Batteries vs fuel cells

Batteries and fuel cells can both be used as power supplies when the utility service is not available, and both supply electricity without a rotating generator. However, there are important differences in the internal construction and capabilities of fuel cells and batteries. In simple terms, a battery delivers energy it has previously stored, while a fuel cell converts the energy from a fuel to electricity.

Batteries are useful in applications where they can be recharged. This can be accomplished with the power grid supply or with a renewable generation system. When combined with renewable generation, batteries enable a power supply that is independent from external sources. Fuel cells are a better option when there is no way to recharge batteries. For a given amount of energy, a fuel cell and its respective tank are much more compact and lighter than an array of fully charged batteries.

Different forms and arrangements for different types of tidal power plant: location, amount of extraction possible, environment, economic and other types of system available

The earliest exploitation of tidal power was in tidal mill, created by building a barrage across the mouth of a river estuary. Sea water was trapped in a tidal basin on the rising tide and released at low tide through a waterwheel.

Given a rectangular basin, the centre of gravity of the mass of water is at height R/2 above the low tide level. The total volume of water is AR and, for density ρ it will have mass M =ρAR. This can then be allowed to flow out of the barrage through a turbine to the low tide level. The maximum potential energy E available per tide (assuming mean fall R/2, tidal period T) and acceleration due to gravity) is

$$E = Mg\frac{R}{2} = \frac{\rho g A R^2}{2} \text{ so that the average power } P_{av} = \frac{E}{T} = \frac{\rho g A R^2}{2T}.$$

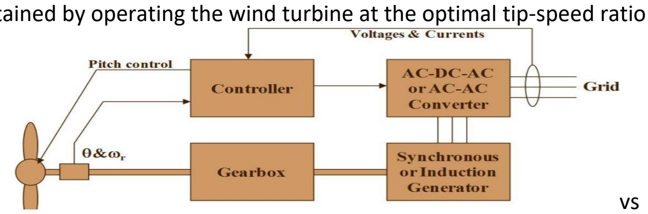
The construction of a barrage would result in higher minimum water levels and slightly lower high water levels in the basin. Currents will be reduced and extreme wave conditions will, in many places, be less severe. The changes that will occur to the tides and currents during construction and then later 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.

	Capital cost [£ million]	Running costs per annum [£ million]	Electricity price [pence per kWh]
Severn (17 TWh/year)	10200	86	6p (16.5 year payback) 5p (20 year payback)
Mersey (1.4 TWh/year)	966	17.6	6.75p (25 year payback)
Conwy	72.5	0.6	8.6p (15-20 year payback)

Other types of system proposals: Offshore tidal lagoon, tidal streams and Ocean currents.

Variable speed vs fixed speed wind turbine

A variable speed wind turbine is one which is specifically designed to operate over a wide range of rotor speeds. It is in direct contrast to fixed speed wind turbine where the rotor speed is approximately constant. The reason to vary the rotor speed is to capture the maximum aerodynamic power in the wind, as the wind speed varies. The aerodynamic efficiency, or coefficient of power, Cp for a fixed blade pitch angle is obtained by operating the wind turbine at the optimal tip-speed ratio.



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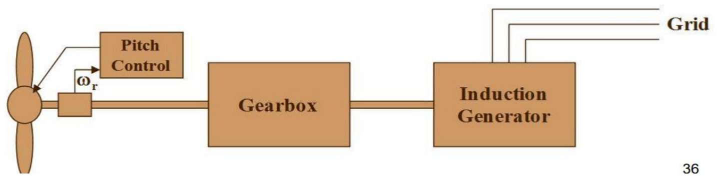

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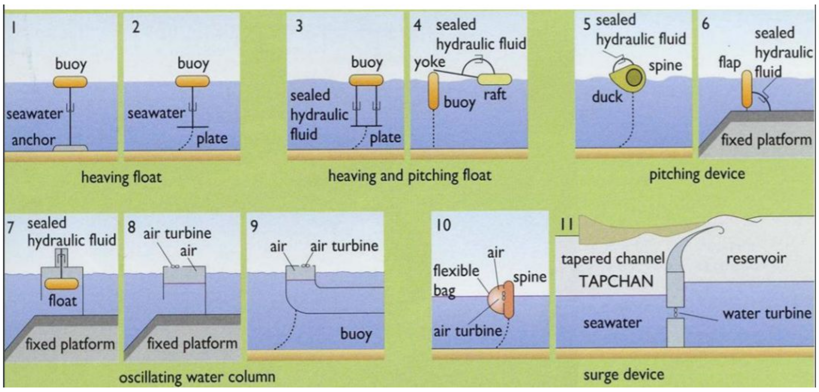
Technologies to capture wave energy and Common types of commercially-available PV cell and comment on their conversion rate and cost.



*sc, single crystal; mc, multicrystalline; single, single junctior multi, multiple junctions

Material*	Band gap (eV)	Efficiency (%) for cell of area ~1 cm²	~1 m²
GaAs	1.4	~24	—
GaAs (multi)	1.8–0.7	~34	—
Si(sc)	1.1	~24	—
Si(mc)	1.1	~20	~13
a-Si(single)	~1.7	~12	~7
a-Si(multi)	~1.7–1.3	~13	~10
CdTe	1.5	~16	~8
$CuIn_{1-x}Ga_xSe_2$	~1.2	~19	~12

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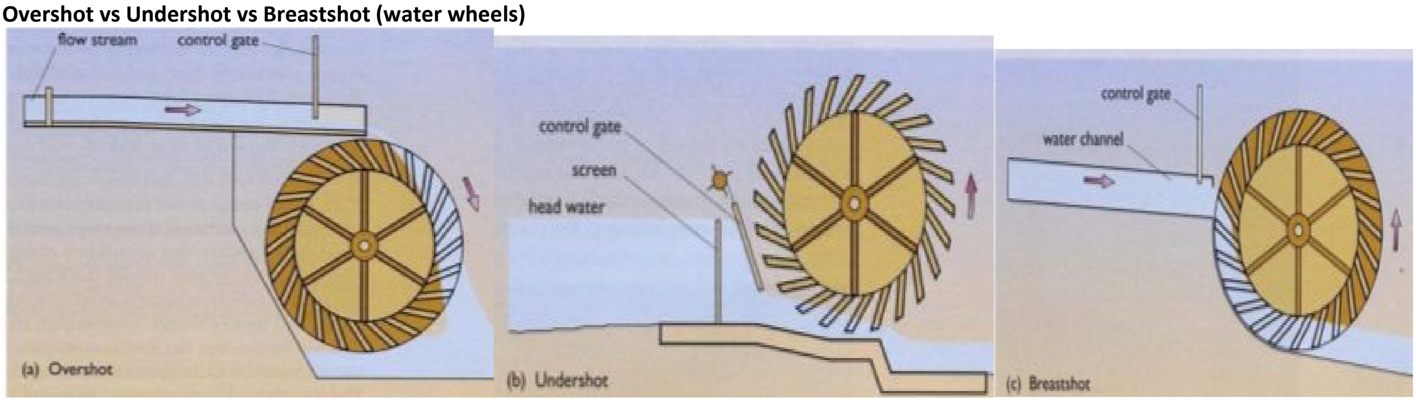
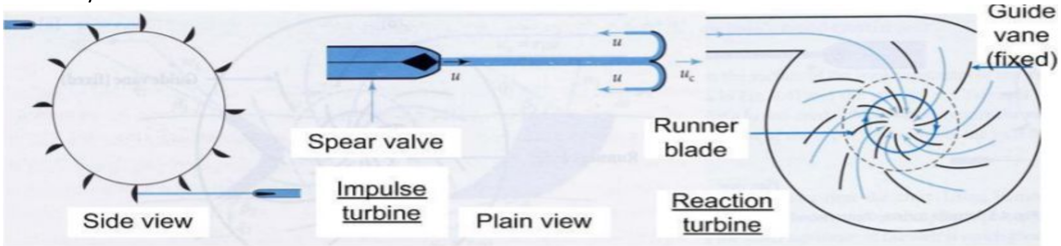
Overshot vs Undershot vs Breastshot (water wheels)



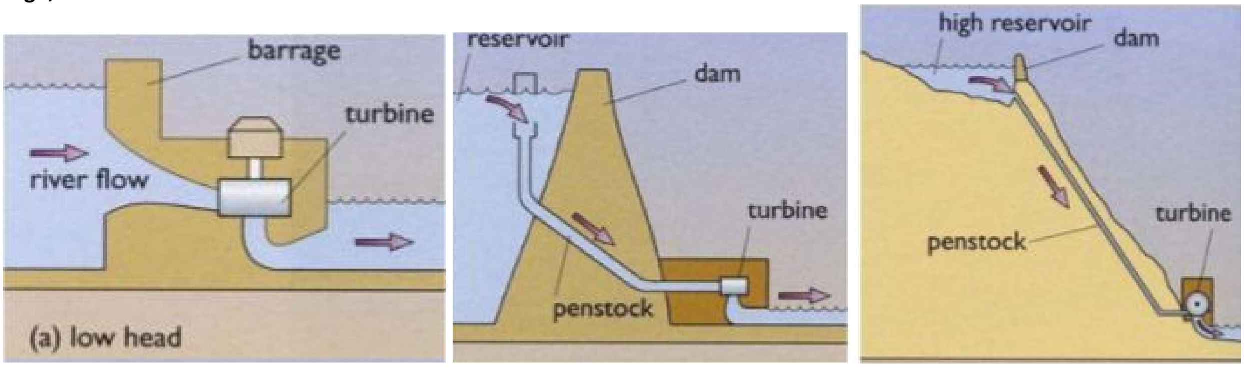
The **Overshot** wheel is driven by water falling from above on the blades with closed sides – effectively buckets. Overshot wheels do not suffer the flooding problem but need a head at least as high as the diameter of the wheel, making them unsuitable for streams and rivers with gentle gradients.
The **Undershot** wheel 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 it becomes very inefficient if the water backs up due flooding, impeding the motion of the wheel.
The **Breastshot** wheel, a later development, is a compromise. 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

Modern Turbines - Types of turbines

There are two basic designs of water turbines: impulse turbines and reaction turbines. In an impulse turbine (figure, left), 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. In a reaction turbine (figure, right), 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%.

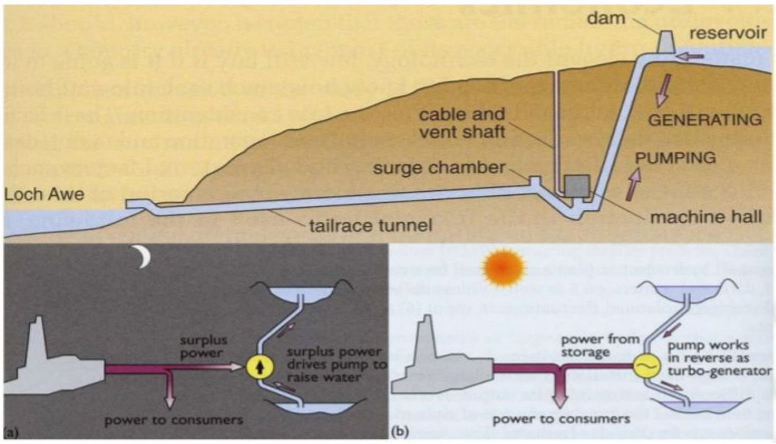


High, medium and low head



The low dam or barrage installation is suitable for “run -of-river” power station.
The medium head installation with a dam at a narrow point in a river valley is typically used for vary large hydroelectric power stations.

- Pumped storage system Bottom (a) at time of low demand; (b time of high demand.



Geothermal energy extraction has niche application. Review georthermal arrangements around the world + envrionment.

Significant environmental concerns associated with geothermal energy include those to do with site preparation, such as 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. Geothermal pollutions are chiefly confined to the noncondensable gases: carbon dioxide (CO_2), with lesser amount of hydrogen sulphide (H_2S) or sulphur dioxide (SO_2), hydrogen (H_2), methane (CH_4) and nitrogen (N_2). In the produced water there is also dissolved silica, heavy metals, sodium and potassium chlorides and sometimes carbonates, depending on the nature of the water-rock interaction at reservoir depth. Today these are almost always reinjected and this also removes the problem of dealing with waste water.

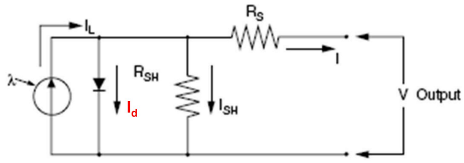
Solar Photovoltaic System:

The highest efficiency for direct conversion of solar energy to electricity is about 15% in practice, provided by photovoltaic (PV) cells.
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.

Declination Angle of the Sun $\delta \approx 23.45^\circ \sin\left[\frac{360}{365}(n-81)\right]$

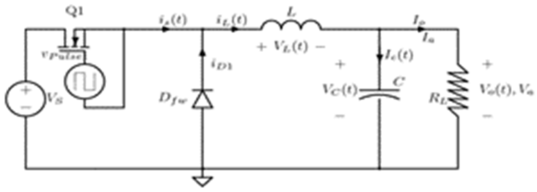
When the sun moves from the east to west, a sun tracking system can increase the energy yield up to 40% over the year compared to the fixed array design.

Equivalent circuit of PV module showing the diode and ground leakage currents:



The load current is therefore given by the expression:

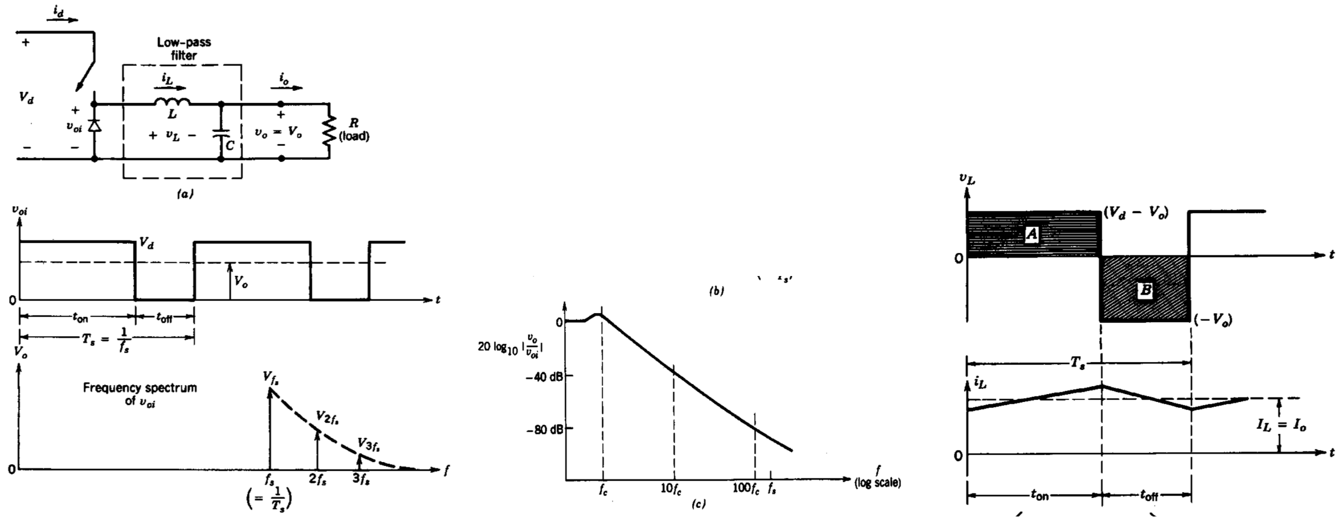
$$I = I_L - I_D\left[e^{\frac{QV_{OC}}{AkT}} - 1\right] - \frac{V_{OC}}{R_{SH}}$$



$$V_{OC} = \frac{AkT}{Q}\ln\left[\frac{I_L}{I_D} + 1\right]$$

The higher the temperature the lower the cell efficiency.

Power Conversion: R1 = R2/D^2



Wind Energy System:

Recent large wind farms projects in Australia: Bald Hills Wind Farm (VIC, 107 MW) Taralga Wind Farm (NSW, 107MW) Ararat Wind Farm (VIC, 240MW) andmore

When assessing a potential wind farm location, typically measure at hub height for a minimum of one year, assessing – Average wind speeds (eventually correlated to long term) – Turbulence – Maximum wind speeds (Gusts, AS1170) – Differences across site (use of more than one mast) • Typically look for sites > 7.5 m/s on average at hub height.

Rotor – Wind turbines (HAWT or VAWT) • Hub – Pitch control • Drive train – gear box • Generator – Synchronous or induction • Main frame / Yaw system – Direction control • Control system – Variable speed control • Balance of electrical system – Transformer • Tower and foundation

HAWT – suitable for both small and large systems, and most commercial wind turbines are HAWT. – Advantages: High wind speed at a grater height, High efficiency – Disadvantages: 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

For the reason of mechanical stability of the turbine, even number of blades are avoided in large systems.

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. Direct drive was developed on the basis of variable speed drive techniques • Using direct drive, the gear box can be eliminated and the following benefits can be achieved – lower maintenance – lower acoustic noise – lower mass – lower losses – lower cost • Direct drive requires the generator to operate at low speeds and high torque. This may result in large generator volume, which would increase the cost of tower, nacelle and installation. • Most direct drive generators are PM synchronous generators. With special design, it is also possible to have direct drive induction generators

Environmental: • Land disturbance • Affects on birds and bats (avi-fauna) • Affects on flora and fauna • Increased human pressure on areas • Decommissioning and site reclamation

Social: • Visual amenity • Noise • Effects on telecommunications • Construction traffic

Hydroelectric

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

Installations can be classified in different ways: – By the effective head of water – By the capacity – the rated power output – By the type of turbine used – By the location and type of dam, reservoir, etc.

As an example, The Hoover Dam on the Colorado River (originally the Boulder Dam) has a total height of 220 m and its reservoir, Lake Mead holds 35 billion cubic metres of water. The two power plants, first commissioned in 1936, now have 17 main turbo-generators with a total output of 2.1 GW.

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.
Synchronous electrical machines are always used as generators in hydroelectric systems
Hydroelectric systems require high capital investment to build, and may cause serious environmental and social problems.

Tidal

- Tidal barrages for electricity generation use large low head turbines and can operate for a greater fraction of the day
- Instead of using costly and potentially invasive barrages located in estuaries to exploit the vertical rise and fall of tides, and the potential energy of heads of water trapped behind dams, it is possible to harness the horizontal flow of tidal currents – that is the kinetic energy of the tides and ocean currents.
- MEYGEN • Four 1.5MW turbines (18-m blades) • Successful connection to the 33kV Ness of Quoys distribution network in June 2016, Scotland • Enough energy to power 175,000 UK homes • Has invested 10 million pounds in the project
- Unlike hydroelectric power plants, tidal power plants have less harmful effects to the environment
- This area is far from being well developed, and there is a great potential for both technical and commercial development.

Wave

- Greater amplitude waves contain more energy per meter of crest length than small waves. It is usual to quantify the power of waves rather than their energy content.
- An increasing consequence of this result is that in deep ocean the long waves travel faster than shorter waves
- To capture the maximum energy from a wave we could construct a device to intercept all of the orbiting part of that wave, but this would be impractical and uneconomic since the lowest orbit actually contain very little energy.
- 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.
- However, 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.
- This loss of energy is very important because it obviously reduces the wave energy resource. Typically, waves with a power density of 50 kW/m in deep water might contain 20 kW/m or less when they are closer to shore in shallow water, depending on the distance travelled in shallow water and the roughness of the seabed.
- The main structure may be anchored to the seabed or seashore, but some part will be allowed to move in response to the force of the waves. Floating structures can also be employed, but still a stable frame of reference must be established so that the "active" part of the device moves relative to the main structure. This can be achieved by taking advantage of inertia, or by making the main structure so large that it spans several wave crests and hence remains reasonably stable in most sea states.
- Wave energy converters can also be classified in terms of their location: – Fixed to the seabed, generally in shallow water, – Floating offshore in deep water, or – Tethered in intermediate depths
- And in terms of their geometry and orientation, as: – Terminators, if their principal axis is parallel to the incident wave front and they physically intercept the waves, – Attenuators, if their principal axis perpendicular to the wave front so that wave energy is gradually drawn towards the device as the wave moves past it, or – Point absorbers, if they draw energy from the water beyond their physical dimensions, but they have small dimensions relative to the incident wavelength. In principle, they could be extremely slim vertical cylinders which execute large vertical excursions in response to incident waves, but in diameter and absorb energy from perhaps twice their own width. Tethered buoy systems, for example, act as point absorbers.
- Wave energy is measured in kW/m wave crest length, and 95% of total wave energy is contained within the depth of a quarter of the wave length.
- The general systems for capturing wave energy can be classified as fixed, floating, and tethered devices.
- The wave energy technology is one of the most environmentally friendly renewable energy technologies.
- In general, building 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.

<u>Biomass</u>

- Energy crops – Any plants that are grown specifically for use as fuel or for conversion into other bio-fuels, such as wood for burning, plants for fermenting to ethanol and crops whose seeds are particularly rich in oil. Examples are: • Woody crops, such as Short Rotation Forestry (SRF) and Short Rotation Coppice (SRC) (figure, left) • Agricultural crops, such as sugar cane, maize, sunflowers, oilseed rape, and soya beans, etc. (figure, right)

Fuel	Energy content		Fuel	Energy content	
	[GJ/t]	[GJ/m^3]		[GJ/t]	[GJ m^3]
Wood (green, 60 % moisture)	6	7	Straw (as harvested, baled)	15	1.5
Wood (air-dried, 20 % moisture)	15	9	Sugar cane residues	17	10
Wood (oven-dried, 0 % moisture)	18	9	Domestic refuse (as collected)	9	1.5
Carcoal	30	---	Commercial wastes (UK average)	16	---
Paper (stacked newspaper)	17	9	Oil (petroleum)	42	34
Dung (dried)	16	4	Coal (UK average)	28	50
Grass (fresh-cut)	4	3	Natural gas (as supply pressure)	55	0.04

World Totals	
Total mass of living matter (including moisture)	2000 billion tonnes
Total mass in land plants	1800 billion tonnes
Total mass in forests	1600 billion tonnes
World population (2017)	7.5 billion
Per capita terrestrial plant biomass	300 tonnes
Energy stored in terrestrial biomass	25000 EJ
Net annual production of terrestrial biomass	400 000 Mtonnes/year

- Charcoal is traditionally produced in the forests where the wood is cut. The kiln, consisting of stacked wood covered with an earth layer, is allowed to smoulder for a few days in the near absence of air, typically at 300-500oC, a process called pyrolysis. The volatile matter is driven off, leaving the charcoal – almost pure carbon, with about twice the energy density of the original wood and burning at a much higher temperature so it is much easier to design a simple and efficient stove for use with this high quality fuel.
- The term refuse derived fuel (RDF)refers to a range of products resulting from separation of unwanted components, shredding, drying and otherwise treating the raw material.
- The most fully processed product, known as densified RDF or d-RDF (figure), is the result of separating out the combustible part which is then pulverized, compressed and dried to produce solid fuel pellets with perhaps twenty times the energy density of the original material. Their reduced ash content makes the pellets suitable for cocombustion with coal in conventional plants.
- Anaerobic digestion – landfill gas and biogas. – In the former case, the digester is the landfill itself, and the operator has only limited control of the process. – In the case of biogas, the feedstock, dung or sewage, is converted to a slurry with up to 95% water, and fed into a purpose built digester whose temperature can be controlled. Digesters range in size from perhaps 1 m3 for a small household unit to some ten times this for a typical farm plant and more than 1000 m3 for a large installation. The input may be continuous or in batches, and digestion is allowed to continue for a period of from ten days to a few weeks. – The process of anaerobic digestion is complex, but it appears that bacteria break down the organic material into sugars and then into various acids which are decomposed to produce the final gas leaving a residue whose composition depends on the system and the original feedstock. – In a well run digester, each dry tonne of input will produce 200-400 m3 of biogas with 50% to 75% methane, an average energy output of perhaps 8 GJ per tonne of input. This is only about half the fuel energy of dry dung or sewage, but the process may be worthwhile in order to obtain a clean fuel and dispose of unpleasant wastes.
- 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.
- 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.

Geothermal

- There are two sources of geothermal energy: (1) When the earth was formed around 4600 million years ago the interior was heated rapidly as the kinetic and gravitational energy of accreting material was converted into heat. (2) The earth contains tiny quantities of long lived radioactive isotopes, principally thorium 232, uranium 238, and potassium 40, concentrated in upper crustal rocks, all of which releases heat when they decay.
- Geothermal resources of most types must have three important characteristics: an aquifer containing water that can be accessed by drilling, a cap rock to retain the geothermal fluid, and a heat source.

	Material	Porosity [%]	Hydraulic conductivity
Unconsolidated sediments	Clay	45-60	$<10^{-2}$
	Silt	40-50	10^{-2}-1
	Sand, volcanic ash	30-40	1-500
	Gravel	25-35	500-10000
Consolidated sedimentary rocks	Mudrock	5-15	10^{-8}-10^{-6}
	Sandstone	5-30	10^{-4}-10
	Limestone	0.1-30	10^{-5}-10
Crystalline rocks	Solidified lava	0.001-1	0.0003-3
	Granite	0.0001-1	0.003-0.03
	Slate	0.001-1	10^{-8}-10^{-5}

[1]

- The geothermal heat pump (GHP) concept can be used to extract heat from warm shallow ground water to supply a single domestic dwelling (figure, left). In winter heat is removed from the earth and delivered in a concentrated form via a heat pump. Because electricity is used to increase the temperature of the heat, not produce it, the GHP can deliver three to four times more energy as heat.

- Geothermal energy is independent of sun
- Around the world, there are many spots suitable for exploitation of geothermal energy in the form of either electricity generation or direct use of heat.
- The major impacts of geothermal energy on the environment are the noise and pollution caused by drilling of wells, and releasing of gases originally trapped underground.
- 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

- Common energy storage devices are: • Batteries, • Supercapacitors, • Flywheels, • Superconducting magnetic energy storage (SMES) • Compressed air.
- Batteries store energy in the form of chemical energy. The one way conversion efficiency is about 85 to 90%

  The ***state of charge* (SOC)** of the battery at any time is defined as:

  $$SOC = \frac{\text{Ah capacity remaining in the battery}}{\text{Rated Ah capacity}}$$
-
- There are many types of rechargeable batteries. The commonly used ones are: – Lead-acid (Pb-acid) – Nickel-cadmium (NiCd) – Nickel-metal hydride (NiMH) – Lithium-ion (Li-ion) – Lithium-polymer (Li-poly) – Zinc-air
- Lead-acid battery is the most common type of rechargeable battery used today because of its maturity and high performance over cost ratio, though it has the least energy density by weight and volume.

  The table gives the average cell voltage during discharge in various rechargeable batteries

Electrochemistry	Cell volts	Remark
Lead-acid	2.0	Least cost technology
Nickel-cadmium	1.2	Exhibits memory effect
Nickel-metal hydride	1.2	Temperature sensitive
Lithium-ion	3.6	Safe, contains no metallic lithium
Lithium-polymer	3.0	Contains metallic lithium
Zinc-air	1.2	Requires good air management to limit self-discharge rate

-
- Nickel-cadmium battery is a matured electrochemistry, in which the positive electrode is made of cadmium and the negative electrode of nickel hydroxide. The two electrodes are separated by NylonTM separators and placed in potassium hydroxide electrolyte in a stainless steel casing.
- Lithium-ion battery is a new development, which offers three times the energy density over that of Pb-acid. Such a large improvement in energy density comes from lithium's low atomic weight of 6.9 vs. 207 for lead. Moreover, Li-ion has a higher cell voltage, 3.5 V vs. 2 V for Pb-acid and 1.2 V for other electrochemistries. This requires fewer cells in series for a given battery voltage, thus reducing the manufacturing cost.
- The C/D ratio is defined as the Ah input over the Ah output with no net change in the SOC.

Electro-chemistry	Operating temperature [°C]	Overcharge tolerance	Heat capacity [Wh/kgK]	Mass density [kg/l]	Entropic heating on discharge [W/A]
Lead-acid	-10 to 50	High	0.35	2.1	-0.06
Nickel-cadmium	-20 to 50	Medium	0.35	1.7	0.12
Nickel-metal hydride	-10 to 50	Low	0.35	2.3	0.07
Lithium-ion	10 to 45	Very low	0.38	1.35	0
Lithium-polymer	50 to 70	Very low	0.40	1.3	0

-
- 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.
- The supercapacitor is still a young technology that has yet to experience widespread implementation. It does, however, enjoy a great amount of attention with regards to its potential application in a number of areas.
- The flywheel stores kinetic energy in a rotating inertia. It has been used as a mechanical device for equalizing the speed of rotation.
- Therefore, 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.
- 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.