Power Stations

Unconventional sources of energy

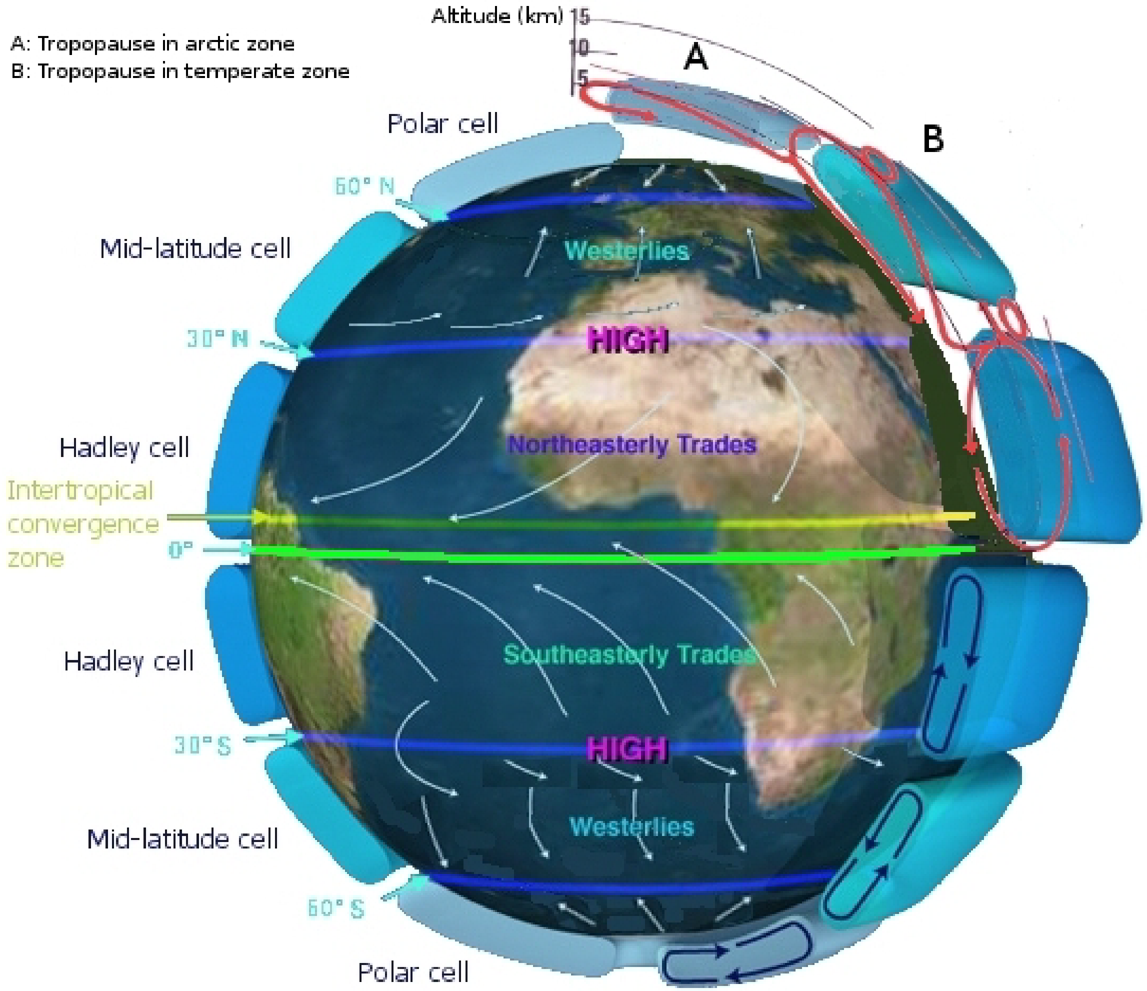
Introduction

- **Renewable energy** - generally defined as energy that comes from resources which are continually replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat.
- About 16% of global energy consumption comes from renewable resources, with 10% from biomass, mainly used for heating, and 3.4% from hydroelectricity. New renewables (small hydro, modern biomass, wind, solar, geothermal, and biofuels) accounted for another 3% and are growing rapidly.
- The share of renewables in electricity generation is around 19%, with 16% of electricity coming from hydroelectricity and 3% from new renewables.

Renewable Energy Consumption

Energy Source	QBtu / % (1994)	QBtu / % (2003)	QBtu / % (2011)
Hydroelectric	3.037 / 3.43	2.779 / 2.83	3.171 / 3.26
Geothermal	0.357 / 0.40	0.314 / 0.32	0.226 / 0.23
Biomass	2.852 / 3.22	2.884 / 2.94	4.511 / 4.64
Solar Energy	0.069 / 0.077	0.063 / 0.06	0.158 / 0.16
Wind	0.036 / 0.040	0.108 / 0.11	1.168 / 1.20
Total	**6.351 /7.18**	**6.15 / 6.3**	**9.135 / 9.39**

Wind power



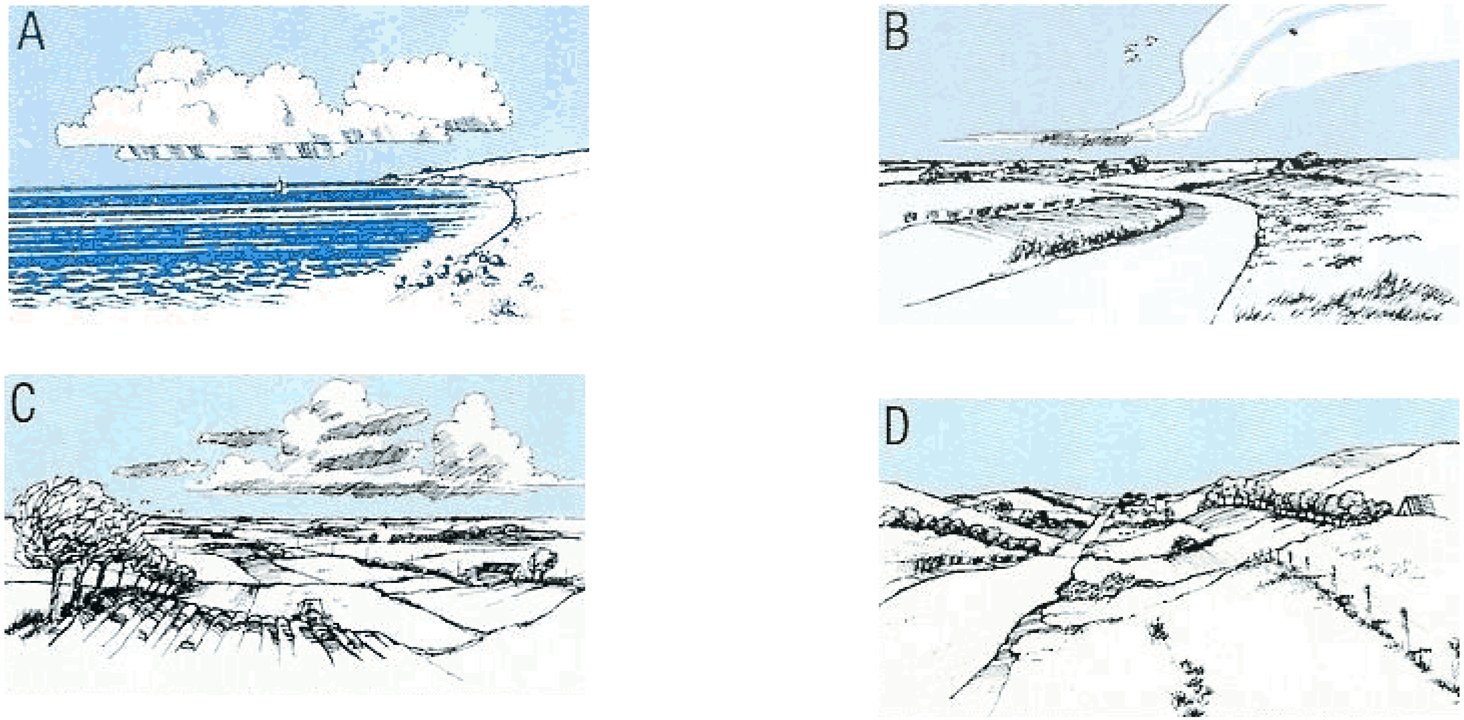
A: Tropopause in arctic zone
B: Tropopause in temperate zone
Altitude (km) 15
10
5
A
B
Polar cell
60° N
Mid-latitude cell
Westerlies
30° N
HIGH
Hadley cell
Northeasterly Trades
Intertropical
convergence
zone
0°
Hadley cell
Southeasterly Trades
30° S
HIGH
Mid-latitude cell
Westerlies
60° S
Polar cell

Wind power

- Wind power - Wind power is proportional to the third power of the wind velocity.
- Further insufficiencies, such as rotor blade friction and drag, gearbox losses, generator and converter losses, reduce the power delivered by a wind turbine.

$$P = dE/dt = \frac{1}{2}\rho A v^3$$

Wind potential of the landscape



Achievable efficiencies

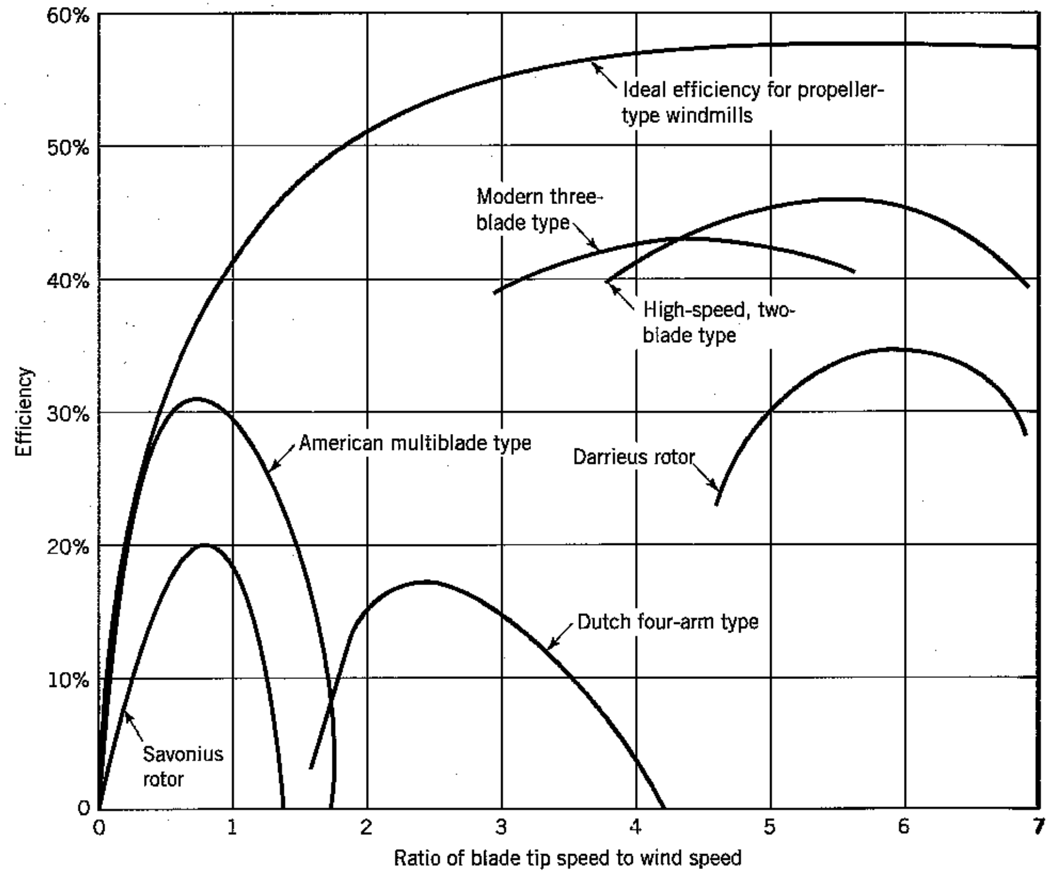
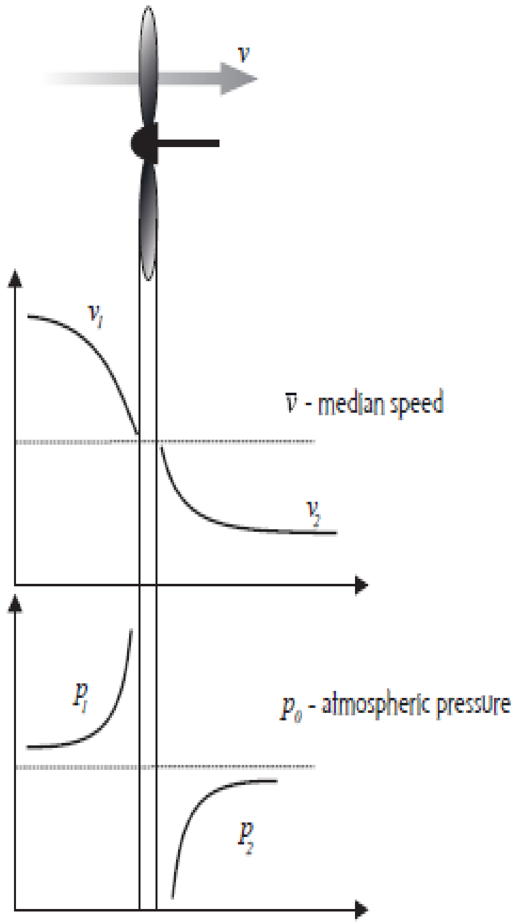


Figure 5.6 Typical efficiencies of several types of windmills plotted against their tip-speed ratio. The maximum efficiencies are seen to vary from about 16 to 46%. The ideal efficiency shown is a mathematical ideal, never to be achieved in practice. (Basic data from R. Wilson and P. Lissaman, *Applied Aerodynamics of Wind Power Machines,* Oregon State University.)

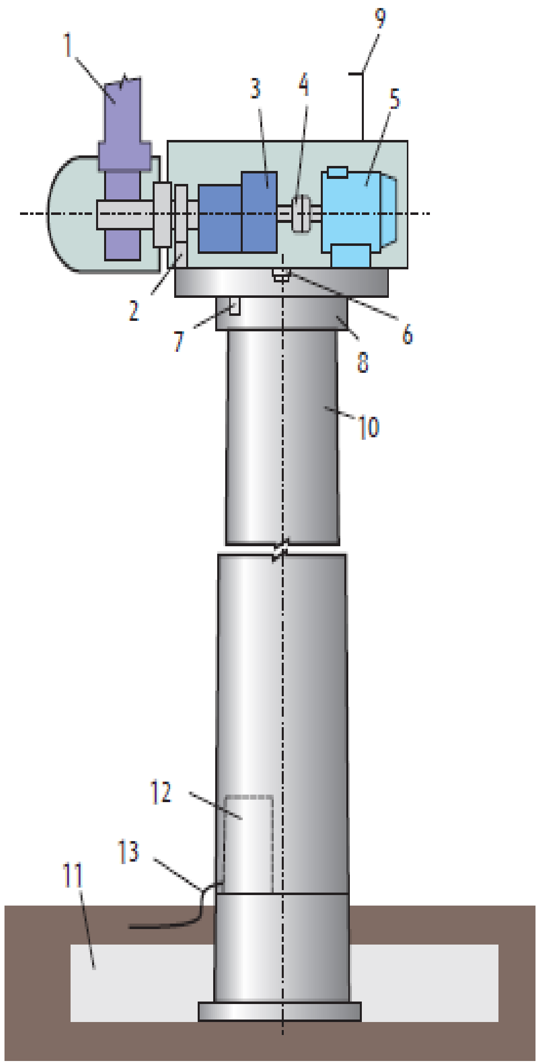
Wind power

- Speed and pressure of wind current before and behind the wind turbine



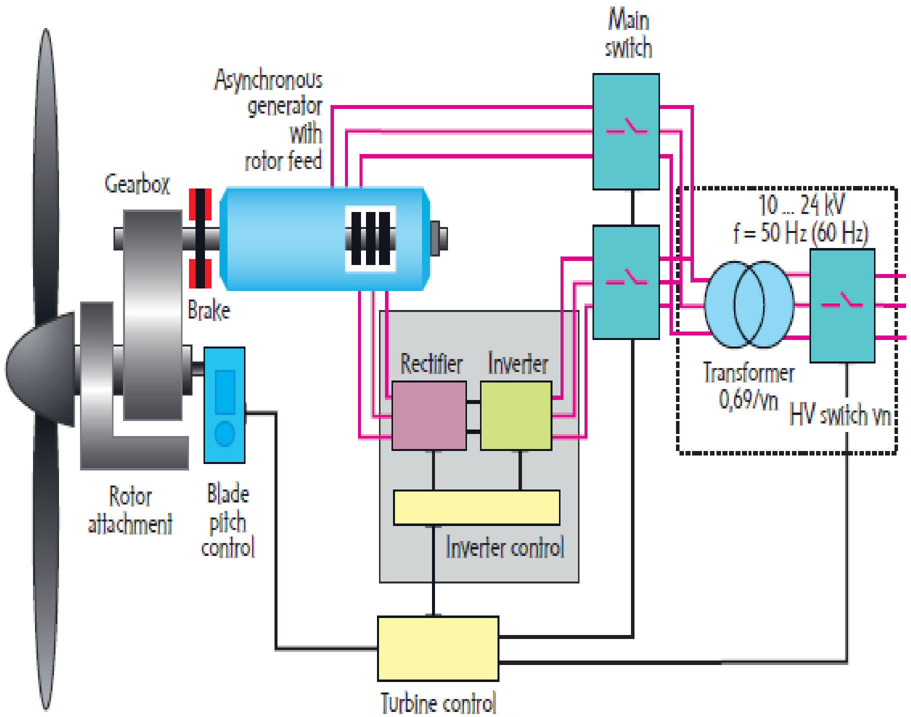
Main components

- 1 – rotor with rotor head,
- 2 – rotor brake,
- 3 – gearbox,
- 4 – coupling,
- 5 – generator,
- 6 – gondola yaw power unit,
- 7 – gondola yaw brake,
- 8 – gondola bearing,
- 9 – wind speed and direction sensor,
- 10 – modular tower,
- 11 – reinforced concrete foundation,
- 12 – junction box – power cabling and control cabling,
- 13 – electric connection



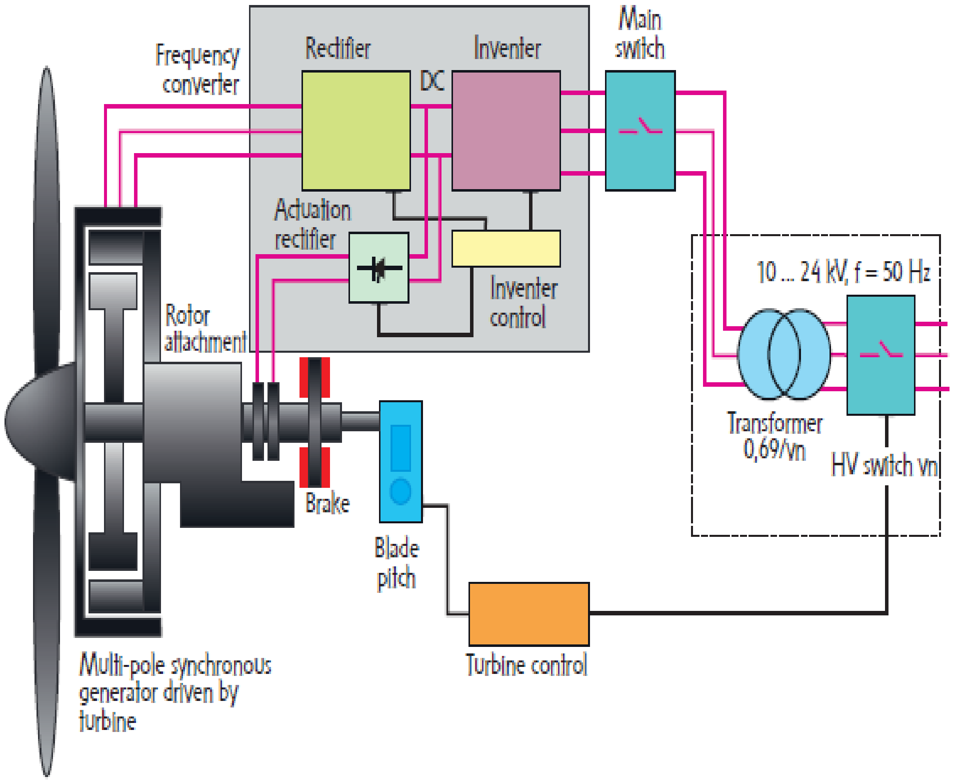
Wiring diagram

- Asynchronous generator connected to a rotor



Wiring diagram

- Multipolar synchronous generator driven directly by a turbine



Solar energy

- How much energy is available?
  - Above the atmosphere, we get 1400 W/m2 of radiated power from the sun
  - At the ground, this number is smaller due to scattering and absorption in the atmosphere about 63%, or ~850 W/m2 with no clouds

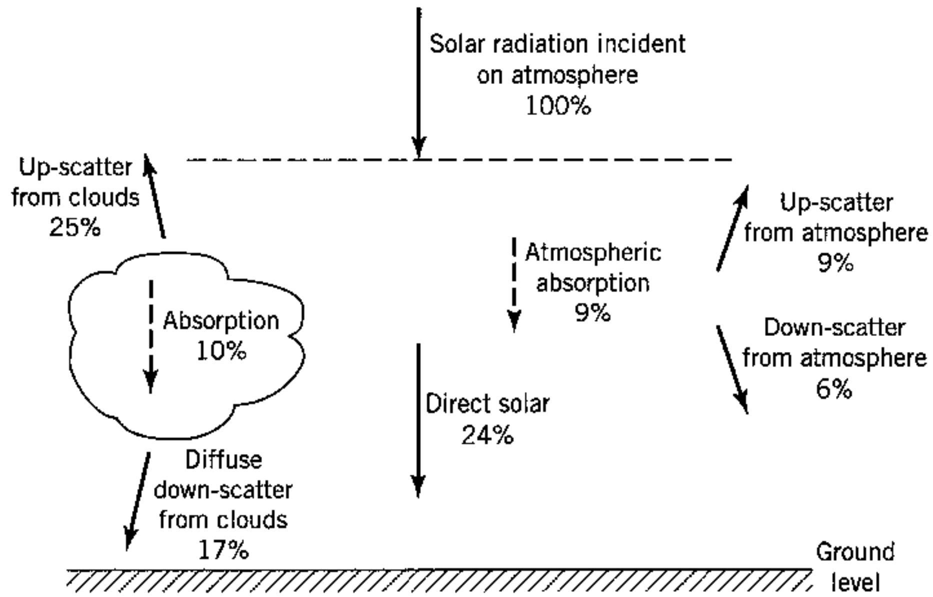


Figure 4.2 Absorption and scattering of solar radiation in the atmosphere. The values shown are for average weather, and are averaged over all seasons and latitudes.

Average Insolation

- The amount of light received by a horizontal surface (in W/m^2) averaged over the year (day & night) is called the *insolation*
- We can make a guess based on the facts that on average:
  - half the incident light reaches the ground
  - half the time it is day
  - the sun isn't always overhead, so that the effective area of a horizontal surface is half it's actual area
- So 1/8 of the incident sunlight is typically available at the ground
  - 171 W/m^2 on average

Orientation Comparison

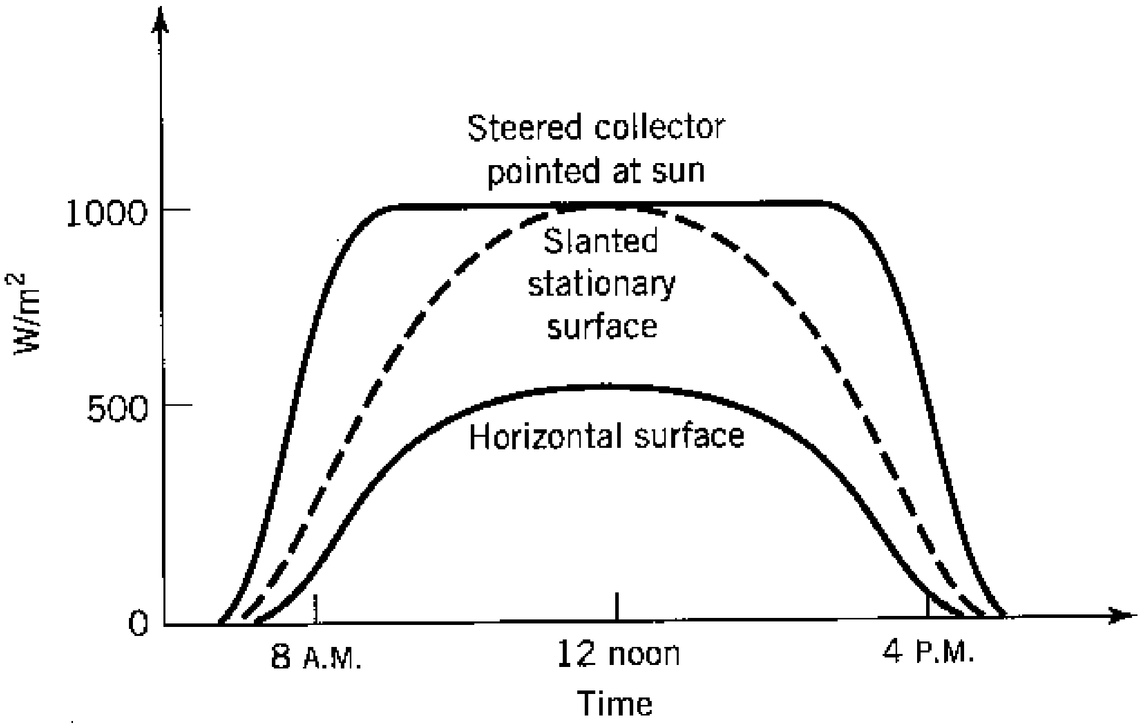


Figure 4.4 Solar power incident on three types of collectors for a typical winter day at 40° N latitude. The *energy* collected each day is given by the area under each curve.

Solar energy

- **Solar power** is the conversion of sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP). Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaics convert light into electric current using the photoelectric effect.

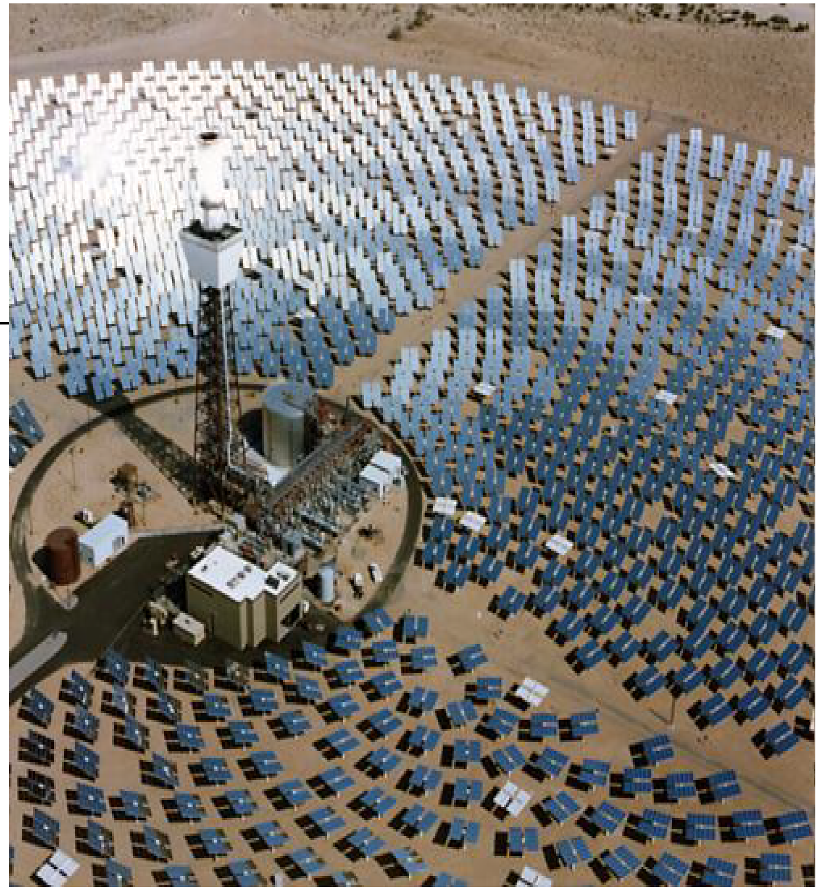
Solar hot water: up to 50% efficient; usually keep conventional backup

Solar Thermal: ~30% efficient; cost-competitive; requires direct sun; heats fluid in pipes that then boils water to drive steam turbine

Photovoltaic (PV): direct electricity; 15% efficient

Solar energy

- Solar tower 10 MW



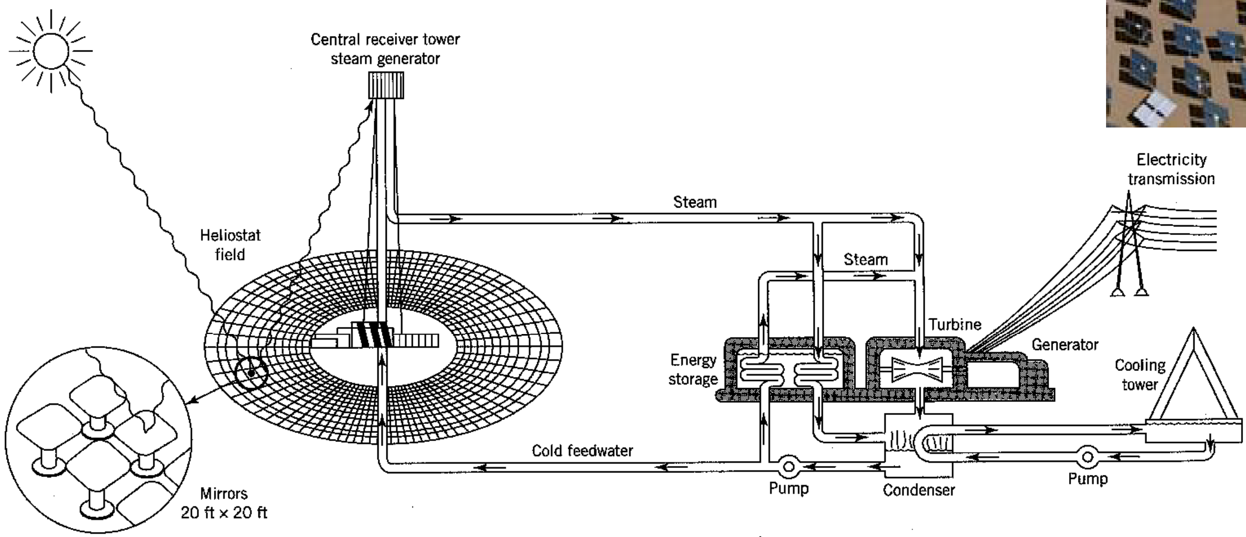
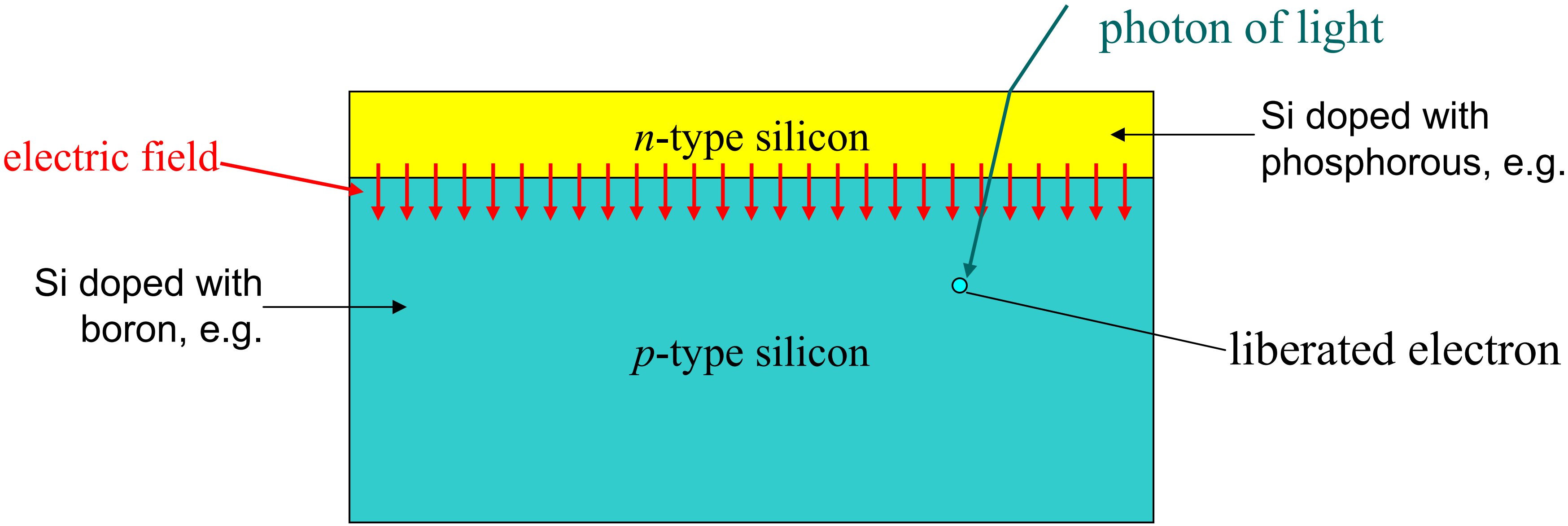


Figure 4.11 A schematic view of a 10 MW_e solar-thermal power plant near Barstow, California. The receiver and boiler that absorb the sunlight reflected from 1900 heliostats are at the top of a 90 meter tower. The heliostats are each steered by computer control to reflect the sunlight onto the receiver. The steam from the boiler can be either delivered directly to the turbine and generator or to storage. The storage system can provide steam for 4 hours of generation at a level of 7 MW_e without sunlight. (Figure supplied by the Solar Energy Research Institute.)

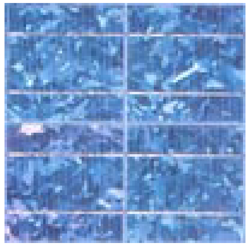
Photovoltaic (PV) Scheme

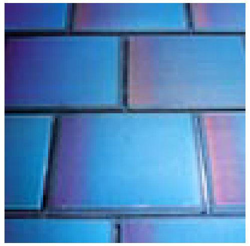
- Highly purified silicon (Si) from sand is “doped” with intentional impurities at controlled concentrations to produce a p-n junction
- A photon incident on the p-n junction liberates an electron
  - photon disappears, any excess energy goes into kinetic energy of electron (heat)
  - electric field sweeps electron across the junction, constituting a current
  - more photons → more electrons → more current → more power
- Characteristic voltage is 0.58 V



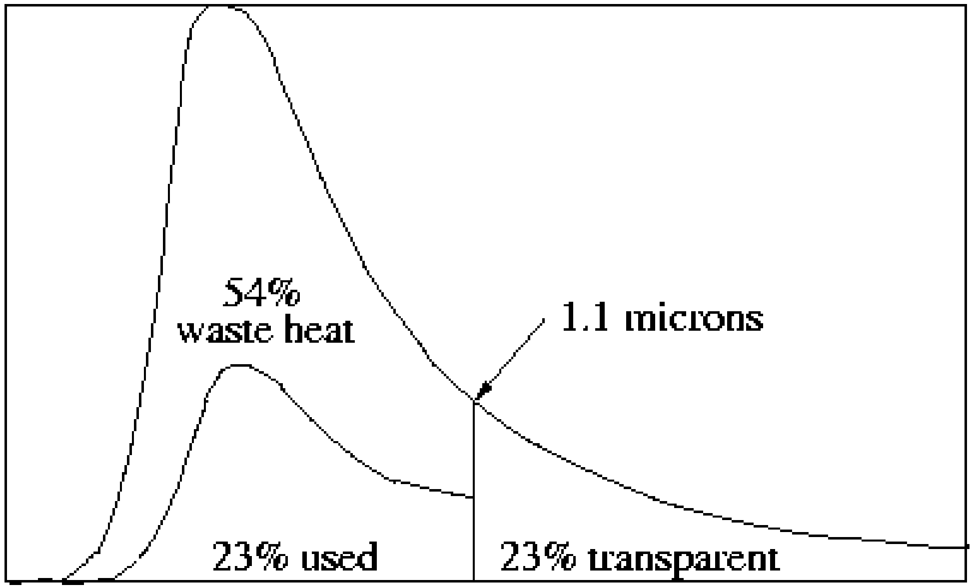
Photovoltaic types

- Single-crystal silicon
  - 15–18% efficient, typically
  - expensive to make (grown as big crystal)
- Poly-crystalline silicon
  - 12–16% efficient, slowly improving
  - cheaper to make (cast in ingots)
- Amorphous silicon (non-crystalline)
  - 4–8% efficient
  - cheapest per Watt
  - called "thin film", easily deposited on a wide range of surface types



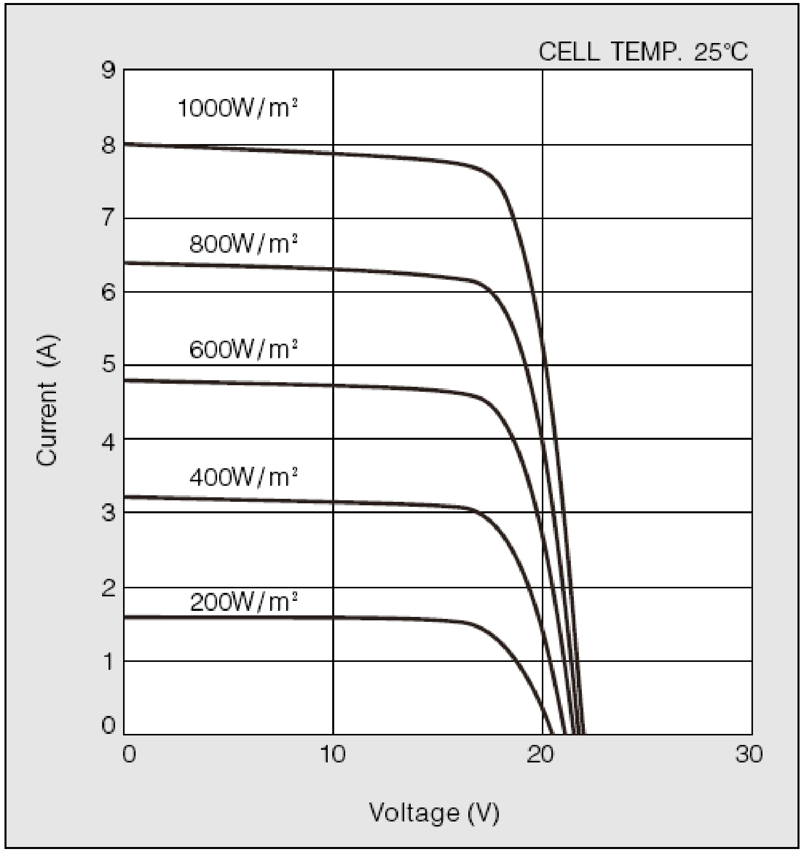


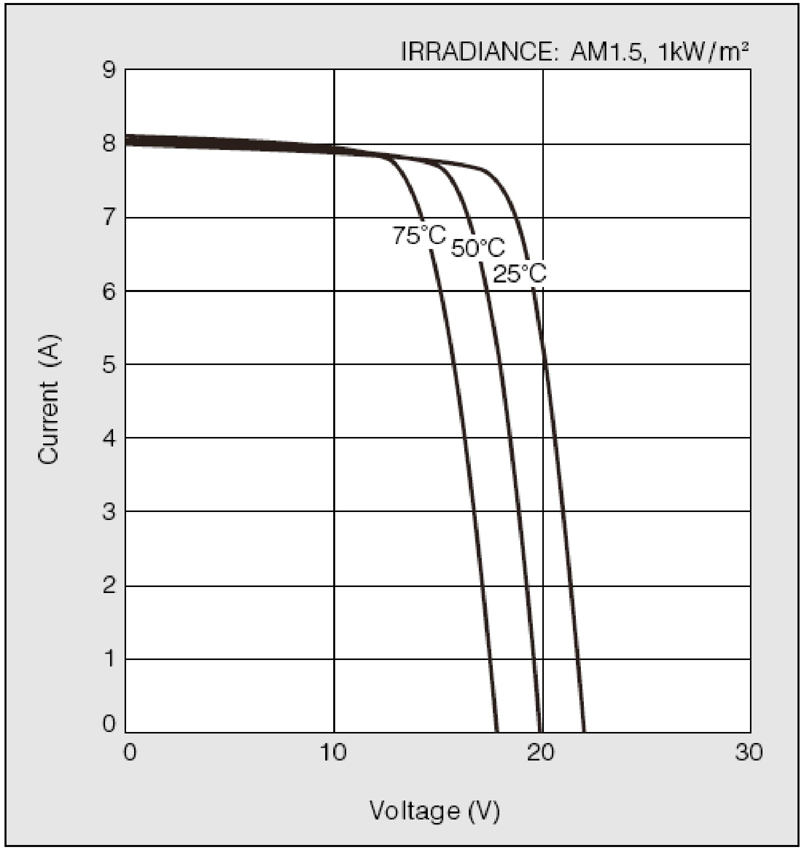
Silicon Photovoltaic Budget



- Only 77% of solar spectrum is absorbed by silicon
- Of this, ~30% is used as electrical energy
- Net effect is 23% maximum efficiency

Typical I-V curves





Biomass

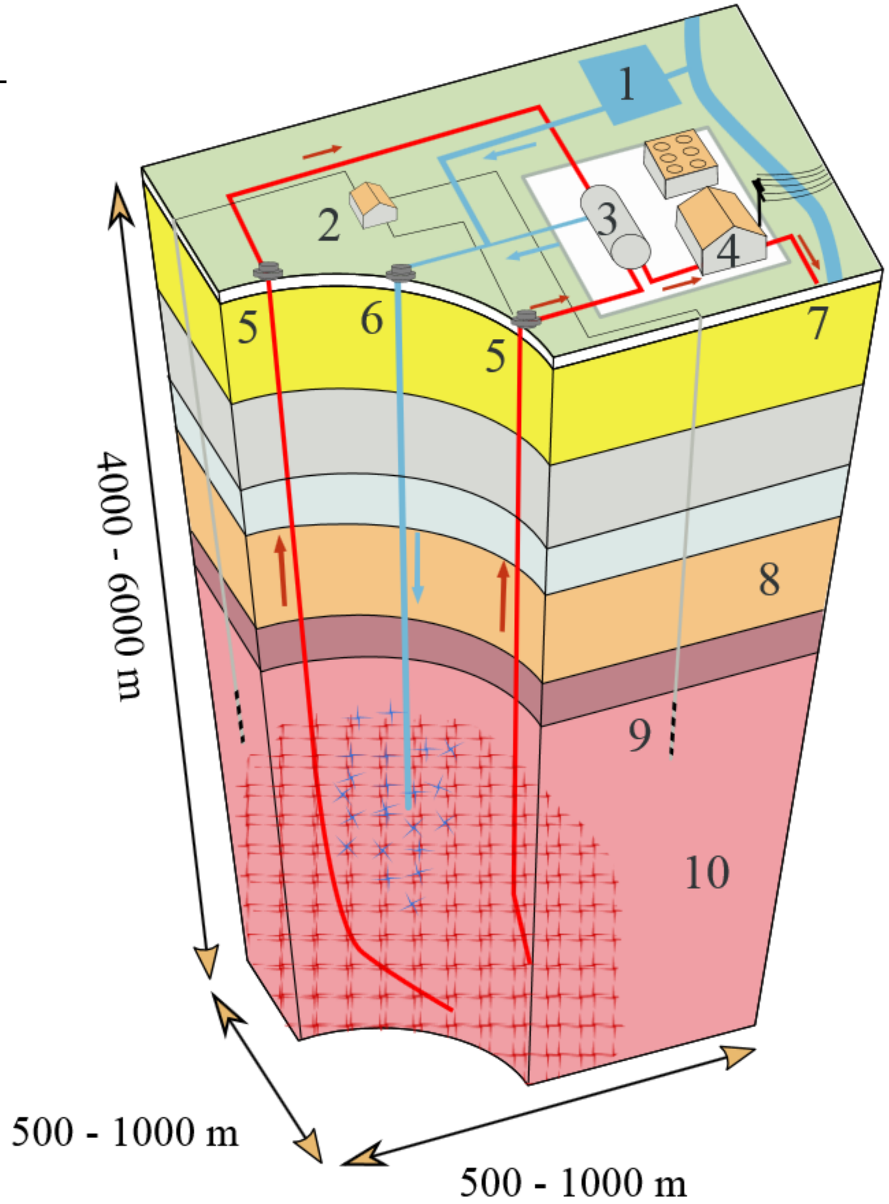
- **Biomass** - biological material derived from living, or recently living organisms.
- Biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel.
- Conversion to biofuel can be achieved by *thermal*, *chemical*, and *biochemical* methods.
- Under the EU energy directive, biomass is an eligible source of renewable energy. However, this is a controverisal classification. The European Environment Agency Scientific Committee (agency of the European Union devoted to the monitoring of the European environment) stated in its published opinion in 2011 that the assumption that biomass is carbon neutral is a ‘serious accounting error’ and that using biomass can result in increased carbon emissions and thereby accelerate global warming.

Methods of biomass conversion to energy

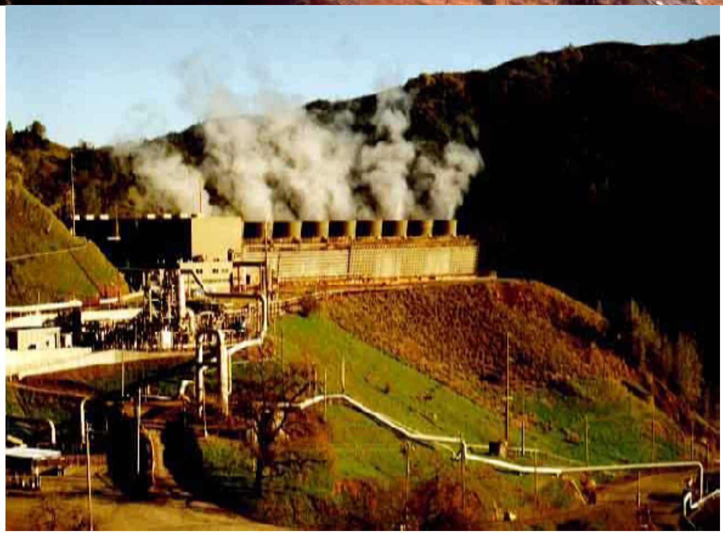
Type of Biomass Conversion	Method of Conversion	Energy Output	Waste Material or Secondary Raw Material
Termochemical conversion (dry processes)	burning gasification pyrolysis	heat bound to a carrier generator gas generator gas	(ash) tar oil, carbon fuels tar oil, solid flammable remains
Biochemical conversion (wet processes)	anaerobic fermentation aerobic fermentation	biogas heat bound to a carrier	fermented substrate fermented substrate
Physical-chemical conversion	esterification of bio-oils	methylester, bio-oils	glycerol

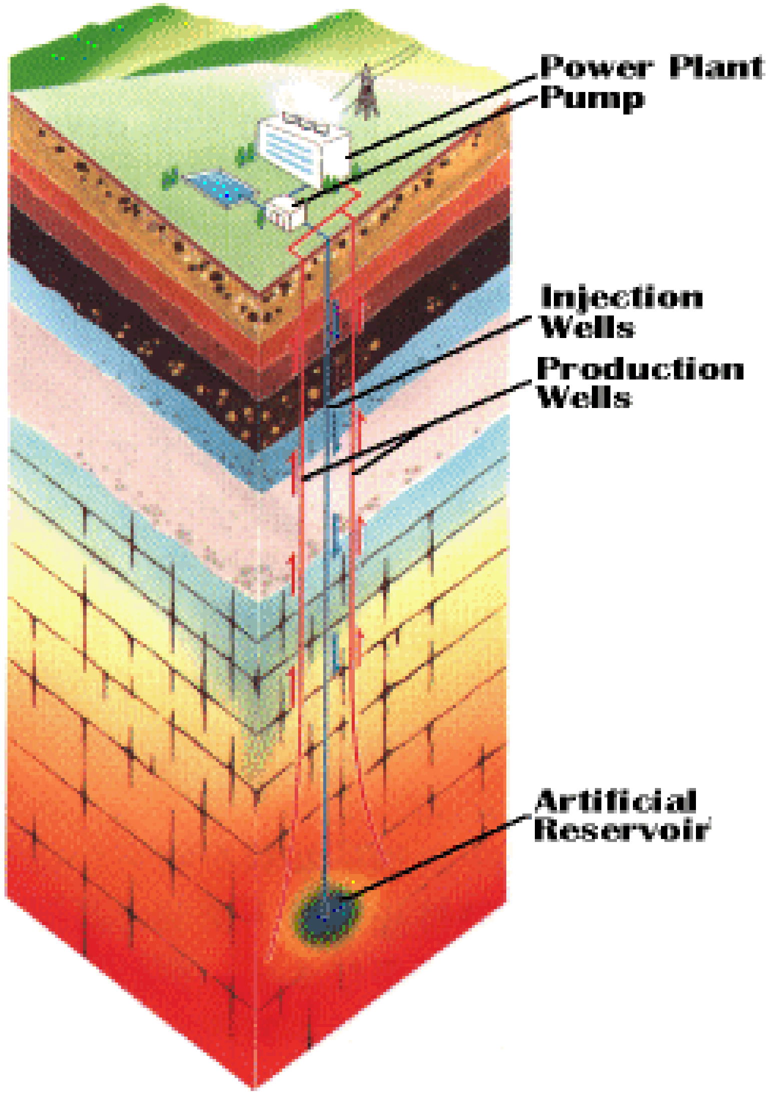
Geothermal energy

- Enhanced geothermal system
  1:Reservoir 2:Pump house 3:Heat exchanger 4:Turbine hall
  5:Production well 6:Injection well
  7:Hot water to district heating
  8:Porous sediments 9:Observation well 10:Crystalline bedrock

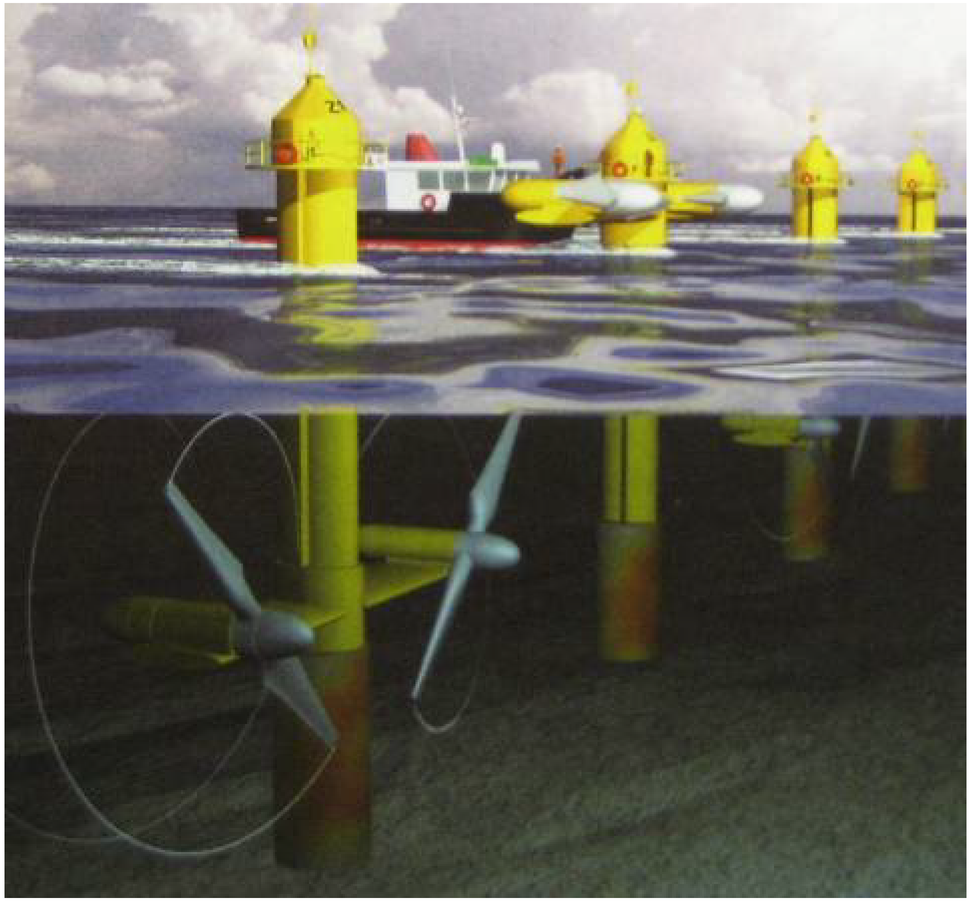


Geothermal energy



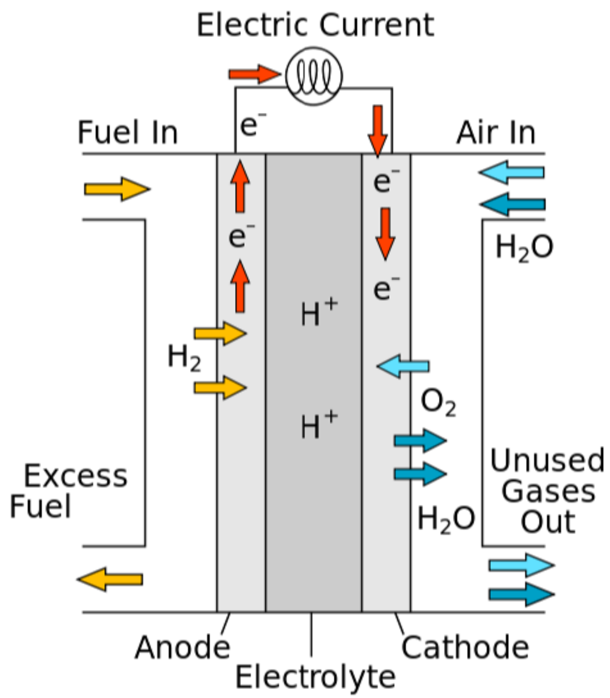


Tidal power



Wave power

Fuel cells



Electric Current
Fuel In
Air In
e⁻
e⁻
e⁻
e⁻
H_2O
H^+
H^+
H_2
O_2
Unused Gases Out
Excess Fuel
H_2O
Anode
Electrolyte
Cathode

Comparison of Fuel Cell Technologies

Fuel Cell Type	Common Electrolyte	Operating Temperature	Typical Stack Size	Efficiency	Applications	Advantages	Disadvantages
Polymer Electrolyte Membrane (PEM)	Perfluoro sulfonic acid	50-100°C 122-212° typically 80°C	< 1kW–100kW	60% transportation 35% stationary	• Backup power • Portable power • Distributed generation • Transporation • Specialty vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up	• Expensive catalysts • Sensitive to fuel impurities • Low temperature waste heat
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90-100°C 194-212°F	10–100 kW	60%	• Military • Space	• Cathode reaction faster in alkaline electrolyte, leads to high performance • Low cost components	• Sensitive to CO_2 in fuel and air • Electrolyte management
Phosphoric Acid (PAFC)	Phosphoric acid soaked in a matrix	150-200°C 302-392°F	400 kW 100 kW module	40%	• Distributed generation	• Higher temperature enables CHP • Increased tolerance to fuel impurities	• Pt catalyst • Long start up time • Low current and power
Molten Carbonate (MCFC)	Solution of lithium, sodium, and/ or potassium carbonates, soaked in a matrix	600-700°C 1112-1292°F	300 kW-3 MW 300 kW module	45-50%	• Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP	• High temperature corrosion and breakdown of cell components • Long start up time • Low power density
Solid Oxide (SOFC)	Yttria stabilized zirconia	700-1000°C 1202-1832°F	1 kW–2 MW	60%	• Auxiliary power • Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte • Suitable for CHP & CHHP • Hybrid/GT cycle	• High temperature corrosion and breakdown of cell components • High temperature operation requires long start up time and limits