Bio-energy
what is bio-energy?

All of the Earth's plant and animal material, or 'biomass', exists in a thin layer around the surface of the planet called the biosphere. The biosphere is really a huge store of solar energy, which is continually replenished through photosynthesis by green plants.

Energy obtained from biomass is called bio-energy. At the beginning of the 21st century, over 10 per cent of the total energy used by people on the planet comes from biomass. Most of this comes from simply burning wood, rice husks or other plant and animal residues on a small scale for heat production.

However, in many LEDCs (less economically developed countries), biomass is not used in a sustainable way. If trees aren't grown specifically for burning, using them can cause deforestation. Wood is only a renewable energy if it is grown specifically for the purpose.

A farmer harvests trees for fuel.
Photo courtesy of NRE Slide Library/DTI

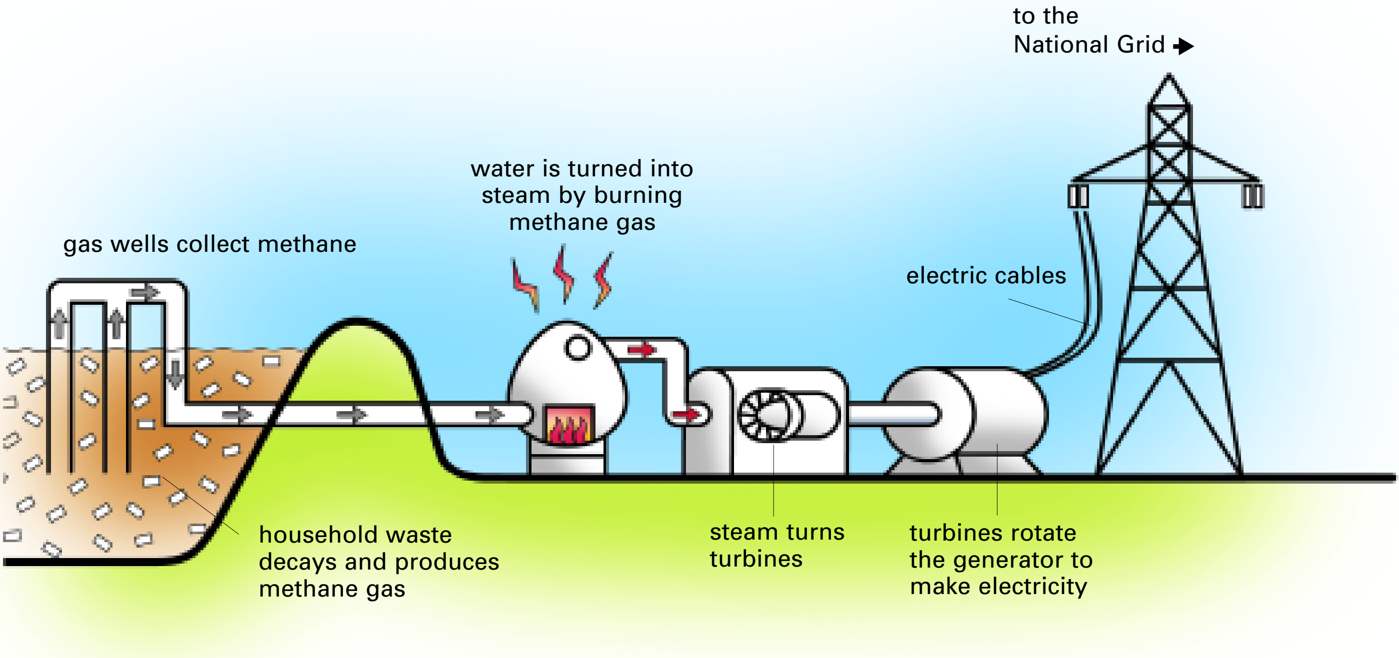
How does bio-energy work?

Over the last few decades new, large-scale ways of generating bio-energy have been developed. These can be split into two main types.

- **Energy crops** are any plants that are specifically grown as fuel, such as wood, oilseed rape and sugar beet. A form of bio-diesel can be produced from vegetable oils, and other crops can be fermented to produce ethanol, a high-energy substance similar to petrol.
- Waste is an important source of bio-energy.
  - **Farm waste, sewage plants** and **landfill sites** give off methane as the material rots. Methane can be burnt to produce steam, which can turn a turbine and generator to produce electricity, or produce heat.
  - **Food waste** can be treated and used to produce methane. The end-product is a dry material that can be used as a safe fertiliser. This produces energy **and** saves on waste disposal costs.
  - **Plant waste** can also be burnt to produce electricity, or it can be used to produce gases, which can then be burnt to power a gas turbine or even a car engine.

At some stage in the process, most forms of bio-energy involve combustion (i.e. burning something) and the release of carbon dioxide into the atmosphere. However, this is offset by energy crops, which absorb carbon dioxide from the atmosphere. Even allowing for carbon dioxide emissions in planting, harvesting, processing and transporting the fuel, replacing fossil fuel energy with bio-energy will typically reduce net carbon dioxide emissions by over 90 per cent.

Using landfill gas to generate electricity



How much does electricity from bio-energy cost?

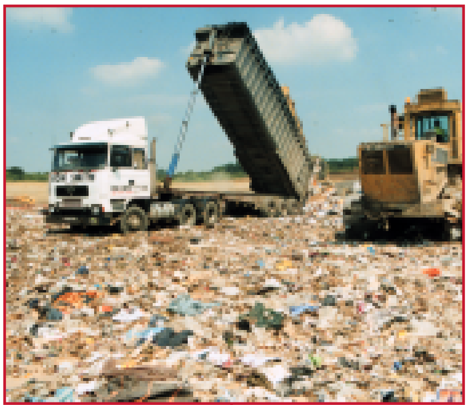
Currently, the cost of producing electricity in a coal-fired power station can range from 2.5p to 3.2p per kWh, in a nuclear power station 2.2p per kWh and bio-energy from a poultry-litter-fired power station 6.8p per kWh. However, as large-scale bio-energy production becomes more established, these production costs will fall.

Advantages

- The fuel is cheap.
- Using waste materials to generate energy makes good environmental and economic sense.

Disadvantages

- Burning the fuel creates carbon dioxide, a greenhouse gas. This can be balanced by growing energy crops, which absorb the same amount of carbon dioxide that is created by burning them.
- Collecting waste in big enough quantities can be difficult, and the vehicles used may create more greenhouse gases.



The UK produces 28 million tonnes of household waste every year. Although we can use some of it to produce energy, we should also do more to minimise waste by recycling. Only 11 per cent of the UK's waste is used to make electricity at the moment.

Courtesy of NRE Slide Library/DTI

See www.dti.gov.uk/renewables/schools for a bio-energy case study

Geothermal energy
what is geothermal energy?

Coal miners know that the deeper you dig, the hotter it gets. This is because of the heat that radiates from the Earth's molten core. Geothermal energy is the natural heat that exists within the Earth.

In some areas, heat from deep within the Earth can rise up to the surface naturally, as hot liquids or gases. For example, water that is either already present deep underground (or has flowed underground through cracks and fissures) can become heated and re-surface naturally as superheated steam or a hot spring. If these heated fluids do not rise to the surface, boreholes can be drilled to reach them.

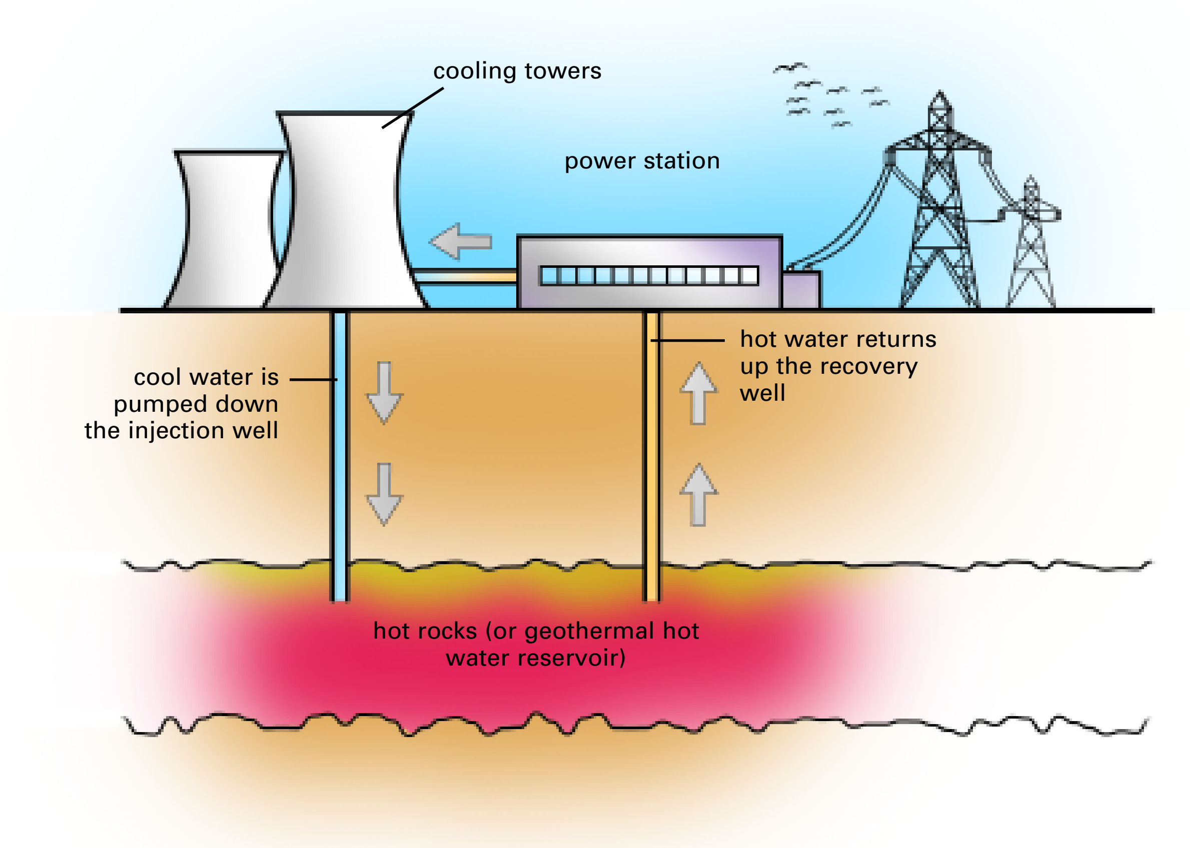
A geothermal energy plant uses this heat.

Mammoth Hot Springs, Yellowstone, USA.
Photo courtesy of www.pdphoto.org

How does geothermal energy work?

The method for using geothermal energy is quite simple: one or more boreholes are drilled into an underground reservoir; hot water then flows or is pumped to the surface and is used in a steam turbine to generate electricity, or for direct heating. Places that are near a tectonic plate boundary (i.e. are volcanic), like Iceland and Japan, have many places where boreholes can reach reservoirs of water at high temperatures and pressures.

Exploiting geothermal energy using Hot Dry Rock technology

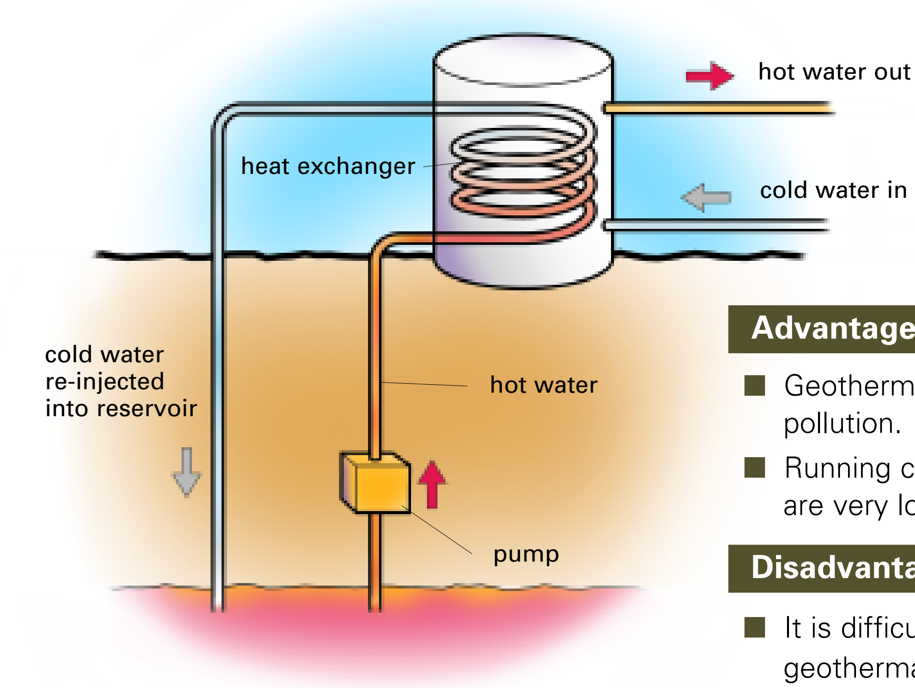


Because of the cost of drilling deep boreholes, only the top 6km of the earth's crust is generally considered for geothermal energy projects.

We can also extract thermal energy from hot rocks where water is not naturally present. **Hot Dry Rock** (HDR) technology involves finding a site where there are rocks at a suitable temperature. The rocks are fractured and water is injected into a borehole and circulated through the cracked rock several kilometres below the surface. The water is heated through contact with the rock and is then returned to the surface through another borehole, where it is used to generate electricity. The water is then re-injected into the first borehole to be reheated by the rocks and used again.

The amount of energy that can be extracted in using HDR is potentially huge, with one cubic kilometre of rock providing the energy equivalent of 70,000 tonnes of coal if cooled by 1°C.

Southampton Civic Centre uses heat from a geothermal well.
Photo by kind permission of Southampton City Council



Lower-temperature reservoirs may not be suitable for producing electricity, but can instead be used for direct heating. An example is the Southampton Geothermal District Heating Scheme, where water at 70°C is pumped up from a depth of 1800m and provides heat to a number of buildings within 2km of the borehole.

How much does geothermal energy cost?

There are currently no geothermal power stations in the United Kingdom producing electricity for commercial use.

Advantages

- Geothermal energy doesn't produce any pollution.
- Running costs for a geothermal power station are very low.

Disadvantages

- It is difficult to find suitable sites for geothermal power stations.
- The hot rocks have to be of a suitable type and depth, and the rocks above them have to be soft enough to drill through.
- If not carefully managed, a borehole can 'run out of steam' and may not be useable again for several decades.
- Occasionally, dangerous gases and minerals can come out of a borehole and it may difficult to dispose of them. An extreme example happened at a borehole drilled at Krafla in Iceland in 1977. Rising magma entered the borehole at 1138m below the ground and, within 20 minutes, 3 tonnes of magma had erupted through the hole.

See www.dti.gov.uk/renewables/schools for a geothermal energy case study

Hydroelectricity
what is hydroelectricity?

This picture shows water being released under pressure, after it has turned the turbines inside the dam to generate electricity (Laggan Dam).
Photo courtesy of Roy Dyckhoff

Hydroelectricity is electricity generated by the flow of water. Like most other renewable energy sources, it is actually indirect solar power. Each year the Earth receives 1.5 billion TWh (terawatt hours) of solar energy. Nearly a quarter of this is consumed in the evaporation of water. This means that the water vapour in the atmosphere is actually a massive store of solar energy. Unfortunately, only a fraction of this energy is available for us to use: when the water vapour in the atmosphere condenses, most of the energy it holds is released into the atmosphere as heat. However, a tiny fraction, about 0.06 per cent, is held as gravitational potential energy by the rain that falls on mountains and hills. Hydroelectric power (HEP) stations can transfer this energy into electrical energy for use in homes and businesses.

Hydroelectricity is a well-established technology and is already a major contributor to world energy supplies. Hydroelectricity provides about one sixth of the world's annual electrical output and over 90 per cent of the total global output from renewable energy sources. In the UK it provides about 0.8 per cent of the total electrical demand per year. It is also very efficient, with large-scale hydroelectric plants reaching energy conversion levels of 90 per cent.

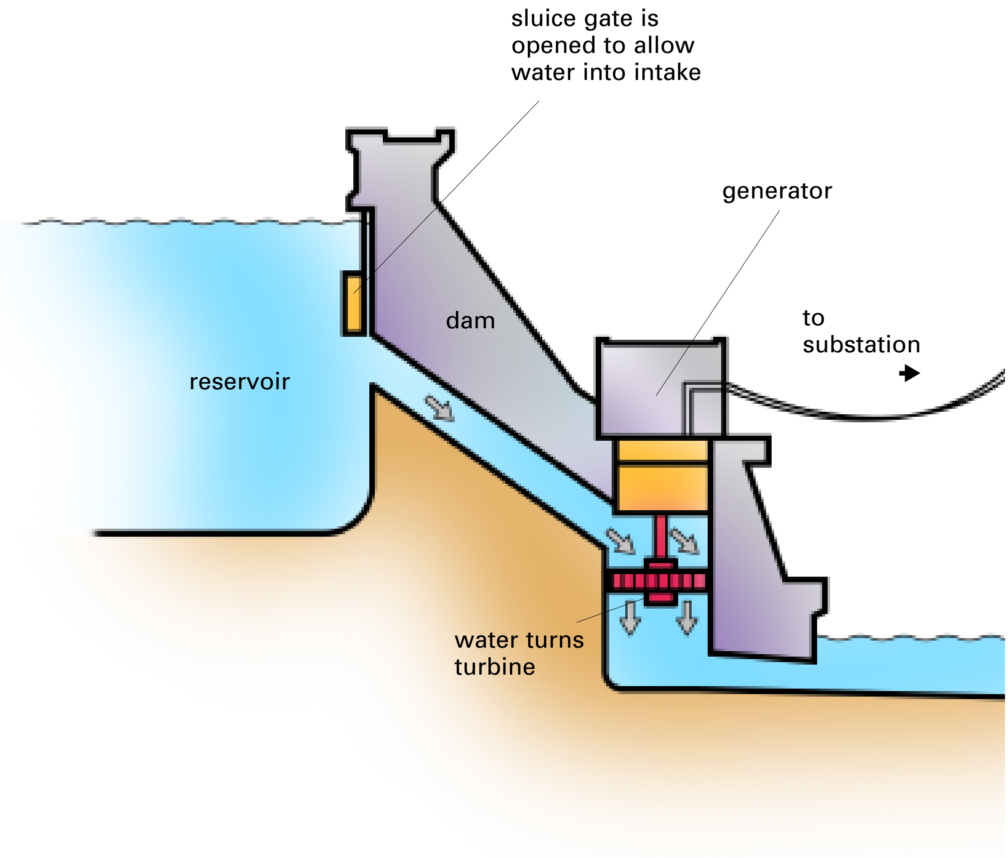
Britain had over 1500MW (megawatts) of HEP capacity in 2003, just under 1 per cent of the UK's total energy needs. More recently in the UK there have been more small-scale HEP projects based on weirs or locks. These may produce less than 1MW each, but Britain has hundreds of rivers, and if all the potential sites were used it could produce 10,000GWh of electricity per year.

How does hydroelectricity work?

A hydroelectric plant works uses water flow to turn a water wheel or turbine, which then turns a generator, which produces electricity. Most commercial hydroelectric plants use a dam in a river to create a powerful flow of water through a turbine. There are several ways in which this can be done.

- In a **diversion** scheme, water is channelled from a dammed river or lake to a powerhouse containing the turbine and generator some distance away.
- **River weirs and river and canal locks** can be used for smaller scale HEP schemes, generating up to 1MW each.

Hydroelectric dam



- In **run of river schemes**, the turbine and generator are located in or alongside a dam. For example, in the Elan Valley in Wales, four dams hold 199 million tonnes of water. This is the main water supply for Birmingham. In the 1990s, turbines were fitted to the dam outlet pipes. When water is released, the turbines produce enough electricity to power nearly 11,000 homes.
- **Pumped storage** is not really a renewable energy source but a way of storing energy. This system uses two reservoirs, one above the turbine and one below. At times of low demand, electricity powers the turbine to pump water from the lower reservoir back up to the higher one. This water can then be released when electricity is needed. An example is the Dinorwig Power station in Wales, where water from a mountain lake is used to generate 288MW.

Large-scale hydroelectric plants can produce over 200 times more energy during their lifetimes than the energy needed to build and run them in the first place. This is ten times more than oil-fired power stations.

How much does hydroelectricity cost?

Currently, the cost of producing electricity in a coal-fired power station can range from 2.5p to 3.2p per kWh, and in a nuclear power station 2.2p per kWh. Electricity from a large-scale hydroelectric plant costs only 0.016p per kWh to produce but can rise to 0.07p per kWh for micro-hydro schemes.

Advantages

- Once construction is completed, operating costs are very low.
- No waste or pollution is produced.
- The technology is very reliable.
- Water can be stored behind the dam to deal with peaks in demand.
- Power output can be increased very quickly to meet sudden demand.
- Electricity can be generated constantly.

Disadvantages

- Dams are very expensive to build.
- Large-scale flooding may cause environmental problems.
- Suitable sites are limited.
- HEP sites are often remote, which leads to higher distribution costs.

See www.dti.gov.uk/renewables/schools for a hydroelectricity case study

Hydrogen fuel cells

what is a hydrogen fuel cell?

Hydrogen fuel cells use hydrogen gas to produce electricity. They are extremely efficient and can potentially be made in any size to power mobile phones, cars, or even to power large projects.

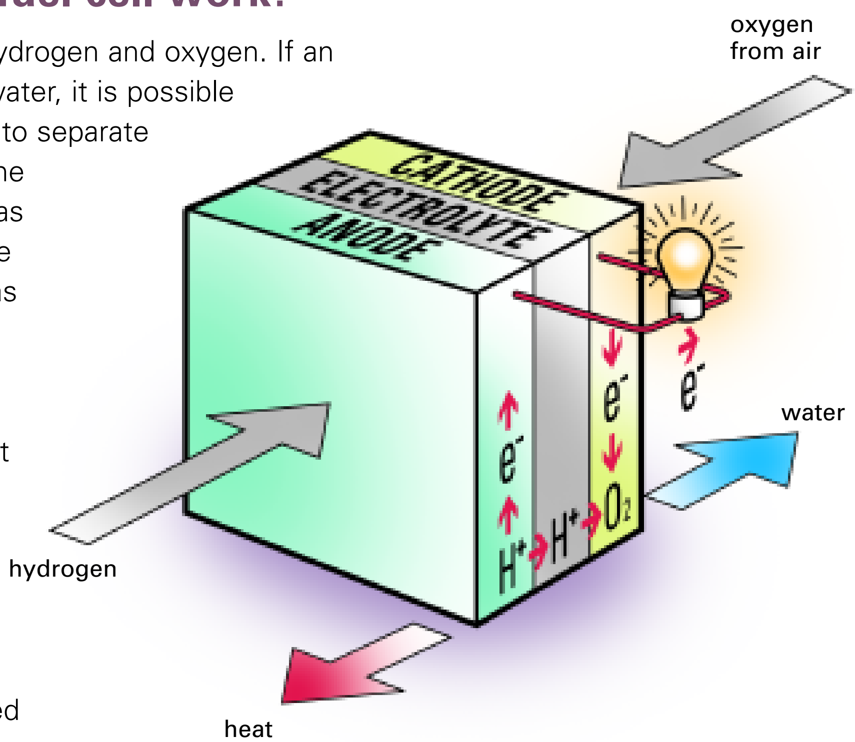
Until recently, they were difficult and costly to build and were only used in very specialised areas, such as on spacecraft and satellites.

Advances in technology in the last decade mean production costs have come down and power output has greatly improved. However, if we were to use fuel cells for mass transport or other large scale applications, the costs would have to come down a lot more.

How does a hydrogen fuel cell work?

Water is a compound made from hydrogen and oxygen. If an electric current is passed through water, it is possible to split the water molecules back into separate hydrogen and oxygen molecules. The oxygen and hydrogen are released as gas and can be collected in separate containers. This process is known as electrolysis. A fuel cell is a device that uses electrolysis in reverse. It converts hydrogen and oxygen into water, producing electricity and heat in the process.

Although there are a number of different kinds of fuel cells, they all work in the same way and have a similar basic set-up. This consists of two electrodes separated by an electrolyte.



The **proton exchange membrane** (PEM) cell is one of the more promising variations of fuel cell. The PEM cell's electrolyte is a thin membrane made from Teflon. This membrane is treated so that protons may pass through it, but it does not conduct electrons. The membrane is sandwiched between the two electrodes. The fuel, hydrogen, enters at the anode and the oxidant, oxygen, enters at the cathode. Both the anode and cathode are coated with particles of platinum, which catalyses the reaction.

On the anode, hydrogen molecules split into protons and electrons. The protons travel through the membrane. This leaves the anode with a negative charge and the cathode with a positive charge. This forces the electrons on the anode to travel around an external circuit to reach the cathode, where they combine with the protons and oxygen to form water.

London is one of several European cities testing how well electric buses powered by fuel cells work. The buses are quiet and produce almost no pollution. They are refuelled with bottles of liquid hydrogen, which are stored on the roof of the bus.

Photo courtesy of Matthew Wooll

This is all done without the need to burn the hydrogen. Energy is converted in a fuel cell much more efficiently than in conventional power sources, such as internal combustion engines, and they produce almost no pollution.

Fuel cells also have no moving parts so they make no noise and are less prone to wear and tear. Fuel cells, in themselves, are not renewable energy sources as they require hydrogen fuel. As the use of fuel cells increases and renewable energy from other sources becomes more available, it should be possible to produce the hydrogen fuel directly from renewable sources, such as biomass. In Iceland there are plans to produce hydrogen using geothermal and hydroelectric power, which are both renewable sources of energy. The hydrogen will be used to power fuel cells to drive the country's cars.

Advantages

- There's no pollution: the only waste product is water and some heat, some of which can also be reclaimed.
- There's no noise.
- Fuel cells can be built in a huge range of sizes to suit almost any use.

Disadvantages

- Cost: fuel cells are more expensive than existing technologies.
- Fuel cells rely on hydrogen, which has to be made. Most of the methods we use to produce hydrogen today use non-renewable energy, resulting in emissions of CO_2 and pollutants.
- It will be some time before hydrogen is as freely available as petrol is now.
- Hydrogen, like petrol, is flammable and potentially explosive, though systems can be designed to allow safe use.

See www.dti.gov.uk/renewables/schools for a fuel cell case study

Solar energy

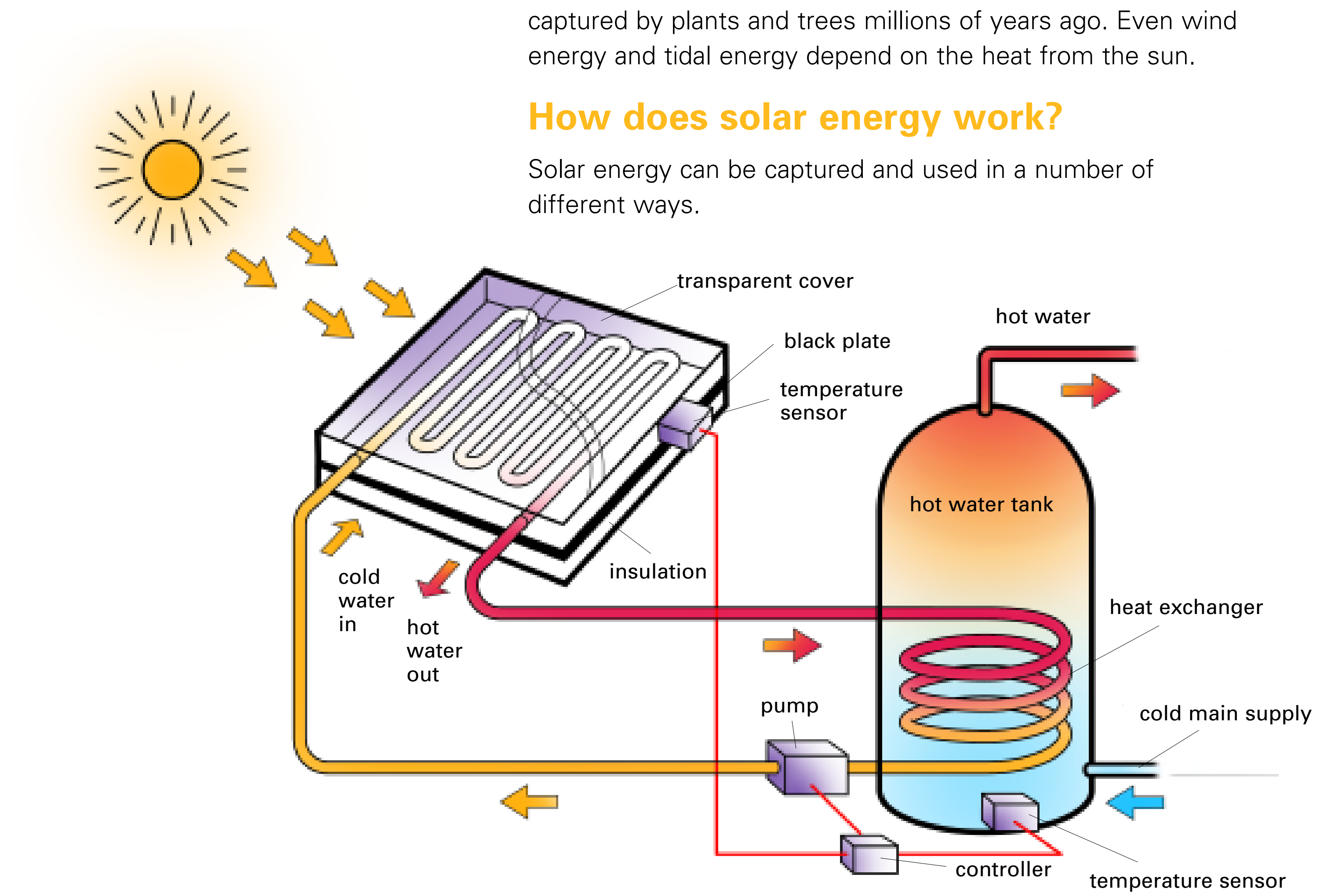
what is solar energy?

Solar energy is energy from the sun. The sun is incredibly powerful, delivering enough energy to the earth each minute of the day to meet global demand for a whole year.

The sun actually gives us almost all the energy we use, either directly or indirectly. Fossil fuels release solar energy captured by plants and trees millions of years ago. Even wind energy and tidal energy depend on the heat from the sun.

How does solar energy work?

Solar energy can be captured and used in a number of different ways.



- **Active solar** water heating is a simple way of providing hot water. A series of pipes run through a flat box with a transparent cover and a black, insulated base. This is the collector panel and it needs to be tilted to face the sun – in Britain, it must face south. Water is pumped through the pipes and heated by the sun. It is then circulated through a heat exchanger to heat water for use in the home. It's surprisingly efficient, even in the chilly UK. Some systems do not use a pump to circulate the water and rely on convection currents to carry the hot water up to a storage tank. These are known as thermosyphon systems.

Active solar water heating can produce water temperatures of 80–90°C because the glass on the front of the collector panel allows visible light and short-wave infrared radiation into the collector. This warms the collector pipes and is re-radiated as long-wave infrared radiation. However, long-wave infrared radiation cannot pass back out through glass, so this thermal energy is trapped in the collector and causes the temperature to rise significantly. The same effect can be felt in a car on a sunny day.

- **Passive solar design** involves making new buildings – or adapting old ones – in a way that saves energy. An energy-saving building keeps heat loss to a minimum by using lots of insulation and a good design that allows the sun's heat to warm rooms directly. This can reduce heating bills by up to 20 per cent.
- **Solar thermal engines** use mirrors to concentrate the sun's energy. Depending on the exact design of the mirrors, temperatures in excess of 1500°C can be reached. It is possible to use these systems to produce steam for running a turbine and generator to produce electricity.
- **Photovoltaic cells** (PV cells) use semi-conductors to convert sunlight directly to electricity. PV cells can be arranged in panels and can be fitted to almost anything, even a backpack. Experimental cars have been built where the body of the car is covered in PV cells which generate electricity to power the vehicle.

How much does electricity from solar energy cost?

Currently, the cost of producing electricity in a coal-fired power station can range from 2.5p to 3.2p per kWh, and in a nuclear power station 2.2p per kWh. At present there are no solar power stations in the UK producing electricity on a commercial basis. For individual users of PV systems, the cost of electricity has been calculated at 41–57p per kWh. This is due to the high cost of the initial installation. As the market for this kind of technology expands, the cost will come down and it is estimated that by 2020, PV users will be paying about 10–16p per kWh.

Advantages

- Once the solar power plant is constructed, running costs are very low.
- Solar energy can be used to generate electricity in remote places.
- No waste or pollution is produced.
- Energy is usually generated at or near where it will be used, keeping transmission and distribution costs to a minimum.

Disadvantages

- It doesn't work at night.
- Photovoltaic cells are very expensive.

See www.dti.gov.uk/renewables/schools for a solar energy case study

Wind energy

what is wind energy?

Wind is created because the atmosphere is heated unevenly by the sun – the equator gets more heat than Britain, and we get more heat than the Polar regions. These uneven temperatures cause convection currents where warm air rises and cooler air moves in to replace it. This movement of air is the wind.

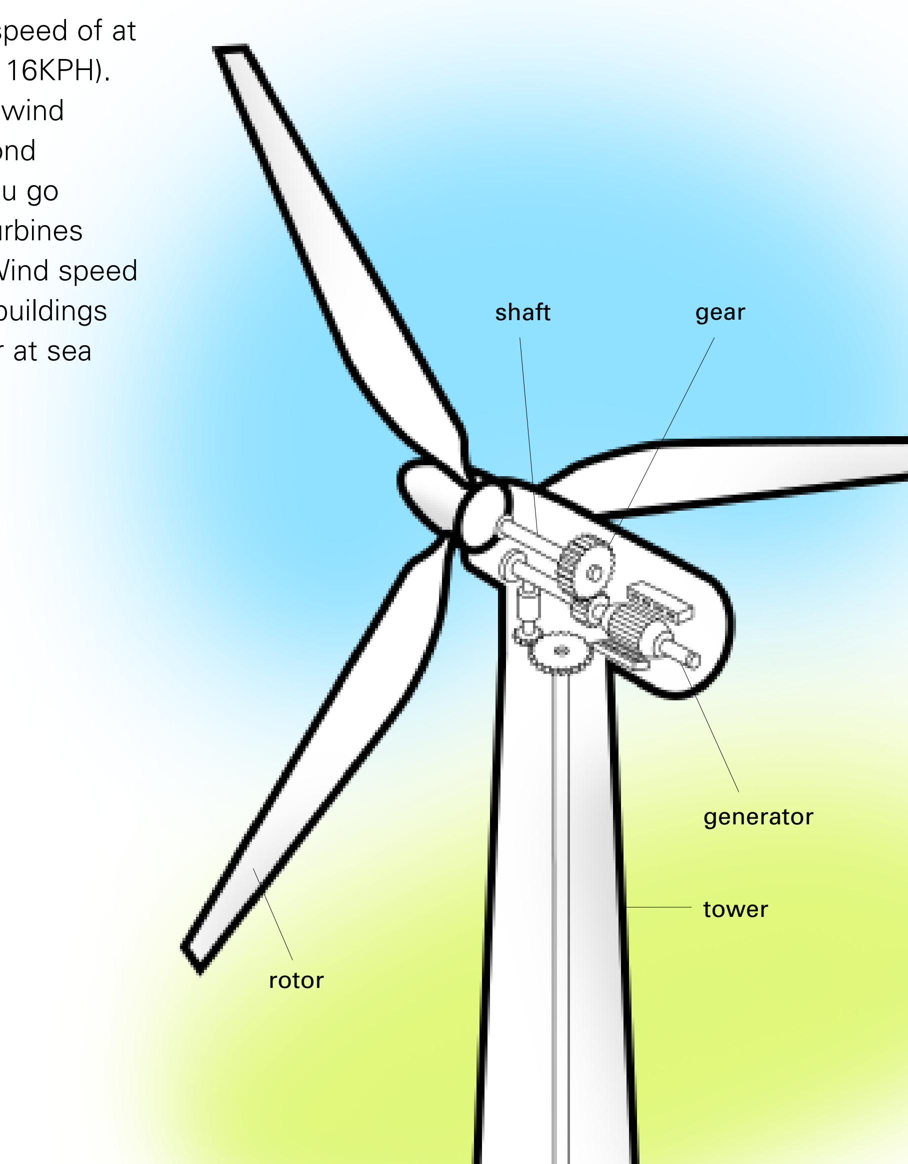
Thanks to its position on the edge of the continent, Britain is the windiest place in Europe. We receive around 40 per cent of the wind energy in the region.

How does wind energy work?

The force of the wind spins a large propeller (rotor). The propeller is connected to a generator: this is a machine that contains coils of wire and powerful magnets. When the wire coils are spun quickly inside the magnets, they produce electricity.

To produce power, you need a wind speed of at least four metres per second (around 16KPH). To reach maximum output, you need wind speeds of around 15 metres per second (53KPH). Wind speed increases as you go higher above ground level, so wind turbines are usually mounted on tall towers. Wind speed also increases if there are no hills or buildings to slow it down. It is normally windier at sea than on land.

Inside a wind turbine



How much does electricity from wind energy cost?

Since the 1980s, the technology has been available to allow wind power to generate large enough amounts of electricity to make it commercially viable. Wind energy is now one of the most cost-effective methods of electricity generation available. For commercial wind power stations, large numbers of turbines may be grouped together in **wind farms**.

There are over 1000 wind turbines at 89 sites in Britain. There are offshore wind farms at Blythe, North Hoyle and Scroby Sands. Most wind farms are located in the west of Britain, with the exception of Scroby Sands, off the east coast near Great Yarmouth.

Currently, the cost of producing electricity in a coal-fired power station can range from 2.5p to 3.2p per kWh, and in a nuclear power station 2.2p per kWh. Electricity from an onshore wind farm costs between 3.7p and 5.4p per kWh, and from an offshore wind farm between 5.5p and 7.2p per kWh to produce.

This offshore wind farm is at Blythe, England.
Photo © E.ON UK

Novar Wind Farm, Ross-shire, Scotland
Photo © npower renewables 2005

Advantages

- Once the wind turbine is constructed, running costs are very low.
- No waste or pollution is produced.
- The land occupied by a wind farm can still be used for farming.
- Wind farms can become tourist attractions.

Disadvantages

- No wind, no power
- Some people object because they feel wind farms spoil the view.
- Wind farms create a constant low-level noise.
- They can interfere with television reception and radar.

See www.dti.gov.uk/renewables/schools for a wind energy case study

Wave energy
what is wave energy?

Anyone who has seen the sea on a rough day will realise the energy that it contains. For over 200 years, people have been trying to harness this energy but it is only since the 1970s that it has been possible to do this in any meaningful way.

The Atlantic seaboard of the British Isles has one of the best wave energy climates on the planet, with an energy potential of 60–70 kilowatts per metre (kW/m) in deep water off the Western Isles, falling to 15–20kW at the shoreline.

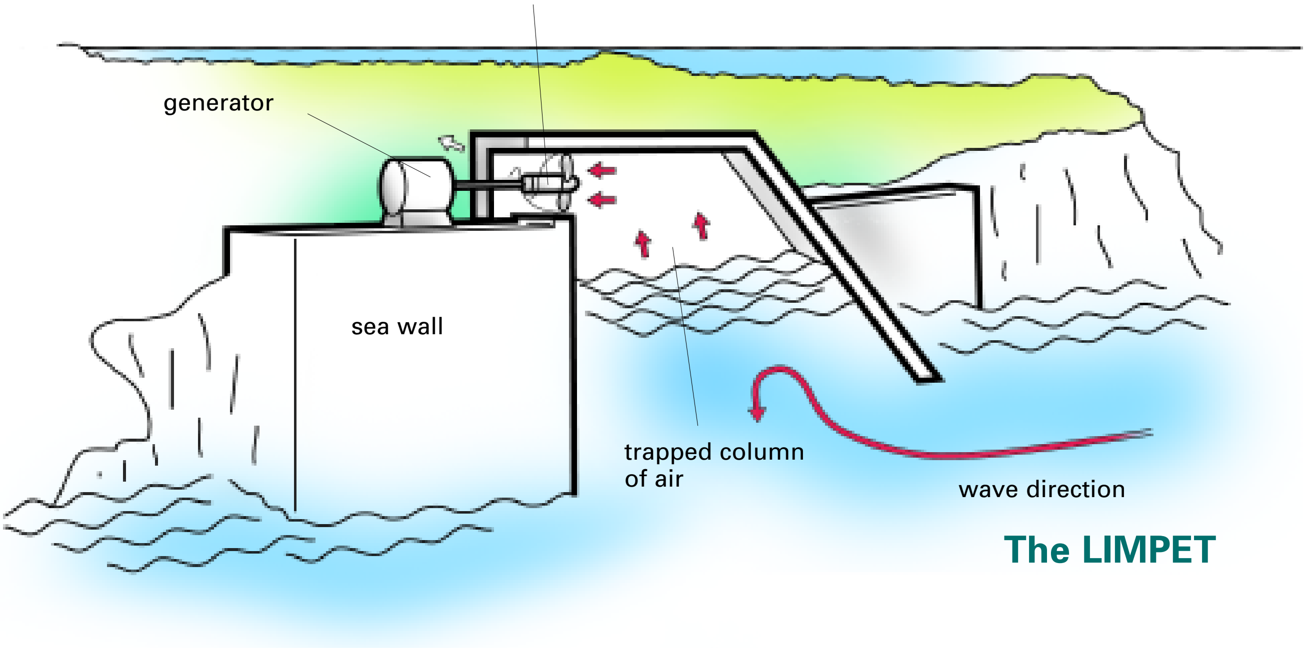
LIMPET at Islay, Scotland
Photo courtesy of Wavegen

How does wave energy work?

There are many methods of getting energy from waves, but they fall into two main types.

Fixed devices are those that are fixed to the sea bed or the seashore. Most of these are of the **oscillating water column** (OWC) type, such as the LIMPET (Land Installed Marine Powered Energy Transformer) in Islay, Scotland. In its simplest form, this is a tube set half in and half out of the water. As waves go past it, the water inside the column moves up and down, making the air in the column rush in and out. As the air moves, it spins a specially designed turbine called a Wells turbine, which turns in the same direction regardless of which way the air moves so it can be turned by both incoming and retreating waves. This turbine is then connected to a generator, which produces electricity.

The LIMPET was the world's first large wave power machine and can supply electricity to about 350 homes.



The LIMPET

Floating devices or **barrages** are generally found offshore. There are currently a huge variety of different floating wave energy conversion devices including the Duck, Clam and Pelamis from the UK, the Whale and Backward Bent Duct Buoy (BBDB) from Japan, Floating Wave Power Vessels (FWPV) from Sweden, and Swan DK3 and Wave Dragon from Denmark.

Pelamis is a wave-power project off the Scottish coast. It is a series of giant metal tubes joined together with flexible hinges. The movement of the waves causes sections of the snake to move up and down. Each hinge is connected to a pump, which pumps oil through a hydraulic motor as it moves. The motor generates electricity as it spins.

Pelamis first began generating electricity in 2004. Its location was chosen for ideal waves, the depth of sea, and to avoid passing ships. It is fixed to the sea bed by strong cables. Pelamis is Greek for 'sea snake'.

How much does electricity from wave energy cost?

Currently, the cost of producing electricity in a coal-fired power station can range from 2.5p to 3.2p per kWh, and in a nuclear power station 2.2p per kWh. At present it is difficult to calculate a cost for wave-generated electricity as there is still no overall agreement on the best type of generator to use and the best places to locate them. Best current estimates show electricity generated by wave devices costing 5p–7p per kWh.

Pelamis near Orkney, Scotland
Photo courtesy of Ocean Power Delivery

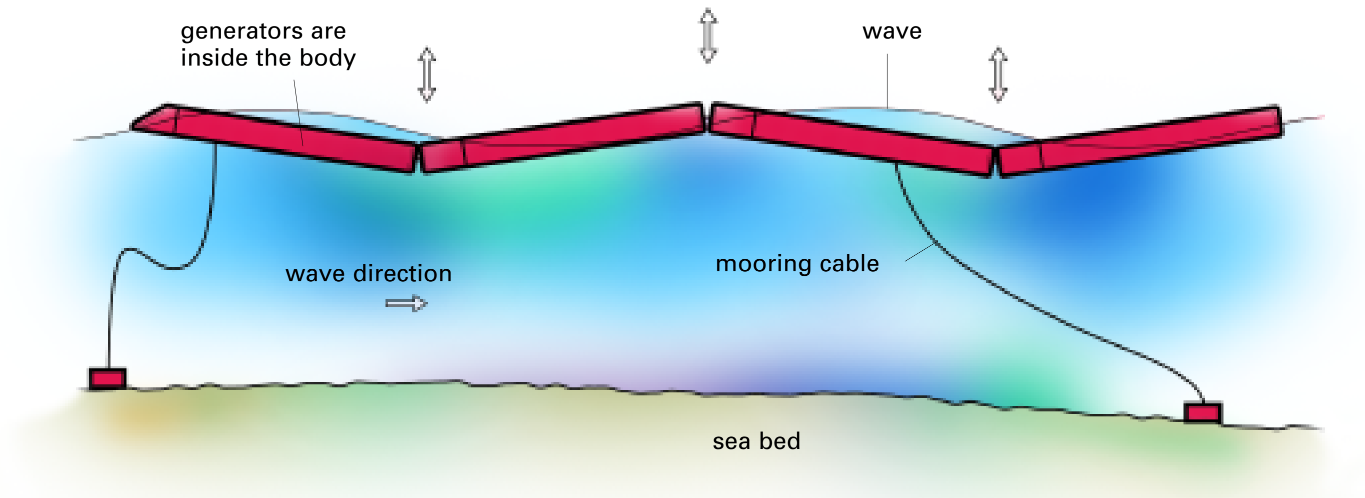
Advantages

- Once constructed, running costs are very low.
- No waste or pollution is produced.
- Wave-energy generators can produce large amounts of energy.

Disadvantages

- Wave-energy generators are only effective where they are exposed to strong waves.
- They can be noisy.
- Wave-energy generators may be a hazard to ships and leisure craft.

Pelamis



See www.dti.gov.uk/renewables/schools for a wave energy case study

Tidal energy
what is tidal energy?

Tidal energy uses the natural ebb and flow of the tides to generate electricity. Like geothermal energy, tidal energy is not a form of indirect solar power. The action of the tides is largely due to the gravitational interaction between the earth and the moon. Around the coast of the UK, the sea level rises and falls twice daily. Electricity can be generated from tidal energy using barrages or dams in those places where the tide moves in and out of a bay or inlet, and the difference between high and low tide is at least 5 metres. Today there is only one major tidal power station in operation in Europe. This is the 240MW (megawatt) barrage on La Rance river in France.

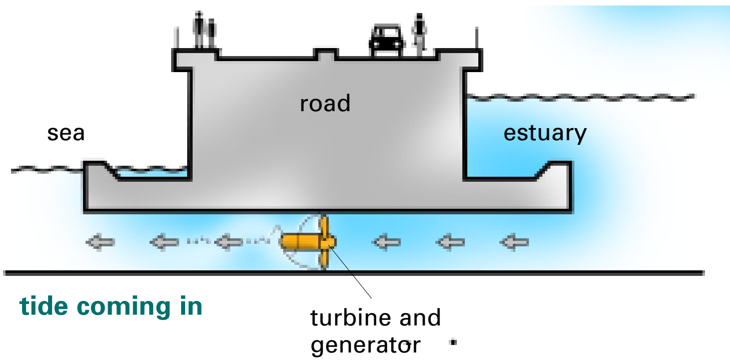
Tidal barrage at La Rance, France
Photo courtesy of EDF Médiathèque / G. Halary

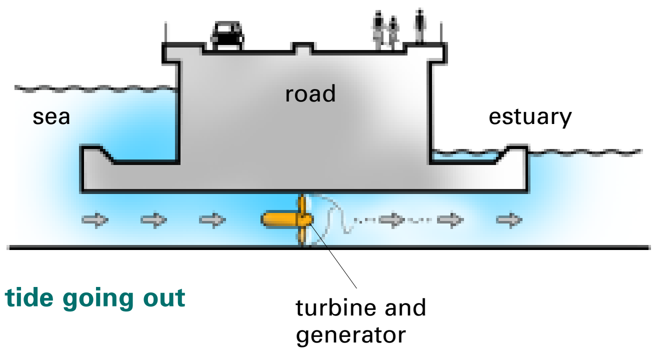
How does tidal energy work?

- In a **barrage scheme**, a bay or inlet is dammed with gates and turbines fitted along the length of the dam. The gates are opened to allow the tide to flow in, and turn the turbines, which turns the generators to produce electricity. At high tide the gates are closed and the water is held until the tide level outside the gates has dropped. The water is then released, running through the turbines and turning the generators as it escapes. So electricity is generated by water flowing both in and out of the dam.

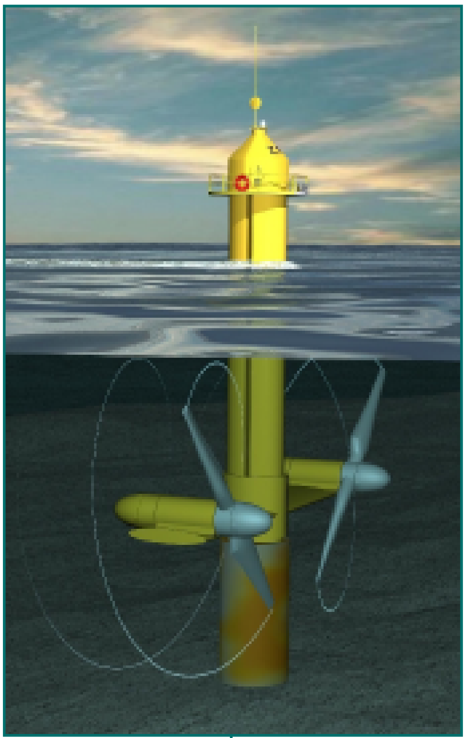
  The use of barrage-type tidal energy schemes is restricted by the number of available sites. In the UK, about 30 potential sites have been identified. The biggest of these would be the proposed Severn Barrage, which would span the River Severn. If such a scheme ever goes ahead it would generate nearly five per cent of the electricity consumed in the UK in 2002. As of 2004, there are no barrage-type schemes operating in the UK.

Tidal barrage





- A **tidal stream generator** is one alternative being developed, which avoids the damage to the environment that barrage schemes can cause. It works like an underwater wind turbine. The tide-flow turns a propeller blade, which drives a turbine. These can be used in **tide races**: places where the tide speeds up to 4–6 knots as it passes through a narrow gap. Tide races such as the Menai Straits and Ramsey Strait off the Welsh coast would be ideal locations for a seabed turbine, along with other places with strong tidal currents such as Morecambe Bay.



Marine turbine
Image courtesy of Marine Current Turbines

How much does electricity from tidal energy cost?

Currently, the cost of producing electricity in a coal-fired power station can range from 2.5p to 3.2p per kWh, and in a nuclear power station 2.2p per kWh. At present there are no tidal power stations in the UK producing electricity on a commercial basis.

Initial estimates for the cost of electricity from a farm of hydroplane-type devices (see case study on website) producing 5MW of electrical power are between 5p and 19p per kWh.

Advantages

- Running costs are very low.
- No waste or pollution is produced.
- The technology is very reliable.
- No fuel is required.
- The amount of electricity and the time it is produced is totally predictable.

Disadvantages

- There are only a few suitable places for tidal energy projects.
- Tidal stream technology is at a very early stage of development.
- Tidal schemes are expensive to install compared with other renewable energies.
- Damming bays or inlets can affect the environment over a large area.
- Barrage schemes will only provide energy for about 10 hours each day, as the tide moves in and out.

See www.dti.gov.uk/renewables/schools for a tidal energy case study