CH2356 Energy Engineering

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Solar Power

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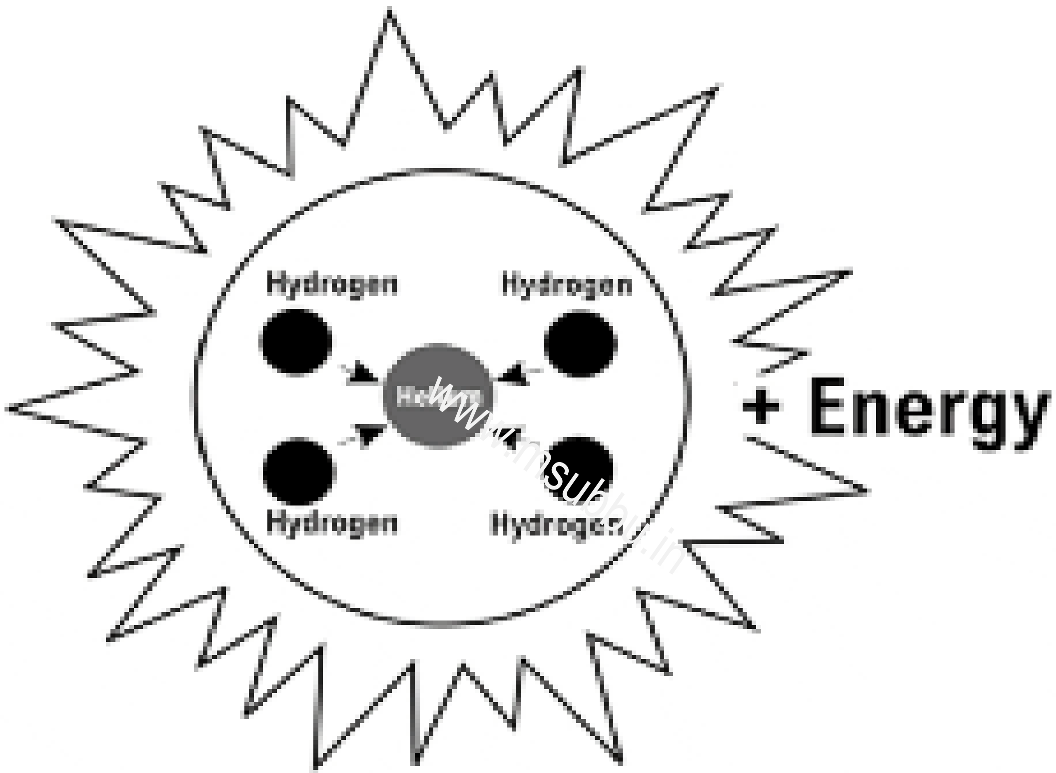


During a process called FUSION, four hydrogen atoms combine to form one helium atom, with a loss of matter. This matter is emitted as radiant energy.

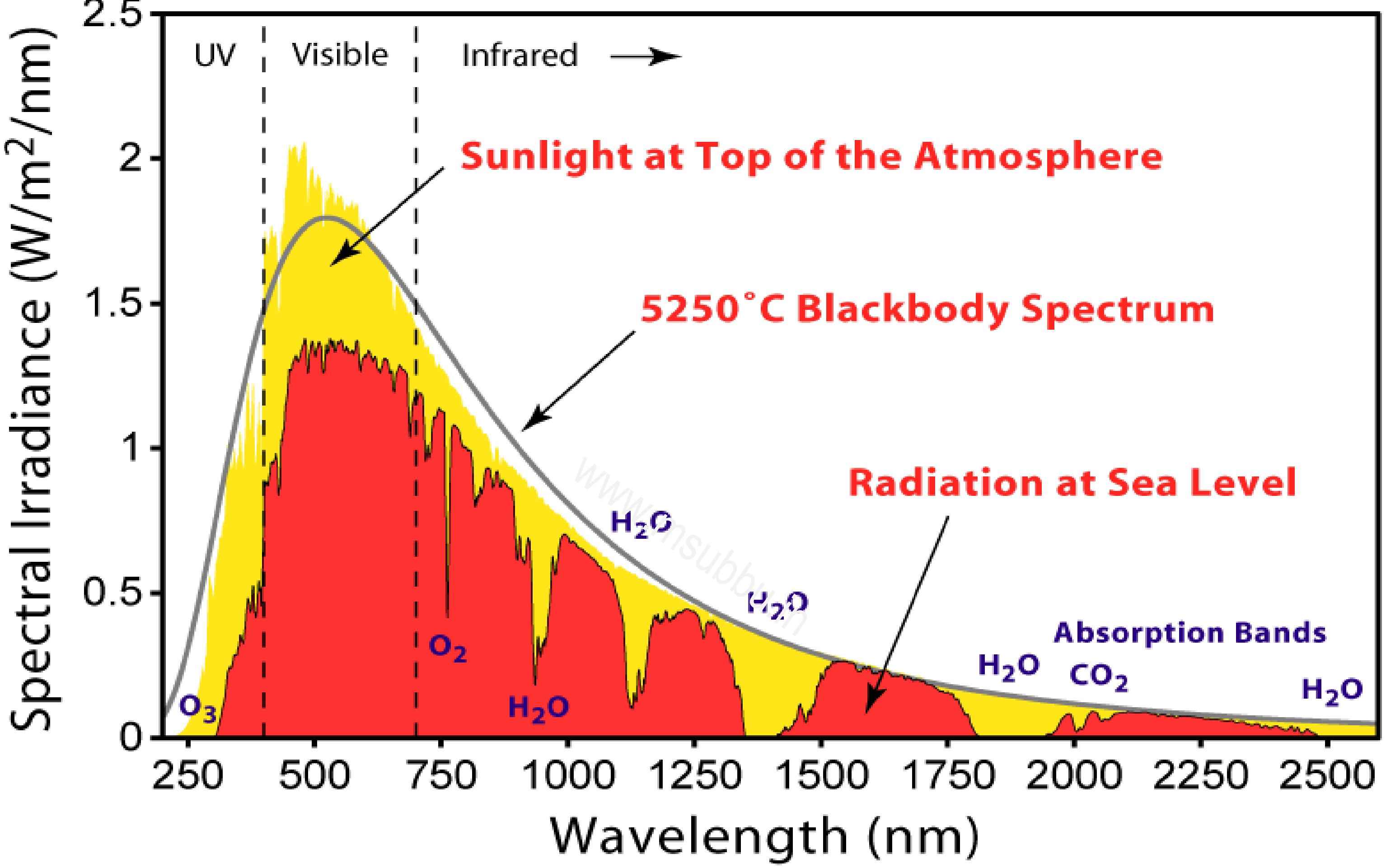
About Solar Energy

- Solar energy is the most ancient source, and it is the root material for almost all fossil and renewable types.
- Among the renewable energy sources, solar energy comes at the top of the list due to its abundance, and more evenly distribution in nature than any other renewable energy types such as wind, geothermal, hydro, wave and tidal energies.
- Approximately 1 % of the world's desert area utilized by solar thermal power plants would be sufficient to generate the world's entire electricity demand.

The Solar Spectrum

- Solar intensity outside the atmosphere: 1.36 kW/m^2
- Incident solar intensity on the atmosphere: 1.0 kW/m^2; due to absorption by water vapor, CO_2, etc.
- Radiation reaches the Earth's surface by direct radiation (focusable by mirrors) and diffuse radiation (unfocusable)
- The diffuse percentage is strongly dependent on how clear the sky is, and a typical yearly average if about 30%.

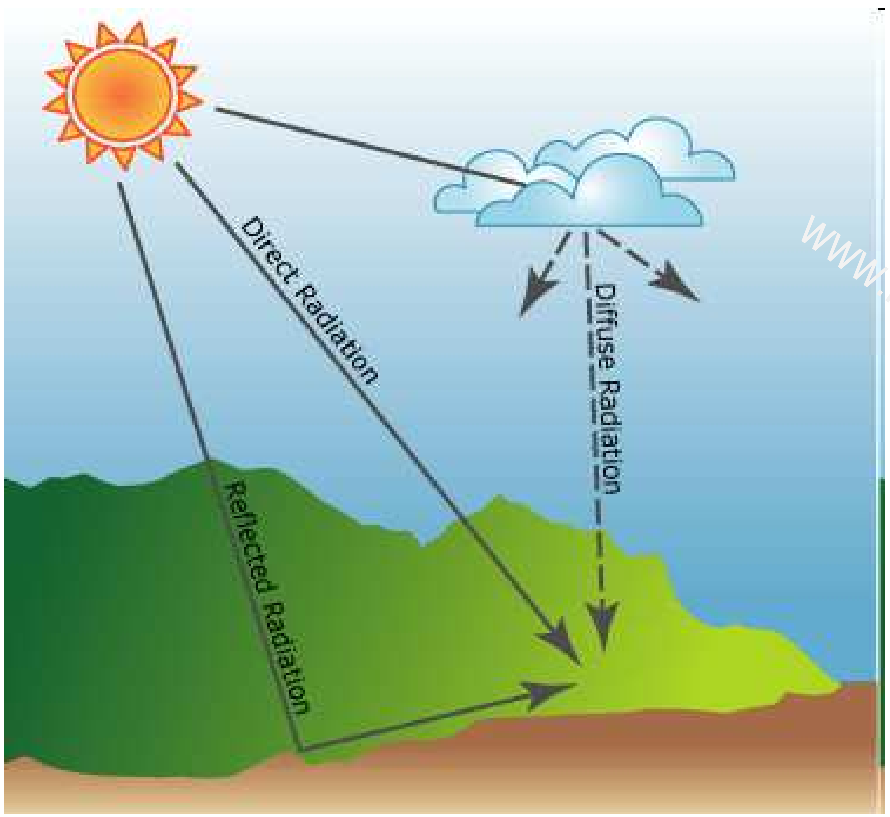
Solar Radiation Spectrum

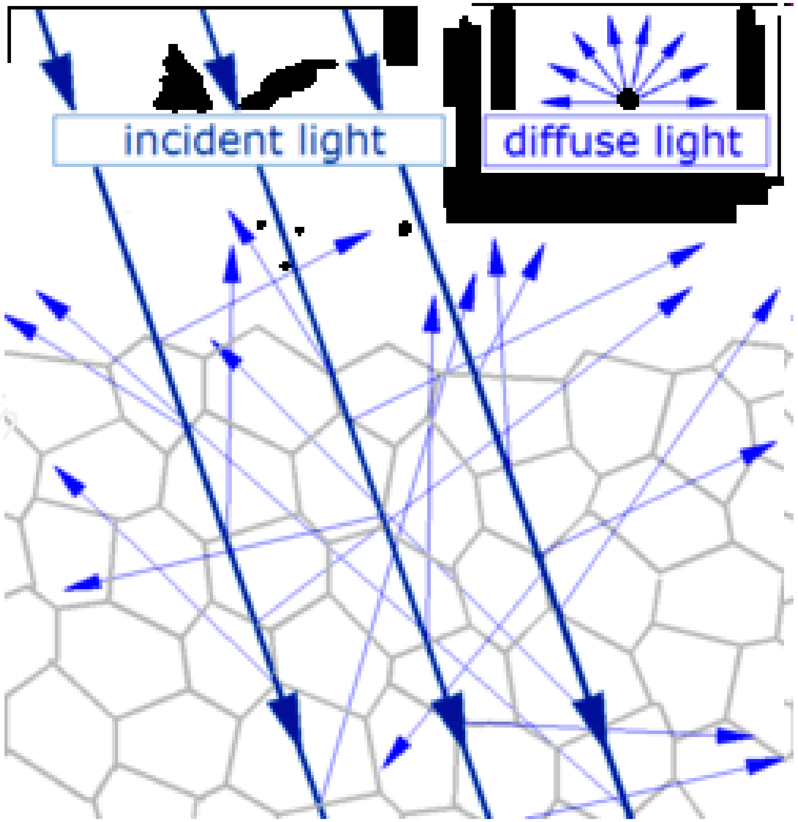


Solar intensity outside the atmosphere: 1.36 kW/m^2

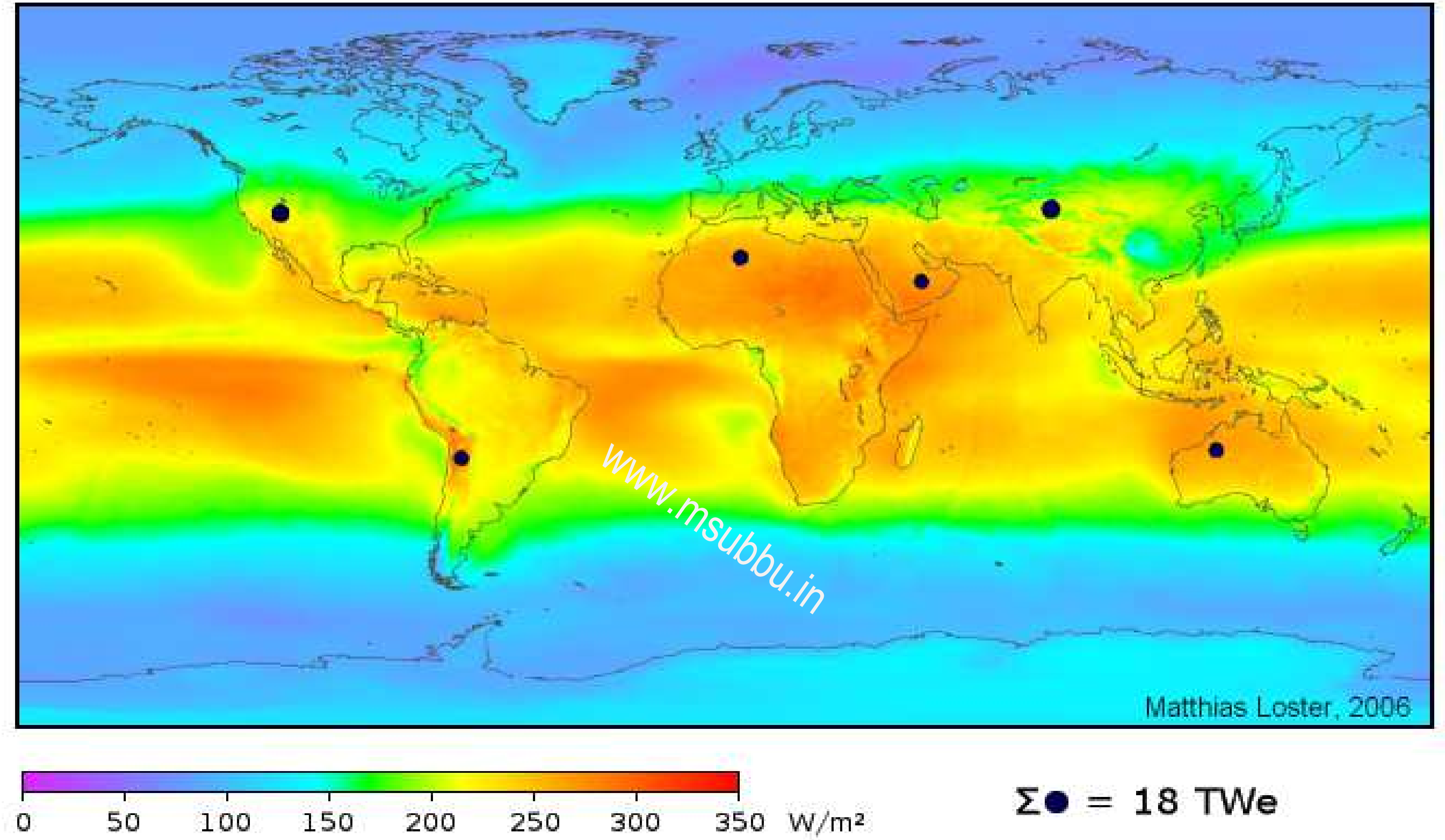
Incident solar intensity on the atmosphere: 1.0 kW/m^2; due to absorption by water vapor, CO_2, etc.

Direct and Diffuse Radiation





Solar Potential



Insolation for most part is from 150 to 300 W/m² or 3.5 to 7.0 kWh/m²/day.

World's solar potential is about 100,000 TW. The small black dots show the area of solar panels needed to generate all of the world's energy using 8% efficient photovoltaics.

Solar Map of India

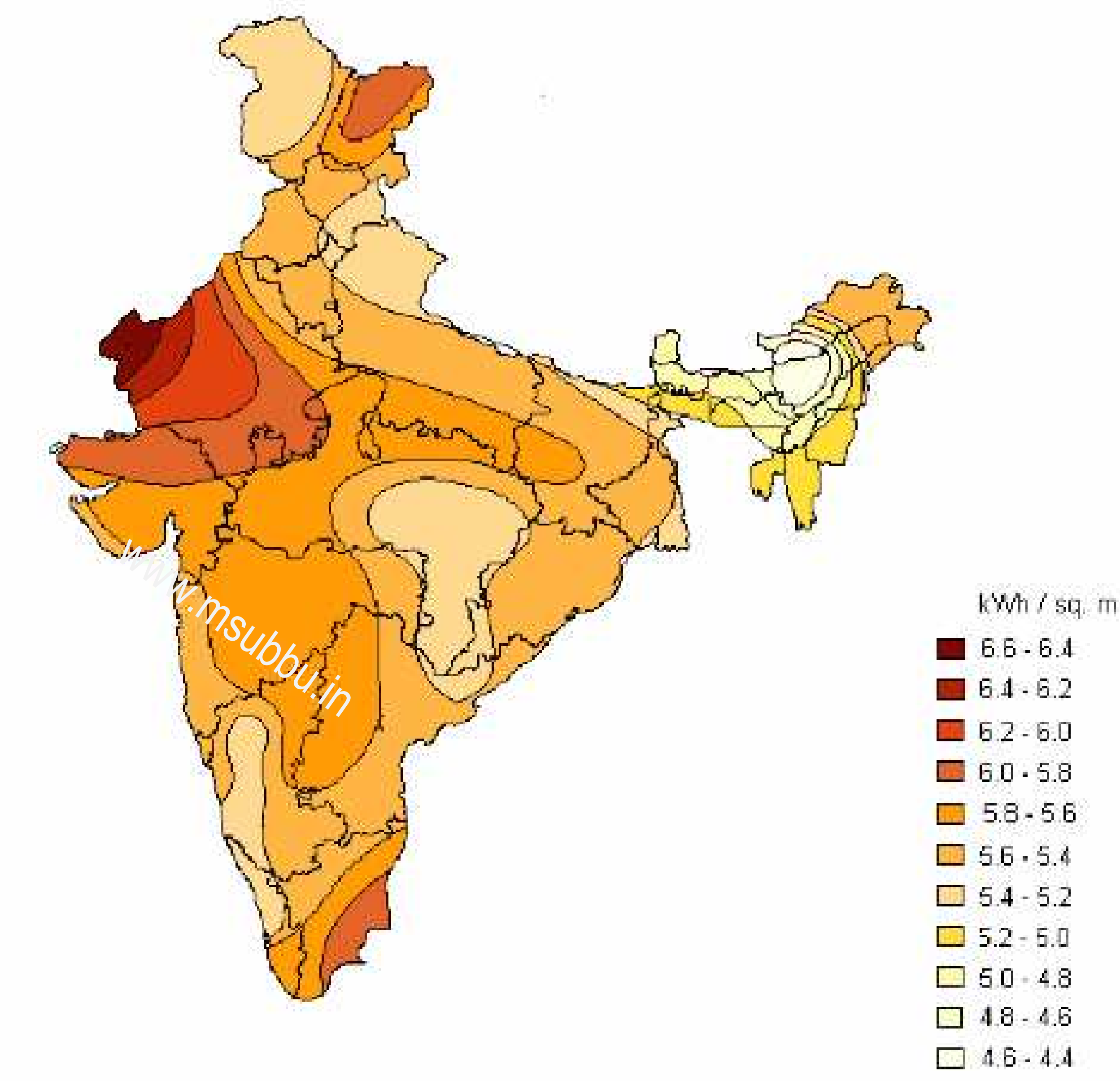


Figure 1 Solar radiation on India

Source: TERI

Solar Potential of India

- India is endowed with vast solar energy potential. About **5,000 trillion kWh per year** energy (173 W/m^2) is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day.

- In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/m^2

- India is both densely populated and has high solar insolation, providing an ideal combination for solar power in India.

- In solar energy sector, some large projects have been proposed, and a 35,000 km^2 area of the Thar Desert has been set aside for solar power projects, sufficient to generate 700 to 2,100 gigawatts.

Solar Energy Developments in World

- The solar thermal power industry is growing rapidly with 1.2 GW under construction as of April 2009 and another 13.9 GW announced globally through 2014.
- Spain is the epicenter of solar thermal power development with 22 projects for 1,037 MW under construction, all of which are projected to come online by the end of 2010.
- In the United States 5,600 MW of solar thermal power projects have been announced.
- Globally, solar is the fastest growing source of energy (though from a very small base) with an annual average growth of 35%, as seen during the past few years

Solar Energy Contribution in India

No.	Sources / Systems	Cumulative Achievements (upto 31.03.2010)
A. Grid Interactive Power		
1	Solar Power	10.28 MW
	From all renewable sources	**16817.29 MW**
B. Off-Grid Power		
1	Solar PV Power Plants	2.46 MW_p
	From all renewable sources	**404.56 MW_{eq}**
	Total Solar Power	**12.74 MW / 17221.86 MW = 0.07%**
C. Decentralized Energy Systems		
1	SPV Home Lighting System	5,83,429 nos.
2	Solar Lantern	7,92,285 nos.
3	SPV Street Lighting System	88,297 nos.
4	SPV Pumps	7,334 nos.
5	Solar Water Heating - Collector Area	3.53×10^6 m^2

Source: http://mnre.gov.in/achievements.htm

Opportunities for Solar Power in India

Solar thermal power generation can play a significant important role in meeting the demand supply gap for electricity. Three types of applications are possible:

1. Rural electrification using solar dish collector technology: by hybridizing them with biomass gasifier for hot air generation.
2. Integration of solar thermal power plants with existing industries such as paper, dairy or sugar industry, which has cogeneration units.
3. Integration of solar thermal power generation unit with existing coal thermal power plants. Savings of upto 24% is possible during periods of high insolation for feed water heating to 241°C.

National Solar Mission of India

- Target of 20 GW by the year 2022 (i.e. by the end of 13^{th} Five Year Plan)
- The Mission anticipates achieving grid parity by 2022 and parity with coal-based thermal power by 2030.
- The key driver for promoting solar power would be through a Renewable Purchase Obligation (RPO) mandated for power utilities, with a specific solar component. This will drive utility scale power generation, whether solar PV or solar thermal

National Solar Mission (contd.)

The mission would be responsible for:

- Deployment of commercial solar technologies in the country
- Establishing solar research facility
- Encouraging private sector for manufacturing solar cells, equipments, etc.
- Promoting collaborative research with international activities

Progress of Solar in India

- Bangalore has the largest deployment of rooftop solar water heaters in India that will generate energy equivalent to 200 MW everyday and will be the country's first grid connected utility scale project soon.
- Bangalore is also the first city in the country to put in place an incentive mechanism by providing a rebate, which has just been increased to Rs 50, on monthly electricity bills for residents using roof-top thermal systems which are now mandatory for all new structures.
- Tata Power has decided to set up 50 MW solar photovoltaic power project at Mithapur in Gujarat. This proposed project will be the largest single solar photovoltaic installation in the country

Challenges and Constraints

- The investment cost stand-alone solar thermal power plants are in the range of Rs. 20-22 Crore / MW, and that of solar pv based power systems are in the range of Rs. 30-25 Crore / MW, compared to the investment cost of ~ Rs. 6 Crore / MW for coal based plants.

- The cost of production ranges from Rs 15 to Rs 30 per unit compared to around Rs 5 to Rs 8 per unit for conventional thermal energy.

- Per capita land availability is a scarce resource in India. The amount of land required for utility-scale solar power plants — currently approximately 1 km² for every 20–60 megawatts (MW) generated — could pose a strain on India's available land resource.

Research Directions

- Improving the efficiency of solar pv cells
- Finding new materials
- Improving the battery life, energy storage systems
- Application oriented research

Converting Solar Energy

- There are three processes for converting solar energy
  - heliochemical: the photosynthesis process
  - heliothermal: heating of a secondary fluid (solar thermal)
  - helioelectrical: photovoltaics (solar cells)

Solar Collection Systems

- There are three general categories of solar-energy collection systems:
  - direct conversion of sun rays to electricity with solar cells (photovoltaics),
  - flat-plate systems producing low-temperature (<150°F) thermal energy for heating and cooling of buildings; the thermal energy generated in the collector is usually removed by either air or an ethylene glycol-water solution, and
  - concentrating solar collection systems that produce high-temperature thermal energy for the generation of electricity.

Solar Photovoltaics

- *Solar photovoltaic* (solar cell) is a direct conversion of the sun's electromagnetic radiation to electricity, and is not limited by Carnot cycle efficiency considerations.

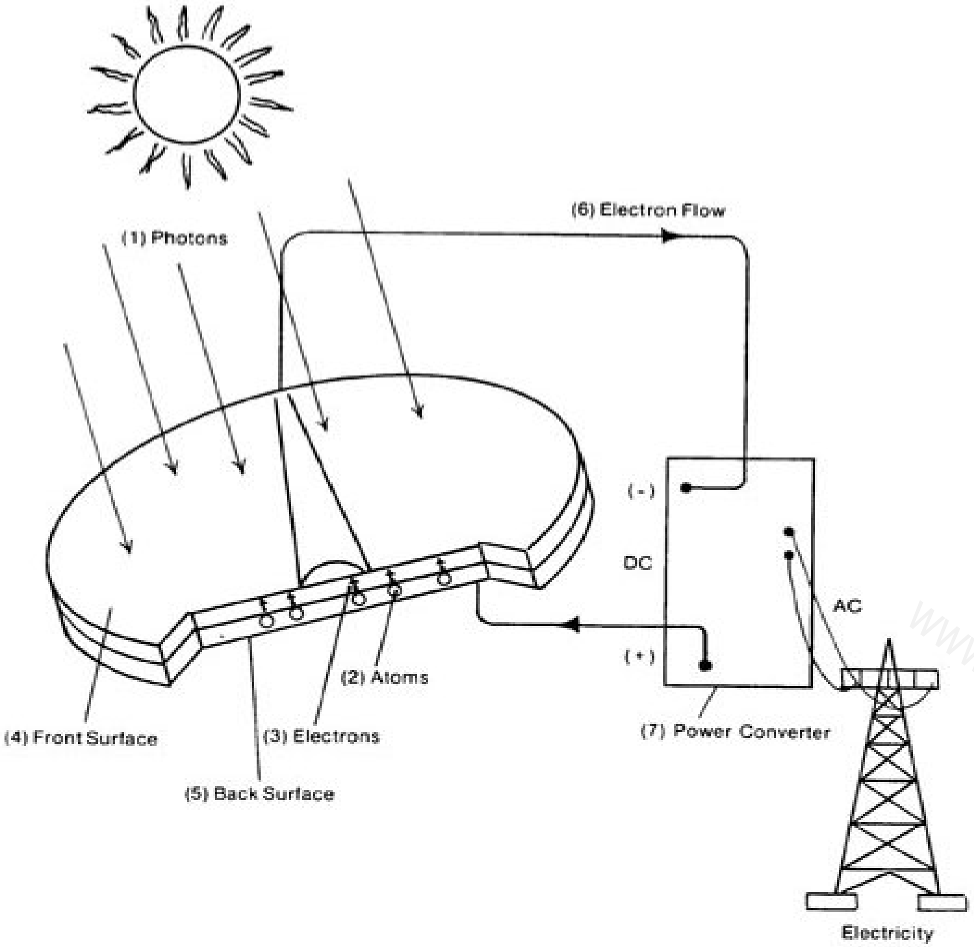
- Photovoltaic (PV) cells employ a solid-state diode structure with a large area on a silicon wafer. The surface layer is very thin and transparent so that light can reach the junction region of the silicon sandwich. In that region the photons are absorbed, releasing charges from their atomic bonds. These charges migrate to the terminals, raising the potential.

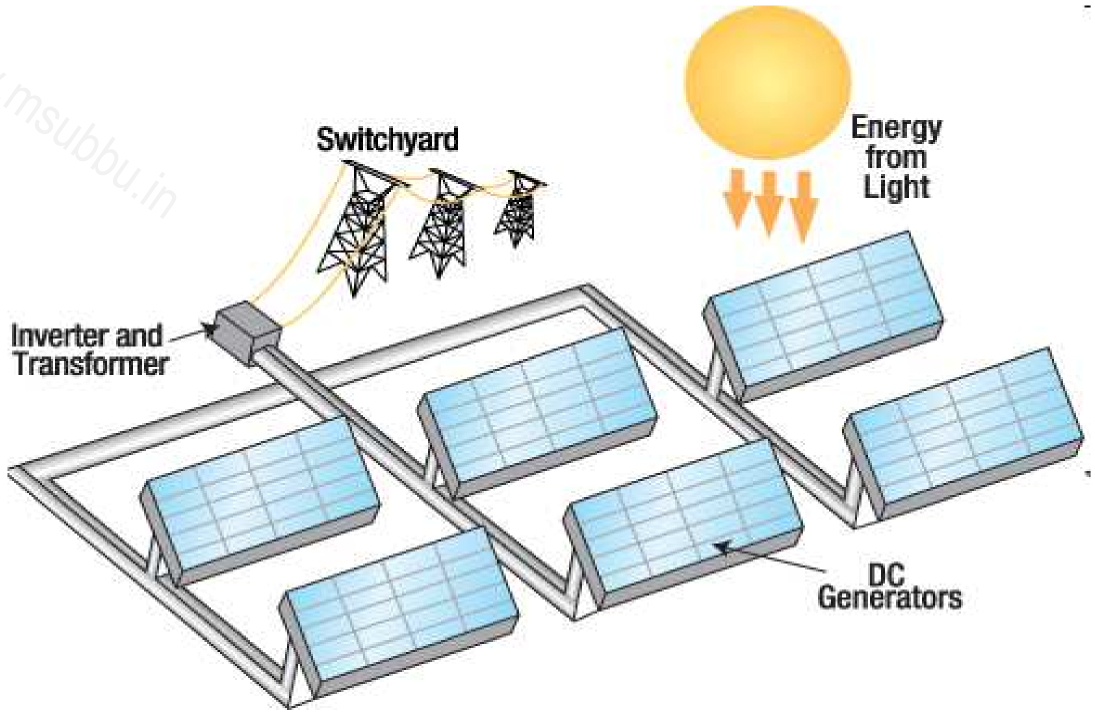
- A single cell has an open circuit the voltage of approximately 0.6-1.0 volts and a short circuit current of a few mA.

- In order to increase both current and voltage, the individual cells are placed into (solar) arrays where cells may be connected in series to raise the voltage and current output can be raised by parallel connection of cells.

•A more efficient conversion (15%) of solar energy to electrical energy is provided by photovoltaic (PV) cells.

Photovoltaic 'tree' in Styria, Austria

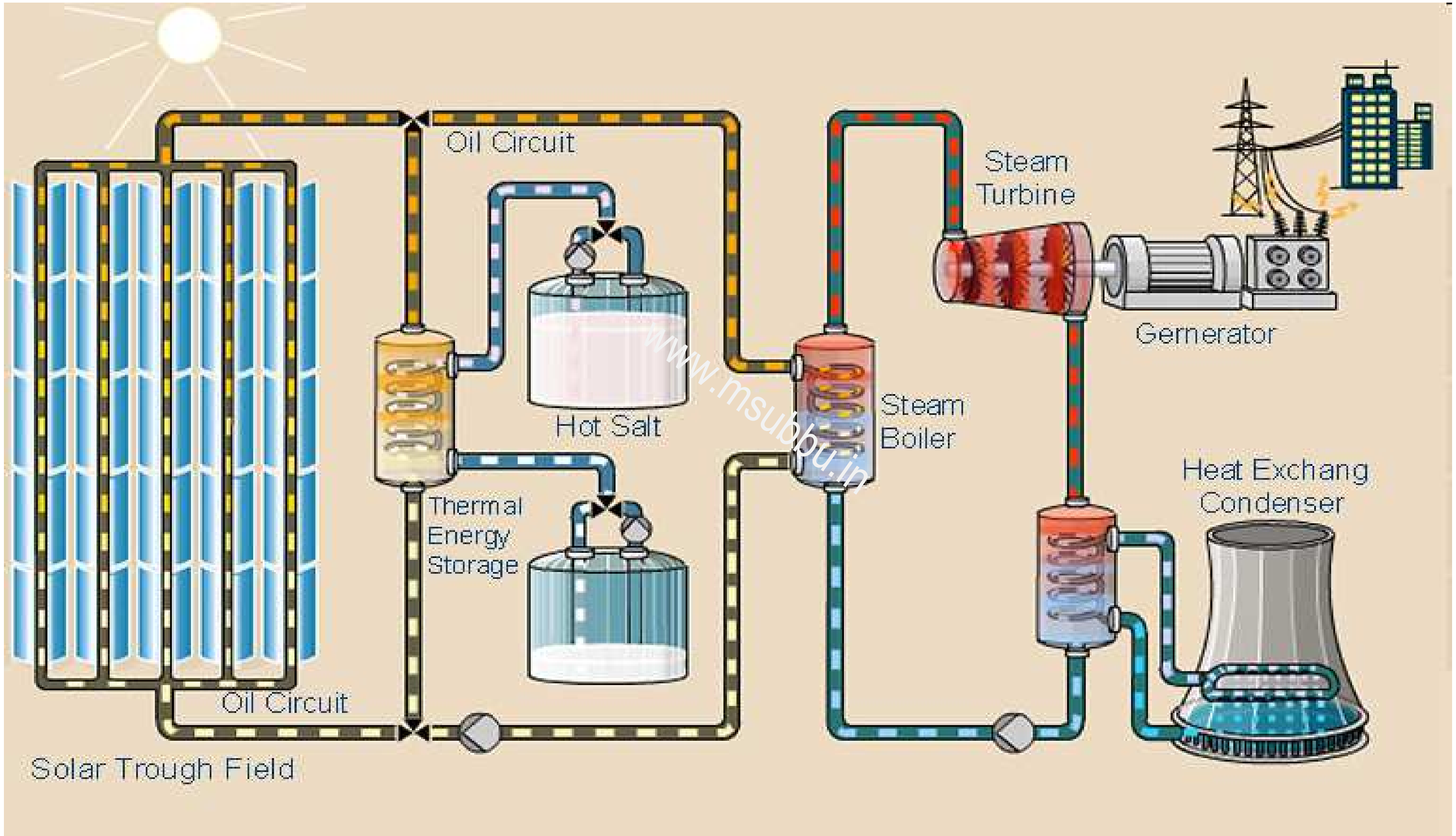

(1) Photons
(6) Electron Flow
(-)
DC
(+)
AC
(2) Atoms
(3) Electrons
(4) Front Surface
(5) Back Surface
(7) Power Converter
Electricity

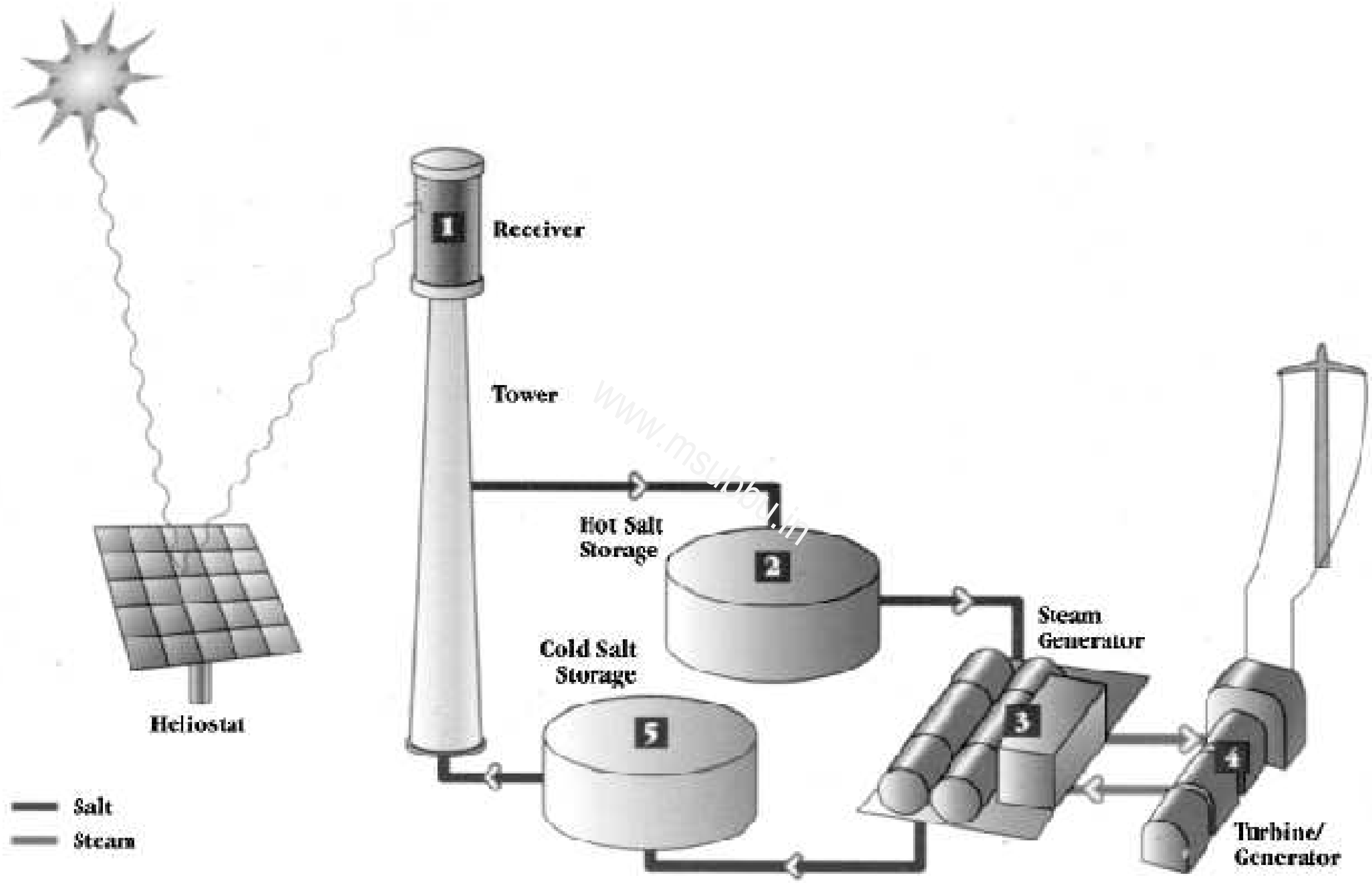

Switchyard
Energy from Light
Inverter and Transformer
DC Generators

Solar Thermal

- *Solar thermal* is the use of a vapor power cycle that requires the concentration of solar energy to reach high temperatures and reasonable thermal efficiency.

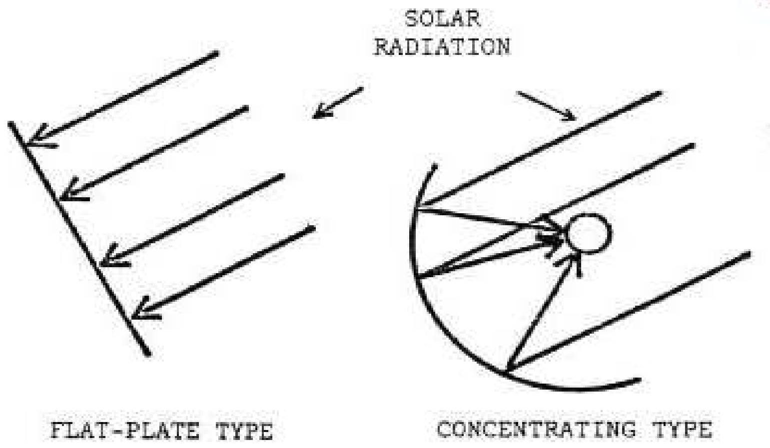
- Solar thermal energy concentration devices include parabolic mirrors and arrays of focused mirrors (heliostats)


Oil Circuit
Steam
Turbine
Gernerator
Hot Salt
Steam
Boiler
Thermal
Energy
Storage
Heat Exchang
Condenser
Oil Circuit
Solar Trough Field


Receiver
Tower
Hot Salt
Storage
Steam
Generator
Cold Salt
Storage
Heliostat
Turbine/
Generator
Salt
Steam

Solar Thermal Collectors

flat-plate collector	40 to 120°C
parabolic concentrator	150 to 800°C
heliostats	250 to 1500°C

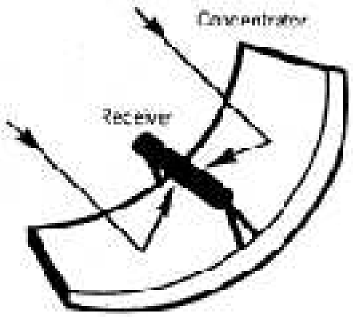


Classification of Solar Thermal Systems based on Focus

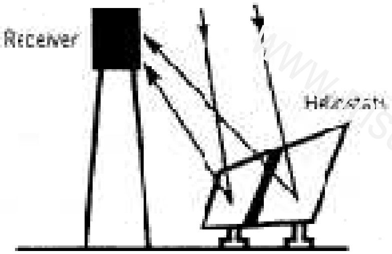
- *large point focus*: power tower systems with heliostats. Molten salts and liquid metals are used as the working fluid that then boils water for use in a Rankine cycle. Sizes of 100 kWe to 100 MWe.

- *small point focus*: use parabolic hemispherical dishes to reflect light to a focal point on each individual dish. These are for remote stand-alone systems (5-25 kWe), and

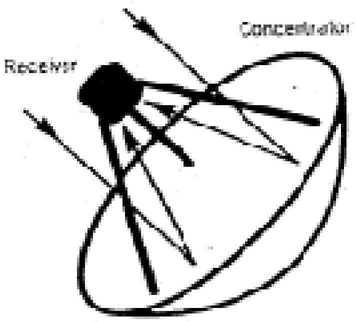
- *line focus systems*: use parabolic shaped troughs, and have lower efficiency.



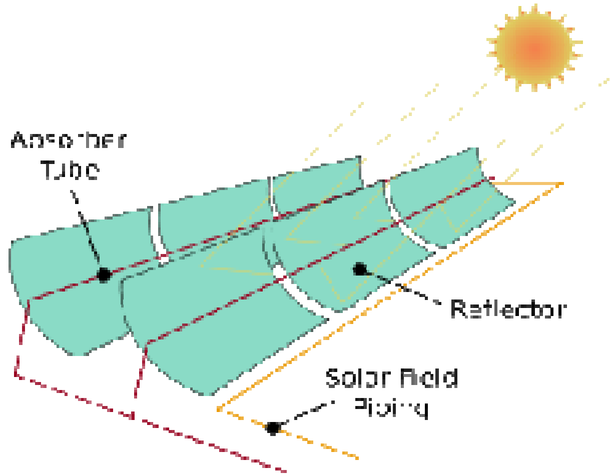
(a) Trough



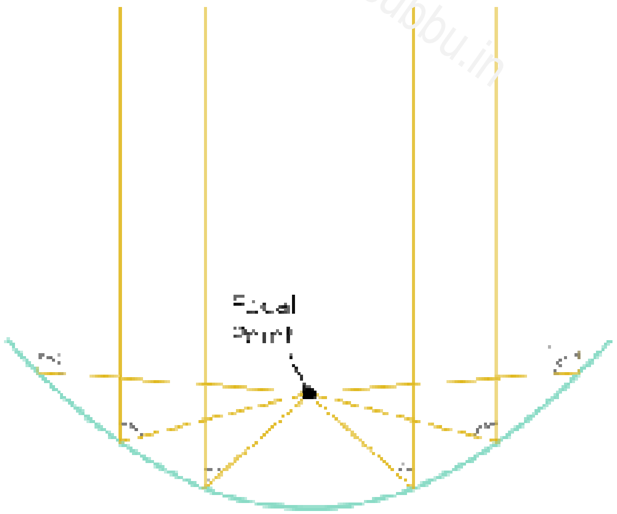
(b) Central Receiver



(c) Dish



Absorber Tube
Reflector
Solar Field Piping



Focal Point

Parabolic Trough Solar Collector

Solar Energy Generating Systems (SEGS)

- **(SEGS)** is the largest solar energy generating facility in the world.
- It consists of nine solar power plants in California's Mojave Desert, where insolation is among the best available in the United States.
- Installed capacity: 354 MW
- The average gross solar output for all nine plants at SEGS is around 75 MW — a capacity factor of 21%

SEGS - Installations

- The facilities have a total of 936,384 mirrors and cover more than 1,600 acres (6.5 km^2). Lined up, the parabolic mirrors would extend over 229 miles (370 km).

- The installation uses parabolic trough solar thermal technology along with natural gas to generate electricity. 90% of the electricity is produced by the sunlight. Natural gas is only used when the solar power is insufficient to meet the demand

SEGS - Mirrors

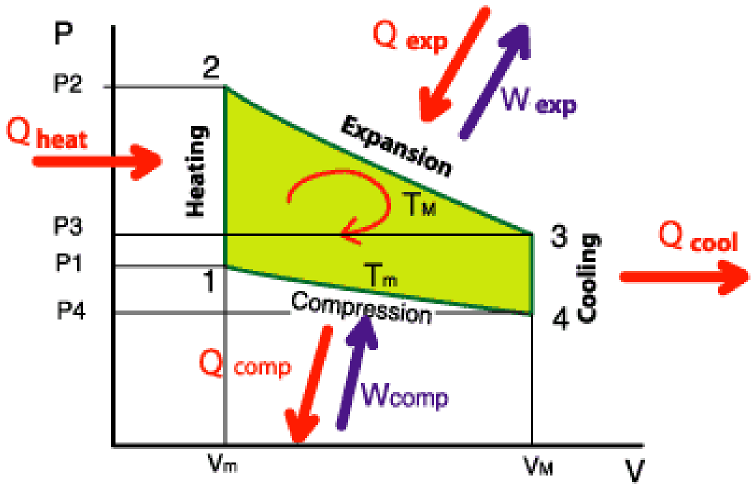
- The parabolic mirrors are shaped like a half-pipe. The sun shines onto the panels made of glass, which are 94% reflective, unlike a typical mirror, which is only 70% reflective.
- The mirrors automatically track the sun throughout the day.
- The greatest source of mirror breakage is wind, with 3000 typically replaced each year.

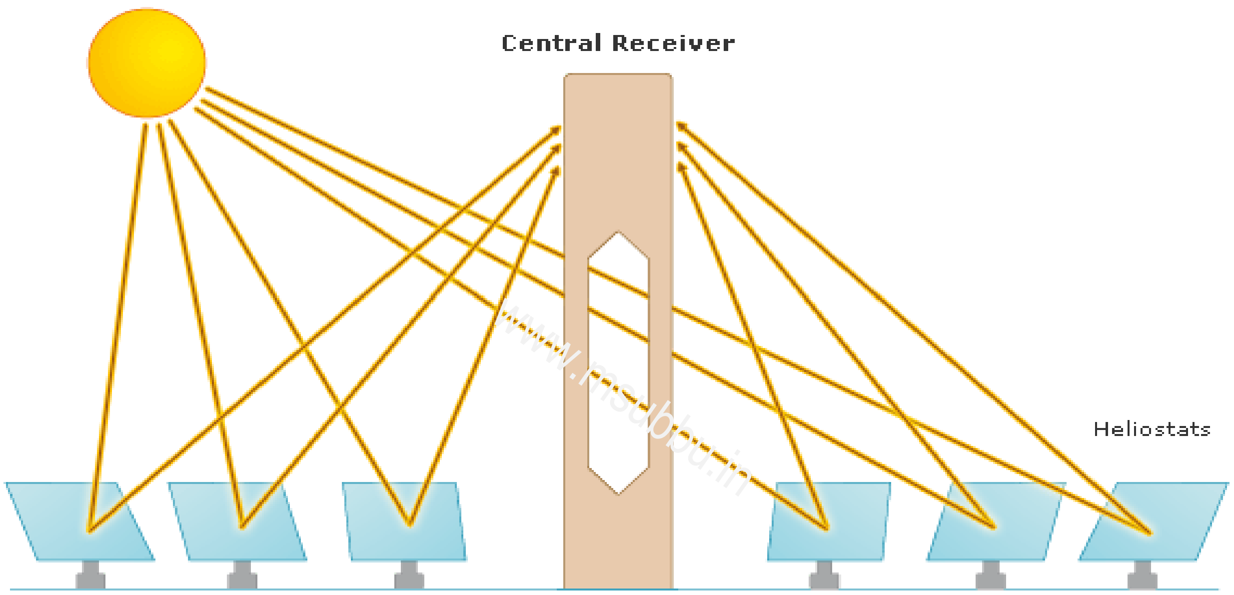
SEGS – Heat Transfer

- The sun bounces off the mirrors and is directed to a central tube filled with synthetic oil, which heats to over 400 °C.
- The reflected light focused at the central tube is 71 to 80 times more intense than the ordinary sunlight.
- The synthetic oil transfers its heat to water, which boils and drives the Rankine cycle steam turbine, thereby generating electricity.

Dish-Stirling Systems

- Dish–Stirling systems can be used to generate electricity in the kilowatts range.
- A parabolic concave mirror (the dish) concentrates sunlight; In the focus is a receiver which is heated up to 650°C. The absorbed heat drives a Stirling motor, which converts the heat into motive energy and drives a generator to produce electricity.
- The system efficiency of Dish–Stirling systems can reach 20% or more. The electricity generation costs of these systems are much higher than those for trough or tower power plants.



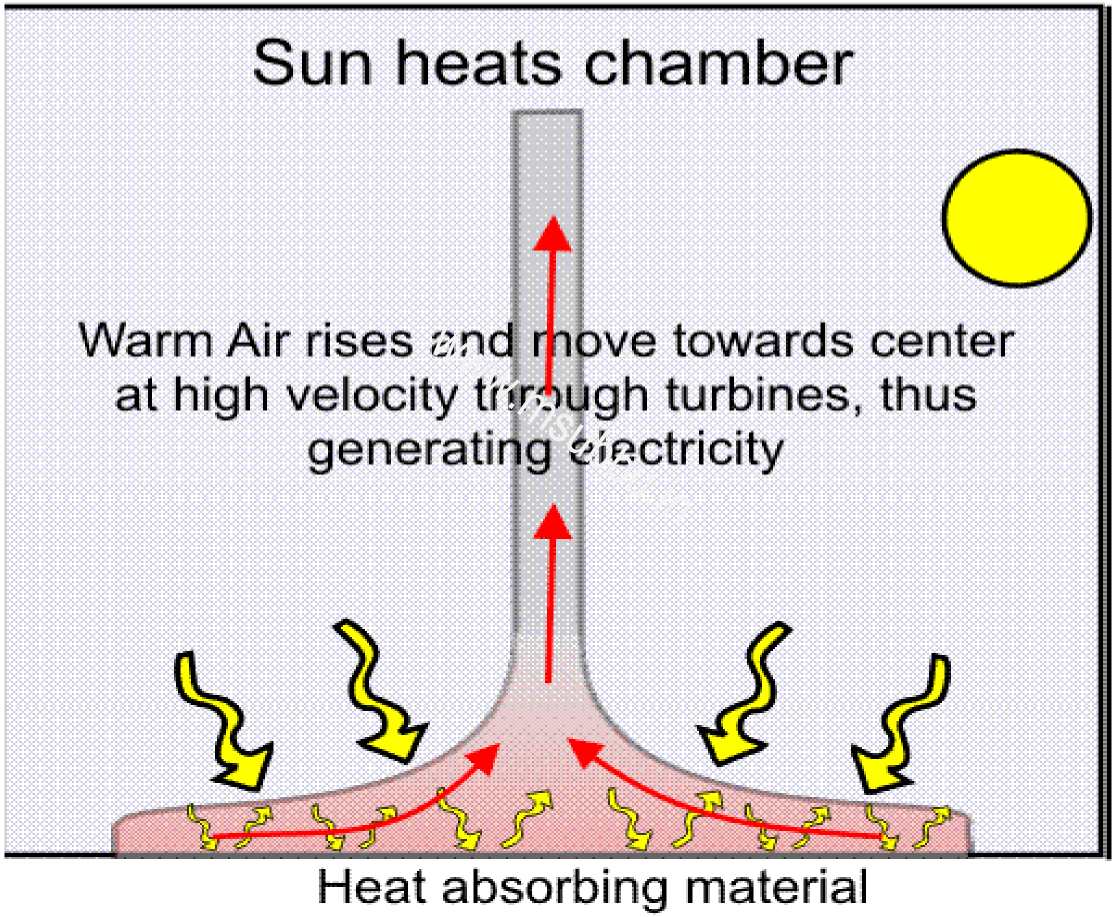

Central Receiver
Heliostats

Aerial Photo of the Solar One 10 MWe Central Receiver Power Plant in Daggett, CA

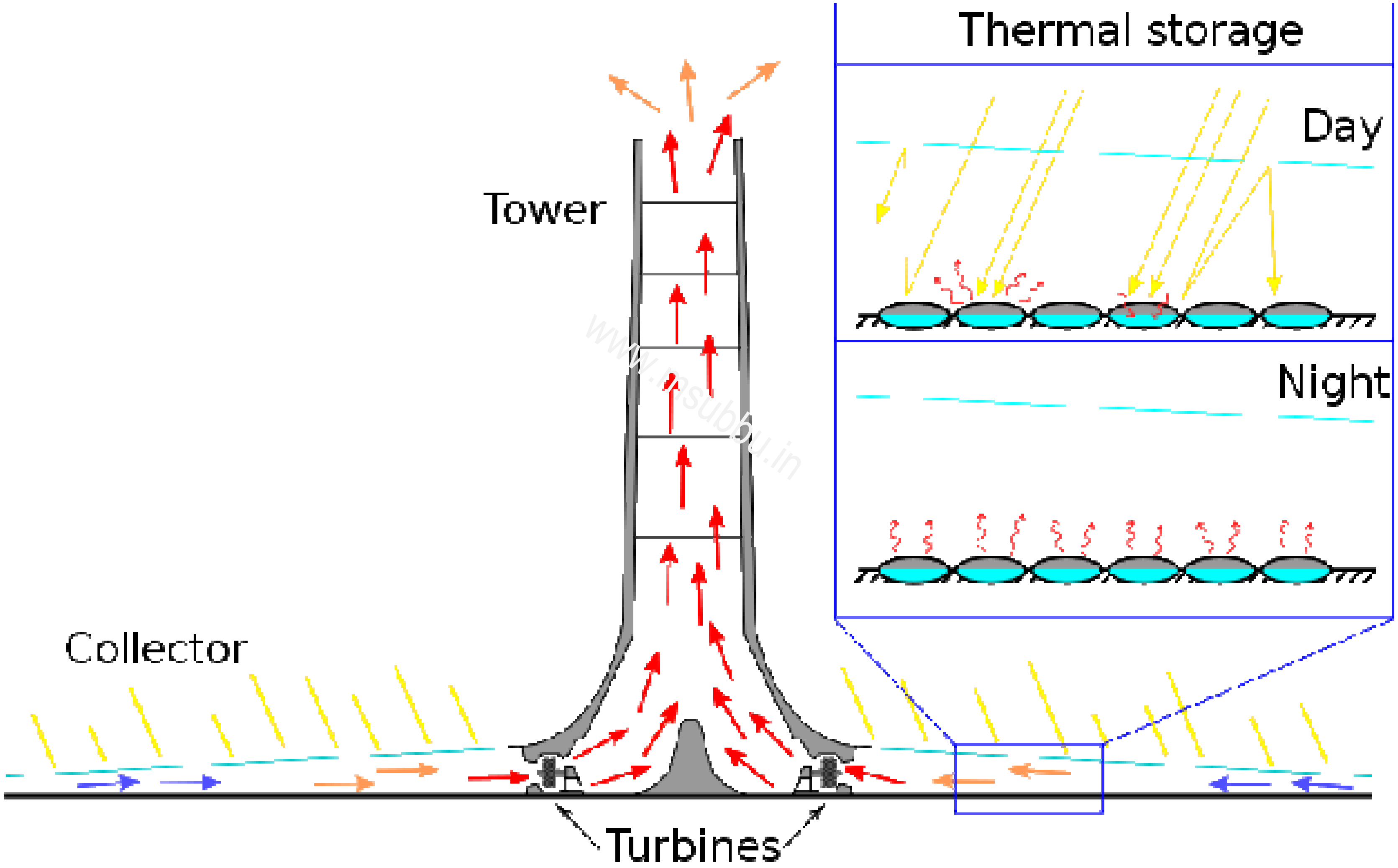
Efficiency of Solar Thermal Power Plants

- Altogether, solar thermal trough power plants can reach annual efficiencies of about 15%; the steam-cycle efficiency of about 35% has the most significant influence. Central receiver systems such as solar thermal tower plants can reach higher temperatures and therefore achieve higher efficiencies.

Solar Chimney



Solar Chimney



Solar Chimney

- The **solar updraft tower** is a proposed type of renewable-energy power plant. It combines three old and proven technologies: the chimney effect, the greenhouse effect, and the wind turbine.

- Air is heated by sunshine and contained in a very large greenhouse-like structure around the base of a tall chimney, and the resulting convection causes air to rise up the updraft tower. This airflow drives turbines, which produce electricity.

- Heat can be stored inside the collector area greenhouse to be used to warm the air later on. Water, with its relatively high specific heat capacity, can be filled in tubes placed under the collector increasing the energy storage as needed.

The First Pilot Plant

A pilot solar chimney project was installed in
Spain to test the concept. This 50kW capacity plant was successfully operated between 1982 to 1989.

Figure 6 50 kW Solar chimney pilot project , Manzanares, Spain

The chimney had a height of 195 m and a diameter of 10 m with a collection area (greenhouse) of 46,000 m² (about 11 acres, or 244 m diameter) obtaining a maximum power output of about 50 kW.

Based on the test results, it was estimated that a 100 MW plant would require a 1000 m tower and a greenhouse of 20 km^2. Conversion efficiency of solar energy to electrical energy is about 0.5 %.

Advantages of Solar Energy

- The advantages of solar energy include
  - its nonpolluting nature;
  - it is nondepletable,
  - reliable, and
  - free fuel.

Disadvantages of Solar Energy

- The disadvantages of solar energy are
  - the solar energy concentration is very dilute, so collectors with large surface area are needed.
  - In addition, solar radiation is neither constant nor continuous for terrestrial applications (i.e., low capacity factor).
  - The solar energy received depends on latitude, season, time-of-day, and atmospheric conditions.