How do we measure energy?

What is energy?

Energy is the ability to push or pull a certain distance against a force. The Earth's gravity pulls down on an object like an apple, so to lift an apple away from the Earth requires energy. We measure energy in joules. To lift an apple a metre off the ground requires one joule of energy. This unit was named after James Joule who noticed that when you do work on an object, like squeezing the air inside a bicycle pump to pump up your bike tyres, a certain amount of heat was produced. This helped us to realise that energy could not be created or destroyed, only changed from one form into another.

When we say we "use" electricity, we aren't using up energy, just transferring it to the surroundings in different forms. When you turn on a light bulb, the energy is converted in the light bulb to heat and light and is spread out from there. It's a bit quicker to say "use" though.

There are a number of forms you might find energy in. Food and fuels contain energy in the chemicals that make them up that allow us to live and our cars to move. A moving object like a car has kinetic energy and will also release heat and sound energy as it moves. Some "hybrid" cars have the ability to convert kinetic energy into electrical energy for use at another time instead of burning up fuel. A burning flame is releasing the chemical potential energy in a fuel to the surroundings not only as heat but as light. The energy stored within a fuel is released by rearranging the atoms to make new chemicals but energy can also be released by changing the makeup of atoms themselves and we call this nuclear potential energy.

To generate electricity, we need to find an energy source where there is lots of energy concentrated in one place. We can then convert that energy to electrical energy for use by people all over the country.

How much electrical energy do we use?

The average demand on the UK's power grid is around 40 GW. GW stands for giga watt which is a billion watts. You might see items around the house which are rated in watts. A typical energy efficient light bulb might be marked "10 W" which means that every second it releases 10 J of energy into your room. An old style filament light bulb might be marked 60 W but not be 6 times brighter because filament light bulbs release more energy as heat which isn't what we turned on our light bulb for!

If you left on a 10W light bulb for 24 hours, you would release 864,000 J of energy, you'd need about the same amount of energy to lift a London bus by a metre six times!

Although this figure varies through the year, on average a person in the UK uses about 55 MJ (megajoules or millions of joules) of electrical energy every single day. Enough to lift a London bus above the top of the Shard – the tallest building in London!

Filling the "Energy Gap"

We take our electricity for granted in the UK but imagine what it would be like to live not knowing if when you flick that switch a light will come on? If we don't make sure we have enough capacity to generate electricity in the future then power cuts could become more frequent.

How much energy do we need now?

Although our average demand on the National Grid which distributes our electricity is 40 GW, we can currently produce about 85 GW which is good because we don't all spread out our energy use evenly throughout the day. At peak times, we need over 50 GW and this value can change very quickly too. When this happens we call it a "pickup". The largest pickup ever recorded here was immediately after the penalty shoot out of the 1990 World Cup Final against West Germany. As the footballer Gazza cried, fans who had been glued to the TV got up and did other things causing an immediate surge of nearly 3 GW, the equivalent of 1,120,000 kettles all being boiled at the same time!

Will this amount remain constant?

Energy demands have risen in the recent past but thanks to more energy efficient technology, our demand for electricity is stabilising and is likely to remain reasonably constant or even drop slightly in the next few years before rising as more people start to use electric vehicles and electric-powered "heat pumps" to heat their houses from 2020 onwards.

So what's the problem?

The problem we have is that many UK power stations are planning to close. Either they have come to the end of their useful life or we can no longer use the fuel that they run on. You will find out about these reasons on some of the other posters. If we don't have the right mix of energy sources, we could find people asking too much of the system, resulting in power shortages.

Choosing the right energy mix

What do we have to think about when choosing where we want to get our energy from?

Security of supply

As a resource runs low its price will increase. If we rely too much on other countries to supply our energy resources then natural disasters or political disturbances could stop us getting as much fuel as we need, or make it very expensive.

Predictability

Some sources of energy like solar or wind only work when the sun is shining or the wind is blowing so we couldn't rely totally on them.

Affordability

If the source of energy is too expensive to use, many people will find it difficult to afford to live comfortably and pay their energy bills.

Cleanliness

Many sources of energy we currently use release large amounts of pollution into the atmosphere. Burning fossil fuels like coal, oil and gas releases

- carbon dioxide (CO_2) which increases the warming effect of our atmosphere,
- sulphur dioxide which causes acid rain
- oxides of nitrogen which cause acid rain and help to form other toxic chemicals like ozone

Other sources of energy use toxic chemicals or release lots of pollution when we build the power station to use them.

Nuclear

Energy changes:

NUCLEAR POTENTIAL ENERGY ⇨ HEAT ENERGY ⇨ KINETIC ENERGY ⇨ ELECTRICAL ENERGY

What is Fission?

All the stuff you can see around you is made up of tiny particles called atoms. Atoms themselves consist of an even tinier central nucleus surrounded by electrons. Some atoms are small like helium; other atoms are bigger like gold. The largest naturally occurring atom is in an element called uranium. In its most common form it's 238 times heavier than the lightest atom (hydrogen) and when scientists tried firing subatomic particles called neutrons at it, they found rather than making a larger atom as they expected, it split into two in a process they called fission and released a lot of energy. In a nuclear reactor, we capture this heat and use it to generate electricity.

How does it work?

When one form of uranium splits it fires out more high energy neutrons that can smash into nearby atoms splitting them which releases *even more* neutrons. We call this a chain reaction. We can control the speed of this reaction use it to heat water. The hot water produces steam which spins turbines. The kinetic energy in the spinning turbines is used to drive generators which produce electricity.

What's good about nuclear power?

Nuclear has a lot going for it. From just one kilogram of nuclear fuel, we can get about 24,000,000,000,000 J which is the same energy as we can get from 180 tankers of oil. In terms of atmospheric pollution, it's a very clean fuel – producing less CO_2 per joule of energy produced than many other energy sources including hydroelectric and wind. Nuclear is also very safe, resulting in very few deaths for the amount of energy it produces – much less than almost any other energy source including even wind power!

Although nuclear fuel is not "renewable" as such, we do have enough to keep us going for a long time and we have the technology to build reactors that can use low-grade fuels that well effectively never run out.

What's not so good about nuclear power?

Nuclear power stations do produce nuclear waste, of which only a small amount is "high level" waste that has to be stored safely to stop people from being harmed by it for up to 1000 years. This amounts to 25 ml of waste per person in the UK – the same person on average throws out over 80 kg of hazardous waste in their bins each year. New nuclear technologies can reduce this problem still further.

Accidents do happen but are extremely rare, you may have heard of the incident at Chernobyl in 1986 or more recently at Fukushima in Japan last year but for all the news attention – no-one was directly killed by radiation at Fukushima in Japan and around 50 were killed directly at Chernobyl. Compare this with the 50,000 people who have died in China in the last decade mining coal.

Although nuclear is good as a "base load" power supply meaning it can constantly run without interruption, it's not so good at changing the level of output quickly to meet supply so we couldn't rely totally on nuclear. It's also fairly expensive to build new nuclear power plants although they do generate a lot of energy over their lifetime to compensate for this.

Coal

Energy changes:

CHEMICAL POTENTIAL ENERGY ⇨ HEAT ENERGY ⇨ KINETIC ENERGY ⇨ ELECTRICAL ENERGY

How is it formed?

Coal is a black or brown/black solid mostly consisting of carbon that formed from prehistoric trees that grew in low-lying wetland areas. These trees absorbed energy from the Sun and through photosynthesis stored this as chemical potential energy. When they died, layers of mud were laid down on them (probably during floods) that prevented microbes from getting the oxygen they would need to decompose the wood. As more mud was laid down on the tree material, the pressure on it increased and over millions of years of heat and pressure, the material changed into coal in a process known as carbonization. This is why it is called a “fossil fuel”

How does it work?

The coal is ground down and blown into a boiler where it is burned converting its chemical potential energy to heat energy. This heats water in pipes turning it to steam which drives turbines. This kinetic energy is converted in the generators to electrical energy.

What’s good about coal power?

Coal generates more electricity than any other source on the planet at the moment. Over 40% of world’s electricity is generated by it and it’s relatively cheap to build coal-fired power stations. It’s one of the most abundant fossil fuels on the planet but it is not renewable and current estimates are that it will run out in the 2120s. Another good thing is that the world’s supply of coal is reasonably well spread out and there are large amounts in countries with stable governments. We still have plenty of coal in the UK. Another big advantage of coal is, like other fossil fuel powered stations, we can relatively easily turn the supply on or off to help adjust the amount of energy supplied to meet the demands of the country.

What’s not so good about coal power?

Coal’s big problem is that it’s a very dirty fuel to burn. As well as producing lots of CO_2, it also produces oxides of sulphur and nitrogen which are harmful to humans and cause acid rain. Although there is a good mix of coal from around the world, we do currently rely heavily on one country for most of it. In 2009 more than half our imported coal came from Russia. Coal can be more dangerous to get at than other fuel sources too. Although safety there is improving, last decade alone over 50,000 people died in China in coal-mining accidents.

What does the future hold for coal power?

We can’t build any more coal-fired power stations in the UK without breaking agreements we have made to lower the amount of CO_2 we are releasing in to the atmosphere but there might be another way which is called Carbon Capture and Storage (CCS). CCS removes CO_2 from the gases leaving the boiler, compresses it and buries it deep underground but this needs some of the energy the plant was making. The more we trap, the more expensive it will be. CCS is a relatively new, unproven technology but In Norway they have been storing CO_2 under the North Sea and there is no evidence that any is leaking out yet. Another issue with CCS is that it won’t stop all the CO_2 getting into the atmosphere. Also other gases like methane and carbon monoxide are released from the mines and the rocks that are left behind from the extraction process so there’s no way we can stop all the greenhouse gases being released with this technology.

Solar

Energy changes:
LIGHT ENERGY ⇨ ELECTRICAL ENERGY

How does it work?
Nuclear reactions in the Sun release light and heat energy in a process known as fusion. Around 1366 J of this energy arrives over every square metre of the top of the Earth's atmosphere every second and solar panels capture some of this energy for us.

Photovoltaic (PV) panels capture the light and convert it directly into electricity. PVs contain a type of material called a semiconductor. Semiconductors are neither particularly good at conducting electricity nor are they good insulators. We can tune the properties of a semiconductor to our needs by adding a small amount of other chemicals which we call "doping". When light falls on a PV panel, the electrons (tiny particles within the atoms that make it up) can become excited by this energy allowing them to move and carry an electric current.

What's so good about solar power?
One of the best things about solar is that during use it is effectively pollution free and there is a plentiful supply of energy from the Sun for us to use. Compared to other renewables it has a high amount of energy released for the amount of area your generator takes up. Once a solar cell is running, as it has no moving parts it requires very little maintenance and will keep running for a long time.

What's not so good about solar power?
Firstly, the time when Solar can produce the most power for us (during the summer) is when we need it the least! Unlike countries near the equator, we do not point directly at the Sun, even at midday the Sun is not directly overhead, especially not in the winter and of course it's not light all the time. Even when it's day time, clouds usually get in the way so on average we only get around 10% of the energy that arrives at the top of the atmosphere.

Chemists are doing lots of research into photovoltaics to make them more efficient, cheaper and out of more environmentally friendly materials but they are still relatively expensive and energy intensive to produce and a number poisonous chemicals and of heavy metals like cadmium and arsenic are used in their production. Setting up a good recycling and disposal scheme should reduce the effect these chemicals could have if not properly disposed of.

What does the future hold for solar power?
Not all solar power has to be using panels. Some companies are investigating ways of using mirrors to concentrate the Sun's power onto a tank of material which when heated can be stored and later used to form steam and drive turbines in the traditional way.

Prices will continue to fall as scientists find new ways of making solar panels with less materials or using technologies like organic cells which use dyes to capture sunlight, carbon nanotechnology and even solar cells made out of plastic. New battery technologies and "smart chargers" that take electricity when it is cheapest will help us store solar energy in electric cars for use at other times.

Wind

Energy changes:
KINETIC ENERGY ⇨ ELECTRICAL ENERGY

How does it work?
The UK is the windiest country in Europe so all we need to do is put up a windmill. Sensors inside will detect the direction of the wind and angle the rotors the right way so that they spin and drive a generator. They can also brake the rotors to prevent them from being damaged by spinning too fast.

What's so good about wind power?
We have a lot of wind in the UK and it will never run out. Onshore wind farms produce energy at a cost very similar to traditional energy sources and produce little CO_2. The only CO_2 associated with wind farms is in their production, installation and maintenance. When the wind is blowing, we can drop the output from our other power stations (usually fossil fuel-powered) and reduce the amount of CO_2 we release into the atmosphere. We currently have 3400 wind turbines spread over 300 sites with a capacity of up to 0.006 GW. It's not a lot compared to our peak supply needs (over 50 GW) but it's estimated to save us up to 6.4 million tonnes of CO_2 each year.

What's not so good about wind power?
The most obvious problem with the wind is that it's not always blowing! This presents problems for short-term storage (see the solar poster). We'd also need a lot of onshore turbines to get a significant amount of energy from wind power. To get around 50 GW of electricity we'd need to have the windiest 10% of the country entirely covered with turbines. This would be double all the windmills currently deployed all over the world. Getting planning permission for the ones we have is difficult enough as some people don't like the way they look.

What does the future hold for wind power?
To solve the issues we have with finding space for turbines without people finding them ugly to look at and to try and get more reliable, higher wind speeds we are looking at developing off-shore wind farms. We would be able to get a lot more energy from off-shore wind farms but building turbines out at sea is a lot more difficult and dangerous which will make the electricity they generate more expensive.

As well as short term storage solutions, we are also looking at ways that we can share our renewable energy resources with other European countries so that when it's windy here we could send a bit of energy abroad and they could send us some when it's windier there than here.

Natural Gas

Energy changes:

CHEMICAL POTENTIAL ENERGY ⇨ HEAT ENERGY ⇨ KINETIC ENERGY ⇨ ELECTRICAL ENERGY

How is it formed?

Natural gas is primarily formed in two ways. Some gas was formed from microscopic prehistoric creatures that lived in ancient seas millions of years ago. These creatures absorbed energy from the Sun and through photosynthesis stored this as chemical potential energy. When they died, they sank to the bottom of the sea where layers of mud were laid down on them that prevented microbes from getting the oxygen they would need to decompose them. As more mud was laid down, the pressure increased and over millions of years of heat and pressure, the creatures' remains changed into oil and natural gas.

The United Kingdom did very well out of the natural gas deposits under the North Sea in the latter parts of the 20th century. These were formed by the burial of algae and bacteria during the Jurassic period as sea levels rose over 150 million years ago.

The natural gas delivered to us would have virtually no smell making it difficult to detect potentially dangerous leaks if it were not for the butyl mercaptan we add. We are extremely sensitive to compounds like this and we can detect it in tiny quantities down to 0.000001% of the air! Mercaptans are a group of chemicals that are responsible for some of the nastiest smells around. The related compound *methyl* mercaptan is produced by bacteria in your mouth and is one of the compounds that cause bad breath. This is why people sometimes might say your breath is a bit "gassy"!

What's so good about natural gas?

At the moment, it's expected the amount of gas we need in our energy mix is going to increase in the next 15 years, much of which will be replacing older coal-powered stations that are closing down. Gas has similar advantages to coal. Like other fossil fuel-powered stations, we can relatively easily turn the supply on or off to help adjust the amount of energy supplied to meet the demands of the country. It has traditionally been a relatively cheap source of energy, helped by our secure supply of gas right on our doorstep in the North Sea. It's a much cleaner burning fuel than coal with lower CO_2 emissions but the greenhouse gas problem is still there.

What's not so good about natural gas?

We currently use a lot of natural gas from the North Sea but supplies have been falling for over 10 years now and to keep up our levels, we need to import gas from other countries. This leaves us vulnerable to supply problems and rapid changes in prices. In the last decade, disputes between Russia and the Ukraine have caused gas supplies to Europe to be disrupted. Meanwhile in the next few years we will be increasing the amount of gas in our energy mix.

As well as the carbon dioxide released through burning, leaks of natural gas are a problem too. The methane in natural gas is 25 times stronger a greenhouse gas than carbon dioxide. In the North Sea alone right now, a single leak from a gas platform is releasing 200,000 cubic metres of gas into the air every day. More than enough to fill St. Paul's Cathedral and if it takes them as long as they predict it will, this leak will have had the same impact on our climate as putting an extra 300,000 new cars on the road.

Hydro

Energy changes:

GRAVITATIONAL POTENTIAL ENERGY ⇨ KINETIC ENERGY ⇨ ELECTRICAL ENERGY

How does it work?

All hydroelectric power stations rely on water running from a high area to a low area. As it does so, the kinetic energy of the water can be used to drive turbines generating electricity.

We can drive turbines straight off a water wheel in a river but we can get lots more energy and control over the amount we produce by damming a high valley and allowing the water to run down as we need power. Pumping water up a slope during times when energy is cheap or in low demand is a way of storing energy for use at times of high demand. For example, this kind of storage would be good for storing energy produced during the day by solar panels for use at night. This kind of “pumped storage” can be used to address problems with rapidly changing demands placed on the National Grid. Dinorwig pumped storage facility in Snowdonia is the home of the largest man-made cavern in Europe with all the turbines buried under the mountain. It can deliver up to 1.7 GW and can be up to speed, if in standby, in less than 20 seconds – ready to deal with all those kettles going on when we finish watching our favourite TV shows or sporting events.

What’s so good about hydroelectric power?

Apart from its flexibility in varying supply, hydroelectric power is very secure and reliable – no-one can take our rainwater from us but prolonged drought could be a problem. Although expensive to build, hydroelectric plants have a very long life compared to other power sources and have low operating costs so overall they are not too expensive as an energy source. When running, they produce no pollution, the only carbon dioxide associated with them is in their production (Dinorwig alone needed 1 million tonnes of concrete) and destruction at the end of their life.

What’s not so good about hydroelectric power?

Apart from the large quantities of concrete, cement and steel required, the flooded land itself can be a source of pollution with methane being produced as organic matter decomposes and we also remove land area where trees could have been photosynthesising and absorbing carbon dioxide. These are small issues when compared with the long life cycle and amount of energy that we can produce though. Damming can have other impacts - because of the high land required, hydroelectric plants are often built in areas of great beauty. Much of the machinery and cables can be built under ground but some wilderness land will be lost as the reservoir is filled.

The biggest issue with hydroelectricity is that we can’t use more of it – we need the right mix of rivers and rapidly-changing landscape to build a plant. Currently only around 1.4% of our energy needs come from hydroelectricity and with most of the potential sites already being used, it’s unlikely hydroelectric will play a large part in our future energy mix.

Wave

Energy changes:

KINETIC ENERGY ⇨ ELECTRICAL ENERGY

How does it work?

As the Sun heats the surface of the Earth, some places heat up faster than others and this in turn causes changes in pressure. Air moves from high pressure areas, where there are more particles in a certain volume, to low pressure areas where there are slightly fewer. This moving air is the wind. As the wind passes over the surface of the ocean, friction between the air and the water picks up small waves which will continue to build as long as the wave moves slower than the wind – this is now helped by the fact that the air pressure on the upwind side will be greater than on the downwind side of the wave which is slightly sheltered.

Wave generators float on the surface of the water and bob up and down – they convert this motion to electricity in many different ways. One of the most successful designs at the moment is called the Pelamis Wave Energy Converter. This looks like a giant metal snake. As the snake bends in the water, pistons between the segments pump oil through hydraulic motors which drive generators.

What's so good about wave power?

In theory, we should have a good supply of wave power. To get big waves you need a lot of water and the waves will travel in the direction of the wind that produced them. As it happens, we are surrounded by sea and on the West coast we face the vast expanse of the Atlantic Ocean – the prevailing wind pushes waves towards us. Although we are partially blocked by Ireland from the best waves, we could in theory have 1000 km of wave generators lined up to absorb the energy in the waves with no carbon dioxide emissions except those associated with the building and maintenance of the generators.

What's not so good about wave power?

Although we've been designing wave generators for over a century, they are not used very much. We need the wind to be blowing in order to generate waves so the output can be unreliable, like wind power. The world's first "wave farm" used just three Pelamis off the coast of Portugal and could only generate around 0.001 GW of electricity at best. Following technical difficulties with the equipment and financial problems it was shut down just 2 months later. These wave machines produce a third of the power of a wind generator of the same weight. Despite this, plans were agreed to build the world's largest wave farm off the coast of Scotland 5 years ago using an improved version of the Pelamis - this project is still at the planning stage. Many other companies are making new designs and wave generators now come in all shapes and sizes!

Tidal

Energy changes:

GRAVITATIONAL POTENTIAL ENERGY ⇨ KINETIC ENERGY ⇨ ELECTRICAL ENERGY

How does it work?

The Moon orbits the Earth because it is trapped by Earth's gravity but the Moon has its own gravitational field too. As the Moon orbits around the Earth, the places closest to the Moon feel most strongly attracted whilst the places on the far side of the Earth which are further away feel less of a pull. This does distort the shape of the Earth ever so slightly but as liquids can change their shape much more easily than solids, the water appears to us to rise and fall. If there were no continents getting in the way, a rugby ball-shaped bulge of water pointing towards and away from the Moon would form and as the Earth spins on its axis much faster than the Moon goes around the Earth, we spin underneath this bulge of water. The Sun also contributes to the tides so we get an extra big tide when the Moon and Sun are in alignment.

We can't get energy from nowhere - energy must always be conserved – so what changes occur to move all this water? As the Earth spins, the bulge is always slightly pointing ahead of the Moon, this causes the Moon to act as a brake, pulling back on the bulge. Over time this causes the Earth to slow its rotation and the Moon to move slightly further away from us. The same effect is what caused the same face of the Moon to always be pointing at us; the Earth slowed its rotation down many years ago until it was spinning on its axis at the same rate at which it orbited us. It is this steady increase in the length of the day that means we occasionally add a "leap second" to keep our days in alignment with the Sun.

We can extract tidal power in a number of different ways. Tidal barrages and tidepools work in a similar way. We either build a pool in shallow water that we let fill up at high tide and then let the water flow out at low tide through turbines driving generators or we could do the same by building a barrage to block off an estuary or inlet. A classic example would be the Severn estuary nearby. A barrage from Western Super-Mare to Cardiff could generate up to 10 GW. Tidal stream generators are like wind turbines under the sea which spin as the tide moves through.

What's so good about tidal power?

Tidal is extremely predictable and will last for millions of years. While we're generating power, no CO_2 will be released and although an individual generator couldn't be run the whole time, they could be spread out as it takes a while for the tides to slosh around the top and bottom of the UK into the North Sea. Some energy could also be stored in tidepools. Water is much denser than air so can transfer kinetic energy more efficiently. This lets tidal stream generators provide more energy for the same size of propeller compared to a wind turbine. Tidal energy is low cost compared to its power output and being mostly under water, tidal generators will cause less issues with people complaining about ugly turbines out at sea. The conditions under water are less problematic for the turbines too – there would be no issues with wind storms causing damage as can happen with wind farms.

What's not so good about tidal power?

Tidal power is a relatively untested power source and there are environmental concerns over the construction of tidal barrages too as lots of concrete would be required in construction. The carbon dioxide emissions associated with its productions should be paid off in less than a year of a 120 year lifetime though. Groups like the RSPB strongly oppose the construction of a Severn Barrage as 85,000 birds feed in the inter-tidal area and there could be impacts on the movement of fish and other plant and animal life.