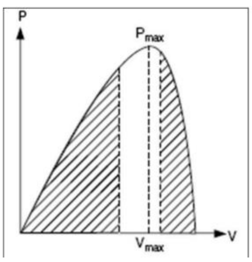
For the hydro we use the potential energy and then turn into mechanical energy through the control flow rate and that will turn the turbine which is a mechanical process and using the generator it converts mechanical energy to electricity and then we use a step up transformer to step up the voltage. So we reduce the loss. **Nuclear:** using different materials. Splitting of uranium atoms, and heat is generated and water can be boiled and turbine is turned and a generator produces electricity. In a nuclear power plant (Fig. 1.18), the heat energy released by nuclear fission is used to produce the steam that rotates the turbine that drives the electric generator.**Wind:** Larger wind turbines have standardized using horizontal-axis three-blade turbines driving an induction generator through a gearbox. Gearboxes need regular oil changes and maintenance. •There are alternatives, Enercon (Germany) have developed direct-drive generators with no gearbox and use a synchronous generator. Fig. 1.22 shows a comparison of the two.**Geothermal:** Constant source for power generation could provide base load. No fuel cost. Negligible land use. Cons: High maintenance required, high transmission cost if remoted located. Requires large volume of water. Renewable energy resources are often not stable. In order to provide stable stream of electricity, hybrid systems are developed. In order for hybrid systems to function well, smart system management strategy and control algorithm are required. **UTILIZATION OF ELECTRICITY:** SOLAR POWERED SUBMERSIBLE WATER PUMP**,** ELECTRIC VEHICLES AND SOLAR APPLICATIONS**,** ENERGY EFFICIENCY IN ELECTRICAL APPLIANCES → Over 65% of total electricity generated is consumed by electric motors. About 62% motors are in the 0.75-7.5 kW range**,** Energy efficiency of current electrical appliances are far too low because of the wide use of single**,** phase induction motors and fixed speed drive**,** Mandatory energy labeling in NSW (Fig. 1.48) could reduce energy used by up to 50% **.Future trends:** The current trend is to use power electronic converters and high efficiency motors in applications to reduce power consumption. Brushless permanent magnet DC and switched reluctance machine offer improved performance. **Conclusion:Excessive** and inefficient use of fossil fuels are causing huge problems of global climate change, resulting in various natural disasters, and energy crisis, which threatens the sustainable development of human civilization. An effective solution to the problem is to develop new technologies and increase the use of clean renewable energy, such as hydro, wind, solar, wave, tide, and geothermal, etc **. Wind energy:** Small applications(<10KW): homes, farms, remote application, Intermediate(10-250kW): village power, Hybrid systems Distributed power, Large (660kW – 10+MW): Central station wind farms, Distributed power. Reduction in cost due to commercial developments and technical improvements. **Price decreases as the size of the farm increases** and the availability of wind increases(more wind speed leads to cheaper energy) **.When assessing a potential wind farm** location, typically measure at hub height for a minimum of one year, assessing: average wind speed, turbulence, maximum wind speed, differences across the site. Typically look for sites > 7.5 m/s on average at hub height. **Main components**: Rotor – Wind turbines, Hub – Pitch control, Drive train/gearbox, Main frame/Yaw system direction control, Control system/Variable speed control, Balance of electrical system/transformer, Tower and foundation. **HAWT**(Horizontal axis wind turbine) suitable for both small and large systems, and most commercial wind turbines are HAWT. Advantages: High wind speed at a greater height, High efficiency. Complex system, High installation cost for large systems (Generator and gearbox installed on top of tower)**, VAWT** – suitable for small systems. Advantages: Gearbox and generator can be placed on the ground. Do not need a yaw system to turn the rotor against wind. Disadvantages: Wind speed is low near the ground. Low efficiency. May need guy wires to hold the turbine, and difficult maintenance. **Number of blades:** For the reason of mechanical stability of the turbine, an **even number** of blades are avoided in large systems. 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. This design is usually called the classical Danish concept: 3 blades with rotor position upwind using electrical motors in their yaw system. Two-bladed wind turbine designs have the advantage of saving the cost of one rotor blade and its weight. However, they tend to have difficulty in penetrating the market, partly because they require higher rotational speed to yield the same energy output. This is a disadvantage both in regard to noise and visual intrusion. Betz' law states that only less than 16/27 (or 59%) of the wind power can be converted into mechanical power using a wind turbine. FIXED SPEED OPERATION(cheap and effective where there is good and steady wind speed)In modern systems, e.g. Opti Slip ® (Vestas, Denmark), the slip of the generator is allowed to vary slightly if the torque varies. This mean that there will be less tear and wear on the gearbox. The slight variation of slip is achieved by varying the rotor circuit resistance. In Opti Slip ®, the external resistors and switches are mounted on the rotor while the control signal is transmitted to the rotor via an optical fibre mounted on the stator and the control signal is sent to rotor every time it passes the optical fibre. In a basic scheme for a fixed-speed wind turbine the torque and power control is via the pitch control. Good pitch control can improve fixed speed operation ,but this will require sophisticated blade pitch variation. Variable speed operation(expensive but good for gusty winds) By allowing the variation of speed, the generator is able to capture the maximum energy contained in gusty wind . the system requires the converter to be rated full capacity as the generator, icreasing the cost. Variable speed operation offers improved operation by the fact it can continuously operate effectively over an extended range of wind speeds. Typically used PM synchronous generators and cage induction generators . Vector control techniques are employed in modern systems. Doubly fed induction generator(very commonly used, expensive and not as robust as squirrel cage rotor): they need a converter of only 1/4 to 1/3 of its capacity depending on the variable speed range. It needs a wound rotor induction generator, which uses slip rings and brushes and the maintenance can be difficult and expensive. Wound rotor is not as robust and economic as the squirrel cage rotor. A special form of vector control is employed in modern systems. Smaller turbines often use variable speed permanent-magnet generators, either standard radial-flux with a slotted stator, or axial flux and air-gap windings. The example here is for a 20 kW machine which is slightly larger than the normal PM generator wind turbine. (efficinecy around 90% at DC10A) The power density, or torque per unit of the total mass is an important criterion for assessing whether a generator is a good design. This is also a function of size. UTS TWIN STATOR DOUBLY FED INDUCTION GENERATOR, Enercon use direct-drive variable-speed synchronous generators. Construction and transportation of these generators can be difficult due to their size. Turbine installation steps: **Site preparation**(construction of access road which can help open up the sire for farming and leisure), **geotechnical survey(**to ensure the site is suitable for the wind turbines), **pouring foundation(**this needs careful calcuations and to be substantial because of the heavy weight and the side forces due to the reaction of the turbine with the wind. **Careful foundation forming to take the stresses of the tower and turbine, MV cabling (**the farm has to be electrically connected with Medium Voltae(MV) cables and also connected to the grid via a substation., **HV connection and substation, tower manufacture(**blades shipping, convoy of turbine generators, transportation of blades to site, assembly of turbines,) **When building a wind** farm the following consideration must be addressed: **environmental**→Land disturbance , Affects on birds and bats(avi-fauna), effects on flora and fauna, increased human pressure on areas, decommissioning and site reclamation . **socially**→Visual amenity, noise, effects on telecommunications, construction traffic.

SOLAR ENERGY: The sun is an enormous nuclear fusion reactor which converts hydrogen into helium at the rate of 4 million tons per second. It radiates energy by virtue of its high surface temperature, approximately 6000 °C . Solar radiation and seasons: The earth circles the sun with its polar axis tilted towards the plane of rotation (Fig. 3.3). In June the North Pole is tilted towards the sun. The sun's rays thus strike the northern hemisphere more perpendicularly and the sun appears higher in the sky (see figure). In December the North Pole tilts away from the sun and its rays strike more obliquely, giving a lower energy density on the ground (i.e., fewer kilowatt-hours reach each square metre of ground per day. Another important factor is that the lower the sun in the sky, the further the rays have to pass through the atmosphere, giving them more opportunity to be scattered back into space. When the sun is 60° to the vertical its peak energy density will have fallen to one-quarter of that when it is vertically overhead. Only 50% of the solar energy reaches the earth's surface and is absorbed**. Incoming energy(100%): 6%** reflected by atmosphere, **20%** refleted by clouds, 4% reflected by earth's surface, **16%** absorbed by atmosphere, 3% absorbed by clouds**, 51%** absorbed by land and oceans(apo **to 51% → 64**% of it is rediated to space from clouds and atmosphere**, 23%** of it is carried to clouds and atmosphere by latent heat in water vapor, 7% of it conduction and rising air, 6% of it radiated directly into space from earth). **Direct and diffuse radiation** – When the sun's rays hit the atmosphere, more or less of the light is scattered, depending on the cloud cover. A proportion of this scattered light comes to earth as diffuse radiation. On the ground this appears to come from all over the sky. Some of it we see as the blue colour of a clear sky, but most is the white light scattered from clouds. What we normally call sunshine, that portion of light that appears to come straight from the sun, is known as direct radiation. On a clear day, this can approach a power density of 1 kW/m2, known as "1 sun" for solar collector testing purpose. The measurement and mapping of solar energy resources over the globe are conducted by using solarimeters, which contain carefully calibrated thermoelectric elements fitted under a glass cover to measure the total energy incident on the horizontal surface. In Australia The resource increases in an inland and northerly direction (avg 32 MJ/m^2). The unit for the daily radiation is 1 Langly = 0.0418 MJ/m2. The average solar power incident on the earth is ~1000 W/m2 or 100,000 TW in total, which is far greater than the current world power consumption of ~15 TW. The highest efficiency for direct conversion of solar energy to electricity is about 15% in practice, provided by photovoltaic (PV) cells. In 2004, the total installed PV power capacity is ≈2.5 GW and it is predicted to reach ~1000 GW by 2030. Currently, PV cells are widely used for applications in areas far from a grid. **For large systems, solar thermal systems can be more cost effective, and a few experimental systems are being built around the world**.

PV systems: The best silicon PV modules now available commercially have an **efficiency** of over 17%, and it is expected that in about 10 years' time module efficiencies will have risen to over 20%. In production, some hazardous materials such as Cd (Cadmium) and As (Arsenic) are used but the quantities are small. With effective safeguards and regulations the **risks** can be kept very small and acceptable. **Energy is required to manufacture** the modules and if it is from fossil fuels then there will be an associated CO2 emission. The **energy payback time** (the time that takes a PV cell to generate the electricity required to manufacture it) is ≈7 yrs for mono-crystalline Si, ≈5 yrs for multi-crystalline Si, ≈3 yrs for amorphous Si, ≈2 yrs for CIS, and ≈1.5 yrs for CdTe cells. For example, ≈1000 kWh/m2 is required to build a Si PV panel, and in Sydney the electricity production is ≈150 kWh/yr/m2 , giving a 7 yr pay-back time.

The lifetime of a solar cell is in general 25 to 30 years. **Basic principles** Typically, a silicon PV cell contains two layers. The top layer consists of a thin sheet of phosphorus-doped (negatively charged or n-type) silicon. Underneath this sheet is a thicker layer of boron-doped (positively charged or p-type) silicon. A unique characteristic of these two layers is that a positive-negative (pn) junction is created when these two materials are in contact. A pn junction is actually an electric field that is capable of creating an electrical potential when sunlight shines on the PV cell. When sunlight hits the PV cell, some of the electrons in the p-type silicon layer will be stimulated to move across the pn junction to the n-type silicon layer, causing the p-type layer to have a higher voltage potential than the n-type layer. This creates an electric current flow when the PV cell is connected to a load. The voltage potential created by a typical silicon PV cell is about 0.5 to 0.6 volts dc under open-circuit, no-load conditions. The power of a PV cell depends on the intensity of the solar radiation, the surface area of the PV cell, and its overall efficiency (FSEC 2005). The efficiency of each individual PV cell directly determines the efficiency of the PV panel. PV cells can be categorized into different types according to their component materials and structural features. Efficiency of commercially available PV panels is typically 7-17%. **"laser-grooved buried-grid"** monocrystalline PV cell structure, developed at the University of New South Wales is used in many high efficiency PV modules. A pyramid-shaped texture on the top surface increases the amount of light "trapped". Buried electrical contacts give very low electrical resistance whilst minimizing losses due to overshadowing. The symbols p+ and n+ denote heavily doped layers that reduce electrical resistance in the contact areas. **POLYCRYSTALLINE SILICON CELLS:** Polycrystalline silicon essentially consists of ramdomly-packed small grains of monocrystalline silicon . Solar cell wafers can be made directly from polycrystalline silicon in various ways. These include the controlled casting of molten polycrystalline silicon into cube-shaped ingots which are then cut, using fine wire saws, into thin square wafers and fabricated into complete cells in the same way as monocrystalline cells. Polycrystalline PV cells **are easier and cheaper** to manufacture than their monocrystalline counterparts, but they tend to be **less efficient** because light-generated charge carriers can recombine at the boundaries between the grains within polycrystalline silicon. By process the material properly to have large grains and oriented in top-to-bottom direction to allow light to penetrate deeply into each grain, the efficiency can be substantially increased. **SILICON RIBBONS AND SHEETS:** This approach involves drawing thin ribbons or sheets of multicrystalline silicon from a silicon melt. AMORPHOUS SILICON CELLS: Solar cells can be made from thin films of silicon in a form known as amorphous silicon (a-Si), in which the silicon atoms are much less ordered than in the crystalline forms described previously. In a-Si, not every silicon atom is fully bonded to its neighbours, which leaves so-called dangling bonds that can absorb any additional electrons introduced by doping, so rendering any p-n junction ineffective. Amorphous silicon cells are **much cheaper** to produce than crystalline silicon. A-Si is also a much **better absorber of light,** so much thinner (and cheaper) films can be used. **Max eff. 14%, initially 6-10%, and stabilizing at 4-8%. MULTI-JUNCTION SILICON CELLS:** One way of improving the overall conversion efficiency of PV cells and modules is the stacked or multi-junction approach, in which two or more PV junctions are layered one on top of the other, each layer extracting energy from a particular portion of the spectrum of the incoming light. A cell with two layers is often called a "tandem" device. Multi junction modules using amorphous silicon are available with stable efficiencies of around 8% from companies such as Unicolar and RWE. Cells of different types can also be used, as in the Sanyo Hybrid HIT module, in which a thin monochrystalline layer is sandwiched between two amorphous silicon layers. This enables very high conversion efficiencies to be achieved with low material and manufacturing energy requirements. **Concentrating PV systems** – Another way of getting more energy out of a given number of PV cells is to use mirrors or lenses to concentrate the incoming solar radiation. In a concentrating PV system, the cells usually need to be cooled, either passively or actively, to prevent overheating. **Silicon spheres:** The US firm Texas Instruments has developed an ingenious way of making PV cells using tiny, millimeter sized, spheres of polycrystalline silicon embedded at regular intervals between thin sheets of aluminum foil. **Photoelectrochemical cells:** - Third generation PV cells – Based on nanotechnology.



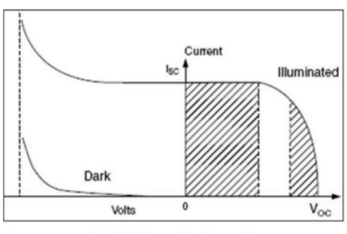


Fig. 3.34. I-V characteristics for PV module

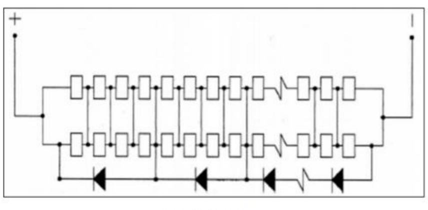
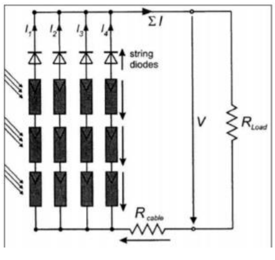
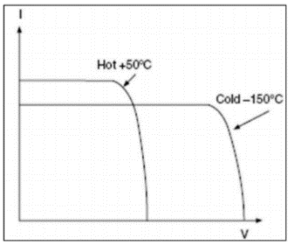


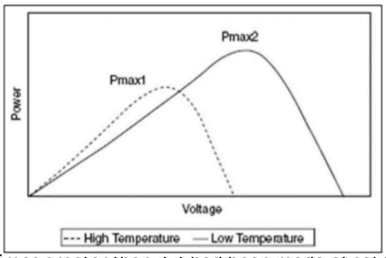
Fig. 3.37. Bypass diodes



BASIC CONSTRUCTION OF PV CELLS, MODULE AND ARRAY ARRANGEMENT: Several PV cells make a module, and several modules make an array. The construction of PV module: frame, weatherproof junction box, rating plate, weather protection for 30-year life, PV cell, tempered high-transmittivity cover glass, outside electrical bus, frame clearance. **The dark current or the reverse diode-saturation current: (Voc/Rsh)** this is the leakage current to the ground. In practical cells, it is negligible compared to IL and ID and is generally ignored. The diode-saturation current can therefore be determined experimentally by applying a voltage VOC to the cell in the dark and, measuring the current going into the cell. **The maximum photovoltage** is produced under OC voltage. Practical photocells. **The photocurrent is several orders of magnitude greater than the reverse saturation current.** Therefore, **the open-circuit voltage is many times the kT/Q value**. Under conditions of constant illumination, IL/ID is a sufficiently strong function of the cell temperature, and the solar cell ordinarily shows a negative temperature coefficient of the open-circuit voltage. In order to minimize the **shadow effect,** bypass diodes in the PV string can be utilized. In addition to using bypass diodes, **parallel connection of PV strings** via string diodes for protection, **TEMPERATURE EFFECTS ON I-V AND P-V CURVE:** The effects of temperature on the I-V characteristic (cell produces less current but greater voltage, with net gain in the power output at cold temperatures). **The effects of temperature on the P-V characteristic** (cell produces more power at cold temperatures). **ELECTRIC LOAD MATCHINGAND STABILITY.** It is important to load the cells and modules correctly. This is often done using a maximum power point tracker (MPT). This shows the operating stability and electrical load matching with constant-resistive load and constant-power load. The necessary conditions for electrical operating stability of the solar array is: $\left[\frac{dP}{dV}\right]_{load} > \left[\frac{dP}{dV}\right]_{source}$ Therefore to keep the system stably a maximum power point tracker is used. The load line is derived from a set of V-I curves at different light intensive. **GRID CONNECTION:** It is important to connect the system correctly, either to batteries or to the grid. There are many schemes for subsidizing the gridconnection in a domestic dwellingA scheme for a typical single-phase PV grid injection system equipped with a Maximum Power Tracker (MPPT)and an energy counter (kWh) is shown below **TILT**: To collect as **much radiation as possible,** a surface should **face south in northern hemisphere** or **north in southern hemisphere** and must be **tilted towards the sun** to an angle depending on the latitude and the time of year(more horizontal position for summer, more vertical for winter, a tilt equal to the latitude gives best performance in spring and autumn). When the sun moves from the east to west, a sun tracking system can increase the energy yield up tob40% over the year compared to the fixed array design. When the sun moves from the east to west, a sun tracking system can increase the energy yield up to 40% over the year compared to the fixed array design. **One method of designing the sun tracker is to use two PV cells mounted on two 45° wedges** and connecting them differentially in series through an actuator motor. When the sun is normal, the currents of both cells are equal and cancel each other. The motor is not activated, and the panel stays. When the panel is not normal to the sun, the currents of the two cells are different and the motor current is nonzero. The motor would drive the panel until it is normal to the sun. **Remote Applications**: PV parking meter, navigation buoy, telemetry system, solar powered pump, solar powered car and ferry etc. When there is no need of electricity, the energy is used to produce hydrogen, which is stored in large tanks and then when there is need of electricity, it is used to produce energy via a fuel cell.

Solar Thermal systems: from the total solar energy flow, 47%(2.55million EJ/year) is direct converted to heat in air/earth/oceans, 23% evaporation/precipication, 30% short wave radiation direct reflected to space. The most important solar property of **glass** is that it is **transparent to visible light** and short wave infrared radiation, but **opaque** to **long wave** infrared re-radiation. Heat loss mechanism: Conduction, thermal conductivity; Convection, reducible by filling double glazing with a heavier less mobile gas, such as argon or CO2, and limiting the space for gas movement; Radiation, Low-E coating. **Heat flow through one Square meter = (U-value)*Temperature difference.** **Double-glazed window** heat escape (Fig. 4.4): air space is about 6-10 mm. If too narrow, convection will be difficult but conduction easy. If too wide, convection currents can circulate. There is also radiation across the airspace – reduced by use of low emissivity coatings.

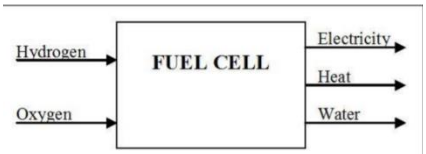




LOW TEMPERATURE SOLAR COLLECTORS absorber plate: very black surface that absorbs nearly all of the incident solar radiation (**high absorptivity).** Most black paints still reflect approximately 10% of the incident radiation (a white surface, by way of comparison might reflect back 70-80%). Some panels use a selective surface that has both high absorptivity in the visible region and low emissivity in the long wave infrared to cut heat loss. An **absorber plate** must have **high thermal conductivity** to transfer the collected energy to the water with minimum temperature loss. **HIGHER TEMPERATURE SOLAR COLLECTORS: Evacuated tube collectors:** The absorber plate is a metal strip down the centre of each tube. Convective heat losses are suppressed by virtue of a vacuum in the tube. The absorber plate uses a special "heat pipe" to carry the circulated energy to the water, which circulates along a header pipe at the top of the array**. heat pipe** is a device that takes advantage of the thermal properties of a boiling fluid to carry large amount of heat. A hollow tube is filled with a liquid at a pressure chosen so that it can be made to boil at the hot end, but the vapour will condense at the cold end. The tube in effect has a thermal conductivity many times greater than if it had been made of solid metal, and it capable of transferring large amounts of heat for a small temperature rise. **Domestic solar thermal applications: Solar heating systems**(conservatory, trombe wall, direct gain); active solar space heating.

Solar thermal electricity generation: HEAT ENGINES, CARNOT EFFICIENCY AND ORCS: It works by boiling water to produce high pressure vapour, which goes into an expander, which extracts energy and low-pressure vapour is exhausted. The expander can be a reciprocating engine or a turbine. These are heat engines. Maximum efficiency=$1 - Tou/Tin$. The ideal efficiency is known as **Carnot efficiency .** Systems that use turbines are often referred to as **Rankine cycles.** Normally, to boil water, its temperature must be raised to at least 100 ºC. This may be difficult to achieve with simple solar collectors. It would be more convenient to work with a fluid with a lower boiling point. In order to do this, a "closed cycle" system must be adopted, with a condenser that changes the exhaust vapour back to liquid and allows it to be returned to the boiler. Systems have been developed that use stable organic chemicals with suitably low boiling points, similar to refrigerants in heat pumps. One that uses an organic fluid and a turbine is known as an Organic Rankine Cycle or ORC. These are used with solar ponds, OTEC (ocean thermal energy conversion) systems and some types of geothermal plants.These low temperature systems are likely to **have poor efficiencies**. For example, the theoretical Carnot efficiency of a hear engine that was fed with relatively low-temperature vapour at 85 ºC, say from a flat plate solar collector, and exhausted at 35 ºC would only be 14 %. **SOLAR PONDS** (LAKE) : The solar pond uses a large salty lake as a kind of flat plate collector. If the lake has the right gradient of salt concentration (salty water at the bottom and fresh water at the top) and the water is clear enough, solar energy is absorbed on the bottom of the pond. The temperature at the bottom can reach 90oC. Because of the **low temperature, the efficiency is low typically 2%.** 50 MW systems fed from a lake of 20 hectares have been demonstrated. In practice, the **major disadvantage** is the requirement of fresh water to maintain salt gradient. The best use is the desalination system in deserts. **OCEAN THERMAL ENERGY CONVERSION:** uses the sea as a solar collector. in deep waters(>1000m) the temperature difference between the warm surface and the cold water at the bottom can amount to 20Celcius. Although the theoretical **efficiency** is likely to be **very low** and the Rankine cycle system used needs to finely tuned to boil at just the **right temperature**, there is lots of water available. Such a system would need **large and expensive equipment**: big pumps and in particular very efficient heat exchangers. **OTEC is not yet economically competitive**, but with technical developments, it is closer to becoming a viable option in some tropical regions. **POWER TOWERS:** It operates with heat storage using molten salt at over 500ºC. A major benefit is that it incorporates thermal storage for many hours with no performance degradation, which allows the system to produce high value electricity to meet peak demands. **SOLAR CHIMNEYS:** The solar chimney exploits the warm air produced in a very large greenhouse, which rises through a tall chimney. Electricity is produced by a generator driven by a turbine at the base. **PARABOLIC DISH CONCENTRATOR SYSTEMS** collects solar energy by using parabolic dishes and the engine and generator are put at the focus of the disc. Both small steam and Stirling engines have been tried and it was found that the Stirling engine was more efficient when the system was operated at 700 – 1000 oC. The overall efficiency can be up to 30%. Experiments were also conducted on using aluminized plastic film with a vacuum thermal insulation at the back to replace the heavy glass mirror. **STIRLING ENGINES(**high efficiency, quiet operation, and the ease with which it can utilize almost any heat source**):** The Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work.

FUEL CELLS: The Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work. **Advantages: High efficiency(pure electrical efficiency can be >45%, and if the thermal outcome is useful, the overall efficiency can be as high as 85%), simplicity, low emissions, silence, flexibility. Major technical challenges: Production and storage of hydrogen.** From fossil fuel economy to hydrogen economy: **Huge amount of infrastructural work** is required, Primary barrier is **cost**, First markets will be in electrical vehicles, portable and residential distributed generation applications, especially in areas with harsh environment, e.g. Antarctica, Rapid cost reductions in the near future. Sources of hydrogen: Electrolysis, separation of hydrogen and oxygen at a certain temperature(265 celcius) using catalysts, by-product of oil refinery, reformation of other fuels such as natural gas, methanol and ethanol. **Main types: Alkaline Fuel cell(AFC), Phosphoric Acid(PAFC), Proton Exchange Membrane (PEMFC, one of the most common ones), Solid Oxide (SOFC), Molten Carbonate(MCFC), Direct Methanol(DMFC), Regenerative(RFC)**. **PEMFC**: The membrane: Sits between the anode and cathode, Split up Hydrogen into protons and electrons, ONLY let the protons cross, Traditionally Teflon-based perflourinated, expensive, low efficiency, Hydrocarbon Polymer, lower cost, higher efficiency (10 – 15 % more power produced). **Catalyst:** The process of separating hydrogen protons and neutrons, Uses a layer of platinum on the membrane, New technology uses bacteria instead of expensive platinum. System consists of: Fuel cell stack, fuel management unit, control unit, thermal management unit.



HYDROELECTRIC POWER SYSTEMS: Water stores energy in the form of potential (river and dam) and kinetic energy (tide and wave). Hydroelectricity is a well established technology, which has been producing reliable power (about 1/6 of the world's total electricity) at competitive prices for about a century. **Resources**: Nearly a quarter of the 1.5 billion TWh of solar energy incident on the earth each year is consumed in the evaporation of water, and about 0.06% is retained by the precipitation that falls on hills and mountains. **Recent estimates** suggest that the energy carried by the world's flowing rivers is just over 40,000 TWh per year – about 15 times the world's present hydroelectric output. Estimates of the technical **potential** are at 14,000 – 15,000 TWh per year. **Three main types of wheel**. **Overshot wheel:** water is falling from above the blades with closed sides .unsuitable for streams and rivers because thy need a head at least as high as the diameter of the wheel. **Undershot:** is driven by the pressure of water against its lower blades, which dip into the flowing stream. **The advantage** is that it can be used in almost any stream or channel but its **inefficient if the water floods**, impeding the motion of the wheel. **The Breastshot(overcoming the flood issue):**The water is channelled between parallel breast walls and strikes the paddles at about the level of the wheel axle. It has the advantage of overcoming the flooding problem without requiring the high head and massive construction of the overshot wheel. There are two basic designs of water turbines**: impulse turbines(**the blades are fixed to a rotating wheel and each blade rotates in air, apart from when the blades is in line with a high speed jet of water**)** and **reaction turbines(**the blades are fully immersed in water and the thrust on the moving blades is due to a combination of reaction and impulse forces.**)** The **efficiency** of modern turbines can be over 90%. Other types: Francis, Pelton, Kaplan, Turgo ,Crossflow. **Pelton:** For sites of the type with heads above 250 m or so or lower for small scale systems, the Pelton wheel is the preferred turbine. A high speed jet of water, formed under the pressure of the high head, hits the splitting edge between each pair of cups in turn as the wheel spins. The water passes round the curved bowls, and under optimum conditions gives up almost all its kinetic energy. The power can be varied by adjusting the jet size to change the volume flow rate, or by deflecting the entire jet away from the wheel. Pelton wheel extracts the maximum energy from the water if the cups move at half the speed of the water jet.

Synchronous machines: A rotating electrical machine is regarded as the synchronous machine if its rotor rotates at the same speed as the rotating magnetic field. The armature winding of a conventional synchronous machine is almost invariably on the stator and is usually a three phase winding. The field winding is usually on the rotor and excited by DC current, or permanent magnets. The DC power supply required for excitation usually is supplied through a DC generator known as exciter, which is often mounted on the same shaft as the synchronous machine. In large turbine generators, AC exciters and solid state rectifiers are used. The stator and rotor of hydroelectric generators are generally **designed** as **axially short** and **large diameter** because The hydroelectric generators are operated at low speeds, and to generate electricity at 50 or 60 Hz, a great number of salient poles are required. **Environmental effects:** Hydrological effects(Water flows, ground water, water supply, irrigation, etc.), Effects of large dams and reservoirs(Eco-systems, catastrophes (earthquake), silt, etc), Social effects(Relocation of people, communities, and cities) **Small scale systems have less effects than large ones. Hydroelectric technology is the most matured and cost competitive in renewable electricity generation.**

TIDES: There are two high tides and two low tides around the earth at any instant. One high tide in on the longitude closest to the moon and the other on the longitude furthest from the moon. On any given longitude, the interval between high tides is approximately 12 hours 25 minutes. The variation in tidal height is due primarily to gravitational interaction between the earth and the moon. This gravitational force, combined with the rotation of the earth, produced at any particular point on the globe a twice-daily rise and fall in sea level, this being modified in height by the gravitational pull of the sun and by the topology of land masses and ocean beds. The difference in height between a high tide and a low tide is called **tidal range**.

ENVIRONMENTAL EFFECTS: The construction of a barrage would result in higher minimum water levels and slightly lower high water levels in the basin. Currents will be reduced and extreme wave conditions will, in many places, be less severe. The changes that will occur to the tides and currents during construction and then later during the operation of a barrage will cause changes in sediment characteristics and in the salinity and quality of the water. These factors have a major bearing on the estuary's environment and ecology

WAVE ENERGY: The waves on the surface of the sea are caused mainly by the effects of wind. The size of orbits decreases exponentially with depth. 95% of the wave energy is contained in the layer between the surface and a depth h equal to a quarter of the wavelength λ, i.e. h = λ/4. **deep ocean** (water depth d>λ/2) the long waves travel faster than shorter waves. **Intermediate**(λ/4<d<λ/2): when waves reach shallow water(shore) their properties are completely governed by the water depth, but in intermediate depths the properties of the waves will be influences by both water depth d and wave period T. **Shallow water waves (water depth d<λ/4):** The velocity under these conditions is equal to roughly three times the square root of the water depth d – it no longer depends on the wave period. Areas where the shoreline is formed by a **steep cliff** which drops into reasonable deep water are most suitable for shore mounted wave energy converters because the incident waves have a high energy content. For most of the coastlines around the world **the near shore water** is quite shallow. Due to the frictional coupling between the water particles at the greatest depth with the seabed, deep water waves gradually give up their energy as they move into shallower water and eventually run up the shore to the beach. The effect of refraction, caused by the reducing depth and hence velocity, is gradually to change the direction of the crest to be roughly parallel with the shore. Knowledge of the depth contours allows us to carry out a "ray tracing" procedure, and with it we can identify those areas where the waves will be concentrated. Clearly such sites would be the most cost-effective for wave developments.**WAVE ENERGY CONVERTERS: in terms of location→Fixed**(most common tested, easier access and easy for maintenance): to the seabed, generally in shallow water. oscillating water column(OWC). In these devices, an air chamber pierces the surface of the water and contained air is forced out of and then into the chamber, the air passes through an air turbine generator and so produces electricity. The Wells turbine is used in and proposed for many OWCs. This novel axial flow air turbine rotates in one direction irrespective of whether the airflow is into or out of the chamber, and has aerodynamic characteristics particularly suitable for wave applications. **Shore mounted devices:** generally, have a lower power density incident upon them than floating devices. Although, they have easier maintenance and access, if compared to seabed. The disadvantage is that shore mounted devices need to be positioned in an area of small tidal range.
Floating offshore in deep water. More energy output than fixed, since the wave power density is bigger offshore than on shallow waters, and space restriction is not an issue.(the **Duck**→ theoretically one of the most efficient of all wave energy schemes, but it will take some years to develop fully the engineering necessary to utilize it at full scale., **Clam and Pelami(snake)**→ consists of a number of cylindrical sections hinged together. The wave induced motion of the cylinders is resisted at the joints by hydraulic rams that pump high pressure oil through hydraulic motors via smoothing accumulators, and the hydraulic motors drive electric generators to produce electricity, **floating OWCs such as the whale**→ massive structure (50m in length, 1000 tons in weight, rated at 110 kW), **Backward Bent Duct Buoy**, **Floating wave power vessels**→ capturing the water from waves that run up its sloping front face. The captured water is returned to the sea via a standard Kaplan hydroelectric turbine. In many respects this device may be compared to a floating version of the TAPCHAN)
Tethered in intermediate depths: Float systems, with the main body of the structure floating on the surface, but moored to the seabed via a pump.**In terms of geometry and orientation→ Terminators**: principal axis is parallel to the incident wave front and they physically intercept the waves, **Attenuators**: principal axis perpendicular to the wave front so that wave energy is gradually drawn towards the device as the wave moves past it, Point absorbers: they draw energy from the water beyond their physical dimensions(Tethered buoy systems, for example). **ENVIRONMENTAL IMPACT:** one of the most environmentally friendly of RES. **No chemical pollution** apart from some lubricating or hydraulic oil which are sealed in the sea. **Little visual impact**(if not shore mounted), **Low noise pollution,** Near shore wave energy schemes will release an estimated 11 g of CO2, 0.03 g of SO2 and 0.05 g of NOx for each kWh of electricity generated, making them very attractive in comparison to the conventional methods.
Economics: Reducing operation and maintenance costs is the key to successful economic implementation of wave energy stations. the "fuel" or wave energy costs are zero, leaving the operation and maintenance costs as the determining factor. Schemes will therefore have to be reliable and robust enough to survive the wave climate for many years. This means schemes designed for long lifetimes and with a small numbers of moving parts (to minimize failures). a wave energy station costs twice as much as that for building a conventional station running on fossil fuels. However, the wave energy station can be competitive if it is reliable with long lifetime and can run with low running cost.
BIOMASS: (32% Paper, 21% Organics, 11% Plastics, 9% Glass, 8% Metals, 2% Textiles, 17% Other). Most power stations use the heat from burning fuel to produce high pressure steam for steam turbines that drive the generators. Bio-energy has in general two sources: energy crops and wastes. The technologies to convert bio-energy to other useful forms are direct combustion, conversion into gaseous fuels, and liquid fuels. Bio-diesel and ethanol may have great significance in replacing petrol in vehicle applications. Biomass is not a clean energy source, but planting energy crops, e.g. trees, and use of bio-fuels in more energy efficient forms may contribute to CO2 mitigation. Bio-energy is land demanding since large area is required to plant energy crops. Bio-energy can be economically viable
Steam temperatures are limited to about 600ºC for technical reasons so the maximum Carnot efficiency is about 65% and in reality more like 45 %. Gas turbines driven directly by the combustion produces of a burning gas at 1000ºC or more should have higher efficiencies but the significant improvement is achieved in the combinedcycle gas turbine (CCGT) system. In order not to corrode or foul turbine blades the gases must be clean so most CCGT plants burn natural gas. A major objective in bio-energy is the production of liquid bio-fuels as substitutes for crude oil products. The three main approaches, the thermochemistry, synthesis, and fermentation, could hardly be more different. Pyrolysis to produce bio-oil – This is the simplest and almost certainly the oldest method of processing one fuel in order to produce a better fuel. The term of pyrolysis is now normally applied to processes where the aim is to collect the volatile components and condense them to produce a liquid fuel or bio-oil. It is characteristic of biomass that the volatile matter carries more of the energy than the char, so this process should be more efficient. **Geothermal:** "high enthalpy"(water and steam at temperatures above about 180 – 200 ºC), "medium enthalpy" (about 100 - 180 ºC) and "low enthalpy" (<100). Geothermal resources of most types must have three important characteristics: anaquifer containing water that can be accessed by drilling, a cap rock to retain the geothermal fluid, and a heat source. Different types of power plants: Dry steam 180-225 oC and 4-8 MPa., single flash steam 155-165 oC and 0.5-0.6 MPa, binary cycle Hot water and using working fluid with a lower boiling temperature than water to extract heat., double flash.
Environmental implications: noise during the drilling of wells, and the disposal of drilling fluids, which requires large sediment-settling lagoons. Longer term effects of geothermal production include ground subsidence, induced seismicity and, most important, gaseous pollution. **Economy:** Compared with the conventional electricity generation technologies, the cost of electricity generated from the geothermal energy is slightly higher. However, it is within the acceptable range.
ENERGY STORAGE: Batteries, Supercapacitors, Flywheels, superconducting magnetic energy storage, compressed air.
Batteries: store energy in the form of chemical energy. The one way conversion efficiency is about 85 to 90%. There are two basic types of electrochemical batteries: **primary converts chemical energy into electric energy.** The electromechanical reaction is non-reversible and the battery is discharged after a full discharge. Used usually when we need a high energy density for single use only. **Secondary(rechargeable battery):** the electromechanical reaction is reversible. After discharge it can be recharged by injecting a direct current from external source. In discharge mode, it converts chemical energy into electric energy. In charge the opposite. In both modes, a small fraction of energy is converted into heat. The round trip conversion efficiency is between 70 and 80%.
The battery is made of numerous electrochemical cells connected in a series and/or parallel combination to obtain the desired battery voltage and current. **Types of rechargeable batteries**: **Lead-acid** Pb-acid (**the most common, CHEAPEST,** however it has the least energy density by weight and volume, shallow cycle used in automobiles to start the engine, deep cycle used for repeated full charged and discharge cycles)
Nickel-cadmium NiCd (**longer** deep cycle, **lighter** and more **temperature tolerant** that Lead acid EXHIBITS **MEMORY EFFECT** which degrades the capacity if not used in long time, For these reasons, NiCd is **being replaced** by NiMH and Li-ion batteries in laptop computers and other similar high priced consumer electronics.),
Nickel-metal NiMH hydride(offers an improvement in energy density over that in NiCd, negligible memory effect, temperature sensitive)
Lithium-ion Li-ion (3 times more energy density than Pb-acid, Higher cell voltage so requires less cells, safe, the Li-ion electrochemistry is vulnerable to damage from over charging or other shortcomings in battery management. Therefore it requires more elaborate charging circuitry with adequate protection against overcharging. contains no metallic lithium) , **Lithium-polymer** Li-poly (contains metallic lithium) , **Zinc-air**(requires good air management to limit self-discharge rate)
Normal charging has three phases: Bulk (fast) charge, which deposits 80 to 90% of the drained capacity, Taper charge, in which the charge rates is gradually cut back to top off the remaining capacity, Trickle (float) charge after the battery is fully charged to counter the self-discharge rate
There are three charging methods: Multiple charge rates, in which battery is charged gently in multiple steps, Single charge rate, which uses a simple low cost on/off regulator, Unregulated charging – This method can be used in PV power systems with a maximum PV voltage kept below 15 V, making it impossible to over charge the battery.
Applications: Electrochemical supercapacitors are still relatively new devices that have yet to experience widespread use. This has originally been due to their limited power and energy capabilities, and they therefore only saw use in low-power, low-energy applications such as for memory backup. Recently, however, significant advances have been made in improving both energy and power density, and new applications for EDLCs are being developed at an increasing rate. The following are a number of possible applications for the EDLC as an energy storage element. **Electric vehicles:** A combination of a high-energy density device such as a fuel cell to provide the average load requirements and a high-power device such as a supercapacitor bank to meet the peak load requirements that result from accelerating or climbing up hills. The utilisation of supercaps also makes regenerative braking possible. Because the supercap bank can be recharged, it is possible to store some of the energy of an already moving vehicle, and therefore increase the fuel efficiency of the EV**. Supercapacitors can also be used on their own to provide the energy needed by power quality systems** that ensure reliable and disturbance-free power distribution. EDLCs then supply the energy needed to inject power into the distribution line and thus compensate for any voltage fluctuations. They can also be used to design systems that grant adjustable-speed drives the ability to ride-through temporary power supply disturbances. Such applications are vital in industrial settings, and can prevent material and financial losses that could occur due to machine downtime.
Flywheels: stores kinetic energy in a rotating inertia. It has been used as a mechanical device for equalizing the speed of rotation. works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy. When energy is extracted from the system, the flywheel's rotational speed is reduced as a consequence of the principle of energy conservation; adding energy to the system results in an increase in the speed of the flywheel. Most FES systems use electricity to accelerate and decelerate the flywheel, but devices that directly use mechanical energy are being developed. Advanced FES systems have rotors made of high strength carbon-composite filaments, suspended by magnetic bearings, and spinning at speeds from 20,000 to over 50,000 rpm in a vacuum enclosure. Such flywheels can come up to speed in a matter of minutes — much quicker than some other forms of energy storage. The round trip conversion efficiency of a large FES can approach 90%, much higher than that of a battery. Modern FES can achieve five times the energy density of the currently available batteries. a smaller rotor can run at a higher speed. The thin rim type rotor has a high inertia to weight ratio and stores more energy per kilogram weight. A good flywheel design therefore has a high σmax/ ρ ratio for high specific energy, and a high YME/ρ, where YME is the Young's modulus of elasticity. **SUPERCONDUCTING MAGNETIC ENERGY STORAGE (SMES) AND HTS:** Round trip efficiency 95% and maximum system now is 5000 MWh. Life time up to 30 years. Current/voltage relationship is highly non-linear **Conclusion:** Batteries are most commonly used energy storage with acceptable energy density and specific power for most applications. Super capacitor features in high specific power and hence is suitable for applications which needs fast charging and discharging, e.g. electrical vehicles. Flywheel can have higher energy density and efficiency than batteries and are suitable for middle or large systems. SMES has high efficiency and long life time, and is most suitable for power grid applications, e.g. power quality compensation. compressed air does not need any high technology and are suitable for large scale applications. **Smart grids:** Smart grid sensing can be used to provide information to consumers and operators so that they better understand consumption patterns and make informed decisions for more effective use of energy. This information can be used as diagnostic tools to alert users of unexpected equipment behavior as well as verify that energy efficiency programs are delivering the desired results. Automated systems can bring greater value to system operations. For example, once installed, advanced meters can provide information to billing systems that inform customers of their bill and allow electronic funds transfers as payment. Reducing energy losses (using automated voltage control), thefts (advanced metering), and outages (distribution automation) also contribute efficiencies, as do capabilities that contribute to workforce productivity gains **Tidal:** Review the different forms and arrangements for different types of tidal power plant. You should refer to: i. Location; ii. Amount of extraction possible; iii. Environmental consideration; iv. Costings; v. Types of system available and being developed. 1 tide every 12 hours and 25 minutes(so 1 tide is 12*60+25= 745 minutes). In 1 year:365*2*60=525600minutes. 525600/745=705 tides). Tides occur due to sun and moon gravitational pull. Spring tide: sun and moon are aligned with earth.(new or full moon. High tide is very high and low tide is very low). Neap tide: when sun and moon are perpendicular to each other(during the moon's quarter phases): small difference between high and low tide. **Waves:** Discuss how waves develop and propagate in terms of stored energy and energy flow→when a wave is formed then the water molecules go into orbital motion. The phase difference creates a travelling wave on the surface. The amplitude of the orbit decreases with depth. How can a wave energy device have a conversion factor>1? → If device capturing energy from a wider wave front that L it can be the case that Cp appears to be more than one. Bouys are like that. Discuss the wave motion of water and how it behaves as the waves propagate into shallow water and onto a beach. Why do waves break and why is the quality of the wave energy much poorer in shallower water? Assuming orbital in deep sea, as waves move into shallower water, the drag from the sea bed makes the orbits move elliptical. The waves slow, the wavelength decreases, and the drag causes the waves to break. The quality is poor. The swallowing sea bed absorbs energy from the wave so shore line locations have much lower energy availability in the waves. Discuss the issues concerned with realising wave energy devices when they are: shoreline→ lower energy and they are more random and poor in quality. However easier to protect device and no sub sea power system to deal with. Deep ocean→ Good waves, lots of energy but problems with location, Difficult to run power system, difficult maintenance and access. Storm damage danger.
Energy storage: Why are laptop-type batteries used? Adv→ small size, cheap, low maintenance and high power density disadv→ protection requires (over charge or discharge)
Biomass: Review the different bio-energy solutions that are available. List their advantages and disadvantages. In this review make reference to key indicators such as conversion rates, ease of processing, greenhouse gas emissions, practicality and final usage. This question should form the main qualitative appraisal of the section.
Geothermal: Geo-thermal energy extraction has niche application. Why is this so? Review and research the different geo-thermal arrangements around the world. What are the disadvantages of these systems in terms of environmental impact?
Can geothermal be applied in a marine environment?

Solar pv

Voc	Open circuit voltage	$V_{oc} = \frac{nKT}{q}\ln(\frac{I_{sc}}{I_L}+1)$
v_{oc}	Normalized open circuit voltage	$v_{oc} = \frac{q}{nkT}V_{oc}$
FF	Fill factor	$FF = \frac{v_{oc} - \ln(v_{oc}+0.72)}{v_{oc}+1} = \frac{V_{mpp}I_{mpp}}{V_{oc}I_{sc}}$
η	Efficiency	$\eta = \frac{V_{oc}I_{sc}FF}{V_{oc}I_{sc}}$
V_T	Thermal voltage	$V_T = \frac{KT}{q} = 0.0259Vv$

q:electrin charge	K:boltzmann constant
T:temperature [K]	n: diode ideal factor (normal =1)
I_{sc} : short circuit current	I_L: saturation current

Wind

K.E	Kinetic Energy	$K.E = \frac{1}{2}mv^2$
p	power	$p = \frac{Energy}{time} = \frac{mass \times v^2}{2 \times time}$
$\dot{m}$	Mass flow rate	$\dot{m} = \frac{m}{time} = \rho.A.v$
P_b	Extractable power	$P_b = \frac{1}{2}\dot{m}({v_1}^2 - {v_2}^2) = \frac{1}{2}\rho.A.{v_T}^3C_p$
a	axial induction factor	$a = \frac{v_1 - v_T}{v_1} = \frac{v_1 - v_2}{2v_1}$
$T.S.R$	Tip Speed ratio	$T.S.R = \frac{rotor\ tip\ speed}{wind\ speed} = \frac{N(rpm) \times D\pi}{60\ v_1}$
T	torque	$T = \frac{Power}{\omega}$
F	force	$F = ma$, (where a: acceleration)

m: mass	v_T: Flow velocity of the mass elements
$\dot{m}$: Mass flow rate, it is constant for stream tube.	
ρ: mass density of the fluid , Under standard condition (sea-level, 15ºC), the density of air is 1.225 kg/m3 .	Cp: Power coefficient
I_{sc} : short circuit current	C_p: power coefficient
v_1: upwind speed	v_2: downwind speed
angular velocity:$v = \omega * r$	N: *rotational speed*

Solar thermal

The *net* heat flow into the plate	$P_{net} = A\tau_{cov}\alpha G - \frac{T_p - T_a}{R_L}$
Plate heat losses.	$\frac{T_p - T_a}{R_l}$
useful output	$P_U = \eta P_{net} = \frac{mc\Delta T}{\Delta t}$
thermosiphon pressure	$P_{th} = \oint \rho g d_z = \rho g H_{th}$
	$H_{th} = \oint\left(\frac{\rho}{\rho_0} - 1\right)d_z = -\beta\oint(T - T_0)d_z \approx \beta(T - T_0)d_z$

$Ap\tau_{cov}G$: The radiant flux striking the plate.	G: is the irradiance on the collector.
Ap: The exposed area of the plate.	τ_{cov}: Transmittance of any transparent cover that may be used to protect the plate from the wind, (assume 1 if ideal).
α_p: fraction of flux is actually Absorbed, (assume 1 if ideal).	m: mass of fluid.
T_p: The plate temperature .	T_a: The outside environment temperature.
R_L: the resistance to heat loss from the plate	H: transfer efficiency, in well-designed collector it is only slightly less than 1.

$mc\Delta T$: thermal capacity	c: specific heat capacity for water 4.18kJ/kg°C.
water density: 997kg/m³	

d_z: The vertical increment	ρ_0: convenient reference density (1.164kg/m³ at 30 °C, 1.298kg/m³ at 5 °C)
β : expansion coefficient	G: is the irradiance on the collector.
g: gravity 9.81m/s²	ρ: convenient density:

Hydroelectricity

The power output of the dam	$P_{out} = \eta\rho g h Q$
volume velocity[m³/s]	$Q = Av$
Tip Speed ratio	$T.S.R = \frac{rotor\ tip\ speed}{water\ speed} = \frac{\omega r}{v} = \frac{N(rpm) \times D\pi}{60\ v}$
Rotational speed for synchronous machine	$N = f\frac{2}{poles}60$

η: systems efficiency (turbine and generator)	ρ: water density (10³kg/m³)
g: gravity 9.81m/s²≈ 10 m/s²	h: head
A: The pipe or nozzle cross-sectional area.	v: *water speed*