Energy

Introduction

By the end of this unit you should be able to:

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What is energy?

Energy is all around us and comes in many different forms. Although it cannot be seen or touched, you can be sure that when anything happens energy is responsible.

Energy is the ability to do work. The "work" comes in many different forms - from a car driving along, to a television set showing a programme, to a human body running a race. In order to make these machines work they need energy. Energy makes things happen.

Energy cannot be created or destroyed: it can only be transformed, from one type into another. Indeed, this is what all machines and living things do - transform energy.

For example, a car converts or transforms the chemical energy in petrol into heat energy inside the engine. The engine then turns the heat energy into mechanical energy, which makes the car move.

A television set converts or transforms electrical energy into light energy - to give a picture - and into sound energy for the soundtrack.

Humans get the energy they need for their busy lives from the chemical energy in food. They transform it into the energy of movement and heat energy.

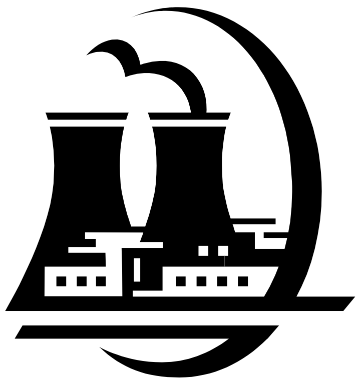
Where does energy come from?

All the energy in the food we eat comes originally from the sun. in this way, the sun is the ultimate source of the energy in food. In fact, all fuels or energy sources come from the sun in some way. To find out why, we must look at the three main areas in which the sun's energy is found on Earth.

By trapping the energy from sunlight, plants make chemical compounds that store a lot of energy. This process is called photosynthesis. This energy then becomes available to the whole of the Earth's living system, or biosphere. It can be passed on as food or fuel. The fuels from the biosphere include **wood**, **charcoal**, **alcohol**, **peat** and **dried animal dung**. **Fossil fuels** (**oil**, **gas** and **coal**) also store the sun's energy because they are made from materials that were once living.

Every day, the sun's energy is absorbed (soaked up) by the atmosphere and the water and land surfaces around the Earth. It is possible to harness (capture) the sun's daily energy in a number of ways. These include **solar collectors**, **wind turbines**, **wave** and **tidal** power stations, **ocean energy** converters and **hydroelectric dams**. This second group of energy sources is especially important because the are all **renewable**. This means that they can be used over and over again as long as the sun shines.

The third kind of energy that it is possible to make use of is the energy that became stored in the Earth itself when it was formed, hundreds of millions of years ago. When the Earth came together after the "Big Bang", radioactive atoms were left behind. Today, radioactive ore (rock) can be mined from the Earth and processed in a **nuclear** power station to release heat energy. Heat is also released by the natural decay (breakdown) of radioactive atoms trapped inside the Earth.
This keeps the rocks beneath the Earth's surface very hot.
This heat can be harnessed by **geothermal** power stations.



Assignment 1: What is energy?

1. Why do humans and machines need energy?
2. What happens to the energy in a system if it is never destroyed?
3. What is the ultimate source of energy for the earth?
4. Describe briefly the three main ways that the sun's energy is available on earth.
5. Give some examples of energy sources that can be used from each of the three groups.

Fossil Fuels

In the eighteenth century, coal became the most important energy source. By the end of the nineteenth century, oil and gas were rapidly taking its place.

These fossil fuels are very popular for several reasons. One reason is that they hold a great deal of stored chemical energy; burning only a small amount of coal, oil or gas releases a lot of energy. Most important, however, is that these fuels can be stored easily and transported to where they are needed. Combustible fuels soon replaced wind and water as the main sources of energy.

Coal and Peat

When plants die, they usually rot very quickly and become soil. When plants die in a watery environment they decay underwater away from air. This slows down the process and the plant material begins to be preserved. In the early stages, a matted soil called peat forms. Sometimes, people cut pieces of peat from bogs and leave it to dry. This is burnt on fires in homes and also on a much larger scale in some power stations.

Hundreds of millions of years ago, when the earth was warmer and wetter, large forests grew. The forests died and decayed in the swamps and river deltas in which they stood. Over many years, layers of sand and mud built up over the decaying plants and this happened again and again. The weight of the layers squashed the material underneath and it turned into a crumbly brown coal called lignite. As the lignite was forced deeper down, the pressure became greater. The pressure and the great heat below the Earth's surface changed the material from a soft, crumbly texture to a hard, black substance. This is the coal that is mined on every continent of the world.

Oil and Natural Gas

Like coal, oil and natural gas are fossil fuels that have taken millions of years to form. Animals, as well as plants, died and settled on the seabed and became buried. Pressure and heat changed the decaying material into oil. Some of the oil decayed even more and made natural gas. These oil and gas reserves supply the world with precious resources that are used today.

Before it can be used, natural gas is purified. The methane is then ready to be piped directly to homes and factories. Oil that comes directly from wells is called crude oil. This is because it is not just one substance but many, all mixed together. It has to be treated before it can be used and the factory where the oil is treated is called a refinery. Crude oil is refined to separate it into products that can be used. These include aircraft fuel, lubricating oil, chemicals from which to make plastics, and many other products.

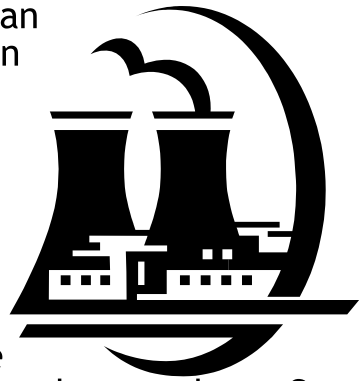
Assignment 2: Fossil Fuels

1. What are coal, oil and natural gas made from and why are they called fossil fuels?
2. What is the danger to the earth's energy supply if we continue to burn coal, oil and gas?
3. What other resource apart from energy can be extracted from oil?

Nuclear Energy

Radioactive uranium ore is used to generate nuclear power. It is mined from the ground in countries all over the world. Compared with other fuels, it is a very concentrated energy source, which means that a great deal of energy can be released from quite a small amount.

The energy in uranium cannot be released by burning. Uranium must be split into smaller atoms to obtain the energy. This decay process can happen naturally in the ground, but in a nuclear power station it is speeded up in a machine called a reactor. This process is called nuclear fission and can be carefully controlled in the reactor to produce a steady supply of heat. This heat energy is used to produce steam, which turns turbines.



Although it seems to be a very efficient way of producing energy, many people are concerned about the safety of these reactors and the large amounts of dangerous radioactive waste they produce. One way to dispose of this waste is to bury it in thick concrete containers, but some people fear that the containers could crack apart and release the radioactivity some time in the future. It is important to note that the waste material remains radioactive for a very long time.

Assignment 3: Nuclear Energy

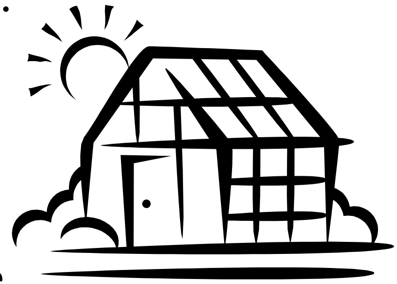
1. What is the name of the material that is used in a reactor to Generate nuclear power?
2. What are the problems associated with the waste materials produced by a nuclear reactor?

Energy and the Environment

The "greenhouse effect"

At present, fossil fuels supply most of the world's power, but when any of these fossil fuels are burnt, carbon dioxide gas is released. There is a small amount of carbon dioxide naturally present in the air, but, because fossil fuels are used so much, it is building up in the atmosphere. In these unnatural quantities, carbon dioxide is one of the gases that cause the greenhouse effect.

Gases such as carbon dioxide allow the sun's heat to enter the atmosphere but stop it escaping back into space. Heat is trapped in a layer around the Earth. As a result of the increased amount of carbon dioxide, temperatures have risen around the world. The air inside greenhouses heats up in a similar way. The glass lets in the sun's heat but stops it escaping back out again. In this way the glass is like a layer of carbon dioxide. Because of this similarity, global warming is known as the "greenhouse effect".



You might think that it would be very pleasant to have a warmer climate, but some scientists think the effect could be very serious. Some animals and plants are very sensitive to temperature, and so global warming could cause them to die out. Also, as the weather gets warmer, the ice caps at the North and South poles will gradually melt. The melting of the southern ice cap will cause sea levels to rise. This will lead to flooding, reducing areas of land and killing off even more living things.

Acid rain

As rainwater falls through the atmosphere, it mixes with carbon dioxide gas and becomes an acid called carbonic acid. This natural acid is so weak that it does not harm the environment.

However, when coal is burned, sulphur and nitrogen in the coal combine with oxygen to give oxides. These mix with rainwater and make it much more acidic. The main acids that this process produces are sulphuric and nitric acids, which are very strong. This acid rain is polluting the environment, causing trees to stop growing and animals and plants in lakes and rivers to die. It also corrodes buildings, making them crumble.

It has become vitally important for scientists and technologists to solve the problem of producing or harnessing energy from the Earth without having to burn fossil fuels.

Oil Pollution

Oil can cause huge problems. Leakage and spills from oil tankers can release tonnes of oil into the environment. All sorts of marine life and birds are destroyed, and beaches are covered in oil. The pollution is very difficult and expensive to clear up properly and safely. The problem is made worse by high winds and rough seas, which break up and spread oil slicks that are already many square kilometres in size.

Assignment 4: Energy and the Environment

1. What is “global warming”?
2. Describe the way that the greenhouse effect is warming the Earth?
3. How is acid rain produced?
4. Why does acid rain have an effect on animals as well as plants?
5. What must be done to reduce the effects of acid rain and global warming?

The need for the conservation of resources

The best way to put fewer greenhouse and acid rain gases into the atmosphere, and to save the fuels we have left, is to use and waste less energy. This does not mean we have to shiver in cold houses, or sweat without air conditioning, or read by candlelight. Our industrial society has been very wasteful with energy over the years and there are many ways in which we can improve.

If we used more energy-efficient methods, we could save three-quarters of all the energy we use in homes, offices, factories and transport. Yet we would live in much the same way as we do today. We could also help less developed countries to build up their industries in a better way.

In the USA, homes and workplaces use nearly two-fifths of all the nation’s energy. Many houses, factories, offices and schools let heat leak away through their roofs, walls and windows. They waste too much light energy. Their machines and appliances have inefficient electric motors and other energy-wasting parts.

The average Swedish house uses less than half the energy of the average American house. This is partly because Swedish homes are better insulated, to keep heat in. They have more lagging in the roof, more insulating material in the walls, more double-glazed windows and more low-energy light bulbs. They have “passive” solar features such as south-facing windows, which make natural use of the sun’s warmth.

There is a “cost trap” however. To become energy-efficient you have to spend first in order to save later. Some people and businesses cannot afford the initial cost of buying energy-efficient equipment or converting their buildings to save energy. Governments help to make long-term savings. They provide grants and other ways of encouraging energy efficiency. They also make manufacturers label their cars, washing machines and other products, telling consumers how energy efficient, or inefficient, they are.

Most homes have incandescent light bulbs like the one on the left in the diagram below. However, compact fluorescent light bulbs, on the right, use less than 25% of the energy to make the same amount of light - and can last ten times longer.

Renewable Energy Sources

Today, we use so much energy that we depend very heavily on fossil fuels that have taken nature millions of years to make. It is not surprising that we are using them up faster than they are being formed. There will be a time when the world's limited resources are used up. Because of this, fossil fuels are known as non-renewable energy sources.

Every day, the Earth absorbs vast quantities of the sun's energy. Even if only a small proportion of this could be harnessed, there would be enough energy for our needs as long as the sun continued to shine. Energy sources that come from daily sunshine are therefore known as "renewable". These include solar power, wind energy, hydroelectricity and energy from the sea.

Many people think that alternatives to fossil fuels should be used more. This is not only because fossil fuels are running out but also because they cause such serious environmental problems. Renewable sources are clean, and most of them are being investigated as alternative energy sources. Some of them are already in use all over the world.

Assignment 5: Renewable energy sources

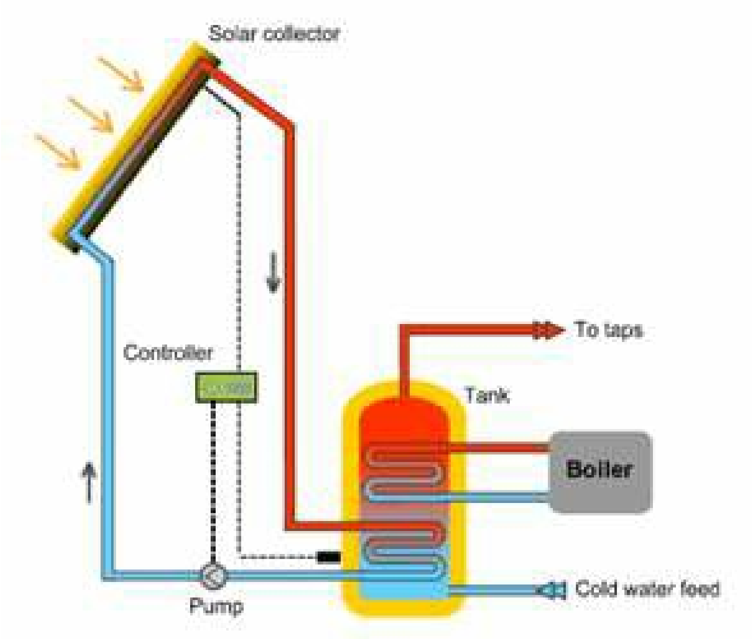
1. What is the difference between a finite and an infinite energy source?
2. Why are fossil fuels thought of as non-renewable, or finite, energy sources?
3. What is a renewable energy source?
4. Name three renewable energy sources.
5. Name a machine that has been used in the Netherlands for many years that harnesses the energy of the wind.

Alternative Energy Sources

Solar Energy

Science and technology now allow us to trap the enormous power of the sun and use it to produce heat and electricity.

Buildings can be designed to absorb heat on “heat collectors” during the day and release it when it is most needed, at night. Solar collectors on rooftops work in the same way, but the heat is stored in a liquid such as water or oil. This is used to heat the building by passing it around a central heating system, or simply to provide hot water.



The sun’s light energy can be turned into electricity using photovoltaic cells that contain crystals of silicon. These cells work in a similar way to a car battery, but instead of being recharged by something that moves, such as an engine, they are recharged by light. They were first made for spacecraft, but now you may find them powering your calculator or watch.

Solar heat can be captured on a vast scale to generate electricity. The sun's light is reflected off many mirrors and on to one small target, to concentrate the energy. This means that much more of the sun's radiation is collected in one place. The intense heat can then turn water into steam to turn a turbine.

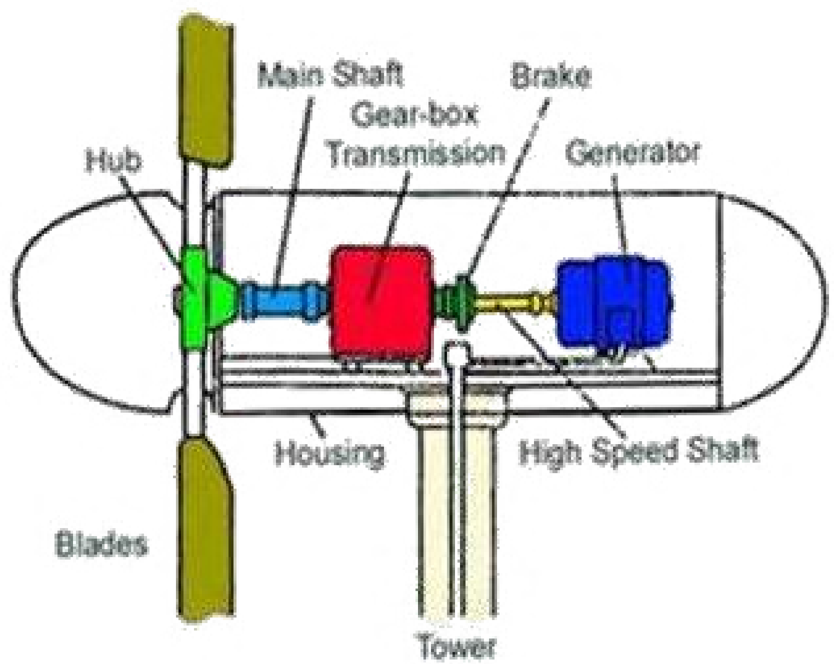
Assignment 6: Solar Energy

1. Describe three ways in which it is possible to harness solar power.
2. If a word has "photo" (for example photosynthesis) at the start of it, what does "photo" refer to?
3. Where would be a good location for a solar power generator?

Wind Energy

Wind power has been used to turn windmills for thousands of years. They were used to turn machinery to raise water from deep wells and to grind wheat. In recent years, new ways have been found to capture the wind's energy more efficiently. However, because winds vary from place to place and from day to day, this can prove to be difficult.

Today's wind turbines are very different from the old windmills. For example, they are designed so that they automatically turn into the wind if its direction changes. To generate enough electricity, wind turbines work together in groups as wind farms. In California, USA, one wind farm has 18,000 wind turbines. The problem with large wind farms is that they look ugly and make a lot of noise. One possible solution to this is to build these wind farms out at sea where they will not disturb animals and humans, but this is very expensive.



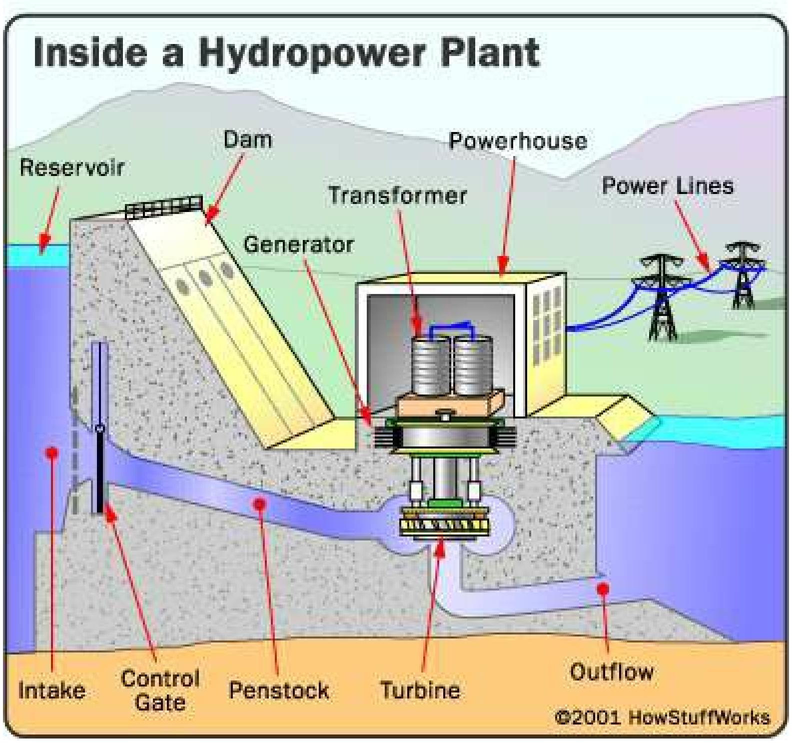
Assignment 7: Wind energy

1. Name one method of transport that harnesses the wind's energy.
2. How can wind farms cause environmental problems?
3. Describe the way that electrical energy is generated using a wind turbine like the one shown above.

Hydroelectric Energy

Water power has been used for centuries. Nowadays, hydroelectric schemes are used to generate large amounts of electricity. Usually a dam is built across a river valley to control the flow of water and store up the energy. The water collects in a reservoir behind the dam. When electricity is needed, the water is allowed to rush through holes in the dam, turning turbines as it flows.

Hydroelectric schemes are used all over the world. They provide a widespread renewable energy source. However, they need to be carefully planned since they can cause large areas of land to be flooded behind the dam. This can seriously damage the local environment in which plants, animals and humans live.



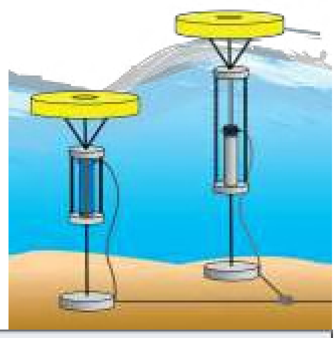
Assignment 8: Hydroelectric Energy

1. Describe the way that electricity is generated in a hydroelectric power station.
2. What is a possible disadvantage of hydroelectric schemes?

Energy from the Sea

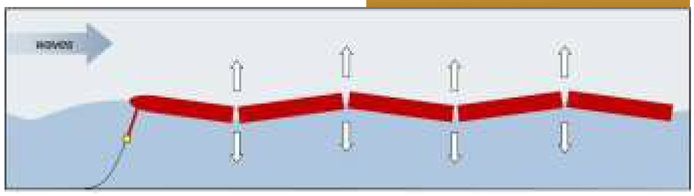
There are several ways in which the sea can provide us with energy for generating electricity. Some of these ideas are still being tested and improved.

Wave Energy

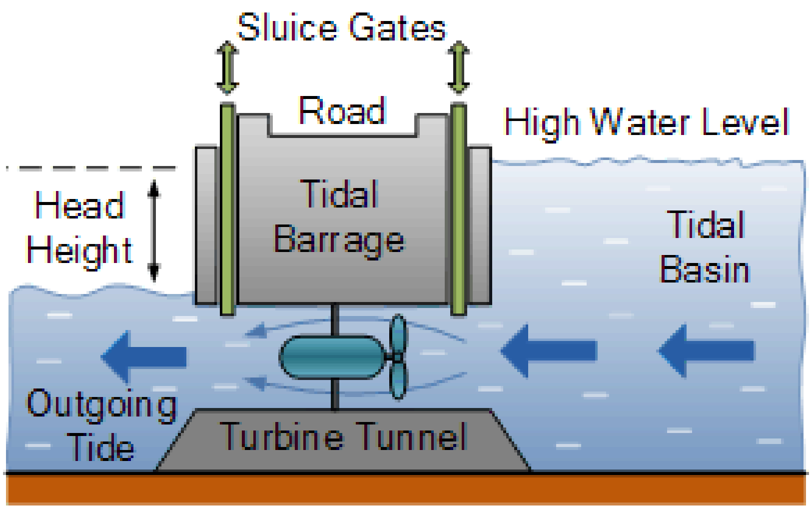


Waves happen because winds transfer their energy to the sea's surface as they blow over the water. Wave power systems use kinetic energy in the waves to turn turbines. These can be either floating or fixed to the seabed, and placed either out at sea or on the shoreline.

Tidal Energy



Tides are caused mainly by forces from the moon and the sun. This force is called gravity and it pulls on the water. Tidal energy can be harnessed by building a barrier right across a river estuary. Electricity is generated in the same was as with a hydroelectric dam, except that it is the push and pull of the tides that causes water to flow over the turbines. However, people fear that tidal schemes may upset estuary environments that are rich in wildlife. Also tidal barriers are a nuisance to shipping.



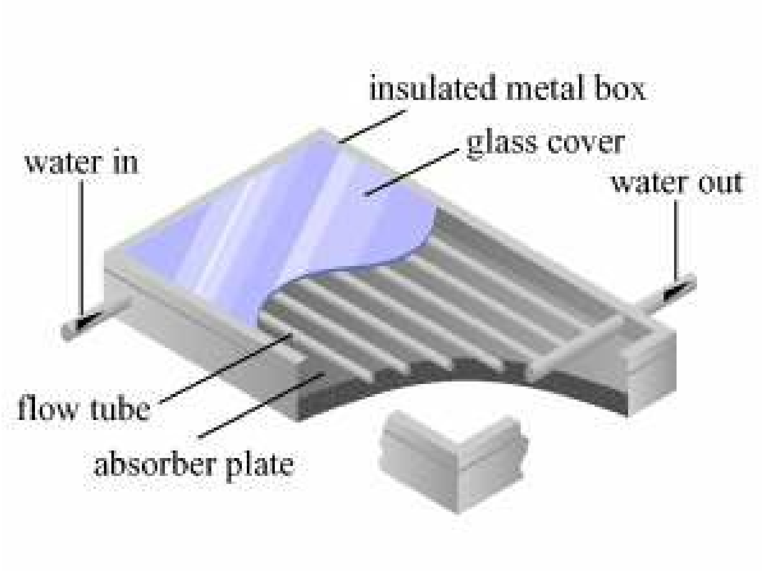
Assignment 9: Energy from the sea

1. Describe two ways that the sea's energy can be harnessed.
2. Describe one negative aspect of harnessing tidal energy.

Homework Assignment 1: Understanding Energy

1. Complete the following statement about energy.

   "Energy can be described as the ability to do…"
2. Where do all the Earth's energy sources originally come from?
3. What is meant by the term "fossil fuels" and what effect do they have on global warming?
4. Make a list of examples of renewable energy sources that can be used to produce energy.
5. What is the difference between a renewable (infinite) and a non–renewable (finite) source of energy?
6. Look at the diagram of a solar collector below and describe how it can be used to help heat a building.



7. Why is it important to conserve energy?
8. Give an advantage and a disadvantage of using nuclear energy to produce electricity.
9. Describe some of the advantages and disadvantages associated with wind and wave energy sources.
10. What are some of the ways that energy is wasted or lost in your home or at school? Describe some possible solutions to this problem.

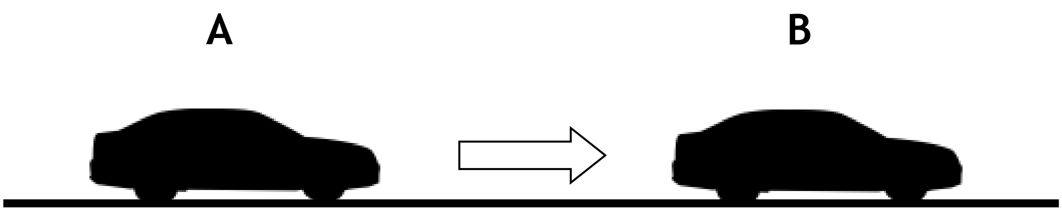
Calculations of Energy

Work and Energy

Work Done

When a force is used to move an object, "work" is said to be done.

Consider pushing a car along a road from position A to position B.



The amount of work you will do depends on how difficult the car is to push (the size of the force) and on how far you have to push it (the distance).

The amount of work can be calculated using the formula

Work Done = Force applied x Distance moved

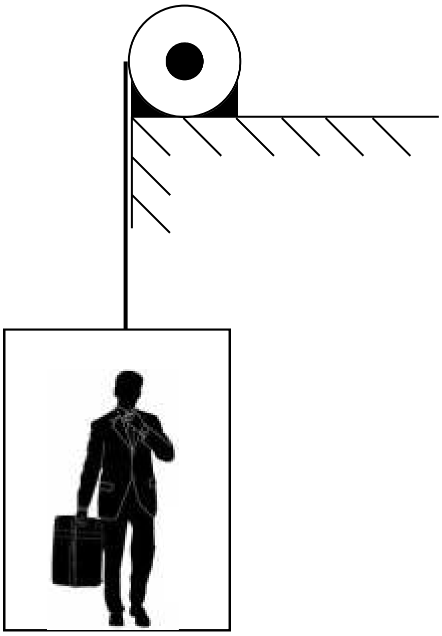
$$W = F \times s$$

Force is normally measured in Newtons (N) and distance in metres (m).

The unit for measuring work is therefore newton metres (Nm), or joules (J).

Worked example: Work Done

A winch raises a lift of mass 1000kg to a height of 20m. Calculate the minimum amount of work that must be done by the winch.



Weight of lift = m x g

= 1000 x 9.81

= 9810 N

Work Done = Force x Distance

= 9810 x 20

= 196200 Nm

Assignment 10: Calculating Work Done

1. Calculate the amount of work done when a force of 150N is used to pull a bag of sand 20m.
2. In lifting an engine out of a car, a mechanic uses a block and tackle. How much work is done if a force of 500N is used in pulling the rope a distance of 4m?
3. During the loading process, a fork-lift truck lifts a pallet of bricks of mass 740kg up to a height of 2m. Calculate the minimum amount of work the truck must do during the lift. Suggest why the actual work done during the lift will be greater than this?
4. A weightlifter “snatches” a dumbbell from the floor to arm’s length, a vertical height of 1.2m. Calculate the mass of the dumbbell (in kg) if the minimum work done in lifting it is 1800Nm.
5. A mass of 50kg is raised to a height of 5m by a rope, which is wound around a pulley on a motor shaft of diameter 150mm. Determine the amount of work done by the motor and the number of revolutions made during the lift.

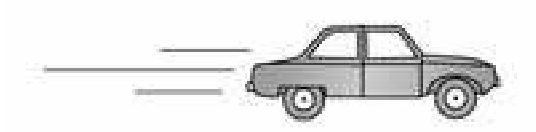
Other forms of energy

Energy is defined as the capacity of a body to make things happen (or to work). It is measured in joules (J). We know that to do more work we require more energy, but we can use various types of energy to do this work for us. Energy comes in several different forms, but the ones we shall deal with are:

- Kinetic
- Potential
- Electrical
- Heat

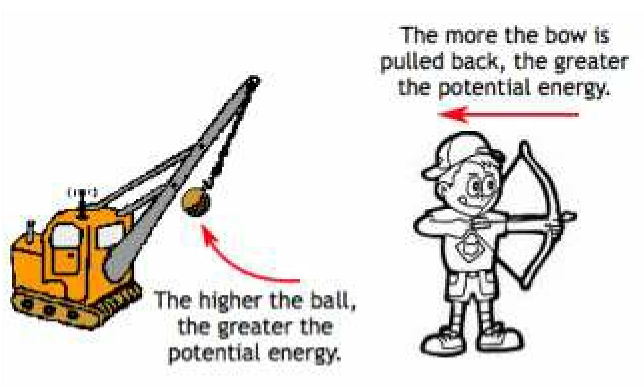
Kinetic Energy

Kinetic Energy is the energy of movement. It is the name given to the energy a body possesses due to its motion. The car in the diagram below can be described as having kinetic energy because it is moving.



Potential Energy

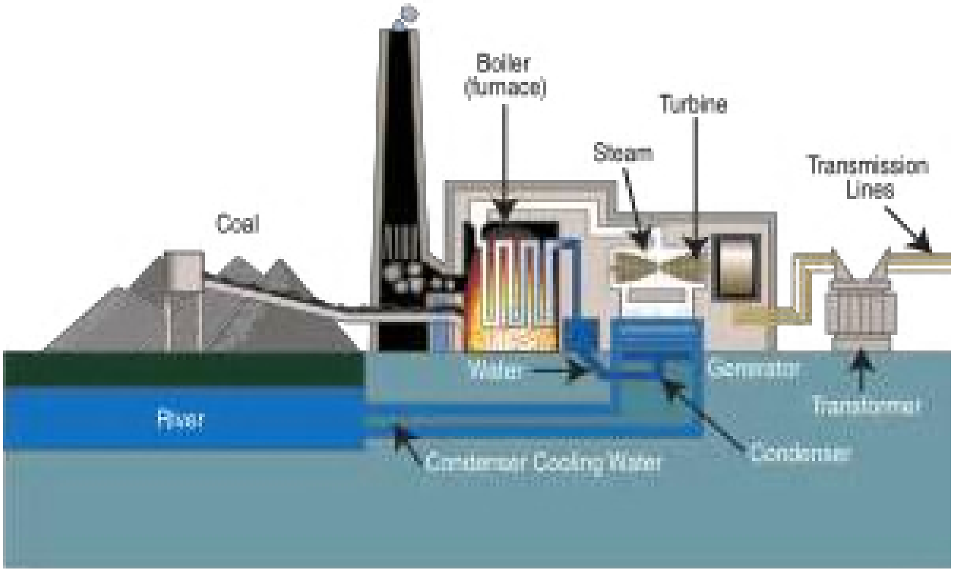
Potential energy can be best thought of as energy stored in a static object. It can be due to how high the object is above a datum (starting point), or due to the fact that work has already been done on the object and the energy is stored in it (for example in a spring). The two examples below have potential energy.



Electrical Energy

Electrical energy is one of the most convenient and commonly used forms of energy since it can be transported easily from place to place (along electrical cables) and can be easily changed into other forms of energy. Most electrical energy is generated in power stations, where one type of energy is converted into electrical energy.

The diagram below shows a simple fossil fuel power station. The fuel is burnt in a boiler and the chemical energy in the fuel is converted into heat energy. This heat energy is used to produce steam at very high pressure (kinetic energy). The high pressure steam is then used to turn turbine blades (rotational kinetic energy). The turbine is in turn connected to an alternator, which converts the kinetic energy into electricity. This electricity can now be transported around the country along electrical cables, which are suspended by pylons.

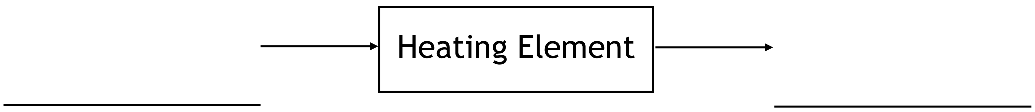


Heat Energy

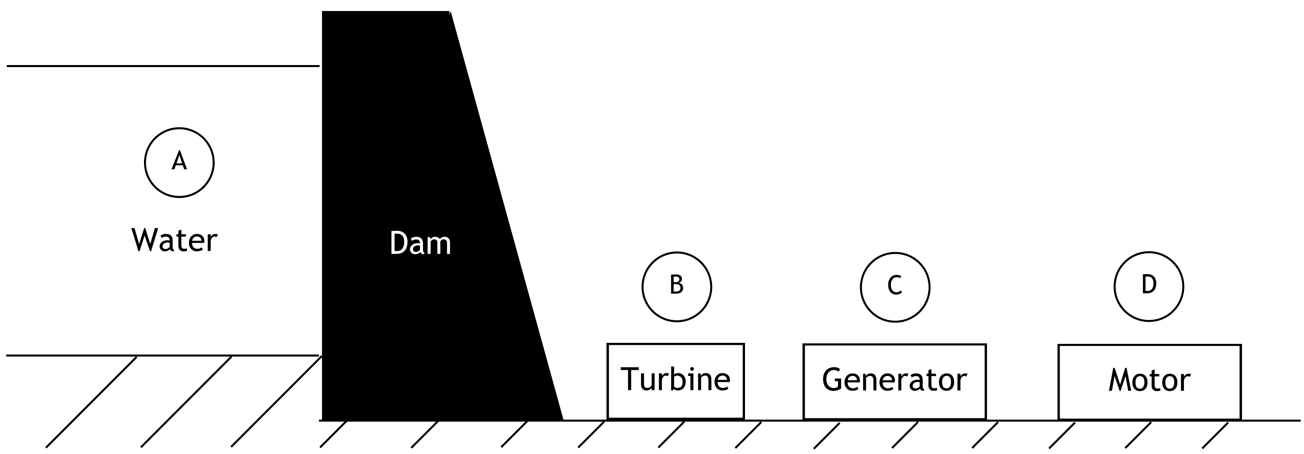
Heat energy is the energy transferred to a body that results in a change in the body's temperature. The diagram below shows a kettle boiling: a certain amount of thermal energy was required to raise the temperature of the water in the kettle to boiling point.

Assignment 11: Identifying different forms of energy

1. When an Olympic diver stands on a diving board 10m above the pool, what form of energy does he possess?
2. When the diver jumps on the diving board it will bend. What form of energy does the board now possess?
3. When the diver is moving upwards, what form of energy does he now possess?
4. When the diver is at the highest point of his dive why does he not have any kinetic energy?
5. A heating element is used to make sure that the water temperature in the pool is maintained at a suitable level. Copy and complete the simple systems diagram below, showing one energy input and one energy output for the heating system that will solve this problem.



6. Name four sources of energy that can be converted (directly or indirectly) into electrical energy.
7. The diagram below shows a representation of a hydroelectric power station. Name the form of energy at each of the stages A, B, C and D.



Calculating Kinetic Energy

The kinetic energy of a moving object is dependent on two factors: the mass, *m*, of the object (in kg) and its velocity *v* (in m/s).

Kinetic energy is calculated using the formula:

$$E_K = \frac{1}{2}mv^2$$

Worked example: Kinetic energy

1. If a buggy of mass 90kg travels at 40m/s, how much kinetic energy does it possess?

$$E_K = \frac{1}{2}mv^2$$

$$E_K = \frac{1}{2} \times 90 \times 40^2$$

$$E_K = 72000\, joules$$

$$E_K = 72kJ$$

Assignment 12: Kinetic Energy

1. During a sheet-making process, 50kg ingots of metal are passed along rollers at a speed of 0.5m/s. Calculate the kinetic energy of each ingot.
2. A racing car drives a lap at a speed of 50m/s. If the car has a kinetic energy of 500kJ, what is the mass of the car?
3. A girl of mass 50kg is riding on her bicycle and has a kinetic energy of 2.5kJ. What speed is the girl moving at, and what is the kinetic energy of the bicycle if it has a mass of 30kg?
4. A crane raises a load of 200kg to a height of 30m in one minute at uniform speed. Determine the kinetic energy of the load when it is moving.
5. An escalator has six people on it with a total mass of 900kg. If the escalator moves at a uniform speed of 0.5m/s, what is the average amount of kinetic energy that each person contains?
6. Since 1975 the US government has required that a container carrying radioactive material must be able to withstand a high speed crash with an impact velocity of 250m/s. By comparison, the UK safety standards (in 1994) are carried out at 50m/s. if the container has a mass of 10kg then calculate the percentage increase in kinetic energy of the American test over the British test.

Calculating Potential Energy

The formula most commonly used to calculate potential energy is:

$$E_P = mgh$$

Where *m* is the mass of the object, *g* is the acceleration of gravity acting on the object and *h* is the height the object above the ground or datum.

Worked example: Potential energy

1. Metal piles are driven into the ground using a pile driver. This consists of a 500kg driver, which is raised by a winch to a height of 3m above the pile and then released. Calculate the potential energy stored when the driver is lifted.

$$E_P = mgh$$
$$E_P = 500 \times 9.81 \times 3$$
$$E_P = 14715\,joules$$
$$E_P = 14.7kJ$$

Assignment 13: Potential Energy

1. Baggage handlers at an airport place suitcases onto a conveyer belt which lifts them up to the hold of the aeroplane. The height that the bags are raised is 3.5m. Calculate the potential energy stored when a 20kg case is moved up the belt.
2. At what height must a drum of mass 100kg be suspended above the ground if it possesses 4kJ of potential energy?
3. Calculate the potential energy available from a reservoir holding 1800 litres of water at a height of 260m. (1 litre of water has a mass of 1kg).
4. Metal piles are driven into the ground using a pile driver. The driver is raised to a height of 5m above the ground and then released. Calculate the weight of the driver is the potential energy stored when it has been lifted is 9810 joules.
5. A fairground roller coaster has many high and low points on its track. If the highest point - the beginning of the ride - is at a height of 50m and the height at the end is 5m, what is the change in potential energy between the start and end for a person of mass 80kg?
6. If a steeplejack has a potential energy of 2000J when he scales a ladder to a height of 10m, what amount of potential energy will he possess at a height of 15m?

Calculating Electrical Energy

Electrical energy can be calculated using the formula:

$$E_e = ItV$$

Where *V* is the voltage of the circuit, *I* is the current flowing through the circuit and *t* is the time (in seconds) that the circuit has been operating.

Worked example: Electrical energy

1. An electric cooking ring has an operating voltage of 230 volts with a current of 5 amps. Calculate how much electrical energy has been used if the cooking ring takes five minutes to heat a pot of soup.

$$E_e = ItV$$

$$E_e = 5 \times 300 \times 230$$

$$E_e = 345000\,joules$$

$$E_e = 345kJ$$

Assignment 14: Electrical Energy

1. A hot air hand dryer is activated for 30 seconds when the switch is pressed. The drier operates from a 230V supply and draws a current of 12A. Calculate the amount of electrical energy used when the drier is operating.
2. A 12 volt car battery has a capacity rating of 35 amp hours (that is, it can supply a current of 35 amps for 1 hour, or 5 amps for 7 hours, or any other combination giving an equivalence of 35 amp hours). Determine the amount of electrical energy the battery can supply.
3. A portable electrical generator can deliver energy at a rate of 6kJ per second. Calculate the current that can be drawn from the generator if the electricity is supplied at a voltage of 110 volts.
4. If the amount of electrical energy used by a 110V, 30A d.c. motor is 1.98MJ, for how long has the motor been in operation?
5. A turbine is used to drive a 110V electrical generator. If the output current is 3 amps, how much electrical energy does the generator produce in one hour?

Calculating Heat Energy

Heat energy can be calculated using the formula:

$$E_h = mc\Delta T$$

Where *m* is the mass of the material in kg, *ΔT* is the change in temperature in degrees (Celsius or Kelvin) and *c* is the specific heat capacity of the material being heated.

The specific heat capacity of a substance is the amount of energy required to raise the temperature of 1kg of the material by 1K.

Worked example: Heat energy

1. A hot water tank contains 200 litres of water at 18°C. Calculate how much energy is required to raise the temperature of the water to 50°C. (1 litre of water has a mass of 1kg.)

   The specific heat capacity of water is 4190J/kgK.

$$E_h = mc\Delta T$$
$$E_h = 200 \times 4190 \times 32$$
$$E_h = 26.82MJ$$

Assignment 15: Heat Energy

1. Calculate the heat energy required to heat 2kg of water from a temperature of 20°C until it begins to boil.
2. A hall has dimensions of 8m x 30m x 10m. Assuming no heat losses, calculate the amount of heat energy required to raise the temperature of the air in the hall from 10°C to 20°C. The density of air is approximately 1.3kg/m^3 and the specific heat capacity is 850J/kgK.
3. The heating element in a shower can produce heat energy at a rate of 7kJ/s. Water enters the system at a temperature of 15°C and is heated to 40°C. Estimate the flow rate (in litres per second) and state any assumptions you have made.
4. 57kJ of thermal energy is supplied to 1.7kg of oil having a specific heat capacity of 2.7kJ/kgK. If the initial temperature of the oil is 3°C, what will be its final temperature?

Power

Power is a measure of the rate of energy transfer; that is, it gives an indication of how quickly the energy is changed from one form to another.

Power can be calculated using the equation:

$$P = \frac{E}{t}$$

P is the power in watts (W).

E is the energy transfer in joules (J).

t is the time in seconds (s) - *t must be in seconds*

Worked example: Power

1. If an electric light bulb uses 60kJ of energy in 10 minutes, what is the power rating of the bulb?

$$P = \frac{E}{t}$$

$$P = \frac{60000}{(10 \times 60)}$$

$$P = \frac{60000}{600}$$

$$P = 100W$$

Assignment 16: Power

1. A winch lifts a 500kg pallet of bricks to a height of 10m in a time of 15 seconds. Calculate the minimum output power of the lift.
2. An electric heater is rated at 3kW. Calculate how much heat energy the heater will deliver in one hour.
3. A car of mass 800kg is moving at a steady rate of 70km/hour. Calculate the kinetic energy of the car and the power output from the car in one minute.
4. An electric motor is rated at 10kW and runs from a mains supply of 220V. If it consumes 10kJ of energy over a period of 30 seconds, what is the current used by the motor?

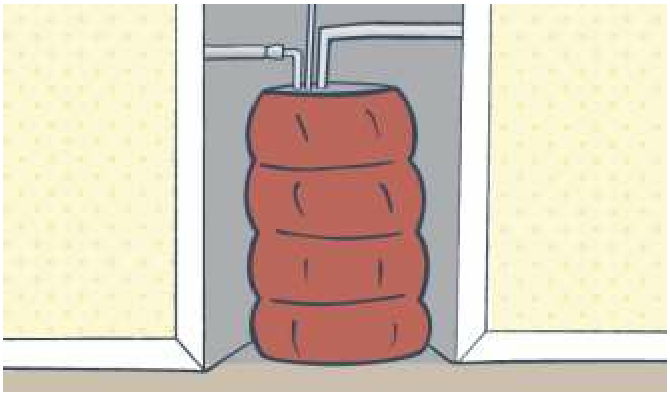
Homework Assignment 2: Calculating Energy and Power

1. A car has broken down and the driver needs to push it for 2km to the nearest garage. If the driver applies and average force of 50N to the car, how much work will be done to push the car to the garage?
2. The car is repaired and is driven on the motorway at an average speed of 70km/h. If the weight of the car is 500kg and the driver weighs 75kg, calculate the kinetic energy of the vehicle. (Hint - convert the speed to m/s.)
3. When the car has been on the road for 45 minutes, the temperature of the water coolant in the engine rises from 20°C to 35°C. How much heat energy has been transferred to the coolant if there is 4 litres of coolant in the engine? (The specific heat capacity of water is 4190J/kgK and 1 litre of water has a mass of 1kg).
4. When the car is running, the 12 volt radio is on all the time. How much electric current does the radio use if 97,200 joules of electrical energy are consumed in 45 minutes and how much power does the radio use?
5. The car stops at a local beauty spot - a cliff view at a height of 125m. The driver is not in the car. What are the individual potential energies of the car and the driver?
6. A golfer swings a club at a ball and hits the ball down the centre of the fairway. If the ball has a mass of 0.1kg and a maximum kinetic energy of 125 joules, what is its highest velocity?
7. A schoolgirl has completed her technology homework and decides to play on her game system for 30 minutes. If the game plugs into the mains and uses 230 volts and 3 amps, calculate the electrical energy and power used by the game.
8. A woman passenger is flying home to meet her parents in Durban, South Africa, on a jumbo jet. When the plane is fully loaded and about to take off it has a total mass of 100,000kg, but when it lands it has used most of its fuel and has a mass of only 80,000kg. If the average speed of the plane is 750km/h, what is the difference between the kinetic energy at take-off and at landing?

Conservation of Energy

In everyday usage, the term energy conservation has come to mean conserving energy in the sense of using less of it to do the same amount of work. Examples include improving the heat insulation of houses and other buildings, improvements in the efficiency of lighting and other electrical devices, making cars which use fuel more efficiently, etc.

The diagram below shows the insulating jacket around a hot water tank. This is used to reduce heat loss.



In technology and science conservation of energy” has an older and different meaning. It is looked up on as a rule.

The rule states that **energy cannot be created or destroyed but can only be changed from one form to another - “transformed” or “converted”.** This rule is also termed a natural law.

The Law of Conservation of Energy

The law of conservation of energy asserts that for a **closed system, where no energy goes in or out, the total energy within the system must always be the same**, although its form may change. On the other hand, in an **open system** such as a power station, this rule leads to the conclusion that the **total energy input to the system must be exactly equal to the total energy output**.

The extent to which the output energy is able to do work - that is, of the desired type - is called the **efficiency** of the system. We calculate this by comparing the useful output from the system with its energy input.

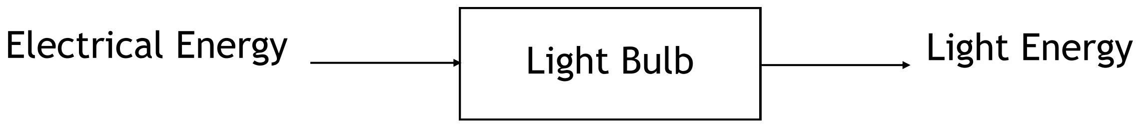
Energy Transformation

How energy can be converted or transformed is of prime importance to the technologist. Some forms of energy are directly interchangeable (for example potential and kinetic) but others need to go through several changes to arrive at the final desired form (for example Chemical —> Heat —> Kinetic —> Electrical).

The following system diagrams show some very simple energy transformations.

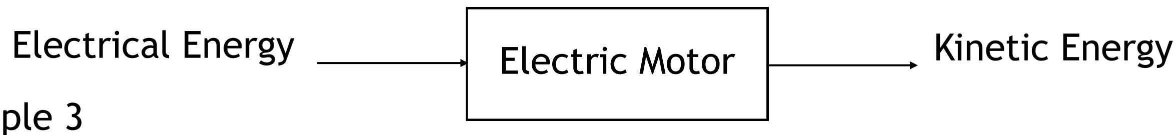
Example 1

A light bulb converts electrical energy into light energy.



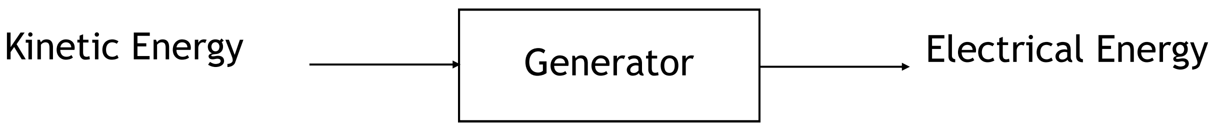
Example 2

An electric motor converts electrical energy into kinetic energy or movement.



Example 3

An electric generator converts kinetic energy into electrical energy.

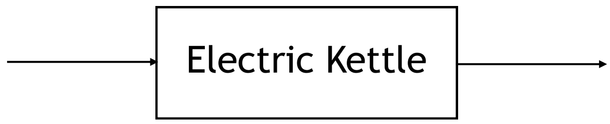


Assignment 17: Simple Energy Transformations

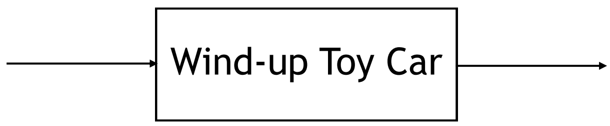
Copy and complete the following system diagrams showing the energy conversions taking place.

1. A stretched elastic band

2. An electric Kettle



3. A wind-up toy car



4. Water passing over a waterfall

More Energy Transformations

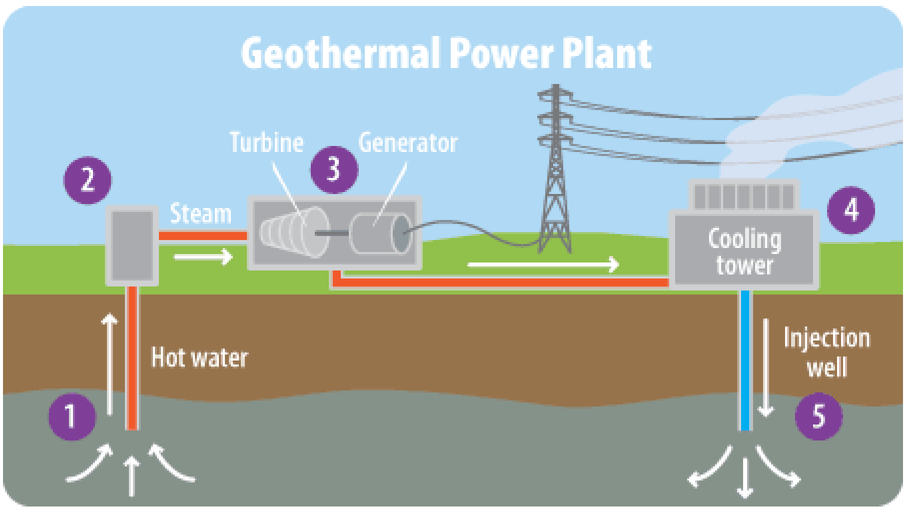
It has been mentioned that some systems will require more than one energy conversion to arrive at the desired energy output, for example when converting geothermal energy into electrical energy.

Geothermal Energy

The Earth is a massive reservoir of natural heat energy. At its "birth" the Earth was a molten mass at temperature of around 6000°C. The Earth has been cooling down ever since, and will continue to do so for millions of years.

In some places on the Earth, this natural heat energy reaches close to the surface. Occasionally, molten materials from the Earth's core escape to form volcanoes. In Iceland and New Zealand, water trapped below ground in cavities becomes heated and escapes under pressure as hot water geysers. Even in Britain, hot water springs occur. The Romans took advantage of "geothermal energy" at the now famous Roman baths in Bath.

If geothermal energy could be harnessed at temperatures of around 250°C or higher, it could be used to make electricity, the heat being used to turn water into high pressure steam to drive turbine generators. To achieve these temperatures, however, it would be necessary to drill deep into the Earth's surface to reach the so-called "hot rocks". In Britain it would be necessary to drill as deep as 6000 metres (about four miles) to reach temperatures for the generation of electricity.

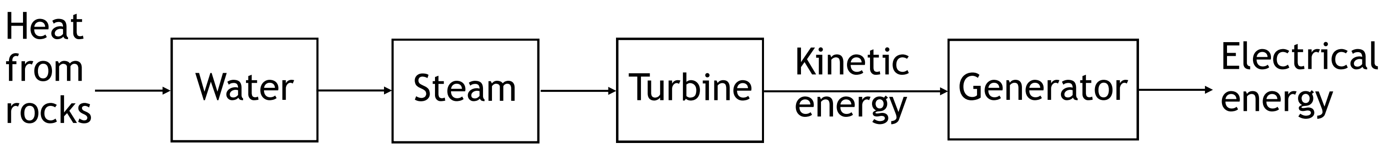


One method of "collecting" geothermal energy for conversion into electricity is shown on the previous page.

The system consists of two boreholes, which penetrate the Earth's crust and then bore into a region of hot rocks. During construction, an explosive charge would be detonated at the bottom of the injection hole under pressure. It would then penetrate the hot rocks, pick up heat, and return to the surface through the second borehole. At the surface, steam would be released from the pressurised system to drive turbine generators.

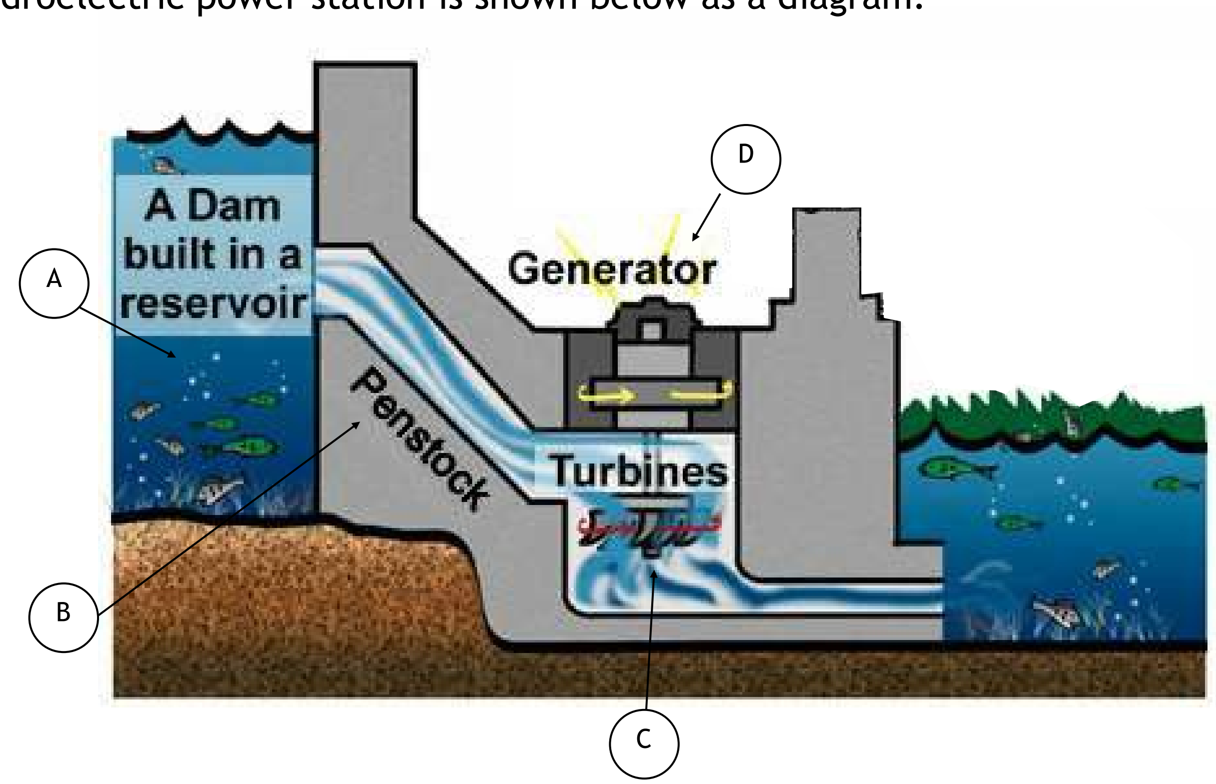
The energy conversions could be described as follows.

The heat energy in the rocks is transferred to the water in the injection-hole pipe. This hot water is changed to high-pressure steam and transported to the surface. The heat energy from the steam is used to turn the blades of a turbine, producing rotational kinetic energy, which is used to create electricity from a generator.



Assignment 18: Complex Energy Transformations

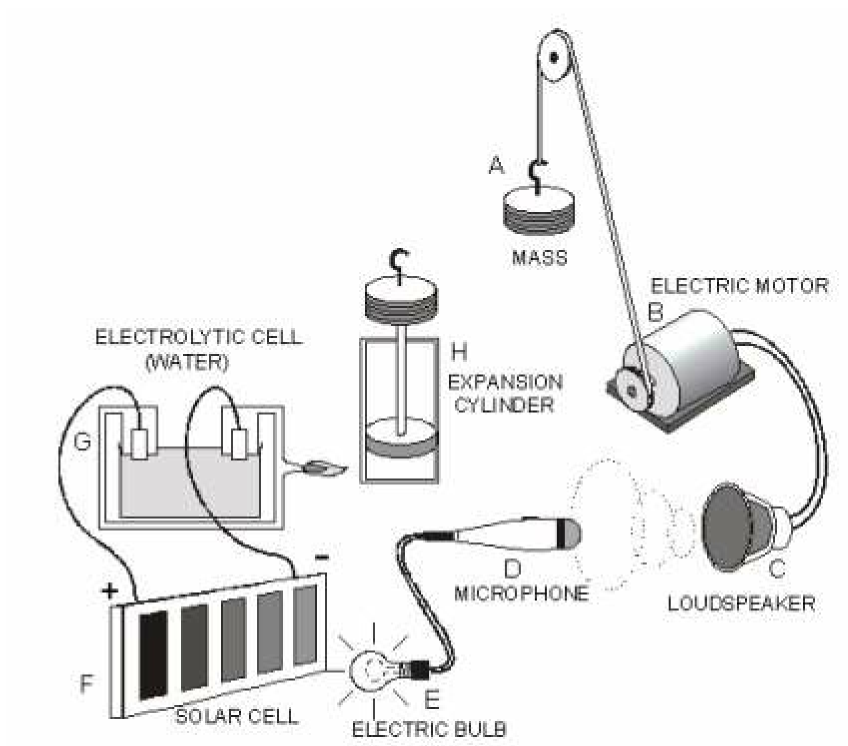
A hydroelectric power station is shown below as a diagram.



1. State the form of energy at each of the points A, B, C and D.
2. Complete the following statement to describe, using appropriate terminology, the energy changes that take place between stages A and D.

   "At A the water has ………. Energy, but as the water flows down the penstock the energy…"

3. Identify the form of energy at each of the points A-H indicated in the diagram below.
4. Describe the energy changes that take place in the system.



Energy “losses” during transformations

Although we have stated that energy cannot be destroyed and that the energy output from a system is equal to the energy input to the system, not all the energy in the system is used efficiently.

When an energy conversion takes place there is always an energy change that we do not desire - usually a loss in the form of heat, sound or friction from the moving parts of a mechanism.

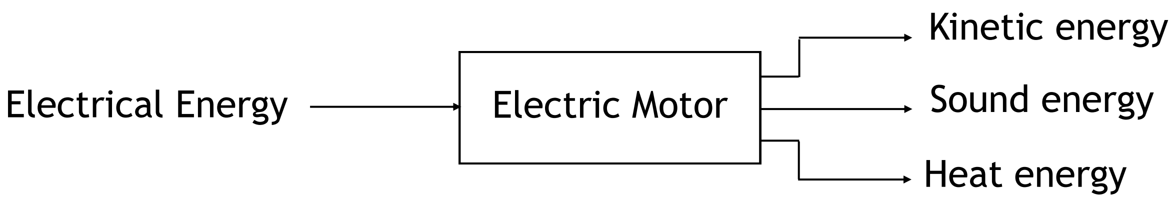
If we look at the simple energy conversions from earlier we can expand the system diagrams to also show the waste energy or energy losses.

Example 1

A light bulb converts electrical energy into light energy.

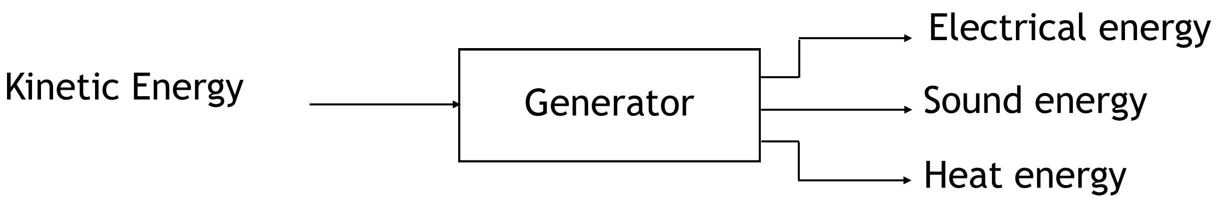
Example 2

An electric motor converts Electrical energy into kinetic energy or movement.



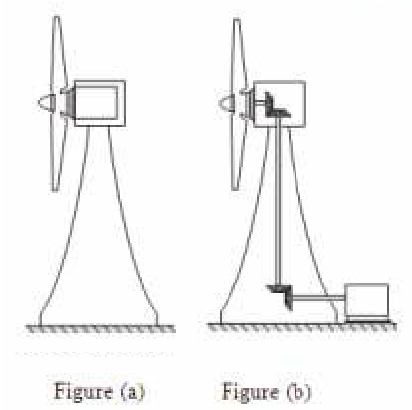
Example 3

An electric generator converts kinetic energy into electrical energy.

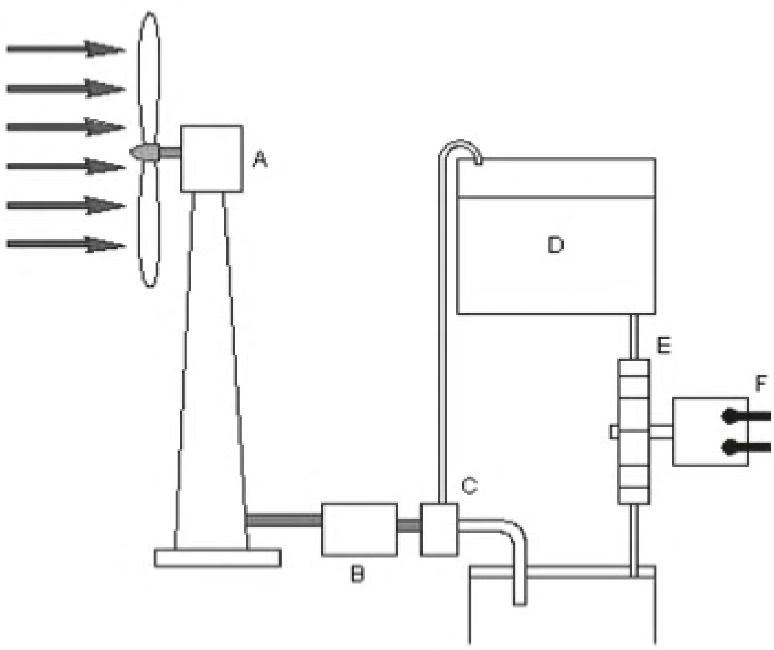


Assignment 19: Energy losses in a system

A wind turbine used for generating electricity can have the generator in either of two positions. It can be as shown in figure (a), located at the top and connected directly to the rotating vanes. Alternatively, it can be at ground level, connected by shafts and gears to the rotating vanes, as shown in figure (b).



1. List the energy conversions that take place when a wind turbine is operating.
2. The system shown in figure (b) does not produce as much electricity as the system in figure (a). Describe any energy losses in the system.
3. The diagram below shows a method of using the energy from wind.
   (a) Identify the forms of energy at points A (wind vane), B (generator), C (pump), D (water tank), E (water wheel) and F (generator).
   (b) Describe the energy changes taking place within the system.
   (c) Identify and describe any energy losses within the system at points A, B, C, D, E and F.



Homework Assignment 3: Transfer of Energy

1. Look at the three drawing below and draw a simple systems diagram for each to show the change in energy between the input and the output.

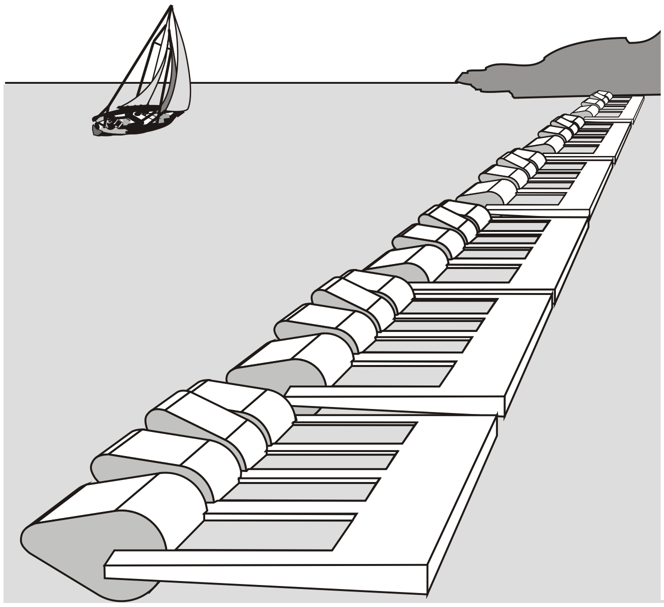
   In each system diagram you should also show any other form of energy produced at the output that may not be required but is actually present.

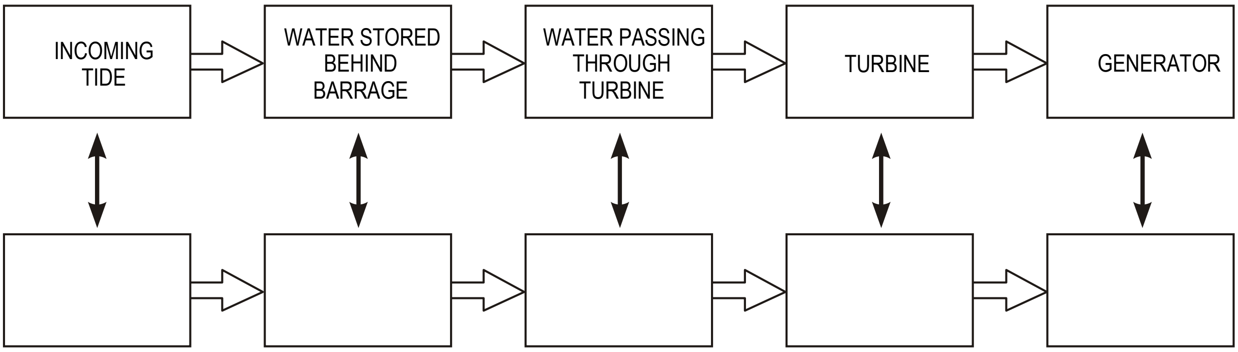
   (a)

   (b)

   (c)

2. A wave barrage (like the one shown below) can be used with a turbine and generator to produce electrical energy. Copy and complete the block diagram, showing the changes in energy throughout the system.



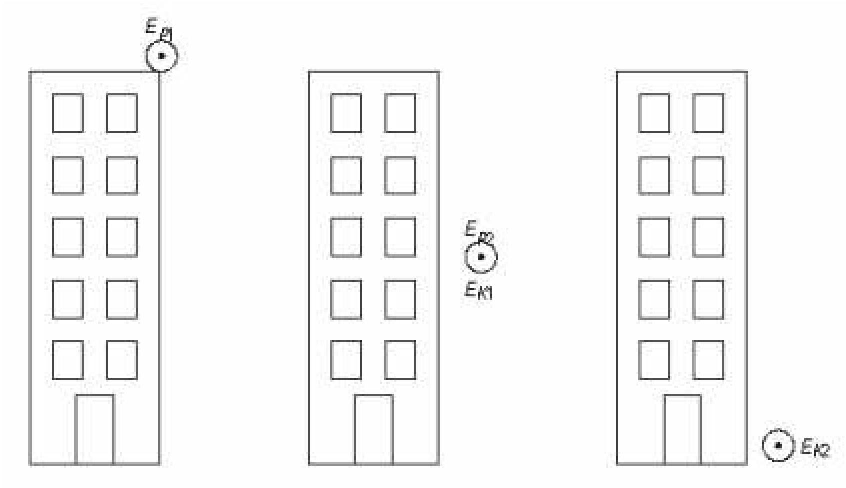


Calculating Energy Transfers

It has already been stated that energy cannot be created or destroyed: it can only be made to change form. During an energy transformation, therefore, the total energy contained within any *closed system* must remain constant. Knowing the total amount of energy at the start (or end) of any energy transformation tells us the total energy at any given time during the transformation.

Example: Energy Transfer

Consider a ball that is released from a high building.



When the ball is at the top of the building, it has gravitational potential energy (E_{P1}).

$$\text{The total energy, } E = E_{P1}$$

When the ball is released, it falls and some of the potential energy (E_{P2}) is converted into kinetic energy E_{K1}. The total amount of energy (E) the ball possesses at this time is equal to the potential energy plus the kinetic energy.

$$\text{Total energy } E = (E_{P2} + E_{K1}) = E_{P1}$$

Just as the ball hits the ground, it no longer has any potential energy; all the potential energy E_{P1} has been converted into kinetic energy E_{K2}. The total amount of energy consists of the kinetic energy alone.

$$\text{Total energy } E = E_{K2} = (E_{P2} + E_{K1}) = E_{P1}$$

Worked Example: transfer of Energy (Potential to Kinetic)

A body of mass 30kg falls freely from a height of 20 metres. Find its final velocity and kinetic energy at impact.

First calculate the initial potential energy.

$$E_P = mgh$$
$$E_P = 30 \times 9.81 \times 20$$
$$E_P = 5.88\ kJ$$

This potential energy is converted or transferred into kinetic energy, which means that the kinetic energy at impact is equal to 5.88kJ.

To calculate the final velocity of the body we begin by taking E_K = 5.88kJ.

$$E_K = \frac{1}{2}mv^2$$
$$5.88 \times 10^3 = \frac{1}{2} \times 30 \times v^2$$
$$v^2 = 392.4$$
$$v = 19.8m / s$$

This type of calculation can be completed for any type of energy conversion: knowing the total energy at any given time (start, end, middle, etc.) tells us the total amount of energy at all other given times.

Assignment 20: Calculating the Transfer of Energy

1. A 5kg mass is raised steadily through a height of 2m. What work is done and what is the body's potential energy relative to the start?
2. A body of mass 30kg is projected vertically upwards with an initial velocity of 20m/s. What is the initial kinetic energy of the body and to what height will it rise?
3. A mass of 20kg is allowed to fall freely from a certain height above a datum. When the body is 16m above the datum, it possesses a total energy of 3,531J. What is the starting height of the object?
4. In a stamping machine, the die has a mass of 35kg and falls through a height of 2m on to a metal block. If the depth of indentation is 10mm, find the average stamping force. Assume no rebound.
5. A boy stands on a skateboard at the top of a steep hill that has a height of 500m and allows gravity to increase his speed all the way to the bottom of the hill. If the boy has a mass of 60kg, calculate his potential and kinetic energy at the top, middle and bottom of the hill. (Ignore friction or any other resistance.)
6. An electric kettle takes 5 minutes to boil some water. The original temperature of the water is 20°C and the kettle contains 2 litres of water. Calculate how much electrical current is used by the kettle from a 230 volt mains supply. (The specific heat capacity of water is 4190J/kgK.)

Homework Assignment 4: Calculating Energy Transfers

1. A woman bungee jumper jumps from the top of a bridge with a height of 75m. The length of the bungee elastic is 25m and the woman has a mass of 60kg.
   (a) Calculate the potential energy of the woman as she stands on top of the bridge.
   (b) Calculate the maximum speed that the woman reaches and state at what height this will happen.
2. An electric kettle is used to boil some water. The kettle holds 1.5 litres of water when full and operates from a 230V, 13 amp supply. If all the electrical energy supplied is converted to heat energy, how long will it take the kettle to boil from an initial temperature of 15°C? (The specific heat capacity of water is 4190J/kgK.)
3. A goalkeeper kicks the ball out of his hands straight up into the air. The ball reaches a maximum height of 30m.
   (a) Calculate how much kinetic energy the keeper gives the ball if it has a mass of 2kg.
   (b) Calculate at what speed the ball leaves the goalkeeper's foot.
4. A motor and gearbox system is used to raise a load from the ground to the roof of a building site. The load weighs 100kg and the motor runs from a 110 volt supply and draws a current of 15 amps. If the roof is 25m above the ground, calculate:
   (a) The potential energy of the load when it has been raised
   (b) The amount of electrical energy used in that time
   (c) The time taken to raise the load
   (d) The average speed at which the load is being raised
   (e) The kinetic energy of the load when it is being raised.

Energy Efficiency

It was stated earlier that it was very important to try and conserve energy and to waste as little as possible. It is possible to look at how well an energy system is operating by calculating the efficiency of the system.

Calculating Efficiency

The efficiency of an energy transformation is a measure of how much of the input energy appears as useful output energy. The efficiency of any system can be calculated using the equation:

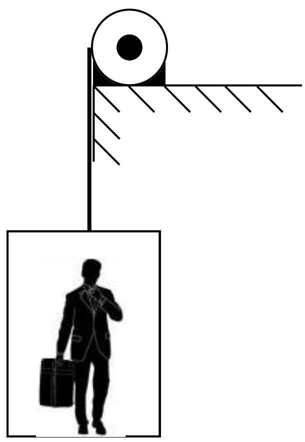
$$\text{Efficiency, } \eta = \frac{\text{Useful energy output}}{\text{Total energy input}}$$

$$\eta = \frac{E_{out}}{E_{in}}$$

Note: η is the ratio of output to input energy. This can never be greater than one. In order to convert η to a percentage, the efficiency, η, is multiplied by 100.

Worked example: Efficiency

An electric lift rated at 110V, 30A raises a 700kg load to a height of 20m in two minutes. By considering the electrical energy input and the potential energy gained by the mass, determine the percentage efficiency of this energy transformation.



Energy into the system is electrical:

$$E_e = ItV$$
$$E_e = 30 \times 120 \times 110$$
$$E_e = 396kJ$$

Potential energy gained is calculated as follows:

$$E_P = mgh$$
$$E_P = 700 \times 9.81 \times 20$$
$$E_P = 137.3kJ$$

Percentage Efficiency

$$= \frac{E_{output}}{E_{input}} \times 100\%$$
$$= \frac{137.3}{396} \times 100\%$$
$$= 34.7\%$$

Assignment 21: Efficiency

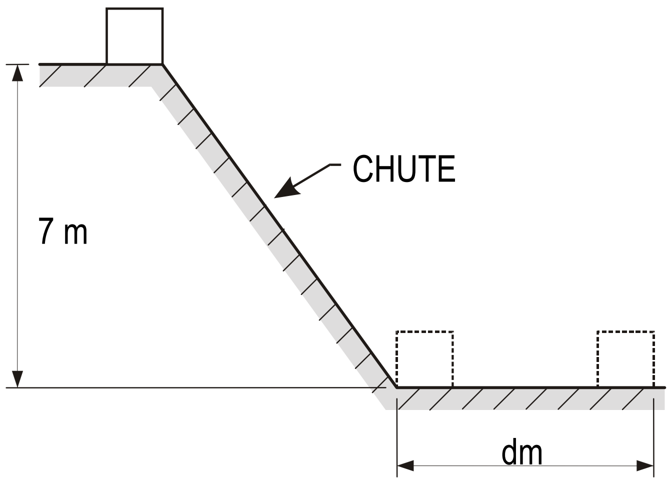
1. An electric kettle is rated at 240V, 10A. When switched on it takes three minutes to raise the temperature of 0.5kg of water from 20°C to 100°C. Determine:
   (a) The electrical energy supplied in the three minutes
   (b) The heat energy required to raise the temperature of the water
   (c) The efficiency of the kettle.

2. In a hydroelectric electricity generating station, water is allowed to flow downhill through a turbine, which is connected to a generator. The water falls through a vertical height of 500m at a rate of 5,000kg/s. If the energy transfer is 65 per cent efficient, determine the amount of electrical energy produced per second.

3. Boxes in a factory are transferred from one floor to another using a chute system as shown below. The boxes start from rest at the top of the chute and during the decent there is a 40 per cent loss of energy. The boxes weigh 10kg each.

   (a) Calculate the velocity of the boxes at the bottom of the chute.

   (b) What is the distance *d* that each box will travel along the bottom floor before coming to rest if the frictional force opposing the motion of each package is 25 per cent of its weight?

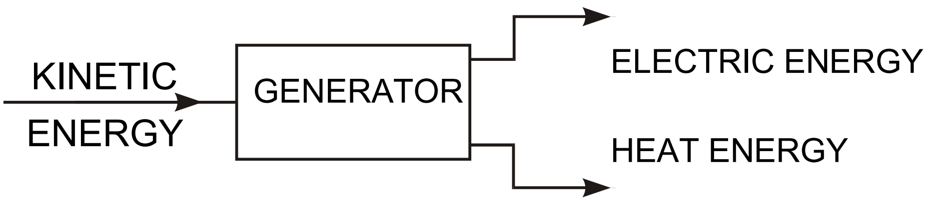


Energy Audits

It has already been stated that energy cannot be created or destroyed: it can only be made to change form.

During an energy transformation, all the energy going IN to the system must come OUT and appear as other forms. It is not possible to *destroy* energy: it must go somewhere!

Unfortunately, not all of the energy being put into a system appears as *useful* energy at the output. For example, a generator is designed to convert kinetic energy into electrical energy; however, due to the frictional forces, some heat energy will also be produced.



Since this heat energy is *useless* in terms of generating electricity, it is sometimes referred to as *waste* energy or (confusingly) as *lost* energy.

Even systems that are designed to produce heat will have some energy losses. For example, the element of a kettle is designed to heat up water, but not all of the energy will go into heating up the water. Some of the energy is used to heat up the kettle; some heat will be "lost" into the room, etc.

Since we know, however, that the total energy in any closed system must be constant, we can still carry out meaningful calculations if we remember to take all types of input and output energy into account.

In the generator example above:

- The input energy is in the form of kinetic energy (E_K)
- The total output energy will be electrical energy plus the heat energy ($E_e + E_h$).

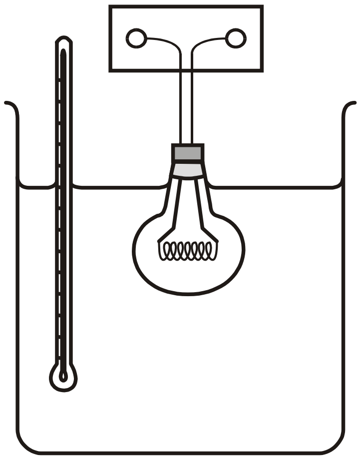
Hence, through conservation of energy, $E_K = E_e + E_h$

In order to ensure that we have taken all energies into account, it is useful to carry out an energy audit.

An energy audit is a list of all the energies coming IN and going OUT of a system. The total for the energies IN must be the same as the total for the energies OUT.

Worked Example

In order to estimate the efficiency of an electric light bulb, the bulb is immersed into a beaker of water as shown.



Assuming all the heat energy generated by the bulb is transferred to the water, use the data provided to calculate the efficiency of the light bulb as a light energy producer. Calculate also the amount of waste energy.

Data	Power supply = 12V
	Current drawn by bulb = 5A
	Volume of water in beaker = 0.5 litres
	Initial temperature of water = 18°C
	Temperature of water after 10 minutes = 30°C

Energy IN to the system is electrical energy (E_e)

$$E_e = ItV$$
$$E_e = 5 \times 600 \times 12$$
$$E_e = 36000J$$
$$E_e = 36kJ$$

Energy OUT of the system is light (E_l) and heat (E_h)

$$E_h = mc\Delta T$$
$$E_h = 0.5 \times 4190 \times 12$$
$$E_h = 25140J$$
$$E_h = 25.1kJ$$

Energy OUT = Energy IN

Energy IN = 36kJ

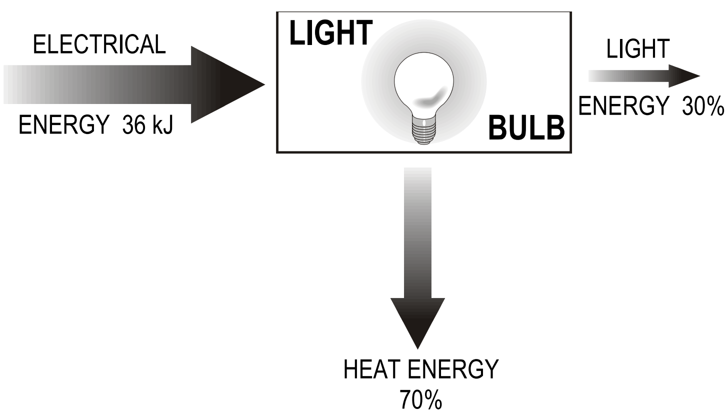
Energy OUT = E_h + E_l = 25.1kJ + E_l

Therefore 25.1 + E_l = 36kJ

E_l =10.9kJ

$$Efficiency = \frac{EnergyOUT}{EnergyIN}$$
$$Efficiency = \frac{10.9}{36} \times 100\%$$
$$Efficiency = 30\%$$

Waste energy (heat energy) 70% of input =25.1kJ. This can be represented by a systems diagram.



Assignment 22: Energy Audits

1. A deep fat fryer uses 2kJ of electrical energy per second. It can raise the temperature of 1.5kg of cooking oil from 20°C to 80°C in six minutes. If the specific heat capacity of the oil is 2400 J/kgK, calculate the heat energy taken in by the oil every second and hence the efficiency of the fryer.
2. When full, a container of water holds 1.5 litres of water. The initial temperature of the cold water is 20°C. a heater that operates from a 240V supply draws a current of 8A and has an efficiency of 75 per cent. Determine how long it will take to heat the container of water to 90°C.
3. A lift is used to raise a mass of 200kg to a height of 10m in two minutes. If the lift motor produces 12MJ of energy in one hour, how efficient is the lift?
4. A vending machine, which dispenses hot drinks, heats one cupful of water (0.15kg) from 30°C to 90°C. The heating element operates from a 240 volt supply and has a resistance of 12 ohms.
   (a) Calculate the current drawn by the heating element.
   (b) Calculate the heat energy transferred to the water.
   (c) Calculate the time taken to heat the water if the system is 100 per cent efficient.
   (d) Calculate the percentage of energy lost if it actually takes 10 seconds to heat the water.
   (e) Draw a system diagram showing the input to and outputs from the system. Include the percentages.