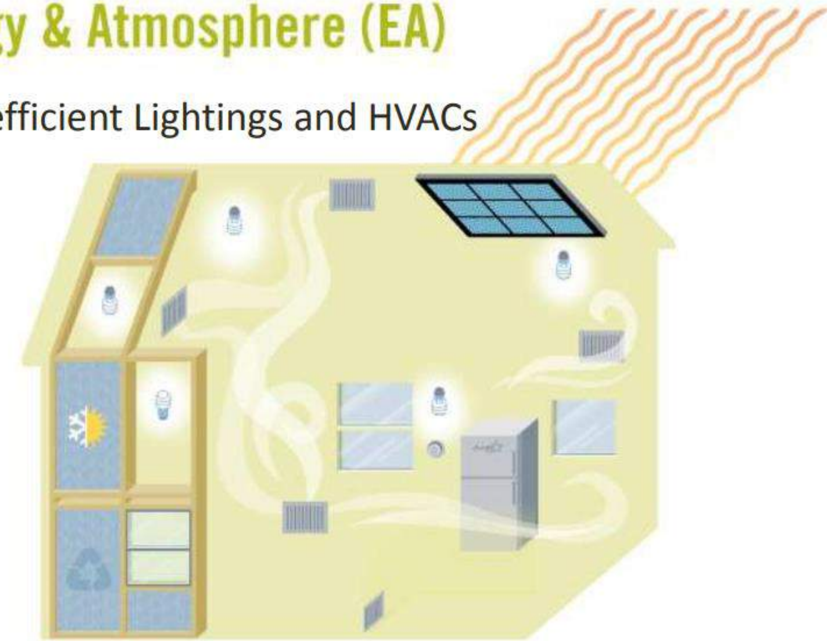


Water Efficiency (WE)



Energy & Atmosphere (EA)

Highly efficient Lightings and HVACs

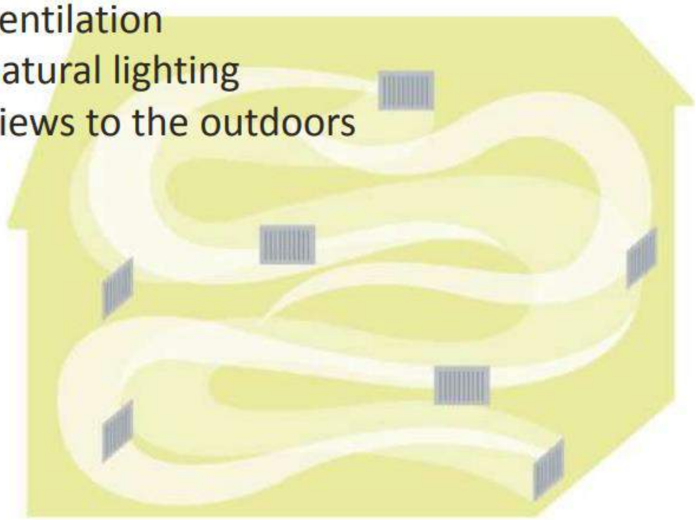


Materials & Resources (MR)

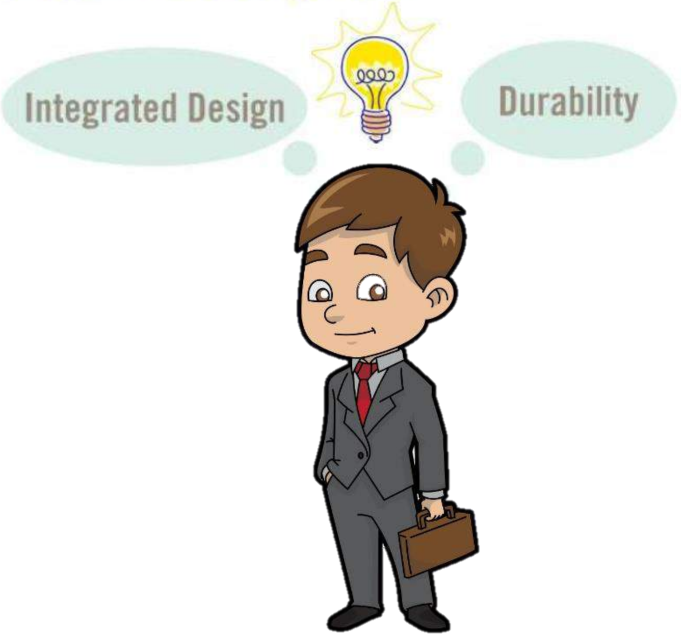
Environmentally friendly materials
Good waste management plans
Recycling programs

Indoor Environmental Quality (EQ)

Clean breathing air
Good ventilation
Good natural lighting
Good views to the outdoors



Innovation & Design (ID)



LEED Green Building Certification

- LEED stands for…
  - Leadership in Energy and Environmental Design
- Developed by the U.S. Green Building Council (USGBC) in 2000
- A U.S. green building certification standard also used by numerous projects outside the U.S.
  - One of the most well known standards

LEED Green Building Rating System™

- LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: :
- Sustainable site development.
- Water savings.
- Energy efficiency.
- Materials selection.
- Indoor environmental quality.

LEED has 4 levels of certificates

LEED CERTIFIED

LEED SILVER

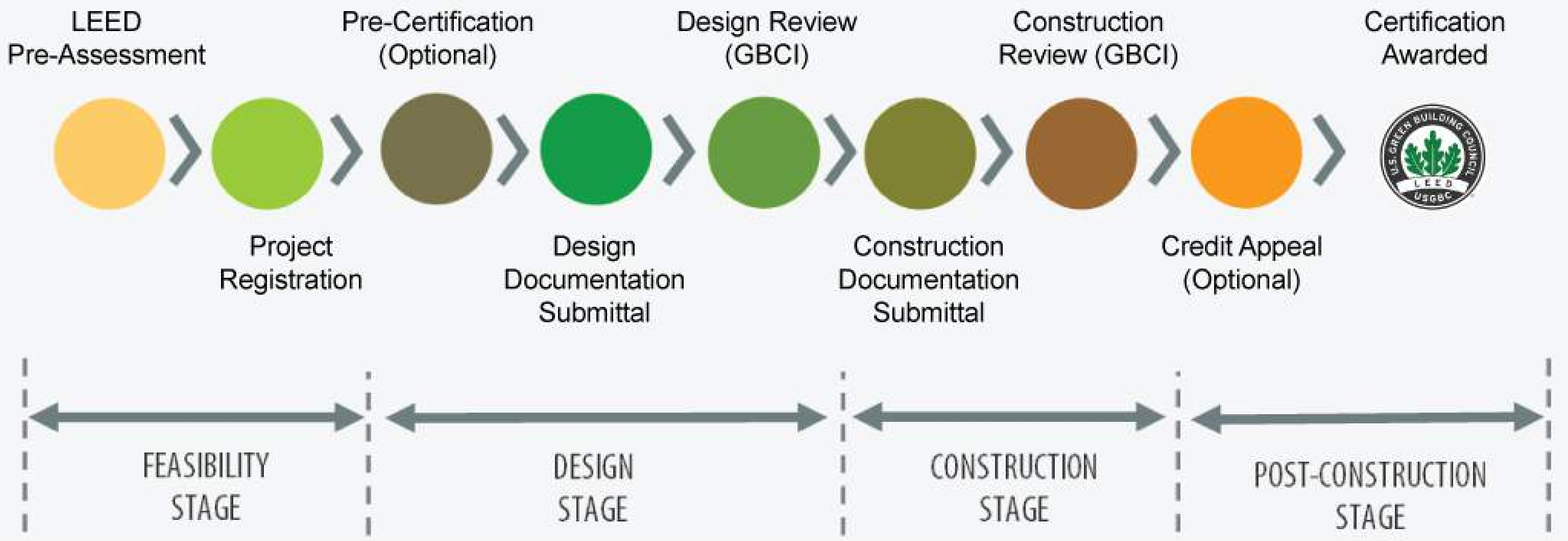
LEED GOLD

LEED PLATINUM

Less Points → More Points


Types of LEED certifications
HOMES
NEIGHBORHOOD DEVELOPMENT (IN PILOT)
COMMERCIAL INTERIORS
CORE & SHELL
NEW CONSTRUCTION
SCHOOLS, HEALTHCARE, RETAIL
EXISTING BUILDINGS
OPERATIONS & MAINTENANCE
DESIGN
CONSTRUCTION
OPERATIONS
Source: http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1988


LEED CERTIFICATION REQUIREMENTS
In order to achieve LEED certification, projects must earn points in these categories:
U.S. GREEN BUILDING COUNCIL
LEED
USGBC
Innovation
Introduction of novel features and procedures
Indoor Environmental Quality
Use of natural light and efficient air conditioning
Materials and Resources
Responsible construction waste management and sustainable sourcing of materials
Location and Transportation
Land protection and access to public transporation and green vechicles
Sustainable Sites
Sufficient green open space and light pollution reduction
Energy and Atmosphere
Optimizing sustainable energy production and metering
Water Efficiency
Indoor and outdoor water reduction
Source: www.usgbc.org



LEED rating system - Certification process

LEED Credit Categories

Sustainability in Buildings

"Sustainable building design should aim to provide a balanced solution, offering optimum working/living conditions, alongside reduced environmental impact, both now and in the future. Taking the complete building lifecycle into consideration, there are many factors involved, from the location of the building, its design, subsequent operation and maintenance, to the construction materials and practices used, and how any future changes of use are addressed."

D. McLean (IET)

Embodied Energy

"Embodied energy is the energy consumed by all of the processes associated with the production of a product. "

- Sum total of the energy necessary for an entire product;
- It's all the direct and indirect energy required to produce a product;
  - Extraction of resources needed through mining
  - Manufacturing of materials and equipment
  - Transportation and product delivery

Types of embodied energy

- ***Initial embodied energy;*** and
- ***Recurring embodied energy***

The ***initial embodied energy*** in buildings represents the **non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site, and construction.** This initial embodied energy has two components:

Direct energy the energy used to transport building products to the site, and then to construct the building; and

Indirect energy the energy used to acquire, process, and manufacture the building materials, including any transportation related to these activities.

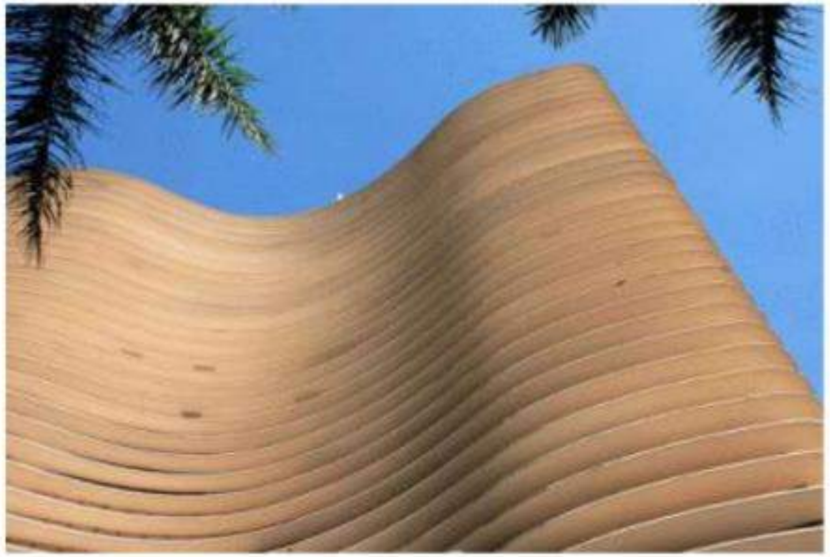
RECURRING EMBODIED ENERGY

The ***recurring embodied energy*** in buildings represents the **non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the building.**

How is embodied energy measured?

Embodied energy is measured as the quantity of non-renewable energy per unit of building material, component or system.

It is expressed in megajoules (MJ) or gigajoules (GJ) per unit weight (kg or tonne) or area (m^2) but the process of calculating embodied energy is complex and involves numerous sources of data.



UNITS OF MEASUREMENT

- Standard Unit for Embodied Energy: MJ/ kg material

Functional units:
MJ/ m^3 material

- Standard Unit for Carbon emissions: Kg CO_2/ kg material

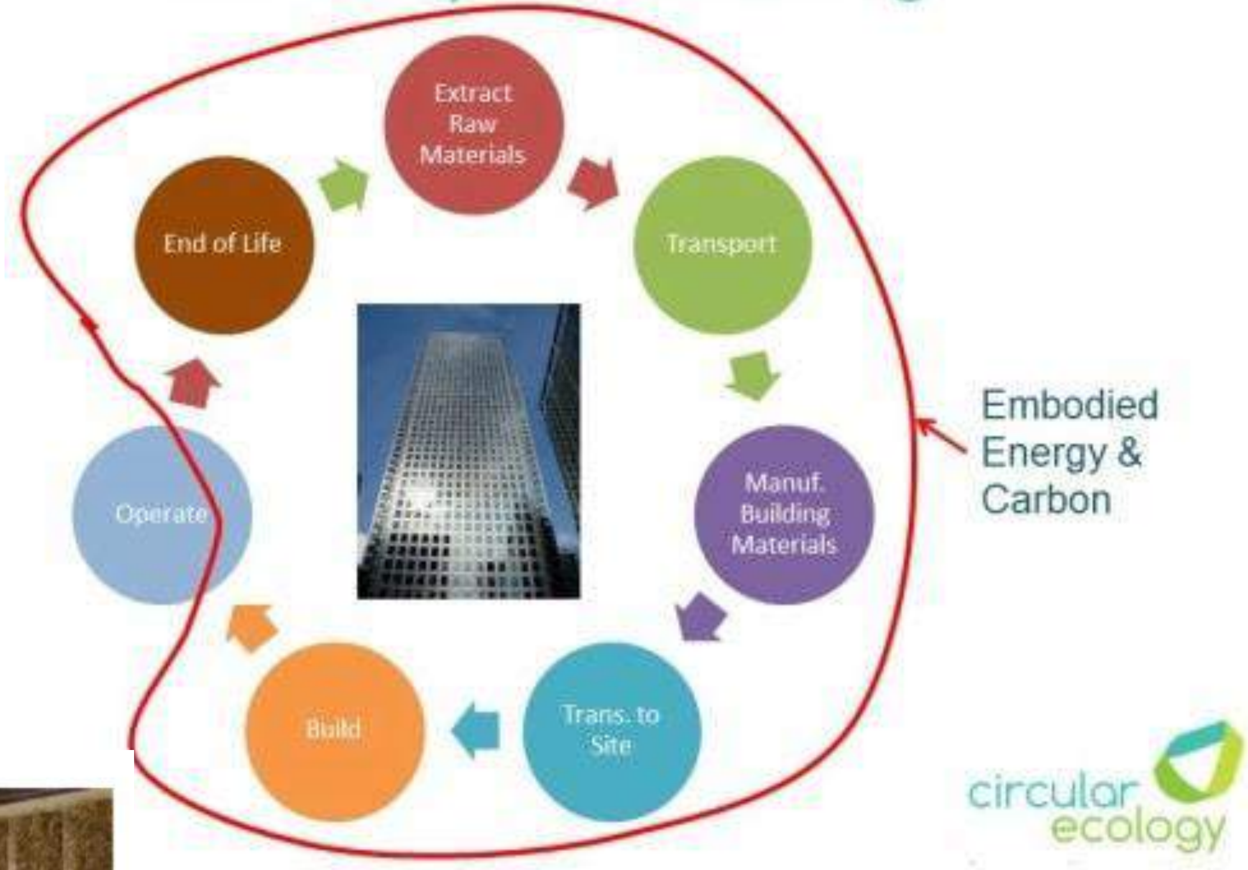
Kg CO_2/ m^3 material

Energy consumption in buildings occurs in five phases.

- The first phase corresponds to the manufacturing of building materials and components, which is termed as embodied energy.

- The **second and third phases correspond to the energy used to transport materials from production plants** to the building site and the energy used in the actual construction of the building, which is respectively referred to as grey energy and induced energy.

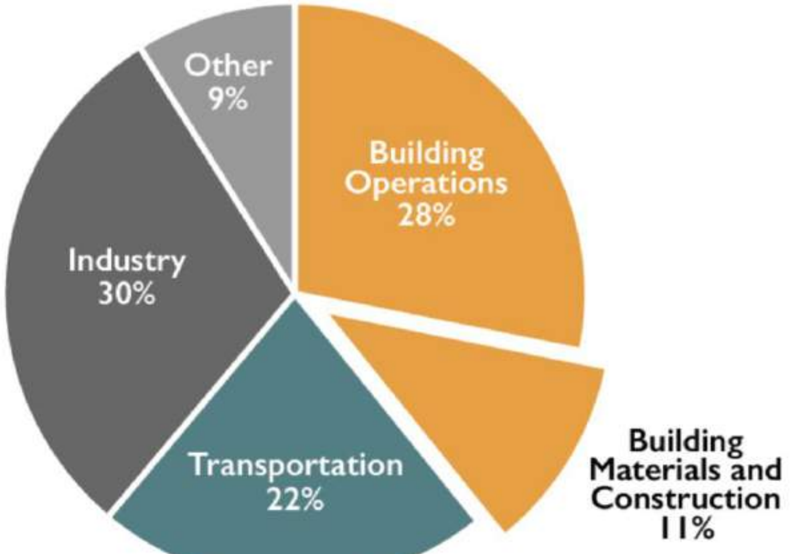
Embodied Energy and Carbon
The Life Cycle of a Building



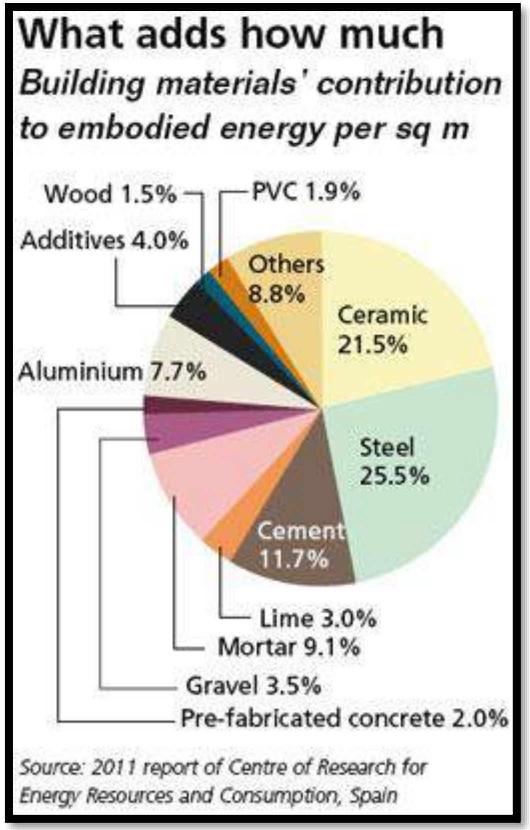
- Fourthly, **energy is consumed at the operational phase**, which corresponds to the running of the building when it is occupied.

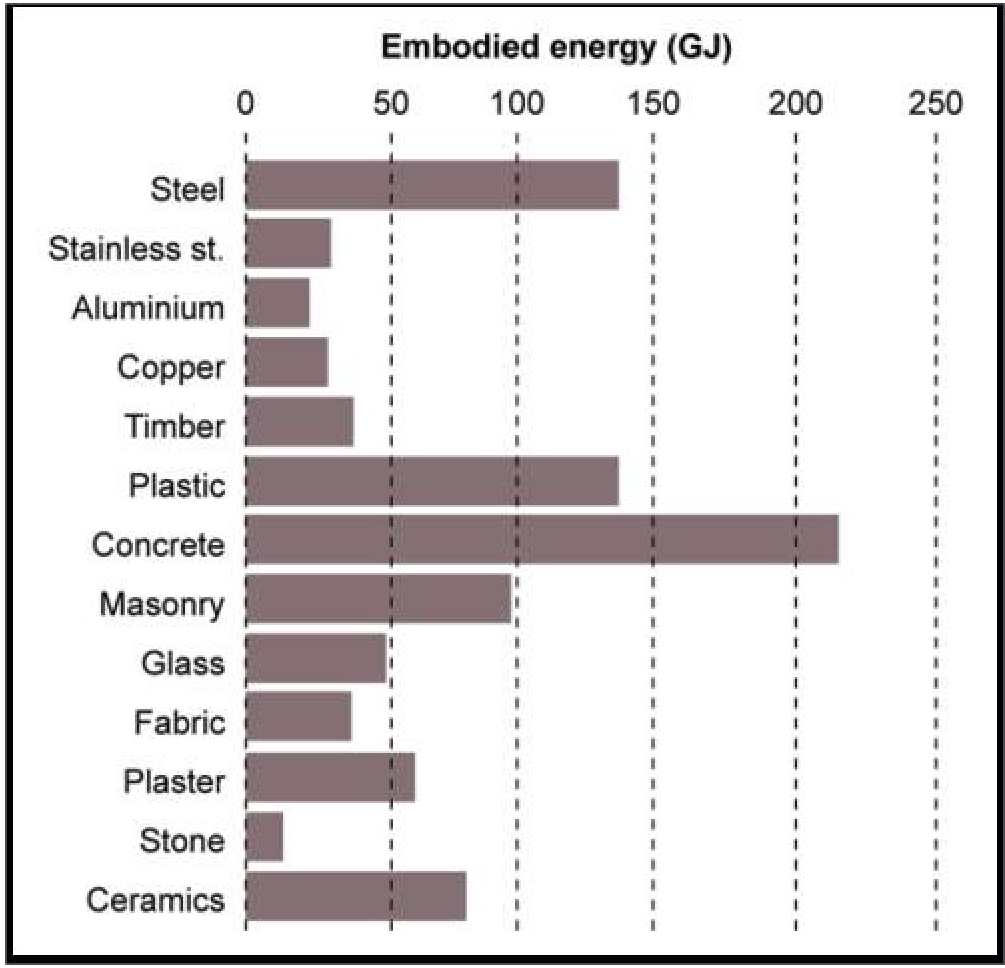
- Finally, **energy is consumed in the demolition process of buildings as well as in the recycling of their parts, when this is promoted.**

Global CO_2 Emission by Sector



Source: © 2018 2030, Inc. / Architecture 2030. All Rights Reserved. Data Sources: UN Environment Global Status Report 2017; EIA International Energy Outlook 2017





Embodied energy depends on:

- efficiency of the individual manufacturing process
- the fuels used in the manufacture of the materials
- the distances materials are transported
- the amount of recycled product used.

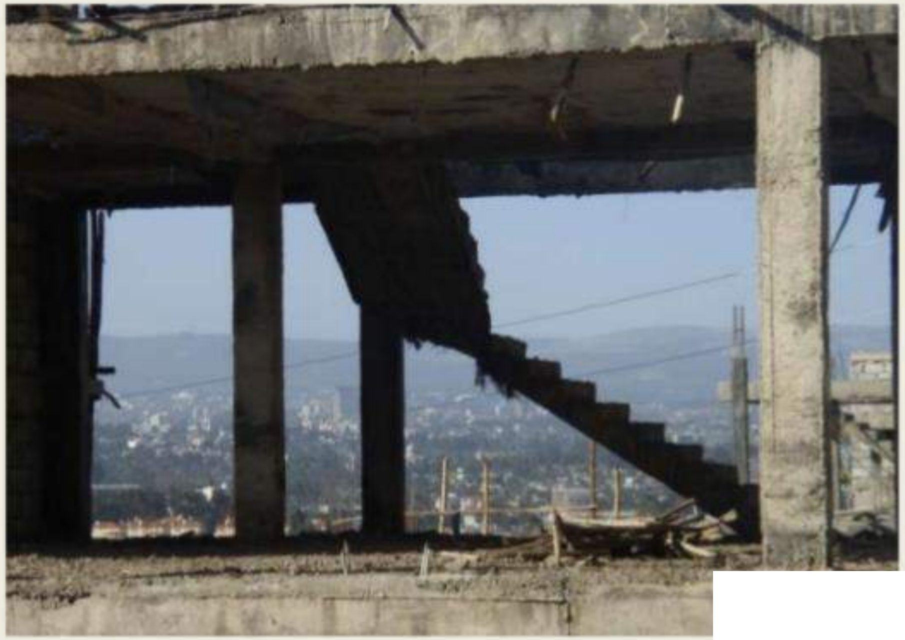
When selecting building materials, the embodied energy should be considered with respect to:

1. the durability of building materials
2. how easily materials can be separated
3. use of locally sourced materials
4. use of recycled materials
5. specifying standard sizes of materials
6. avoiding waste
7. selecting materials that are manufactured using renewable energy sources.

Cities take about 2 % of the land surface but consume 75 % of the world's natural resources.

- Buildings account for 30 to 40% of total global energy usage. (United Nations Environmental Programme)

- The construction sector is responsible for :
- 40% of the consumed resources
- 40% of CO_2 emissions
- 40% of waste (construction and demolition) (UNCHS/ Habitat)



Guidelines for reducing embodied energy

1. **Design for long life and adaptability, using durable low maintenance materials.**
2. Ensure materials can be easily separated.
3. Modify or refurbish instead of demolishing or adding.
4. **Ensure construction wastes and materials from demolition of existing buildings are reused or recycled.**
5. Use locally sourced materials (including materials salvaged on site) to reduce transport.
6. **Select low embodied energy materials (which may include materials with a high recycled content), preferably based on supplier-specific data.**

Construction technique for low embodied energy

Filler Slab

Employ replacing unproductive concrete by a 'Filler' material which reduces weight & cost of slab by reducing amount of concrete used. Also, since weight of slab is thus reduced, lesser steel is required for reinforcement, further reducing cost.

Laying Earthen Pots as Filler material

THE WALL HOUSE, Auromodele

Design Features

- compactly accommodated everyday needs whilst effortlessly expanding
- redefined borders and transitional spaces in response to the climatic conditions, contemporary culture.
- local materials in new and inventive ways given the global resource crunch and rapid urbanisation.
- Landscape design worked with the topography to integrate the indoor-outdoor transition as an integral experience
- balance between hi-tech and low-tech and everyday materials
- techniques that include the participation of those with lower skills and education with few skilled craftsmen

Definition of Energy Audit

- **As per Indian Energy Conservation Act 2001, Energy Audit is defined as:**

"the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption "

Why the Need for Energy Audit

- The three top operating expenses are energy (both electrical and thermal), labour and materials.
- Energy would emerge as a top ranker for cost reduction
- primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs
- Energy Audit provides a " bench-mark" (Reference point) for managing energy in the organization

Types of Energy Audits

1. Preliminary Energy Audit
2. Targeted Energy Audit
3. Detailed Energy Audit

Preliminary Energy Audit

- Preliminary energy audit uses existing or easily obtained data
- Find out the energy consumption area in the organization
- Estimates the scope for saving
- Identifies the most likely areas for attention
- Identifies immediate(no cost or low cost) improvements
- Sets a 'reference point'
- Identifies areas for more detailed study/measurement

Targeted Energy Audits

- Targeted energy audits are mostly based upon the outcome of the preliminary audit results.
- They provide data and detailed analysis on specified target projects.
- As an example, an organization may target its lighting system or boiler system or compressed air system with a view to bring about energy savings.
- Targeted audits therefore involve detailed surveys of the target subjects/areas with analysis of the energy flows and costs associated with those targets.

Detailed Energy Audit

Detailed Energy Audit evaluates all systems and equipment which consume energy and the audit comprises a detailed study on energy savings and costs.

Detailed Energy Audit is carried out in 3 phases

- The Pre-audit Phase
- The Audit Phase
- The Post-Audit Phase

The Ten Steps for Detailed Audit

Step No	PLAN OF ACTION	PURPOSE / RESULTS
	Phase I –Pre Audit Phase	
Step 1	• Plan and organise • Walk through Audit • Informal Interview with Energy Manager, Production / Plant Manager	• Resource planning, Establish/organize a Energy audit team • Organize Instruments & time frame • Macro Data collection (suitable to type of industry.) • Familiarization of process/plant activities • First hand observation & Assessment of current level operation and practices
Step 2	• Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.)	• Building up cooperation • Issue questionnaire for each department • Orientation, awareness creation

	Phase II –Audit Phase	
Step 3	• Primary data gathering, Process Flow Diagram, & Energy Utility Diagram	• Historic data analysis, Baseline data collection • Prepare process flow charts • All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution. • Design, operating data and schedule of operation • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview)
Step 4	• Conduct survey and monitoring	• Measurements : Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data.

Step 5	• Conduct of detailed trials /experiments for selected energy guzzlers	• Trials/Experiments: - 24 hours power monitoring (MD, PF, kWh etc.). - Load variations trends in pumps, fan compressors etc. - Boiler/Efficiency trials for (4 – 8 hours) - Furnace Efficiency trials Equipments Performance experiments etc
Step6	• Analysis of energy use	• Energy and Material balance & energy loss/waste analysis
Step 7	• Identification and development of Energy Conservation (ENCON) opportunities	• Identification & Consolidation ENCON measures ▪ Conceive, develop, and refine ideas ▪ Review the previous ideas suggested by unit personal ▪ Review the previous ideas suggested by energy audit if any ▪ Use brainstorming and value analysis techniques ▪ Contact vendors for new/efficient technology
Step 8	• Cost benefit analysis	• Assess technical feasibility, economic viability and prioritization of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step9	• Reporting & Presentation to the Top Management	Documentation, Report Presentation to the top Management.
Step10	Phase III –Post Audit phase • Implementation and Follow-up	Assist and Implement ENCON recommendation measures and Monitor the performance ▪ Action plan, Schedule for implementation ▪ Follow-up and periodic review

Questions which an Energy Auditor should ask

- What function does this system serve?
- How does this system serve its function?
- What is the energy consumption of this system?
- What are the indications that this system is working properly ?
- If this system is not working, how can it be restored to good working conditions/
- How can the energy cost of this system be reduced?

DETAILED ENERGY AUDIT
A TYPICAL INDUSTRIAL FORMAT OF REPORT

Energy Audit Team
Executive Summary –Scope & Purpose

Energy Audit Options & Recommendations
1.0 Introduction about the plant
- 1.1 General Plant details and descriptions
- 1.2 Component of production cost (Raw materials, energy, chemicals, manpower, overhead, others)
- 1.3 Major Energy use and Areas

2.0 Production Process Description
- 2.1 Brief description of manufacturing process
- 2.2 Process flow diagram and Major Unit operations
- 2.3 Major Raw material Inputs, Quantity and Costs

3.0 Energy and Utility System Description
- 3.1 List of Utilities
- 3.2 Brief Description of each utility
  - 3.2.1 Electricity
  - 3.2.2 Steam
  - 3.2.3 Water
  - 3.2.4 Compressed air
  - 3.2.5 Chilled water
  - 3.2.6 Cooling water

4.0 Detailed Process flow diagram and Energy& Material balance
- 4.1 Flow chart showing flow rate, temperature, pressures of all input-
  Output streams
  4Water balance for entire industry

5.0 Energy efficiency in utility and process systems
- 5.1 Specific Energy consumption
- 5.2 Boiler efficiency assessment
- 5.3 Thermic Fluid Heater performance assessments
- 5.4 Furnace efficiency Analysis
- 5.5 Cooling water system performance assessment
- 5.6 DG set performance assessment
- 5.7 Refrigeration system performance
- 5.8 Compressed air system performance
- 5.9 Electric motor load analysis
- 5.10 Lighting system

6.0 Energy Conservation Options & Recommendations
- 6.1 List of options in terms of no cost, low cost, medium cost and high cost, annual energy savings and payback
- 6.2 Implementation plan for energy saving measures/Projects

ANNEXURE
A1. List of instruments
A2. List of Vendors and Other Technical details

Understanding energy costs

An industrial energy bill summary

ENERGY BILL EXAMPLE			
Type of energy	Original units	Unit Cost	Monthly Bill (Rs)
Electricity	5,00,000 kWh	Rs.4.00/kWh	20,00,000
Fuel oil	200,kL	Rs.11,000 KL	22,00,000
Coal	1000 tons	Rs.2,200/ton	22,00,000
Total			64,00,000

Conversion to common unit of energy

Electricity	(1 kWh)	= 860 kcal/kWh	(0.0036 GJ)
Heavy fuel oil	(calorific value, GCV)	=10.000 kcal/litre	(0.0411 GJ/litre)
Coal	(calorific value, GCV)	=4000 kcal/kg	(28 GJ/ton)

INDIAN GREEN BUILDING COUNCIL

- The Indian Green Building Council (IGBC) was formed in the year 2001 by Confederation of Indian Industry (CII).
- The aim of the council is to bring green building movement in India and facilitate India to become one of the global leaders in green buildings by 2015.

IGBC RATING SYSTEM

- IGBC has developed green building rating programmes to cover commercial, residential, factory buildings, etc.
- Each rating system divided into different levels of certification are as follows:

➢ 'Certified' to recognise best practices.

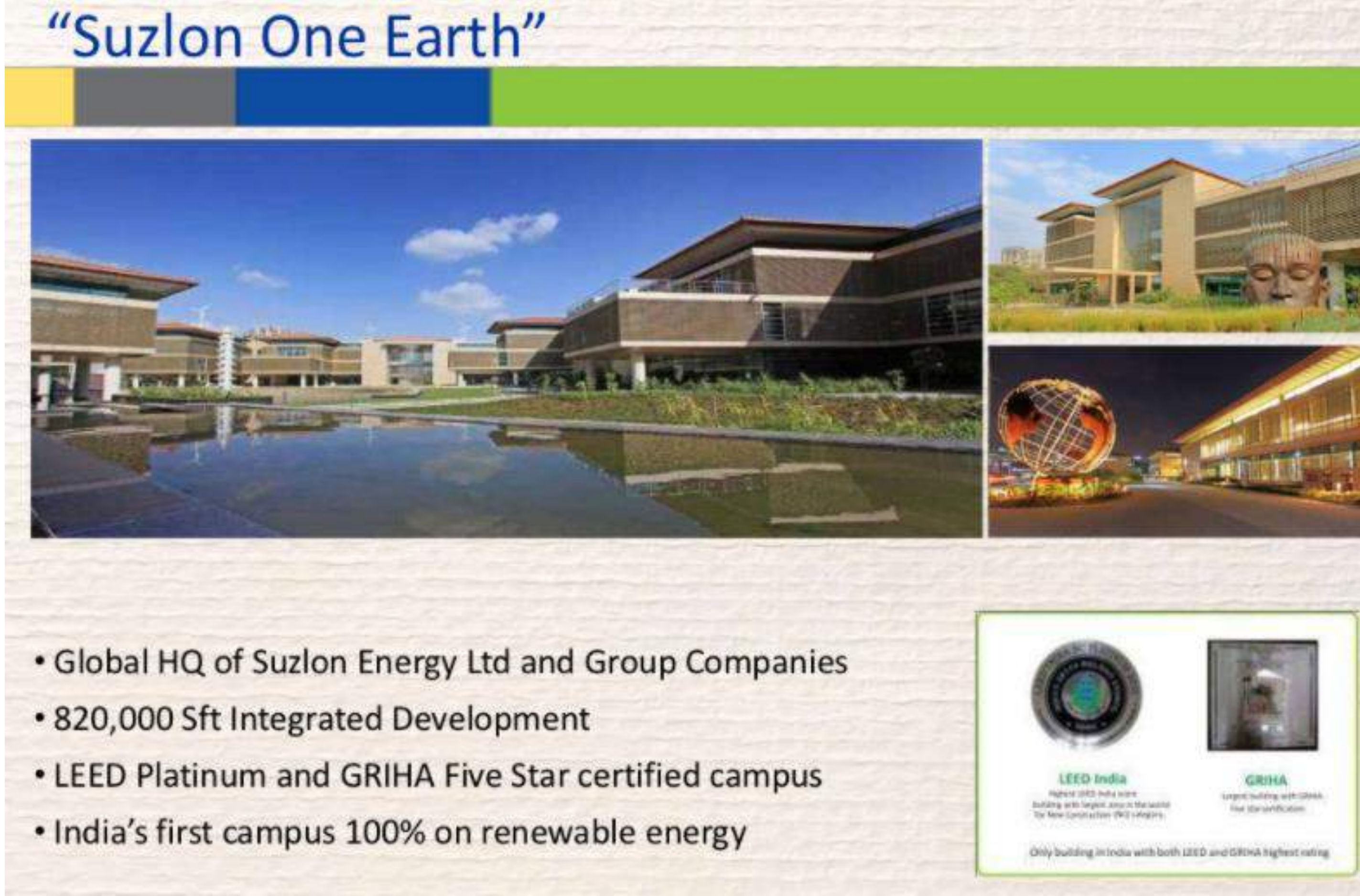
➢ 'Silver' to recognise outstanding performance.

➢ 'Gold' to recognise national excellence.

➢ 'Platinum' to recognise global leadership.

GREEN BUILDINGS PROJECT IN INDIA

- Suzlon Energy Limited-Pune
- Biodiversity Conservation India-Bangalore
- Olympia Technology Park-Chennai
- ITC Green Centre-Gurgaon
- The Druk White Lotus School-Ladakh
- Doon School-Dehradun
- Raintree Hotels-Chennai
- Nokia-Gurgaon
- Rajiv Gandhi International Airport-Hyderabad
- Hiranandini-BG House, Powai
- ABN Amro Bank, Chennai
- Palais Royale at Worli, Mumbai
- Punjab Forest Complex,Mohali



Suzlon One Earth –

One of the world's greenest campus was conceived and managed by Synefra

HALLMARK FEATURES OF THE PROJECT

ENERGY

Focus on renewable resources from construction to Operations and optimization of the needs at source

WATER

Focus on conserving methods from design to operations

WASTE

Focus on waste minimization from source and responsible disposal methods

MATERIAL

Focus on use of environment friendly and certified material through efficient sourcing

The result is an inspiring place to work, running on 100% renewable energy!

THE ENERGY ASPECTS

- **100% renewable energy Campus:** 155 kW on site wind solar hybrid system
  - Wind : 4.75 KW X 18 no. turbines
  - Solar PV : 0.23 KW X 243 Panels
  - BIPV : 0.105 KW X 128 Modules
- **100% External and Common area lighting, Indoor A/c units** and communication server on renewable energy resources
- Efficient envelope design with high performance glazing, over deck insulation, reduced interior light density, day light optimization.
- LED for outdoor and street lighting, occupancy sensors
- **1 year, renewable energy generated**
  - **on-site :*0.122 million* units**
  - **off-site: *4.26 million* units**

47%
Energy Savings

ENVIRONMENTAL ASPECTS

- **CO_2 sensors** in densely occupied spaces
- CO **sensors at parking**
- HVAC system designed for **30% higher ventilation rates** than ASHARE standards.
- Use of **low volatile emitting** adhesives, sealants, paints, carpet and composite wood products.
- The entire Campus is a **NO SMOKING** zone for overall health benefits and environmental quality improvement.

90%
Occupants use Daylight

WATER MANAGEMENT

- **100%** waste water treatment through **on site sewage treatment plant**
- **100%** use of recycled water for landscaping, air-conditioning and flushing
- Landscape with **naturalized and adapted plant species**
- **Innovative rain water harvesting system** -pebble drains to collect excess water
- Use of low flow faucets, touch less urinals with sensors and dual flush
- **Actual data for the year 2010-11 reveals that 0% water is disposed and around 56% water is recycled**

60%
Water Savings

WASTE MANAGEMENT

- Implementation of **Zero waste practices**
- **Waste segregation at source** where **bio degradable** waste processed in OWC on site system and **non-biodegradable waste** processed through approved and certified recycling vendors.
- Total organic waste generated from the campus during last year was 19,000 kg
- Generated **organic manure used for landscaping.**
- **Green housekeeping practices** with appropriate systems and certified products

85%
Recycle Waste

GREEN PRACTICES

- **Green Design Education** –through defined green awareness signage, Wind Gallery and open door policy for visitors on defined days
- **Green Housekeeping** : green housekeeping products and process are practiced
- Designed communication through customized and **commissioned artworks** with themes like motivation, sustainability, vision and team work.
- All systems are controlled and monitored with the centralized **Integrated Building Management System (IBMS)**

THE TEAM

- Chief Architect : Christopher Charles Benninger
- Integrated Design management : Tao Design
- Construction & Engineering : Vascon Engineers
- Interior Architecture, Engineering & Execution : Space Matrix in association with Tao Architecture
- Landscape Architect : Ravi Varsha Gavandi
- Communication Design : Elephant Design
- Sustainability Consultants : Environmental Design Solutions

https://www.youtube.com/watch?v=1-UpvqgeRkk
https://www.youtube.com/watch?v=vh4gZdFhGjc

THE ACHIEVEMENTS

LEED® Facts	
Suzlon One Earth Pune, India	
LEED - India for New Construction V 1.0	March 2010
Platinum	57*
Sustainable Sites	10/13
Water Efficiency	6/6
Energy & Atmosphere	14/17
Materials & Resources	7/13
Indoor Environmental Quality	15/15
Innovation & Design Process	5/5

***Out of a possible 69 points**

LEED India Platinum with 57 points

GRIHA Five star certification with 97 points