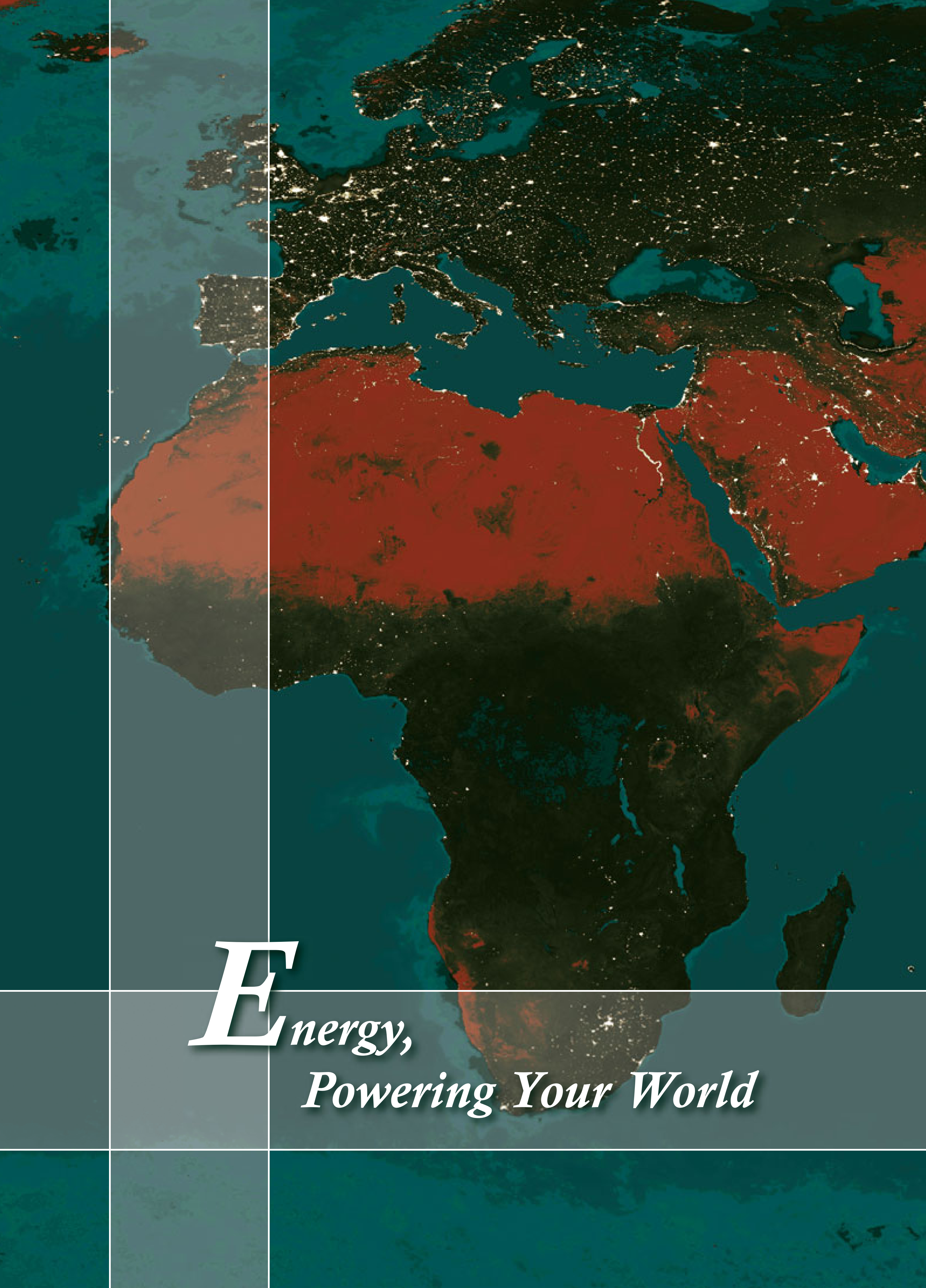
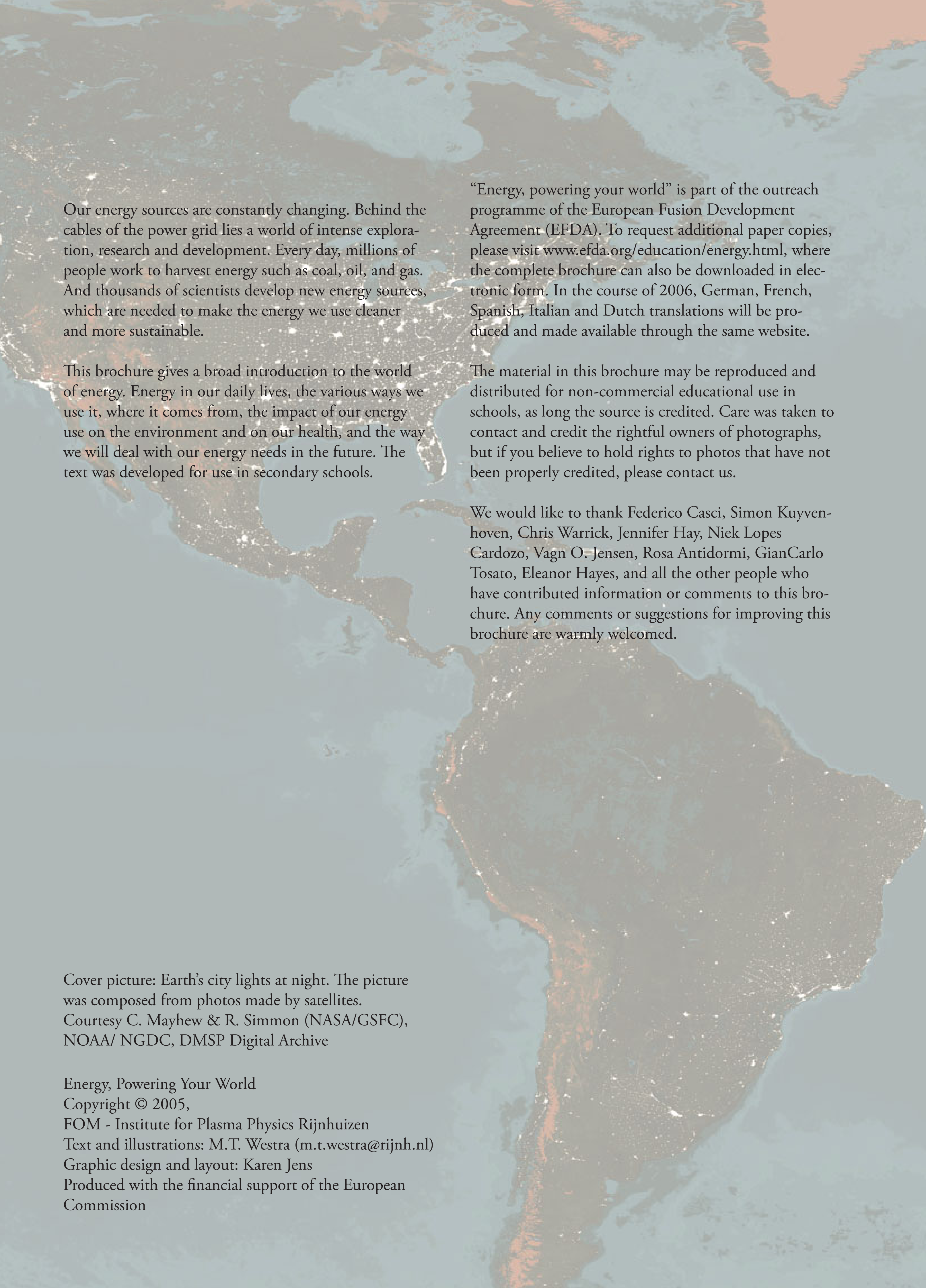


Energy, Powering Your World



Our energy sources are constantly changing. Behind the cables of the power grid lies a world of intense exploration, research and development. Every day, millions of people work to harvest energy such as coal, oil, and gas. And thousands of scientists develop new energy sources, which are needed to make the energy we use cleaner and more sustainable.

This brochure gives a broad introduction to the world of energy. Energy in our daily lives, the various ways we use it, where it comes from, the impact of our energy use on the environment and on our health, and the way we will deal with our energy needs in the future. The text was developed for use in secondary schools.

Cover picture: Earth's city lights at night. The picture was composed from photos made by satellites.
Courtesy C. Mayhew & R. Simmon (NASA/GSFC), NOAA/ NGDC, DMSP Digital Archive

Energy, Powering Your World

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Produced with the financial support of the European Commission

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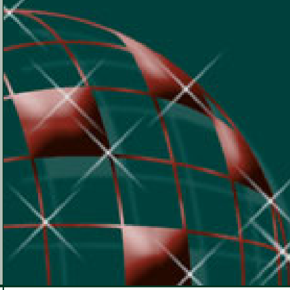
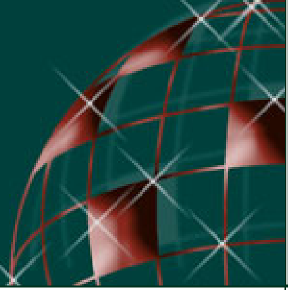


Contents



1 An introduction to energy

A number of energy services: clean water, cooking, hot water, music, industrial production, transportation, computing, light, telecommunication.

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Energy powers our world

Energy is so much part of our life, we hardly notice it. When we take a hot shower in the morning, we use energy. To wash we need soap and a towel made in factories that use energy. The bricks, concrete and windows of your room were made using energy. Our clothes and shoes were also made using energy. And that's just the start of the day.

Without energy, our lives would be a lot less comfortable. Imagine collecting your own firewood to keep warm and getting your own water at a well for cooking, walking everywhere on foot… And of course there would be no radio, no TV, no computers, no phones. Our society needs energy to keep it going.

And we need lots of it, too. To generate all the energy a person in the western world uses (including electricity, petrol for transportation, etc.) using muscle power only, we would need 100 people working for us, or about 10 strong horses. Every hour of the day, every day of the week. The power that flows through the wall socket in your house is as strong as many horses.

We take energy for granted. Only occasionally, in the case of a power-blackout, do we notice how dependent we have become - while we try to remember where we left the candles.

This booklet is about energy: where it comes from, how we use it, where our energy will come from in the future, and what the effects are on our environment, our health, and our society.

What is energy and why do we need it?

Energy appears in many forms, such as motion, heat, light, chemical bonds, and electricity. We say that energy is present in energy sources, like wood, wind, food, gas, coal, oil, and inside atomic nuclei. All these different forms of energy have one thing in common – we can use them to accomplish something we want. We use energy to set things in motion, to change temperatures, and to make light and sound. So we may say: *Energy is the ability to do useful work.*

Energy is important to us because we use it to do the things we need, which we call *energy services*. Among the energy services are cooling and refrigeration, space heating, food-processing, water-cleaning, using mobile phones, driving a car or motorbike, making light and sound, the manufacture of products, and many more. To get the energy services we want, we need energy in a useful form in the right place, at the right time.

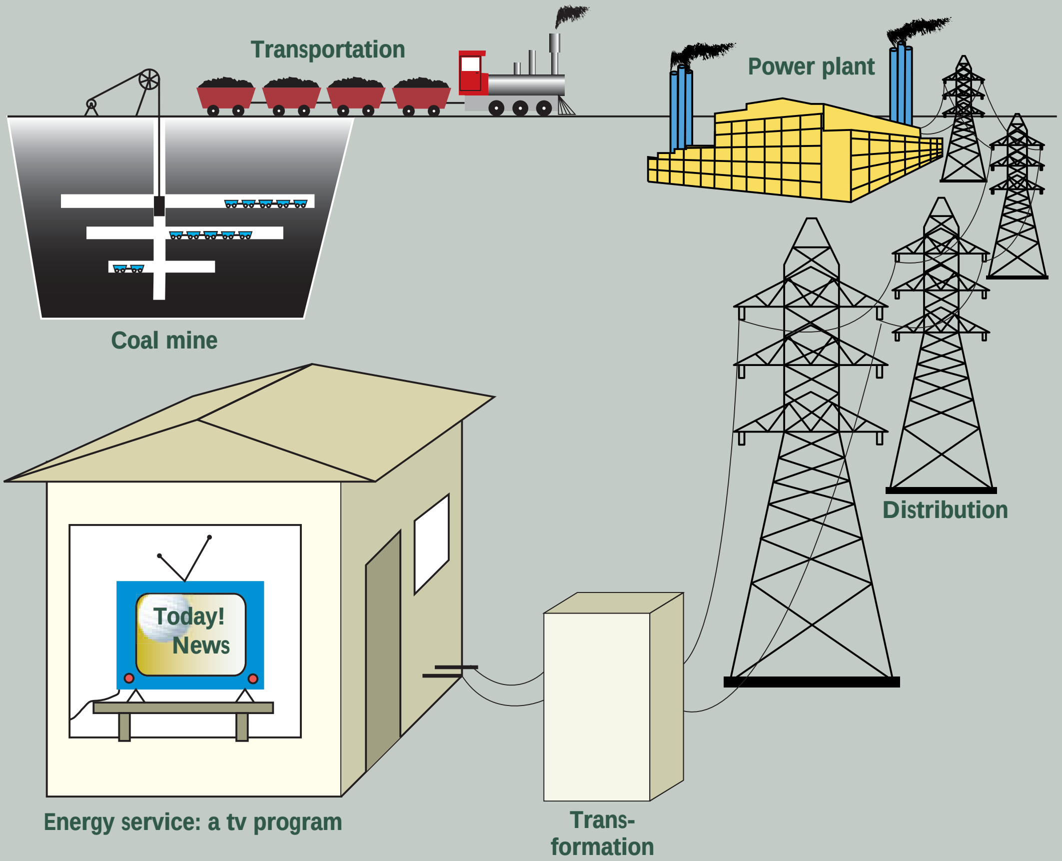
Where does energy come from?

Normally, we don't think very often about what happens beyond the wall socket or petrol station, as long as we can turn on the radio when we plug it in and petrol is available for the cars we use. But to get our appliances working, a long chain of technology is working to provide the energy.

The energy chain starts with the collection and extraction of energy in its primary form, such as oil, sunshine, wind, or coal. This so-called *primary energy* is not very useful at this stage: it needs to be converted into a form of energy that is easy to use. So the next step is to convert the primary energy into so-called *final energy*, such as electricity or petrol. An example of this step is the conversion of coal into electricity in a coal-fired power plant. It is the final energy that is distributed to the users.

Eventually, equipment like light bulbs, TV's, cookers and vehicles use the final energy to do something useful, and deliver the energy services. An example of an energy chain – beginning with the extraction of coal, and ending in a TV-program – is shown in the figure below.

Energy is at the basis of everything we do: almost all of our daily activities need fuel or electricity. To provide all the energy we use, we have coal mines, oil platforms, pipes, distribution of coal and oil over the earth by large ships, power plants, transmission lines, petrol stations, and much more. All together they form a complex system called the *energy system.*



An energy chain: from coal mine to tv-program.

2 A short history of energy

Many of the things in daily life that we really can't do without, like hot water, transportation and telecommunication, need energy. Through the ages mankind has often found new sources of energy and learned to use them to improve his well-being and comfort. The history of our energy use is a fascinating story with one clear trend: we use more and more.


© Bruno Girin / DHD photo gallery

Crossing the oceans using wind energy.

Ancient times

From archaeological evidence, we know that mankind learned to control fire more than 500,000 years ago, and possibly much earlier than that. In those prehistoric times, man's energy needs were still modest. The sun provided heat, and when there was no sun, people burnt wood, straw or dried dung. From drawings found in caves, we know that men and women in the Stone Age (about 30,000 years ago) used firewood for cooking food, heating and lighting their caves and huts. The names of the different historic periods – stone age, bronze age and iron age – derive from the ability of people to use energy to make metals and to manufacture tools and weapons.

Present day use of animal power in India.


© Ross Taylor (Images of the World)

A big change in the use of energy occurred when people decided to give up their nomadic life and settle down. They learned about agriculture, which is a way of turning the energy from the sun directly into food.

Another early source of energy, still used today, is animal power. Horses, oxen, camels, donkeys, elephants – their power can be used for transportation, farming, and to drive machines for grinding grain and pumping water. In the developing world, animal power is still used for many purposes like ploughing the field and for transportation.

Human power was used as well: Roman warships that were used in 260 B.C. were powered by 170 skilled rowers. And a fleet often consisted of a hundred of these ships!

As early as 5000 B.C., wind energy was used to propel ships along the River Nile, and several centuries before Christ, windmills were used in China to pump water. Around 600 A.D., windmills were used in Persia to grind grain.

Water power also has a long history. As early as 4000 B.C., water wheels were used in Greece to power small mills to grind corn, supply drinking water to villages, and drive a variety of machines such as saw mills, pumps, forge bellows, and so on.

One of the first uses of solar power had a military application: It is said that around 240 B.C., Archimedes used a large mirror to set Roman warships on fire during the attack of Syracuse.

Of the fossil fuels, coal has the longest and most varied history. People in China used coal as early as 3,000 years ago, and there is evidence that Romans in England used coal for cooking in 100-200 A.D. In 1298, the famous explorer and traveller Marco Polo published a book about his travels in China, in which he talks about “large black stones which ... burn away like charcoal.” Over the centuries, it has been one of our most important fuels.

Energy in the 1600s

When people in Europe discovered how useful coal was for heating, they quickly began to search for it, and they found it all around. By 1660, coal mining in England had become a booming business, and coal was exported around the world.

Although English cities became very polluted by the burning of large amounts of coal, the English tolerated it as they needed their wood for making charcoal and to build warships. Charcoal was needed in large quantities for iron smelting, and the processing of other metals.

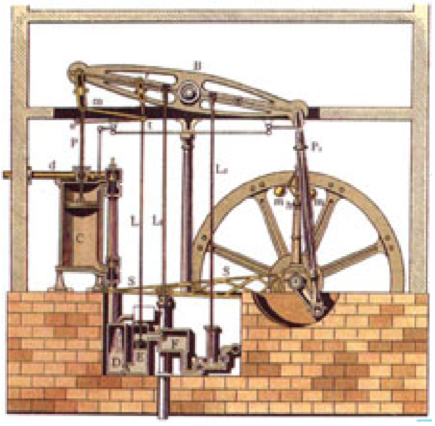
The first energy crisis in history started in 1630, when charcoal (which is made from wood) started running out. Coal from mines could not be used for metal smelting as it contained too much water and sulphur. The water in the coal caused it to burn at a lower temperature, and the sulphur made the iron too brittle. In response to the shortage, large parts of the woods in Sweden and Russia were felled to produce charcoal. In 1709, the ironmaster Abraham Darby (from the little village Coalbrookdale, in England) discovered a way to remove the sulphur from fossil coal by turning it into coke. He was the first to succeed in producing cast iron using coal.

Energy in the 1700s

By this time, most of Europe and especially England had cut down most of their forests. As they came to rely solely on coal for fuel, the demand for coal grew quickly. Another reason for the growing demand was the invention of the steam engine by Thomas Newcomen in 1712, which was used to pump groundwater out of deep coal mines. Previously the water in coal mines had to be hauled out by horse power using a bucket attached to a rope. James Watt improved the steam engine in 1765, so that it could not only be used to pump water, but also to drive other machines.

The importance of the steam engine was that for the first time, the energy released when fuel is burned (called *thermal energy*) could be turned into another form: mechanical energy. With this new invention, machines could be powered by coal, whereas before it was necessary to build a windmill or have falling water nearby. As there was plenty of coal available, it became much easier to power large numbers of machines.

In 1799, an Italian inventor named Alessandro Volta invented the *battery*, which gave the world its first steady supply of electric energy. Volta’s name is still used today: the wall socket in our homes supplies electricity at 230 or 110 Volt (or ‘V’, for short).



James Watt‘s steam engine (1765).

The discovery of electricity

The Greek philosopher Thales of Miletus, who lived 2500 years ago, is credited with discovering that a piece of amber rubbed with wool of fur attracts light objects such as pieces of dry leaves or bits of straw. The Greek world for amber is 'elektron', hence the modern word 'electricity'. Thales also observed that lodestone (natural stone with magnetic properties) attracts iron and other lodestones.

James Watt and the steam engine

A single steam engine could do the work of many horses. James Watt described his machines in terms of how many horses it could replace, so he would talk about a 20 horse-power machine, which could do the work of twenty horses. Watt worked out how much each company saved by using his machine rather than using a team of horses. The company then had to pay him one third of this figure every year, for the next twenty-five years.

Originally, one horsepower was defined by James Watt as the amount of energy needed to lift 33,000 pounds of weight over a distance of one foot in one minute (15,000 kg over a distance of 30 cm in one minute). In today's units one horsepower equals 746 Watt.

Energy in the 1800s: the age of the steam engine

In the 1800s the modern world really took off. A single steam engine at that time could provide the power of 200 men. All over England, factories powered by steam engines popped up producing textile, furniture, and many other things that up to then were all made by hand. Because of this mass production, more people could afford to buy these products, causing the markets to grow and the export to flourish. This period of enormous growth of industrial manufacture is called the *Industrial Revolution*, and it quickly spread to Western Europe and North America.

For the first time in history, energy could be used at any time, at any place, in any quantity. Before, factories depended on power from wind and water, which were certainly not available anywhere at any time. Energy slowly became to be seen as a resource that was available when and where it was needed.

A steam locomotive.

A girl discovering electricity.

© Brookhaven National Laboratory

In addition to powering factories, the steam engine was put to other uses. In 1804, the first steam locomotive was built, and in 1807 the first steam boat took to the water. At the same time, coal gas (gas that is released when coal is heated) was discovered, which was used to light factories, streets and homes. In 1807 the first coal gas lighting was installed in the streets of London, and by 1823 all the major cities in England had gas lighting.

During this age, the steam engine was improved and grew even more powerful. By the end of the 1800s, a single steam engine could provide as much power as 6000 men.

In the mid 1800s, the construction of small dams to generate electricity from hydro power began, and at the end of the 1800s, people experimented with generating electricity by windmills.

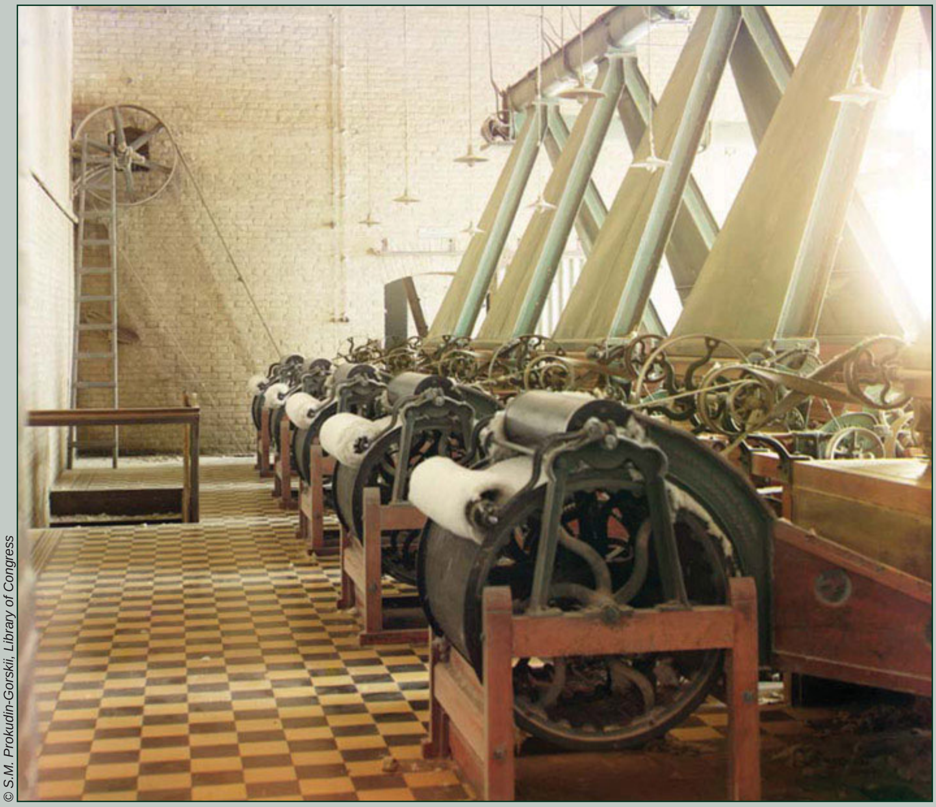
Solar power was first developed by the Frenchman Auguste Mouchout, in 1860. He used concentrated sunlight to make steam, which powered a small steam engine. In 1880, a coal-powered steam engine was attached to the world's first electric generator. The electricity plant of Thomas Alva Edison provided the first electric light to Wall Street and the New York Times.

In 1859, the first petroleum was pumped out of the ground in Pennsylvania in the USA. Previously the petroleum had been a nuisance, contaminating wells for drinking water. For a while it was sold as medicine, but people quickly realised its usefulness for heating and lighting. Be-

Steam power

In the 1800s, many factories sprang up that were powered by steam engines. A large central steam engine with a big flywheel delivered the power for a whole factory. This was accomplished by a system of leather belts, which went from the steam engine to all the machines. In the picture this driving belt is visible in the background.

A cotton mill powered by steam (1800s).



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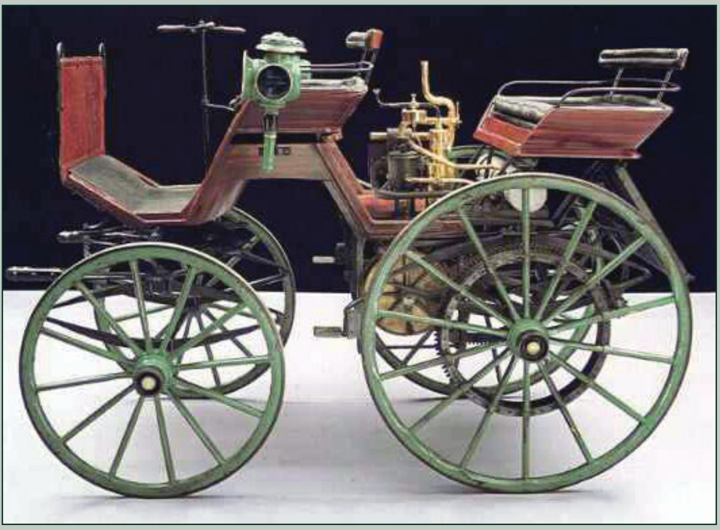
Thomas Edison's first electric lightbulb (1879).

© Charles Edison Fund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Gottlieb Daimler's first four-wheeled automobile (1886).

fore long, people learnt how to refine oil to make petrol and diesel oil, which were used to power a new invention: the combustion engine.

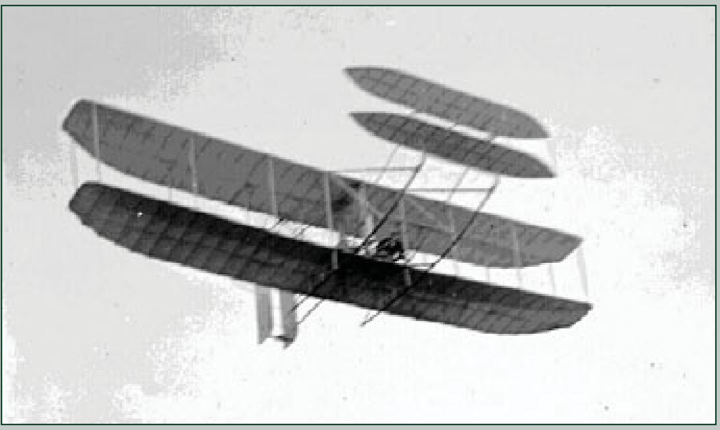
Energy in the 1900s: the age of the combustion engine

With the new fuel petrol available, the French inventor Etienne Lenoir invented the first practical "internal combustion engine" which used burning petrol to drive a piston in the engine. The German inventor Nikolaus August Otto made a better one 16 years later. In 1885, the German engineer Benz took Otto's engine, attached wheels to it, and created the first automobile (although it only had three wheels). The next year, the German engineer Daimler built a four-wheel automobile, powered by a combustion engine. Of course, an early automobile was still very expensive, and primarily a rich man's toy.

But that quickly changed. In the United States, Henry Ford figured out how to make a large number of cars very quickly by inventing the assembly line: every worker stood in the same place all day and added the same part to each car that came by. In 1913, a car factory could produce a thousand cars a day! Cars became cheaper, so more people could afford one.

In 1903, two American brothers, Wilbur and Orville Wright, put a combustion engine in a flying machine, inventing the first aeroplane to run on fuel. At

The first powered airplane of the Wright brothers (1903).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roughly the same time the first geothermal power plant, which uses the heat of the inside of the earth, started producing electricity in Italy.

In 1905, Einstein published his famous theory that explains that mass can be converted into energy. In the middle of the 1900s, during and after the Second World War, physicists discovered how to use the power inside the atom. Lise Meitner, an Austrian scientist, discovered the process of nuclear fission — where a heavy atom splits in smaller parts — releasing large amounts of energy. In 1942, the Italian physicist Enrico Fermi designed and built the first nuclear fission reactor in the United States of America. In 1954 the first nuclear-powered electricity power plant opened in the USSR.

Already in 1929, people had realized that the sun gets its energy from nuclear fusion, in which the nuclei of small atoms fuse together and release a lot of energy. In the 1950s scientists started to research how to harness this source of energy on earth.

The energy use in the 1900s grew very quickly, roughly doubling every 25 years. The cost of energy production was declining, and as a result, energy was abundant and cheap in many western countries including the USA. Saving energy was not important, as there was plenty of it available.

Modern times

Modern problems…

In just over 150 years, we have learned how to use energy to our own advantage, and our life has changed forever. Thanks to the availability of plentiful and affordable energy, our lives are comfortable, we are mobile and productive. But we have also learned that energy comes at a price.

In 1973, Arab oil producing nations stopped supplying oil to western nations for political reasons. Overnight, the prices of oil tripled. This led to a large energy crisis, in which cars lined up at petrol stations to buy fuel. People realised for maybe the first time how dependent they had become on energy, and the importance of using this precious resource wisely. A second oil price shock happened in 1979. The price of a barrel of oil went up to almost 60$, while in 2003 the price was about 25$ a barrel (at year 2000 currency rates).

In 1979, the Three Mile Island nuclear power plant (USA) suffered an accident as a consequence of a series of mechanical failures and operator mistakes. After years of hearing that a nuclear accident could never happen, the public was shocked. The accident added to the sense of crisis people felt. An even more serious accident occurred in Chernobyl (in the former USSR, now Ukraine) in the year 1986. Although the accident was caused by bad design and was initiated by violations of safety rules, and could not have happened in a modern nuclear power plant, it caused many people to change their minds about using nuclear energy as an energy source.

Pollution takes many forms: oil drums in the Antarctic.

© European Community, 2005

Fossil fuels also threaten the environment. When burnt, fossil fuels such as coal, oil and gas produce several air pollutants. Some of these exhaust gases, like carbon dioxide (CO_2), act as a heat-retaining blanket around the earth, causing the so-called greenhouse effect. Due to this effect, temperatures on Earth are rising, with many possibly negative consequences such as more extreme weather events. Since the industrial revolution, the average air temperature on Earth has already risen by 0.6 °C. Other exhaust gases cause air-pollution and urban smog.

Another problem is that energy is not available to everybody. Around 1.6 billion people, one-quarter of the world population, do not have access to modern forms of energy, and therefore lack the comfort, health, mobility and productivity that modern energy makes possible.

Finally, our energy demand is increasing very rapidly. By the year 2050, it is expected that there will be nine billion people on earth, compared with the six billion now, and they will all need energy. People in developing countries will want to use as much energy as we do. For these reasons, it is expected that in 2050 our energy demand will be at least twice what it is today. If we keep producing energy the way we do now, using mainly fossil fuels, our environment will suffer badly. Eventually, fossil resources will become more expensive and finally run out, although this is still far away.

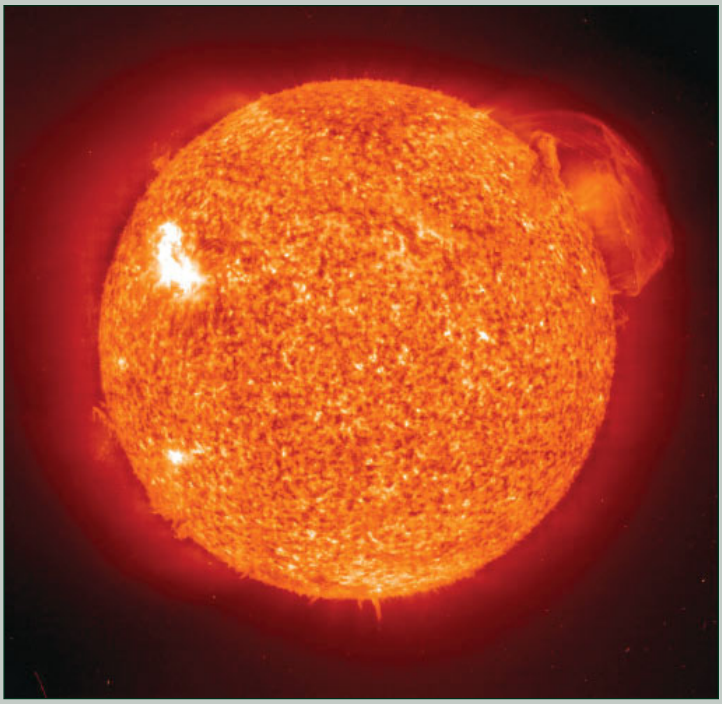
And modern solutions…

When fossil fuels are burned, the greenhouse gas CO_2 is released. But there is a way to prevent this from happening: catch the CO_2 when it is formed and put it in empty natural gas and oil fields, or in un-

Generating eletricity from the wind.

© European Community, 2005

Fusion powers the sun and the stars. Scientists work on harnessing this energy source on earth.



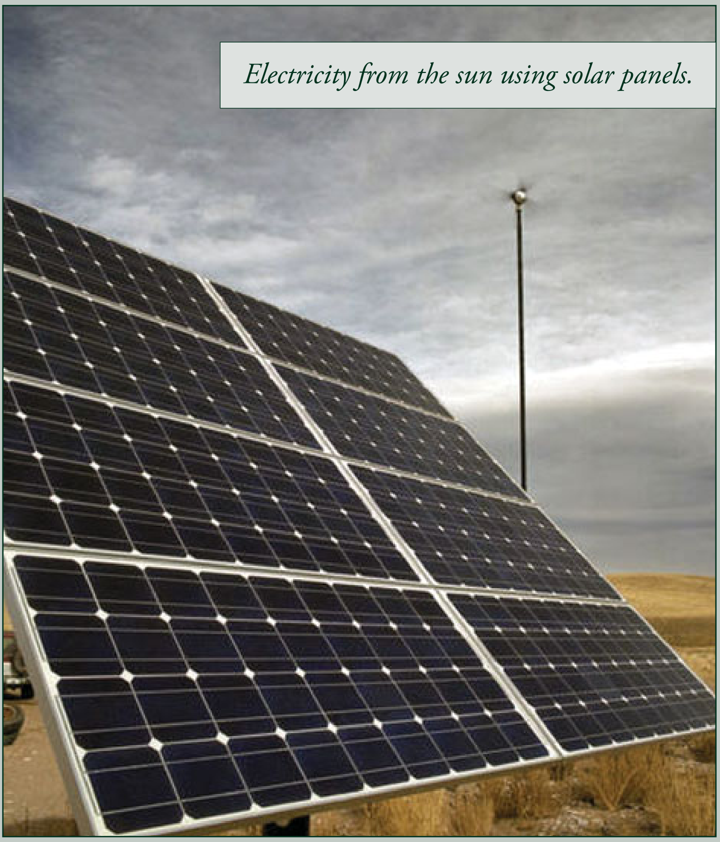
© NASA

derground water bearing layers. This technique, called *carbon sequestration*, could be used as a temporary measure to dampen the greenhouse effect. The idea is that if the gas stayed underground for millions of years, so should the CO_2 that is put back in. Research is being carried out to see if this technique is safe, practical and affordable. This technique is an example of a range of technologies which aim to use fossil fuels in a clean way, and which are therefore called *clean fossil technologies.*

An important goal for the future is to make electricity in a CO_2-free way. At the moment, hydropower, nuclear energy and biomass provide 35% of the worlds electricity without emitting CO_2. New technologies to harness renewable energy sources such as solar, wind, tidal, and geothermal energy presently account for less than 0.7% of our worldwide electricity use. But these technologies are growing fast, and it is hoped that around 2050 they may provide much more.

Much research is devoted to solve the problems linked to the present use of nuclear fission - the disposal of radioactive waste and the safety of fission reactors - and to develop new, safe types of nuclear reactors.

Nuclear fusion, the energy released by the fusion of atoms and the energy source of the sun, could start generating greenhouse gas free and safe energy around 2040. At the moment, national and international research programs are carried out worldwide to develop this source of energy here on earth.



Electricity from the sun using solar panels.

© Warren Gretz (PIX DOE/NREL)

When fossil fuels are burnt, greenhouse gases are emitted to the atmosphere.

© European Community, 2005

3 The energy we use

We use different forms of energy, like gas, electricity and petrol. Can't we narrow this down to just one form of energy, say electricity? Well, yes and no. As we will see later, electricity has disadvantages for some purposes. Depending on what we want to do, we need energy in different forms. We will make the following distinction in what we want to do with energy: heat things (houses, food, water), cool things (food, rooms), produce and manufacture things and materials (industrial use), transport things (cars, trucks, ships, trains, planes), and everything else (make music, light, computers, etc.).

Heating and cooling

Heating and cooling are mainly used to keep the rooms we live in at a comfortable temperature: in the winter we heat them up, and in the summer we cool them down. This depends very much on where you live: people in colder regions will use space heating fuelled by gas, oil, or coal more often then people in warmer regions. People in warmer regions prefer to use air conditioners to keep the temperature down.

Apart from regulating the temperature of rooms, we also use heat for cooking, taking a hot bath, or a shower. We use fridges and freezers to prevent our food from going bad and to cool drinks. In industry, heating and cooling are used for many processes as well.

What type of energy do we use for heating and cooling? For heating spaces, water and food, we normally burn gas, oil, or coal in some type of burner. Burners take many shapes: from the oven in the kitchen to huge gas-fired kettles that provide heat for large buildings. Heating can also be done with electricity, think for example of an electric water heater and an electric oven.

Most cooling appliances such as freezers, fridges and air conditioners run on electricity, although there are also fridges that run on gas. In a household, the freezer and fridge often are the largest consumers of electricity.

Air transport needs a lot of kerosine.

© European Community, 2005

Transport power

Transport power is needed to move something from one place to another. If you carry a bag, your body is the machine that transports it. The food you eat provides the energy for the transport. Every day, tens of millions of tons of goods are transported over roads, water, or through the air, by trucks, trains, ships and planes. Almost all of these transport machines are powered by petrol, gas, oil or kerosene. Only one major transport service is powered by electricity: a large part of the railway system (and similar systems such as trams and metro).

Electric motors are used in factories, pumps, fans and many other applications. In most homes, it is easy to find twenty to forty electric motors driving all kinds of things. For instance, each fridge has a pump, a microwave oven uses two motors (one for the fan, the other for rotating the plate), a stereo set probably contains seven little electric motors, and a computer might have eight of these.

Industrial use of energy

Industry produces many of the everyday products we use such as clothes, food, plastics, and clean water. Industry also produces the construction materials needed for streets, houses, buildings, railways, and so on. The manufacture of all of these products requires a large amount of energy, both in the form of heat (steam, for example) and electricity. Because factories often need heat *and* electric power, the electric power is often generated within the factory, and the waste heat of the power generation is used for the industrial process. This can make a factory very energy efficient.

Other applications

Many services at home require energy and the devices designed to provide them rely almost exclusively on electricity. Surfing the internet and typing a text on a computer require electricity. A stereo set and the television set require electricity. Laundry, ironing, and vacuum cleaning all require electricity. Sometimes electricity is even used to cut bread, to make orange juice, and to clean one's teeth.

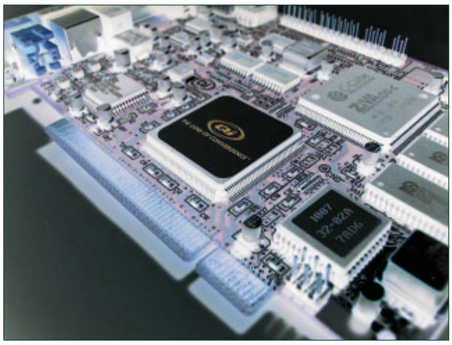
Electricity

Electricity is the most flexible form of energy: it can be used for virtually any application. No noise or gases are produced at the place where electricity is used. You don't need a tank of fuel to power your computer or stereo, electricity is there the moment you need it and in the form you want to have it.

But there are some disadvantages too. The central generation of electricity means it has to be transported from the generation point to your house. This is accomplished by a large and costly distribution system called the power grid, of which the high-voltage transmission lines carried overhead by poles form the most visible part. During distribution, about 10% of the power is lost.

Another disadvantage of electricity is that it is very hard to store. You need large, heavy batteries to store only a small amount of electric energy. In the case of transportation, the need to carry bulky and heavy batteries with you on a vehicle often makes the use of electricity undesirable for that application. Trains solve this problem by having their own power transmission cables, which function like very long extension cables.

The use of electricity is growing at a tremendous pace worldwide. According to the International Energy Agency, world use of electricity will double between 2002 and 2030, and most of the growth will be in developing countries. Currently, a quarter of the world population still does not have access to electricity.



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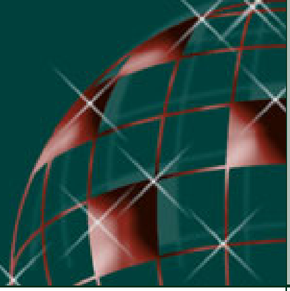
All electronic devices - videos, television sets, computers, etc. - depend on electricity.

Electricity is the most flexible form of energy.



How to measure energy

Energy comes in many forms: we use electricity for light, cook on gas, drive on petrol, and sometimes make a fire with firewood. If we want to know how much energy we use, we have to find a way to compare all these forms of energy. In which units can we measure energy?

All different forms of energy have in common a *capacity to do work*. This capacity to do work can be compared to a standard situation in which work is done, like lifting a mass. That is why energy is measured in joules (J for short), where 1 joule is defined as the amount of energy used when a force of 1 newton is applied over a distance of 1 metre. To give a feel for how much energy this represents: a force of 1 newton is just enough to lift an apple with a mass of 100 grams. So, if you lift an apple with a mass of 100 grams over a distance of one metre, you need one joule of energy to do it. And we can go on: for two metres, you need 2 joules, and to lift a mass of 1 kg (1000 grams) 1 metre, you need 10 joules.

Table 1.
Energy present in different types of food.

Type of food	Portion size	Weight (gr)	Energy content (kJ)	Energy content (kJ/gr)
Butter / margarine	1 Tbsp.	14	419	30
Peanut butter	1 Tbsp.	16	398	25
Peanuts	1 Cup	145	3520	24
Milk chocolate	1 Piece	30	629	21
Potato chips	10 Chips	20	440	22
Chocolate cake	1 Slice	100	1827	18
Cheese	1 Piece	17	293	17
Pork chop	1 Piece	87	1152	13
Apple pie	1 Piece	158	1697	11
Hamburger	1 Serve	98	1027	10
Bread, plain	1 Slice	28	293	10
Ice Cream	1 Cup	148	1467	10
Chicken, Roasted	1 Breast	86	587	7
Boiled egg	1 Egg	50	314	6
Rice, plain cooked	1 Cup	205	943	5
Banana	1 Banana	114	440	4
Cow`s milk (whole)	1 Cup	244	629	3
Yoghurt (naturel)	1 Cup	227	587	3
Cola	1 Can	369	670	2
Apple	1 Apple	138	335	2
Carrot	1 Carrot	72	126	2
Orange	1 Orange	131	251	2
Watermelon	1 Slice	160	210	1
Cucumber	6 Slices	28	21	1

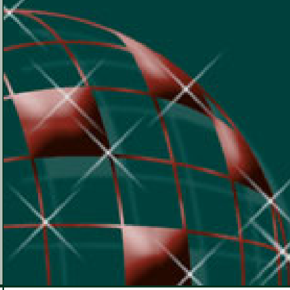
To be precise

The formula for calculating exactly how much energy you need to lift a mass is *Energy = Mass x (Acceleration of Gravity) x Height*, or $E = m \cdot g \cdot h$. On earth, g equals 9.8 m/s^2, so to lift 100 grams of mass (which is 0.1 kg) to a height of 1 metre, you need $E = 0.1 \cdot 9.8 \cdot 1 = 0.98$ joule, which is almost equal to 1 joule.

The calorie

The energy in food is often expressed in a different unit, called the *calorie*. One calorie is the energy you need to heat up one gram of water to one degree centigrade. One calorie equals 4.19 joules. Often a larger unit, the *kilocalorie* or *kcal* is used: 1 kcal = 1000 cal = 4190 joules.

The typical food intake of an adult man is about 2300 kcal and 2000 kcal for a woman, but these figures depend very much on the age, weight, and activity level.



One joule is not very much energy, so we usually talk about kilojoules (1 kJ = 1000 J), or megajoules (1 MJ = 1,000,000 J). All forms of energy can be expressed in joules. For example, when one litre of petrol is burned, it releases 28 MJ of energy.

Our body also needs energy. Food is processed to do useful work like walking, moving muscles, growing, and repairing damage. One banana contains roughly 180 kJ, and a chocolate bar contains at least 1400 kJ. On most food packaging, the energy content of the food is indicated. If you run fast for one minute you use about 150 kJ, and for cycling one minute you need 50 kJ. Even for sleeping, you still need 4 kJ per minute. So on just one chocolate bar, you can run for ten minutes, or sleep for six hours. Table 1 shows the food content of many foodstuffs.

Unit of Enerrgy	Symbol	Equivalent amount of joules
Kilojoule	kJ	1000 J (= 10^3 J)
Megajoule	MJ	1,000,000 J (= 10^6 J)
Kilowatt-hour	kWh	3,600,000 J (= 3.6 •10^6 J)
Ton of oil equivalent	toe	41.87 •10^9 J
Calorie	cal	4.190 J
Kilocalorie	kcal	4190 J

Table 2. Commonly used units of energy.

Food contains a lot of energy: these three peppers in total contain about 300 kilojoules (72 kcal).

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The Ton of Oil Equivalent

The *Ton of Oil Equivalent* (toe) is another unit used to express amounts of energy. It is equal to the average heat content of 1 ton of crude oil. It is equivalent to 41,868 megajoules, and is often used for presenting overviews with many different sources of energy, like coal, oil, gas, nuclear power, etc.

Writing large numbers

In this text we use *exponential notation* for writing large numbers. The idea is to count the number of zeros instead of writing them all down. So 5,000 can be written as $5.0 \cdot 10^3$. In this way 1,000,000 becomes $1.0 \cdot 10^6$, and 5,124,000,000 becomes $5.124 \cdot 10^9$.

Power

As well as energy, there is also *power*. Power is the rate at which energy is used or generated per unit of time, and it is therefore measured in joules per second (J/s), which is also called *watt* (W). For example, if you have a 100 watt lamp, it uses 100 joules every second. So every minute, a lamp of a 100 watt uses 6000 joules. On most appliances such as a television set or a microwave oven, the amount of power they use is indicated. A microwave oven at full power uses about 1000 watt, and a clock radio about 10 watt.

How much is a thousand watt, or ten watt? Let's take our own body as an example. If you walk up the stairs, you need a certain amount of power to do it. Say Linda, who has a mass of 50 kg, runs up three flights of stairs, which is a height difference of roughly 10 metres in total. For this, she needs 4900 joules (using $E = m \cdot g \cdot h$, E = 50 x 9.8 x 10). If she does this in 20 seconds, she has used 4900/20 = 245 watt during those 20 seconds. Linda will probably be quite tired.

When using hands only, healthy human beings can generate only about 50 watts for a long time without becoming tired. Using your feet – when cycling for example – you can generate 75-125 watts for a long time. In spurts, you can generate about a 1000 watts, but only for 30 seconds or so. If people were to generate energy while cycling, this means it would take about 10 people to power a 1000-watt microwave oven!

Energy and power are often used in the same sense, but they mean something very different. Power is a measure of how *quickly* energy is used. If you use 10 joules in 5 seconds, or 10 joules in 10 seconds, then in both cases the *energy* you have used is the same (namely 10 joules). But in the first case, the *power* was 10/5 = 2 watt, and in the second case 10/10 = 1 watt. In the second case, the *rate* at which the energy was used is smaller. Lower power means a lower rate of energy use.

Energy at home

We get energy in our homes in different forms. The one we are most used to is the energy from the wall socket: electricity. Electric energy is supplied by the source of the electric current, such as a battery or an electric generator. In most homes, electric power is purchased from a power company, which has several large electric generators fuelled by coal, gas, or nuclear power. The energy produced by the generators travels to individual homes through power lines. The unit of energy sold to households is 1000 watt during one hour, which is called the *kilowatt-hour*, or kWh for short.

How much energy is 1 kWh? Well, 1000 watt for 1 hour equals 1000 joules per second x 3600 seconds = 3,600,000 joules. And for this you pay about 13 Eurocents (the average price in the European Union). Let's say you hire a first-class athlete to make this much energy for you, for example on a bicycle driving a generator. An athlete can generate 300 watts for several hours, so it will take him more than three hours of hard work to generate that 1 kWh! And you will have to pay him a lot more than 13 Eurocents.

The horsepower

The horsepower is still used to express the power of combustion engines. One horsepower (1 hp) equals 746 watts. Oddly enough, that is about 50% more than a typical horse can sustain during a working day. A modern car can deliver about 200 horsepower, which is 150 kW!

Units of Power

1 watt= 1 joule / second

1 kW= 1000 watt

1 horsepower = 746 watt

With one kilowatt-hour, you can play a stereo set for 20 to 30 hours.

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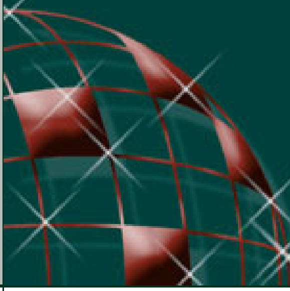


As well as electricity, houses also get energy in the form of fossil fuels such as gas, oil, and petrol. Gas and oil are used for cooking and to heat homes in winter. Petrol, which is sold at filling stations, is used to power motors and cars. Many countries have an underground pipe grid that distributes gas, and gas can also be bought in containers of many sizes for different uses. From table 3, we see that gas gives you a lot of energy for very little money. That is why it is almost always preferable to cook and heat your home with gas, if it is available.

Finally, we might buy small quantities of portable power in the shape of batteries. These are the most expensive: while a small battery for a watch might be cheap, the price per kWh is about 900 Euro!

Form of Energy	Unit size	Cost per unit (Euro)	Energy content per unit (kWh)	Cost per kWh (Euro)
Electricity	1 kWh	0.11	1	0.11
Natural gas	1 m3	0.11	10	0.01
Gasoline	1 liter	1.1	8	0.13
Battery	1 AA penlight	1.0	0.001	900

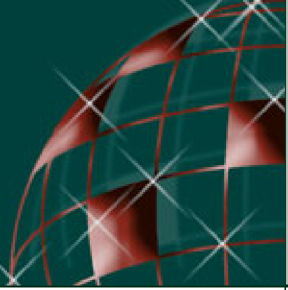
Table 3.
Energy content and approximate costs (in the Netherlands, 2002) of different forms of energy.

Appliance	Power use (Watts)	Average monthly use (hours)	Average monthly energy use (kWh)
Water heater	4500	89	400
Fridge-freezer (500 l)	450	333	150
Air conditioner (room)	700	200	140
Clothes dryer	3500	17	59.5
Water bed heater	375	256	96
Electric Heater (portable)	1500	40	60
Humidifier (portable)	177	230	40.7
Television	200	183	36.6
Dishwasher	1000	25	25
Microwave oven	1500	11	16.5
Computer (with printer and monitor)	200	75	15
Stereo	250	60	15
Refrigerator (150 l)	100	125	12.5
Convection oven	1500	8	12
Ceiling fan	80	150	12
Vacuum cleaner	1560	6	9.4
Clothes washer	500	17	8.5
Lighting (incandescent)	75	100	7.5
Coffee maker	1165	4	4.7

Table 4.
Characteristic energy needs of household appliances (continued on the next page).

What to do with one kilowatt-hour

- Cool your food in an energy-efficient refrigerator for one day
- Lift up the Eiffel tower by 4 cm
- Heat up 1 m^3 of water by 1 degree Centrigrade
- Run an average car with an electric engine for 1.6 km.
- Play a stereo for 20-30 hours
- Let an energy saving fluorescent light bulb of 18 W burn for 55 hours



How to read energy bills and the electricity meter

The energy bill states how many kilowatt-hours of electricity and how many cubic metres of gas were used over a certain period of time. To see how much electric power you use at a certain *moment*, you can look at the electricity meter. Some electricity meters have a disk that you can see spinning around. The more power you use, the faster the disk spins. The total number of kilowatt-hours is shown on a numerical display. In the same way, you can see how much gas you use on the gas meter. In this way, you can measure your energy consumption per hour, per day, per week, etc.

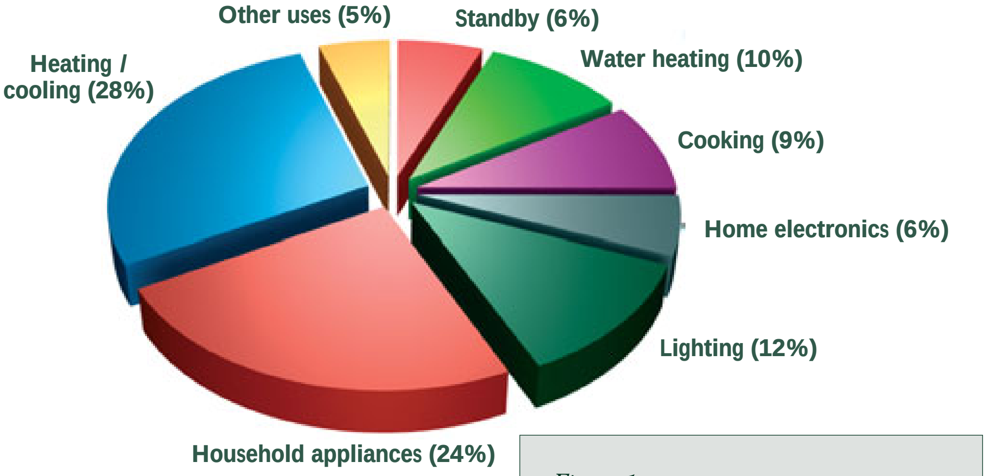


Figure 1.
The use of electricity in households in Europe in the year 2000. Heating and cooling represent the largest fraction, lighting represents only 12% of the electricity used. (source: IEA)

How much energy do we use?

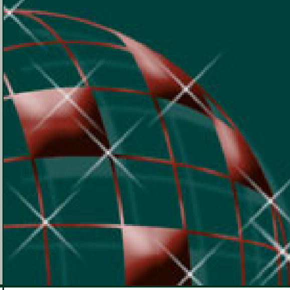
Every day we use energy, but how much? It depends on where you live, on how you live and on what you do. We talked about kilowatt-hours as a unit to measure energy, so now let's see how many kilowatt-hours of electricity we use in a month. Most appliances have a label that displays the amount of power they use. A television, for example, may use about 200 watts, and an electric toaster uses about 1400 watts.

If you want to know how much energy you use, you also have to know *how long* an electric device is used. For example, an electric clock of 5 watt left on for a whole month takes 3.7 kWh per month, while a toaster of 1400 watt, which is only switched on for two hours in total every month, takes less than 3 kWh per month! So small devices which seem to have low power demands, can actually use up quite a lot of electricity. Table 4 (starting on page 17) lists the

In some cases, a clock (of 5 W) uses more energy per month than an electrical toaster (of 1400 W). This is caused by the fact that the clock is in use during the whole month, while the toaster is only used for short periods of time.

Appliance	Power use (Watts)	Monthly use (hours)	Monthly energy use (kWh)
Lighting (Fluorescent)	40	100	4.0
Clock	5	730	3.7
Electric toaster	1400	2	2.8
Hair dryer	1000	2.5	2.5
Hand drill	300	3	1
Toothbrush (with charger)	1	730	1

Table 4. Continued from the previous page.



characteristic energy consumption of many household devices, how many hours per month they are used on average, and how much energy they use per month.

Which devices take a lot of energy? From the table we see that refrigerators, freezers, air conditioners, space heaters, clothes washer/dryers, and electric water heaters are the largest consumers of energy. In other words, the devices that have something to do with heating or cooling use most of the electricity in a household.

Figure 1 shows how electricity is used in European households. Of course, the way energy is used for different applications shows considerable variation accross Europe. The European average electricity use for a family is about 4100 kWh per year, or about 340 kWh per month. There is an easy way to check how much electricity you actually use: check the energy bill! The energy bill states exactly how many kilowatt-hours of electricity were used in a year or in a month.

In table 5, the electricity consumption per person in European countries is listed. It is obvious from the table that there are large differences between countries, due to several reasons. In Sweden, for example, only 1% of the population has access to a gas grid. On the other hand, Sweden has a lot of cheap hydroelectric power. For this reason, people in Sweden use electricity for just about everything, including house heating. This takes a lot of electric power.

Stand-by power

Many electric devices are never completely switched off, but are on stand-by. This stand-by mode takes energy: an average house uses about 100 W of power for electric devices on stand-by. You can try it in your own house: if all the electrical devices are ‘off’, is the meter still spinning?

Country	Population in millions	Total electricity consumpion by all households (1000 GWh per year)	Electricity consumption per person (kWh per person per year)
Sweden	8.9	41.4	4700
Finland	5.2	19.9	3800
Belgium	10.3	25.9	2500
France	59.5	133.0	2200
Denmark	5.4	10.2	1900
United Kingdom	59.2	114.5	1900
Ireland	3.9	7.4	1900
Austria	8.1	15.7	1900
Luxembourg	0.4	0.7	1800
EU-15	379.4	663.6	1700
Cyprus	0.7	1.2	1700
EU-25	453.8	723.8	1600
Germany	82.5	131.1	1600
Czech Republic	10.2	14.1	1400
Netherlands	16.1	22.8	1400
Greece	11.0	15.8	1400
Slovenia	2.0	2.7	1400
Malta	0.4	0.5	1300
Spain	41.2	50.6	1200
Italy	57.1	63.0	1100
Portugal	10.4	11.4	1100
Estonia	1.4	1.6	1100
Hungary	10.2	10.4	1000
Slovakia	5.4	4.9	910
Poland	38.4	21.7	570
Latvia	2.3	1.3	570
Lithuania	3.5	1.8	510

Table 5.
Electricity use per person in European households in 2002. Sweden and Finland use cheap hydro power, which they use for house heating as well. Belgium and France use a large amount of nuclear fission power. The average number of persons in a European household is 2.6. (Source: Eurostat)

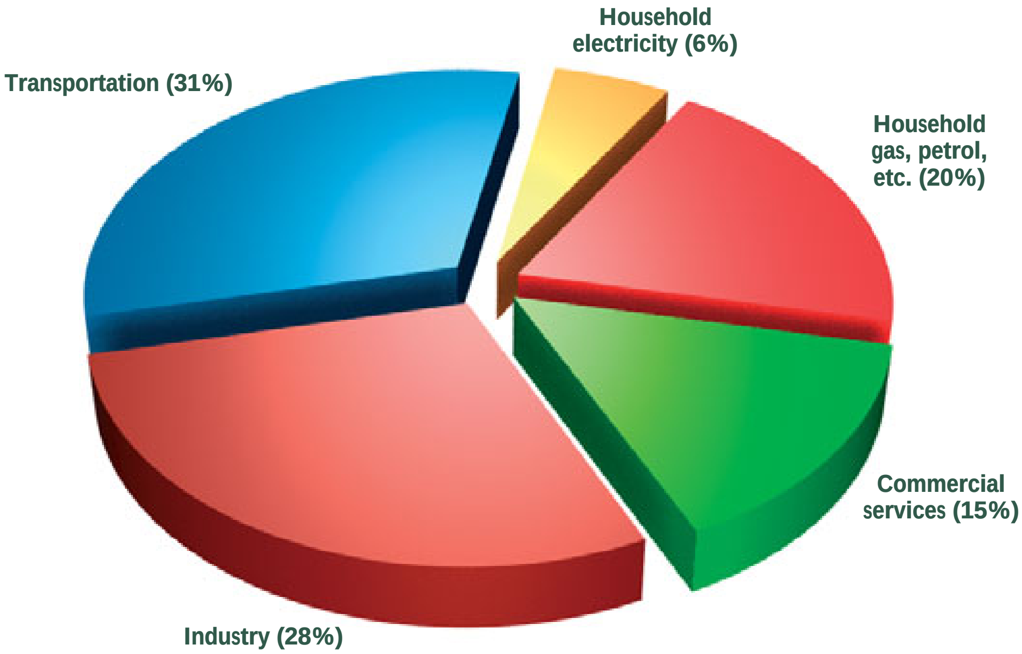


Figure 2.
The use of final energy by different sectors in the EU-25 in the year 2002. The total energy used was 1080 Mtoe. For the difference between primary and final energy, see chapter 1. (Source: Eurostat).

Primary energy use

Up to now, we have just talked about how much electricity is used in a typical household. But we also use gas for heating and cooking, and cars, trains and planes use petrol or other fossil fuels. Factories use energy to make their products, and raw materials to make things. So let's see how much energy a whole country uses.

Every country uses its energy sources in different ways, with different technologies, with different efficiencies. So it is hard to compare one country with another, and one form of energy with another. We will use the same trick as before: we express all the litres of oil, cubic metres of gas, etc, in how much energy they contain, and then add them up. As a unit, we use the *ton of oil* equivalent, the *toe*. One toe equals 41,867 megajoules, and it is the average heat content of one ton of crude oil (equivalent to the volume of about 7.5 oil barrels).

When we talk about *primary energy*, we mean the energy in its raw state, which may for example be transformed partly into electricity, partly turned into petrol for transportation, and partly used directly for heat or industrial processes. Instead of listing the numbers per country, we look at Western Europe as a whole, and compare the values to other regions in the world. In table 6 you can see how much primary energy is used in different regions of the world, and how much is used per person.

Table 6.
Total primary energy supply in different regions in the year 2002 (source: IEA)

Country	Population in millions	Total primary energy use (million toe per year)	Primary energy use per person (toe per year)
India	1049	539	0.51
Africa	832	540	0.65
China	1287	1245	0.97
Brazil	174	191	1.10
European Union (EU25)	455	1692	3.72
USA	287	2290	7.98
World	6196	10231	1.65

From table 6 you see that in Europe, one person uses 3.7 tons of oil equivalent per year. The energy content of 3.7 tons of oil is about $1.5 \cdot 10^{11}$ joule. If you were to use only muscle power, how many people would you need to generate this much energy? An average person can generate about 50 watt continuously, which is $1.58 \cdot 10^{9}$ joules in a year (working day and night, every day of the week, every week of the year). In that case you would need almost one hundred persons to generate the energy each of us uses. Each one of us would need a hundred 'energy slaves' to generate his or her energy.

What about the rest of the world? Energy use varies enormously around the world. From table 6 you see that in the United States of America, people use more than ten times as much energy as people in India and Africa, and more than twice as much as people in Europe.

It is hard to quantify exactly how all this primary energy is used, because the primary energy undergoes several changes before it becomes final energy. The coal that is imported as a primary energy source is consumed in the form of electricity, and imported crude oil is refined, and consumed in the form of petrol. But we can get the general idea by looking at the amount of *final* energy used in different sectors, such as transportation, industry, and households. This is shown in figure 2.

From the figure, we see that transportation and industry each represent about one-third of the energy use of a country, and the rest is used by households and commercial services. The factories that make the products we use need a lot of energy, and the transportation of people, products, raw materials and other things takes a lot of energy too. Surprisingly, household electricity only represents 6% of the final energy use.

Children in Benin, Africa. People in the USA use 13 times as much energy as people in Africa.

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From primary energy to electric energy

To generate electric energy, you need primary energy like coal, gas, wind, sun, or heat from a nuclear power plant. In the case of fossil fuels, which still generate most of the electric energy, fuel is burned to make steam, which is then used to power a steam turbine. The steam turbine powers an electric generator. Not all energy present in the fossil fuel is put into electric energy: a large amount is lost as waste heat.

The part of the energy present in the primary fossil fuel that is put into electric energy varies a lot depending on the fuel and the technology used. On average, about 33% of the energy present in the primary fossil fuel is put into electric energy, so the energy *efficiency* is 33%. This means that to generate one joule of electric energy, you need about three joules of fossil fuel.

The same holds for solar energy. In an average (commercially available) solar panel, about 15% of the energy in the sunlight that strikes the panel is transformed into electric energy, the rest is lost as heat. So a solar panel turns sunlight into electricity with an efficiency of 15%.

Table 7.
Energy embodied in common construction materials.
(Source: CSIRO, Australia)

Material	Embodied energy (MJ per kg)	Embodied energy (toe per ton)
Aluminium (new)	170	4.06
PVC	80	1.91
Hardboard	24.2	0.58
Aluminium (recycled)	17	0.40
Steel	38	0.90
Timber	3.0	0.07
Clay bricks	2.5	0.06
Concrete	1.9	0.05

Using energy efficiently

Obviously, it pays to save energy. If you use less energy, you have to pay less, and there is less impact on the environment. If we want the same energy services using less energy, we need to use the energy more efficiently. Of course, most energy can be saved where most of it is spent, which is in heating and cooling applications, and transportation. Good insulation in a house is cheap, and saves a lot of energy used for heating (and cooling in summer). When a fridge is opened, all the cold air streams out, so a fridge should be kept closed as much as possible. Air conditioning and heating can often be turned down at night. In general, new appliances use a lot less energy than old ones doing the same thing. Old fridges, for example, sometimes use up to three times as much energy as new ones.

Normal (so-called “incandescent”) light bulbs transform about 5% of the energy they use into light, the rest is turned into heat. An incandescent light bulb is actually a little space heater that happens to give of a little light as well. Fluorescent light bulbs do much better: they transform 4 to 6 times more of the energy into light, depending on the type. So if you use fluorescent light sources, you need five times less energy for the same light! And they last a lot longer, to.

Flying takes a lot of energy. The amount of energy it takes for one person to fly from Europe to New York and back, is the same as the electricity used in a household during a whole year.

Many industries are moving towards production methods that use less energy. Smart production processes re-use heat that was lost through the chimney in earlier times. Biomass waste material can be used to make biogas, which in turn can be used as fuel. Thinking carefully about production processes in this way can sometimes save up to 30% of the energy used.


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Manhattan at night, New York, USA.

At the moment, it is estimated that the stand-by power of electrical appliances consumes up to 6% of the electricity in European households. The European Union is trying to set an obligatory upper limit of 1 watt for the stand-by power consumption of all electrical appliances.

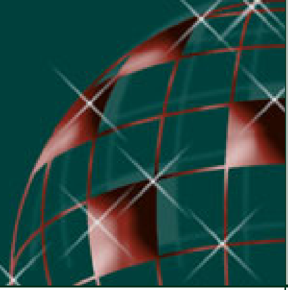
Energy use of the industry

For each material that is made, a certain amount of energy was required to make it. This is called the *embodied* energy. Furthermore, several materials such as plastics are made out of oil products. In table 7 you can see the embodied energy in megajoules per kilogram for some common construction materials. As you see, especially aluminium and PVC (used for plastic tubing) require a lot of energy. Concrete, bricks, and timber have the lowest embodied energy. The construction materials of an average house may easily embody up to 900,000 megajoules, which is equivalent to 250,000 kWh. That is the same as sixty years of electricity use by an average European household!

Some industries use more energy than others, and there are five industrial sectors that are the biggest consumers of all. The first is the energy sector itself: power plants, oil refineries, and coal transformation processes require large amounts of energy to transform raw fuels like coal and oil into the energy form that is needed. The metal industry uses energy to produce steel, copper, and aluminium from ore or scrap metal. Especially the production of aluminium from ore requires a lot of energy, and aluminium factories are often found in the neighbourhood of a cheap source of electricity, like a large hydropower plant. The chemical industry uses energy to produce basic chemicals used elsewhere in industry, plastics and synthetic fibres, and final products like drugs, cosmetics, and fertilizers. The production of paper from wood pulp or other fibres takes a lot of energy for heating and drying. Finally, non-metallic materials such as cement, glass, and all forms of bricks require a lot of energy as they are made in special ovens.

In general, the industry of a country uses a large part of all the energy that is used. In Europe, industry uses 28% of all final energy (see figure 2).

Industry consumes a lot of energy.



4 The sources of energy

There are many sources of energy. We use fossil fuels like coal, oil, gas, we use the power of the wind and from the sun, we have power plants based on nuclear fission, and large hydro dams. Scientists are developing fusion energy, the energy source that powers the sun and the stars.

In 2002 the world consumed a total amount of energy of about 10,230 million tons of oil equivalent (toe). This enormous amount of energy is supplied by many different energy sources, which are shown in figure 3. In this chapter, we will take a closer look at these energy sources.

Energy from fossil fuels

Coal, oil, and gas provide more than 80% of all the energy services in the world. These are called *fossil fuels* because they were formed from prehistoric plants and animals that lived some 300 million years ago. When these ancient living organisms died, they became buried under layers of rock, mud, and sand. During millions of years the remains of the plants and animals were subjected to high pressures and temperatures, which caused them to decompose, and form the fossil fuels that we use today. Different types of fossil fuel – such as oil, gas or coal – were formed depending on what animal and plant material were present, and on the temperatures and pressures the material was subjected to.

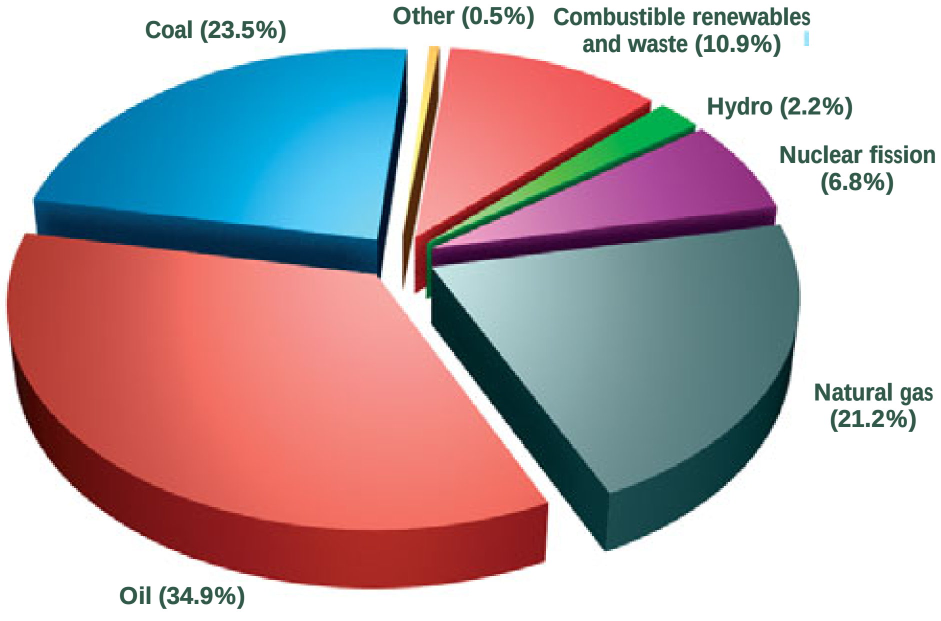


Figure 3.
The sources of primary energy in the year 2002, worldwide. The total amount of energy consumed in 2002 was 10,230 Mtoe. The catergory `other`, comprises geothermal, solar, wind, etc. (source: IEA).

Oil

Oil keeps a country moving. Almost the entire transportation fleet – cars, trucks, aeroplanes, and trains running on diesel – is powered by oil-based fuels. The oil that comes out of a well (so-called ‘crude oil’), is a very complex material, and during the refining process about thirty different fuels are extracted (gasoline, aviation fuel, jet fuel, diesel, etc.). Lubricants made from oil keep the machinery in the factories running. By-products of oil refining can be turned into fertilizers, which are used to improve food production.

Oil and natural gas are created from sea organisms that are buried under ocean sediments when they sink to the bottom of the sea. Oil exists underground as tiny droplets trapped inside pores in rocks. The pores and the oil droplets are small: they can be seen only through a microscope. Oil is composed of hydrocarbons, which are long chains of carbon atoms with hydrogen atoms attached to them.

Natural gas

Natural gas consists mainly of methane (CH_4), a compound that has a carbon atom surrounded by four hydrogen atoms. Methane is highly flammable and can burn very cleanly under the right conditions, meaning that no ash is produced, and very little polluting substances like sulphur dioxide or nitrogen oxides are formed. The CO_2 that is formed when the gas is burned is not poisonous. Natural gas is colourless and in its pure form, odourless.

Today, natural gas provides one-fifth of all the energy used in the world. It is especially important in homes, where it supplies nearly half of all the energy used for heating, hot water, and cooking. Because natural gas has no odour, gas companies add a chemical to make it smell. The odour makes it easy to smell if there is a gas leak in a house.

Natural gas is easy to transport by pipeline, and it burns very cleanly with a high efficiency. Gas is used in power plants to generate electricity, and in factories both as a fuel and as an ingredient in a variety of chemicals, such as fertilizers.

Oil being pumped from the ground.

© Mark Tiele Westra

Each day, we use 84 million barrels of oil worldwide.

Coal

Of all the fossil fuels, coal is the most plentiful and has the longest history. Coal has been used for heating since early mankind, and is now used primarily to generate electricity. Up to 1800, charcoal, which is made from wood, was also extensively used. Coal is formed from the dead remains of trees, ferns and other plants that lived 300 to 400 million years ago.

Different kinds of coal exist, with different properties. Anthracite, which is very hard, gives a lot of heat, but little flame and smoke. Generally, the harder the coal, the more energy is present in it, up to 31 MJ per kilogram. Steam coal, which is used mainly in power plants, has a lower heat content of 25 MJ per kilogram. In some countries, so-called ‘brown coal’ is used, which has an even lower heat content.

Fossil coal is burned in power plants to produce electricity. If the electricity used by an average European household (4100 kWh per year) was produced exclusively by coal, the family would use 1800 kg of coal each year. Even though you may never see coal, you use it every day!

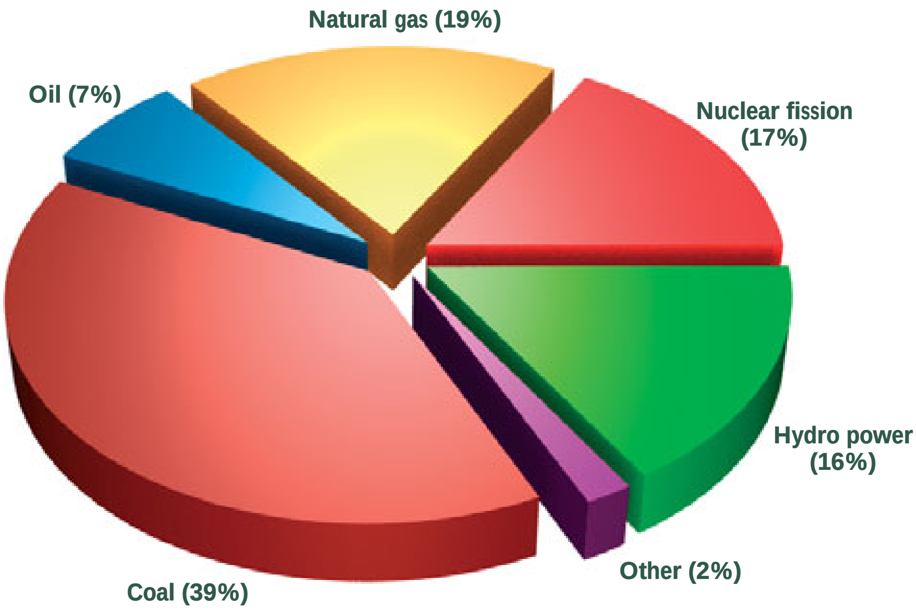
How we use fossil fuels

We use our fossil fuels mainly for transport, space heating, and electricity. The main use of oil is transport fuels, gas is mainly used for space heating and the production of electricity, and most of the coal is used to make electricity as well, as shown in figure 4.

Each year, we consume an amount of fossil fuels that took nature one million years to form. The resources of fossil fuels are plentiful (at least those of coal), and they can satisfy our demand for at least another hundred years. But there are a number of problems with burning fossil fuels. First of all, combustion of fossil fuels produces many pollutants that are released in the air, such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), and small particles. Secondly, the carbon dioxide (CO_2) that is formed (fossil fuels are mostly carbon) acts as a heat-retaining blanket around the earth, enhancing the so-called *greenhouse effect*. There are enough cheap fossil fuels to create a very large climate problem. These problems will be the subject of the next chapter.

Another problem is that fossil fuels are not spread evenly around the world. Around 80% of the world's oil resources are located in the Middle East, and in about 30 years, most European gas resources will be depleted. Many countries want to become less dependent on foreign energy sources.

Figure 4.
Electricity generation by different sources in 2002, worldwide. The total amount of electricity produced was 15,476 TWh. The catergory `other`, comprises geothermal, solar, wind, combustible renewables and waste, etc. (source: IEA).



How to make electricity

With the exception of solar cells and fuel cells, which are discussed below, all electricity is produced by some type of electric generator. In an electric generator electricity is made by turning a coil in a magnetic field. The changing magnetic field drives the electric current through the coil and into the external circuit, where it can be used to do something useful. There are many ways of providing mechanical power to turn the generator, such as steam turbines, gas turbines, or wind turbines.

In the case of a steam turbine, a heat source – such as burning fossil fuels or the heat released by nuclear reactions – is used to make steam. The steam is then fed through a steam turbine, which is mechanically coupled to an electric generator. The electric generator then produces the electricity as shown in figure 5.

A gas turbine works in a similar way: the gas is ignited and burns, and the combustion products expand in the turbine, which is again coupled to an electric generator. Sometimes, the heat of the burning gas is then used to make steam, which powers a steam turbine. This process is called *combined cycle*, and it has a high efficiency. If the waste heat of the steam turbine is also used, for example by a factory or for household heating, it is called a *Cogeneration Plant* or *Combined Heat and Power Plant.*

In the case of a wind turbine, the spinning blades drive an electric generator connected to them. In the case of hydro power, the water is channelled through a hydraulic turbine, which drives an electric generator. Further on, we will have a closer look at all these ways of generating electricity.

The electric power that is produced by large power plants is distributed over a country by the electric power grid, a large network of power-carrying cables. It is important to realize that the electricity is not stored in the power grid: every bit of electric power you use is generated a fraction of a second before it is consumed. This means that as soon as you turn on a light, somewhere a power plant will have to produce a little more power, and it will consume more coal or gas.

In general, a country has a number of large power plants, which produce about 500 MW to 1500 MW of electricity each. Most power plants are fuelled by coal or gas, or with nuclear fission power. Smaller electricity generating units are fuelled by diesel, which is made from oil. These so-called *diesel generators* are much smaller: they generate between 1 kW and 10 MW, and are easily transportable.

A lot of energy is lost during the conversion of primary energy like coal or gas to the final energy service, like light or hot water. When electricity is made in a coal-fired power plant, for example, only about 33% of the energy present in the coal is transformed into electricity, the rest is lost as heat. During the distribution in the power grid, another 10% of the electric power is lost. When the electricity is finally used for some energy service, energy is lost again. On the next page, this is shown using an ordinary lightbulb as an example.

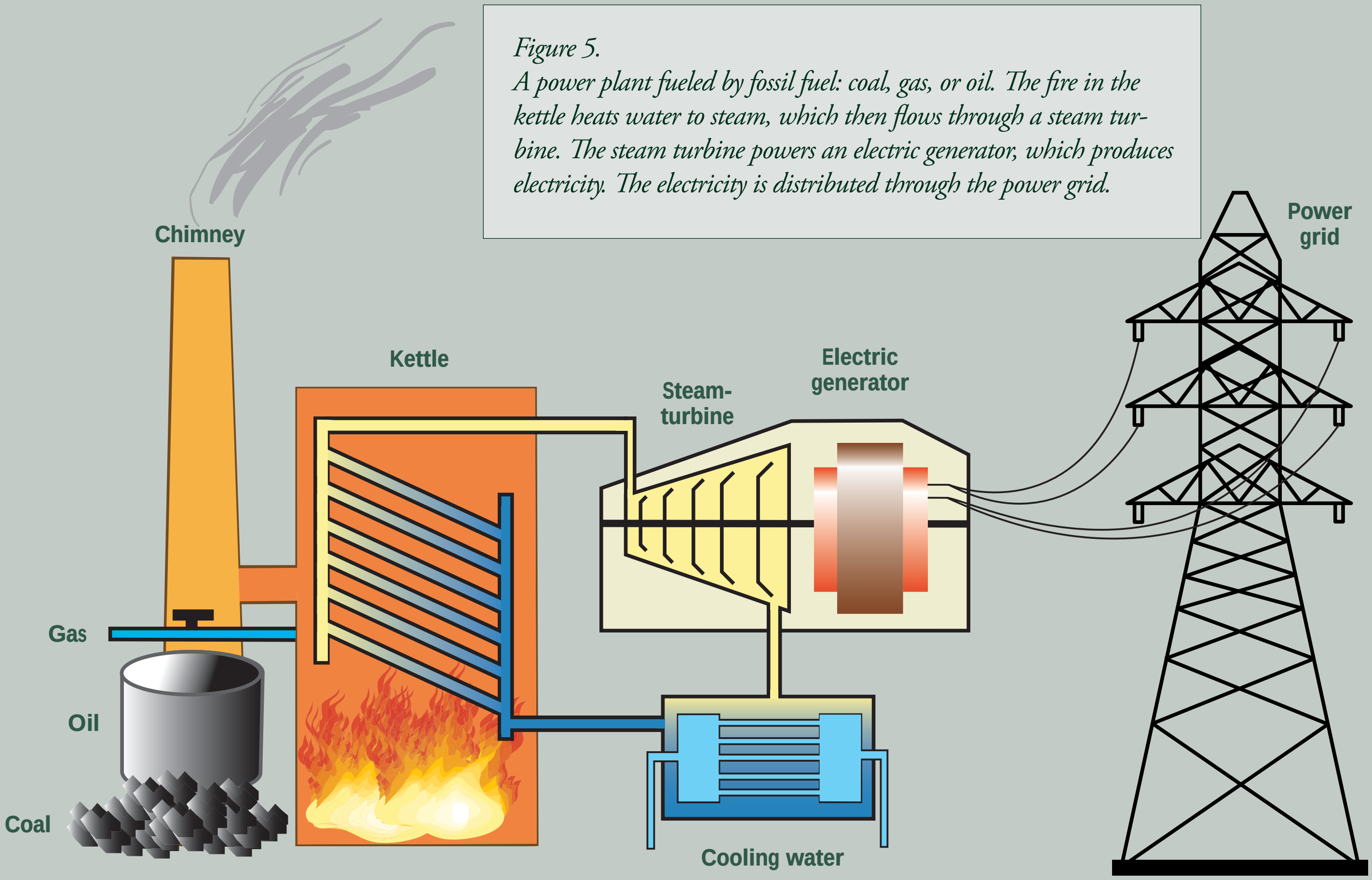


Figure 5.
A power plant fueled by fossil fuel: coal, gas, or oil. The fire in the kettle heats water to steam, which then flows through a steam turbine. The steam turbine powers an electric generator, which produces electricity. The electricity is distributed through the power grid.

Nuclear fission

So far we have been dealing with fossil fuels. Fossil fuels release their energy through a chemical reaction with the oxygen in the air, which means that the atoms rearrange themselves into new, more stable molecules. Such a rearrangement is also possible among the elementary particles – the protons and neutrons — that constitute the nucleus of atoms. In this case, the energy set free in each individual process is millions of times larger, because the forces acting in the nucleus are much stronger than the forces involved in the chemical reactions. Because much more energy is released for every kilogram of fuel, the total amount of material passing through a power plant based on this principle is correspondingly millions of times smaller than in the case of fossil fuels.

There are two types of nuclear reactions which can lead to a release of energy: firstly the splitting of very heavy nuclei, like uranium, which is used in fission reactors, and secondly the merging of very light nuclei, like hydrogen, which happens in stars and in future fusion reactors.

Natural uranium consists of two types: uranium-235 and uranium-238, where

Almost all transport depends on oil.

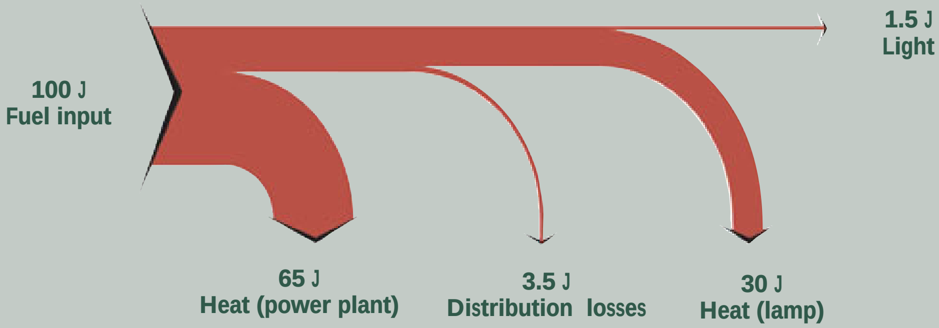


Figure 6.
Energy efficiency from source to final use for an incandescent light bulb (which generates electricity by heating a thin metal filament). Of the original 100 J fuel input, 65 J go into heat produced in the power plant. During distribution via the power grid, another 3.5 J are lost. In the light bulb itself, only 5% of the electrical energy is turned into useful light, which amounts to 1.5 J. In the lamp, 30 J of heat are produced. Fluorescent light sources perform much better: instead of 1.5 J, they transform about 8J (of the 100 J put in) into light.

the number indicates the total number of protons and neutrons in the nucleus. Uranium-238 has three extra neutrons in its nucleus and is stable, while uranium-235 is unstable and therefore radioactive.

Every now and then, a uranium-235 nucleus will spontaneously fall apart and send out two or three neutrons. If a free neutron is absorbed by another uranium-235 nucleus, it triggers a falling apart of that nucleus as well, which again releases free neutrons. If there is enough uranium-235 available in a small space, a chain reaction can begin which produces a lot of energy.

Nuclear fission is already in widespread use, with nuclear power plants providing about 17% of the world's electricity demand. The material used for fission, uranium, is found underground in the form of uranium ore. Uranium ore consists mainly of the stable uranium-238, and it has to be processed before it contains enough of the unstable uranium-235. A small amount of uranium contains a lot of energy: a piece the size of a golf ball can produce as much electricity as twenty train wagon loads full of coal, without producing any acid rain, carbon dioxide, or other polluting gasses.

One of the problems of nuclear fission is that the waste products of the fission reactions are radioactive themselves. These waste materials have to be handled with great care, and stored in a location where they cannot come into contact with the environment for a very long period (some parts for 10,000s of years). Stable geological formations – like underground salt-vaults – are believed to offer the necessary safety as storage locations. The fact that the fission products continue to emit heat also means that the material has to be cooled, even after the power plant has been shut down.

The design of modern fission power plants offers a very high level of safety against accidents such as the escape of radioactive material to the outside environment, for example by using strong protection barriers. These power plants use multiple, independent safety systems, which means that even if a component fails, it does not change the safety of the system.

After a temporary stop in the construction of new plants, many countries are

Einstein and nuclear energy

Einstein discovered that mass can be turned into energy, and energy into mass. This is expressed in his famous formula: $E=mc^2$, in which E is the energy, m is the mass, and c is the speed of light. The formula describes how much energy you get when you turn a mass m into energy. The speed of light is a very big number: 299,792,458 metres per second. The square of that number is a *very* large number. If you change 500 kilogram of mass into energy, you get $4.5\cdot10^{19}$ joules of energy, which is enough to cover the whole electricity use of the world for a year. That is the power of nuclear energy.

However, it is not possible to change mass completely into energy. In a typical nuclear reaction, only a small percentage of the mass of the participating nuclei is converted into energy. In the case of the sun, four hydrogen nuclei fuse together to form one helium nucleus. The helium nucleus is 0.7% lighter than the four hydrogen nuclei, and the missing mass has been converted into energy.

Nuclear power plant in Borssele, the Netherlands.

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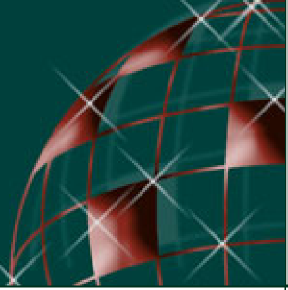
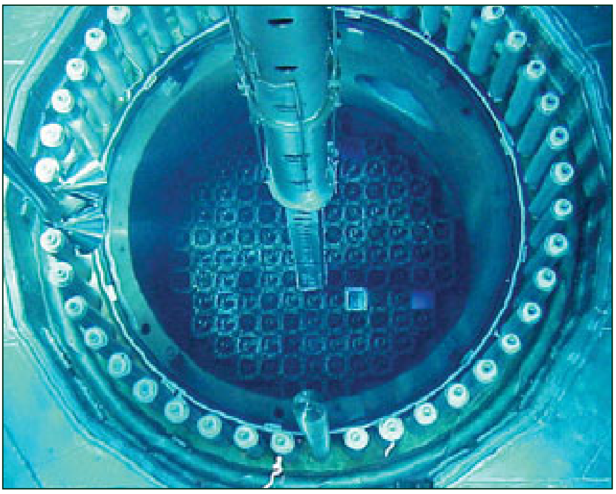


now considering the construction of new nucelar power plants. Despite the present problems in public acceptance, fission energy is the only large CO_2-free source of electric power besides hydro power. Nuclear fission is one of our most important large-scale energy sources. So it is definitely worthwhile trying to solve the problems of safety and waste, and to use the energy available from fission in the best way we can.



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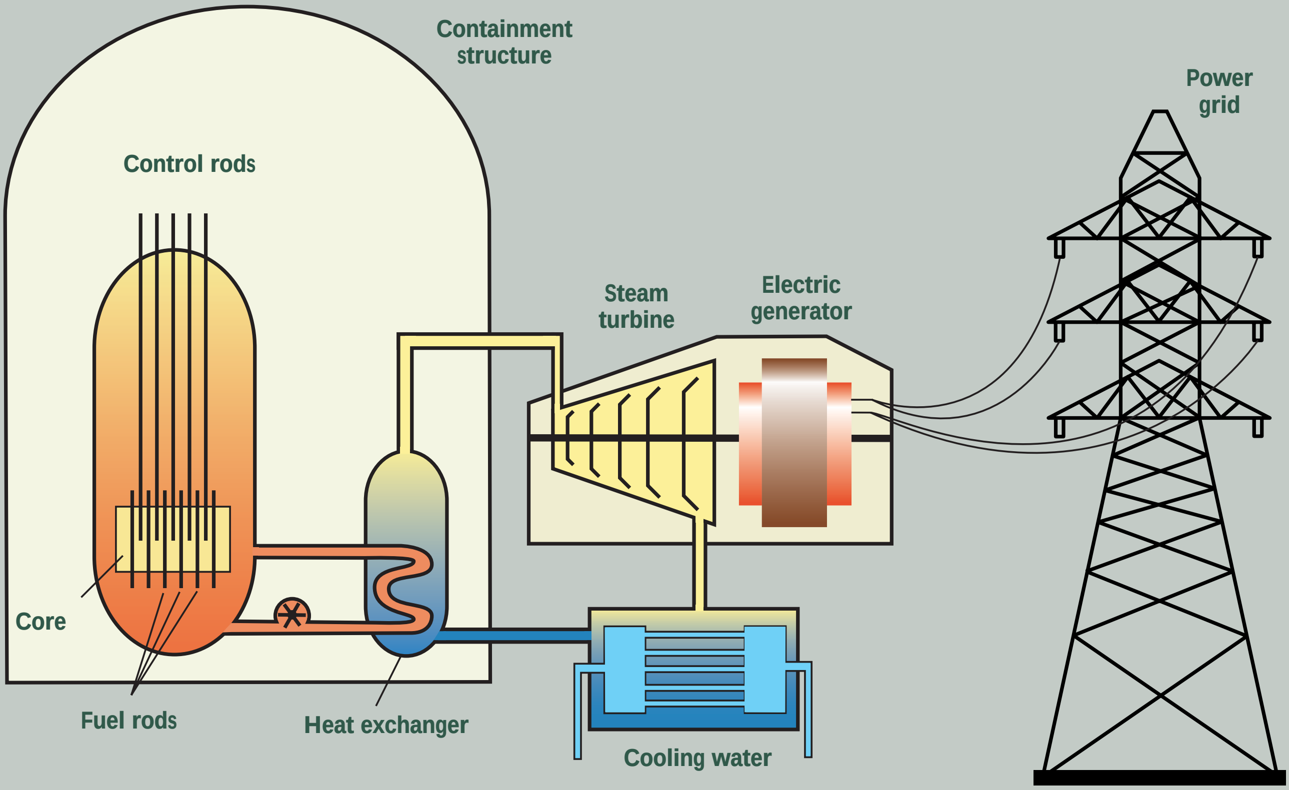
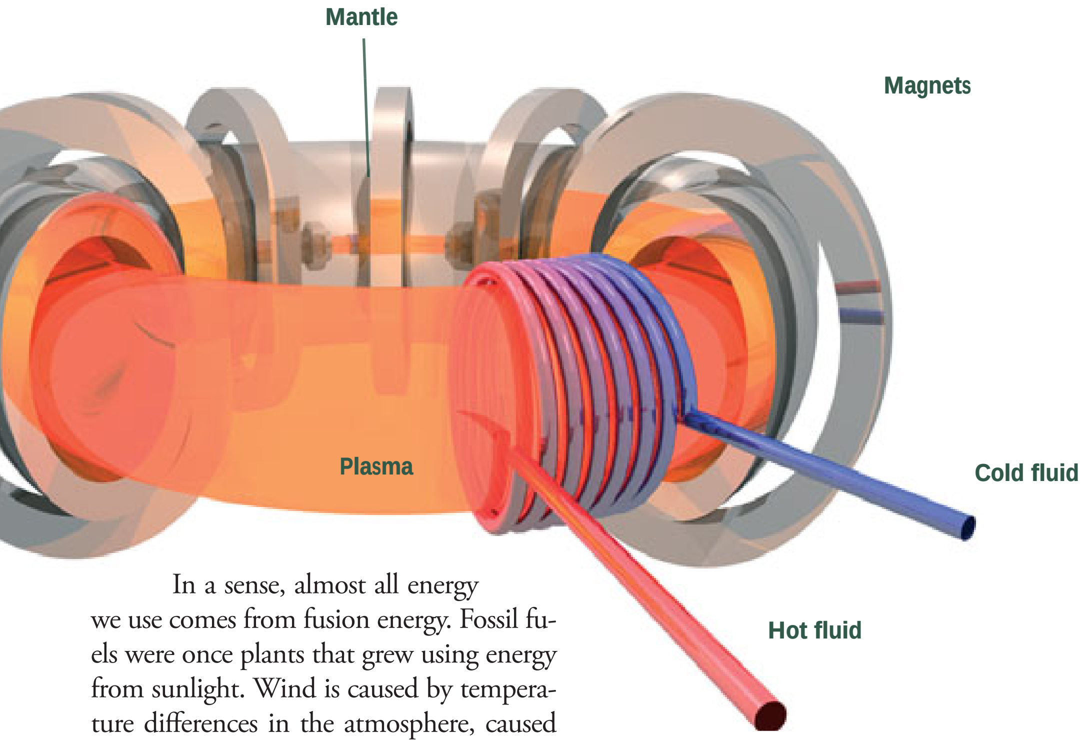
Changing a fuel rod in the core of the reactor.

Fusion energy

Nuclear fusion is the process in which two small nuclei fuse together to form a larger one, and this releases a lot of energy. Fusion is the energy source of the sun and the stars, and is therefore the most common energy source in the universe. The sun fuses the lightest of the elements, hydrogen (600 million tons each second), to form helium. The fusion process does not produce any greenhouse gases.





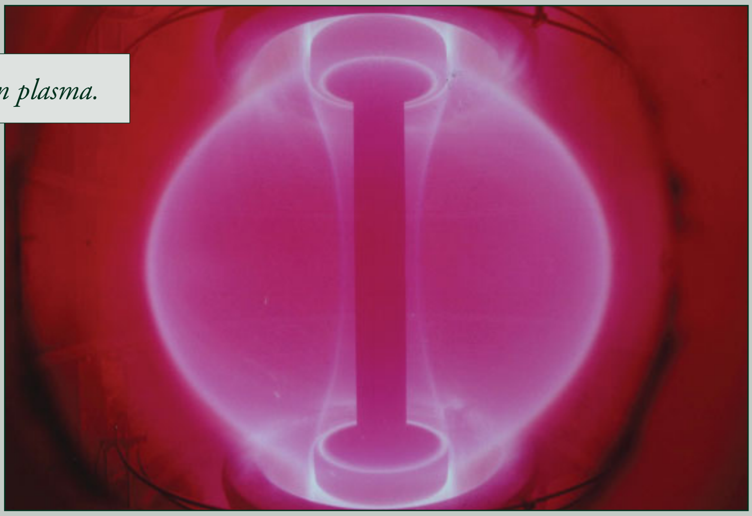
In a sense, almost all energy we use comes from fusion energy. Fossil fuels were once plants that grew using energy from sunlight. Wind is caused by temperature differences in the atmosphere, caused by the sun. Hydro-energy is powered by the cycle of water through the atmosphere, which is powered by the sun. And the sun is powered by fusion.

To use fusion energy more directly on earth, scientists are working to build a fusion power plant. It consists of a large car-tyre shaped metal container, called a torus, as shown in figure 8. Inside the torus a gas is heated to the extremely high temperature of 150 million degrees, which is about ten times hotter than the inside of the sun. The high temperature causes the nuclei to fuse together. The heat that is released by fusion is used to make steam, which drives a steam turbine. A future fusion reactor is expected to produce about 1000 MW, which is the typical size of a modern power plant.

Figure 8.
Principle of a fusion reactor. In the plasma, deuterium and tritium fuse together and release lots of heat. The plasma is contained within a mantle using a strong magnetic field produced by D-shaped magnets. Inside the mantle, a fluid is circulated, which removes the heat produced by the fusion reactions. The hot fluid is used to make steam, which in turn powers a steam turbine to make electricity.

Figure 7. (see left)
Principle of a nuclear power plant. Fuel rods containing uranium are placed in the core of the reactor. The fuel rods get hot by nuclear reactions, and heat up water, which is used to make steam. The steam is used to power a steam turbine. The reactor core is located in a containment structure for safety.

A fusion plasma.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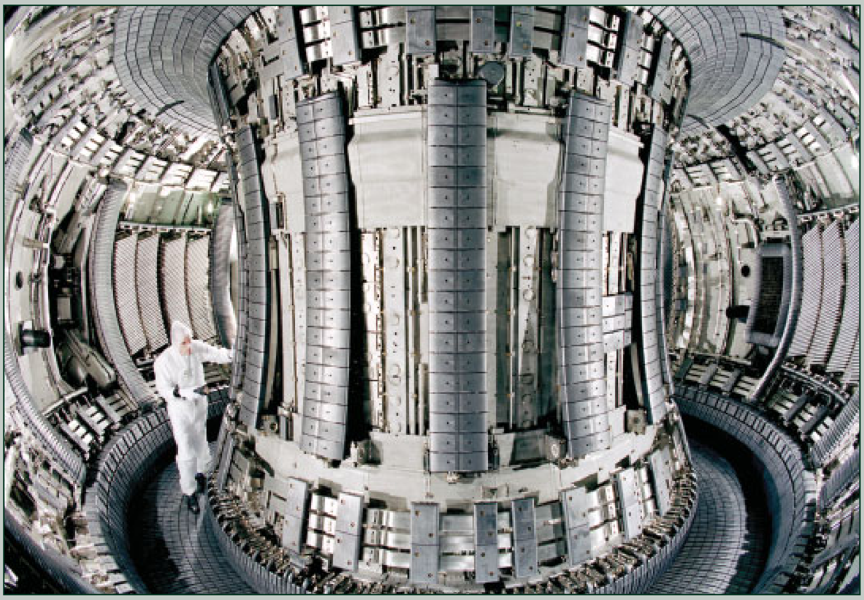
On earth, the fuels that will be used are deuterium and tritium, which are both so-called isotopes of hydrogen. Deuterium has one extra neutron in its nucleus, and is found in ordinary seawater: every cubic metre of seawater contains 33 grams of deuterium. Tritium, which has two extra neutrons, is a radioactive substance with a half-life of 12.3 years, so it is not found in nature. It is produced inside a fusion reactor from lithium, a common metal. In the fusion process, a deuterium nucleus and a tritium nucleus combine to form a helium nucleus and a free neutron.

Fusion fuels carry a lot of energy: the deuterium in a litre of seawater, together with an equal amount of tritium, is equivalent to the energy in 340 litres of gasoline. A typical fusion power plant of 1000 MW would need about 250 kg of fuel each year. There is enough deuterium in the world's oceans to satisfy our energy demand for millions of years.

However, it is hard to make a sun on earth. If you heat a gas to a hundred million degrees, it turns into a plasma, which means that all the electrons are stripped off the atoms. A plasma has to be controlled by very strong magnetic fields, to make sure that the hot plasma doesn't touch the inside of the torus. At the moment research is going on to harness this energy source here on earth, and it is not expected that fusion can contribute significantly to the world energy demand before the second half of this century. It is expected that around 2015 the next great scientific experiment in fusion, ITER, will come into operation. ITER, which will be build near Cadarache in the south of France, has to prove that fusion is feasible from a scientific and technological point of view.

Although there are no waste products from the fusion process itself, the internal structure of the plant becomes radioactive during its operation due to the neutrons that are produced in the fusion reaction. At the end of the lifetime of a fusion plant, those parts of the reactor have to be dismantled and stored for about a hundred years. After that time, no long term storage will be required, and the materials can be re-used. If proper construction materials are used, fusion power plants do not produce long-lived nuclear waste.

Inside the torus of a fusion reactor. The torus shown is part of the JET-experiment (Joint European Torus), near Oxford, England.
The man inside indicates the scale.



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Hydro power

Hydro power uses the energy in falling water to drive an electric generator. In some countries with mountains, like Nepal, water from small streams is used to drive small generators, generating enough energy for one or more households. These systems can be as small as a 100 W and don't need a dam or water storage. They are mainly used in rural areas where the local energy demand is not very high.

Another possibility is to make a dam, which collects water behind it to form an artificial lake. The water is channelled

Renewable energy sources

A *renewable* energy source constantly renews its energy, and will therefore never run out. Solar, wind, and water energy are all examples of renewable sources. Biomass like wood and plants can be a renewable source if they are allowed to grow back. Geothermal heat, the heat inside the earth, can be called renewable as there is so much of it that it will always be available for mankind. When fusion energy comes available, it will also be able to provide energy for millions of years.

Some renewable sources, like sun and wind, are available in almost any place around the world, although the amount available depends on the location. The units that generate electricity from these sources are normally small, such as solar panels or wind turbines. This makes these sources very suitable for generating electricity close to where it is used, which is called a *decentralized* or *distributed* way of generating electricity. This contrasts with the *centralized* production of electricity which uses large power plants combined with a power grid to distribute the energy.


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Hydro power: water from a storage lake behind a dam flows through water turbines.

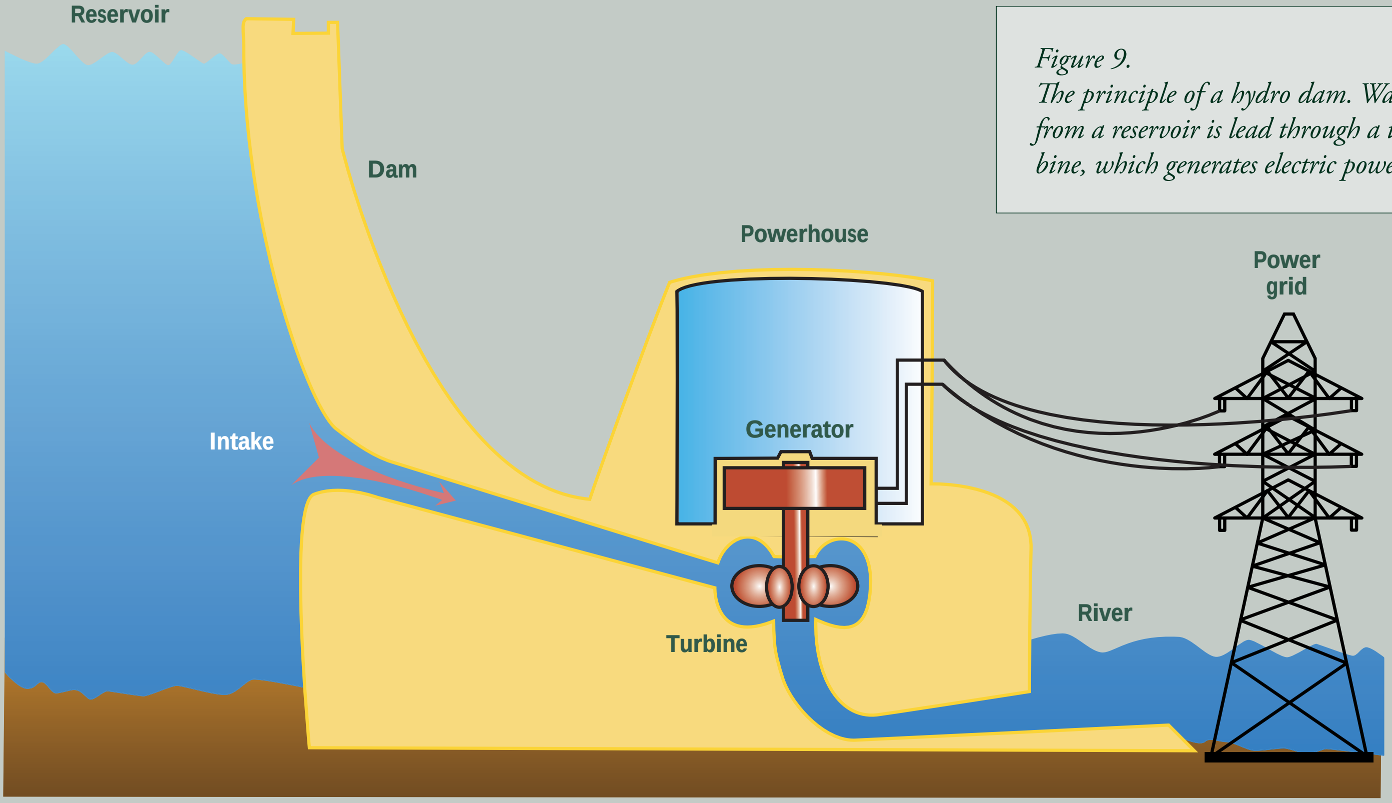


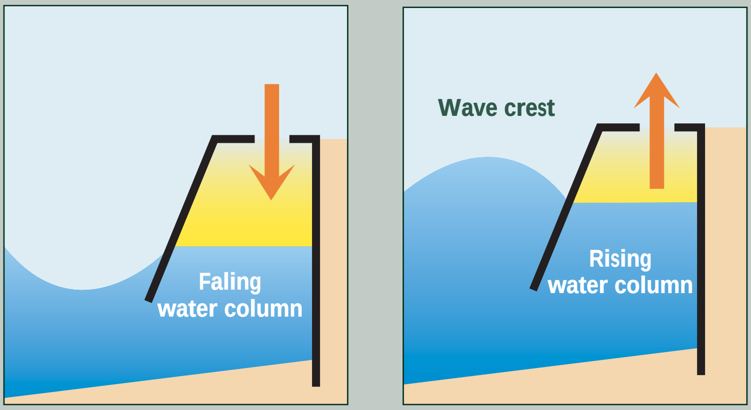
Figure 9.
The principle of a hydro dam. Water from a reservoir is lead through a turbine, which generates electric power.

through gates in the dam to drive large turbines, as shown in figure 9. These systems can be very large, enough to power many large cities. Located at the Brazilian border with Paraguay, and close to the border with Argentina, lies the Itapu Hydro dam. This power station is the largest hydro dam in the world, and generates 9000 MW. It has been in operation since 1984.

While small hydro systems do not have much impact on the environment, large hydro systems consisting of a large dam with a lake behind it, are not so harmless as they might seem. When a new dam is planned in an area where people live, many people will have to leave their homes, which will be flooded by the storage lake. In China, nearly two million people will be evacuated for the construction of the Three Gorges Dam in the Yangtze River and given another place to live. In total, around 40 to 80 million people were displaced because of dam projects during the last century.

Another problem with big storage lakes is the environmental damage done to the flooded area, and the release of methane by rotting plants in the storage lakes. Methane is a powerful greenhouse gas, and adds to the increased global warming.

Figure 10.
Power from the waves: a rising and falling water column compresses air, which is used to power a turbine.



A dam placed along the course of a river affects the original river flow severely, which can have impacts on the downstream area. Dams have affected about 60% of the rivers in the world. Fresh-water fish that normally go up and down a river in the course of a year find a dam in their way. It is estimated that one-fifth of fresh water species has been severely affected by dams.

Today, about 16% of the world's electricity is generated by hydropower, most of it by large hydro systems. Most of the potential locations where hydro electricity can be generated are already in use by now, so this source of energy will not be able to expand much more. To satisfy our increasing energy demand we will have to use other sources.

Energy from the ocean: wave energy and tidal energy

There are some places on earth where the height difference between high and low tide in the ocean is large enough to power a hydro system. Water is collected behind a dam at high tide, and at low tide the water flows through generators and generates electricity. The first tidal power station started working in France, in the year 1968. In 1984, a 20 MW tidal power plant started in the Novia Scotia bay, in Canada. Only about forty sites worldwide are suitable for tidal power plants.

But there is more energy to be extracted from the ocean. The most common technique is to use submerged systems akin to wind turbines that generate electricity when water flows past them. However, there are also different techniques to harness wave energy. Some use tapered-channel systems, which act to amplify the waves, to drive turbines. Others use float systems that rise and fall with the water surface, driving pistons that compress air. The air is forced through a turbine to generate energy.

A promising technique is to use a partially submerged concrete chamber built on the shore-line, with the bottom side open to the sea. Incoming waves force a column of air in the concrete chamber up through a turbine, as shown in figure 10. When the waves recede, air is sucked back through the turbine. The spinning turbine drives a generator that generates electricity. People in Scotland are experimenting with this type of construction: on the Scottish island of Islay, a 500 kW generator of this type has been installed.

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Energy from the sun using solar panels.

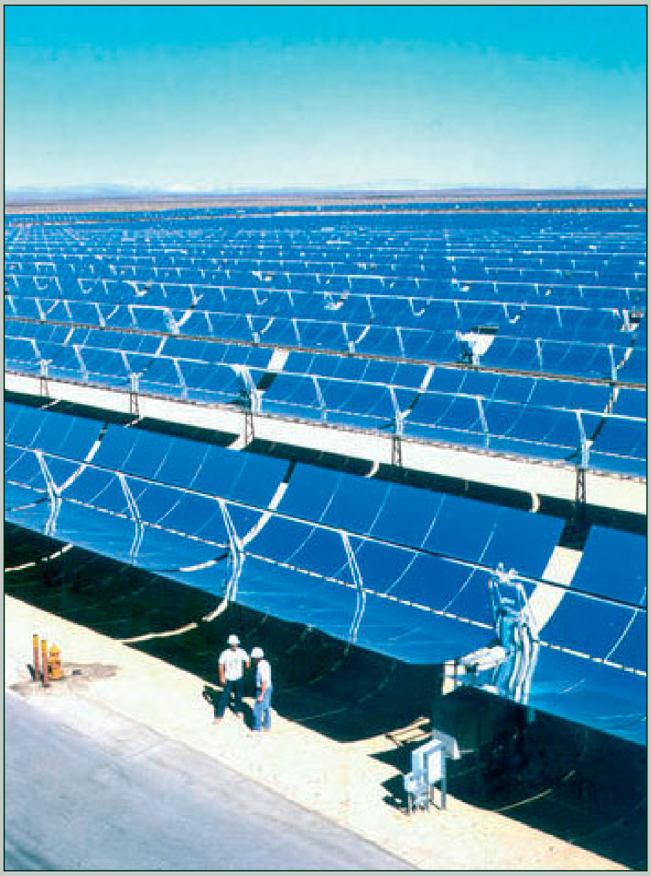
Energy from the sun

When the sun is shining, every square metre of area that is at right angles to the rays of the sun receives about 1000 W of solar power. Averaged over the whole year, each square metre receives about 100-200 W, depending on the location on Earth. Everyone who has ever played with a magnifying glass in the sun knows how much heat there is in sunlight: with only a small magnifying glass, you can easily set something on fire.

The quantity of energy delivered to an area by the sun depends on the location on earth, varying with the latitude from the equator to the poles. Near the poles, the sun strikes the earth at a shallow angle, so a square metre on the poles does not get as much solar energy as a square on the equator, where the sun strikes the earth almost vertically.

Sunlight can be converted to electricity by *photovoltaic panels,* also called *solar panels*. These panels consist of cells made from semiconductor material, the same material that computer chips are made of. Sunlight is composed of photons, which are small packages of energy. When photons strike a photovoltaic cell (PV cell) the energy of the photons is transferred to electrons in the semiconductor material. With their new energy, the electrons can break free from their atoms, and can flow as a current through an external electric circuit. Currently, solar cells are made from silicon, and they convert about 15% of the sunlight into electricity. In Central Europe, this means that if you put a solar panel of one square metre on your roof, you can expect to generate about 120 kWh a year. At the moment, solar electricity accounts for less than 0.01% of the world's electricity use.

In most photovoltaic systems, solar panels have no moving parts, and the only care they need is an occasional cleaning of the surfaces to keep them from becoming soiled. Solar panels have a lifetime of about 25 years. The main problem is that they are still quite expensive: a installed solar panel that delivers about 100 W when the sun is shining vertically on the panel, costs about 500 Euro. To cover the average electricity demand of a household, which is about 4100 kWh a year, you would need about 35 of these panels (in Europe), which will cost around 17,500 Euro. The same electricity coming from a power plant now costs about 500 Euro per year.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Rows of parabolic mirrors concentrate sunlight on the tubes in the middle. Oil inside the tubes, which is heated by the concentrated sunlight, is used to generate electric power.

For this reason, scientists work very hard to make solar cells more efficient and cheaper. A very useful application of solar cells is to bring electric power to places where it is very hard to bring electric power to by other means: for example in rural areas in developing countries, or at sea.

Instead of using solar cells, the power of the sun can also be used to generate electricity using a thermal system. To do this, the sunlight is concentrated using mirrors, which track the sun. A receiver, which can be a large tower or an absorber pipe, depending on the type of system, captures the sunlight and transfers the heat to a fluid. The hot fluid is used to make steam, which in turn powers a steam turbine. The steam turbine then powers the electric generator.

Another way of using solar energy is to convert it into heat, and to use the heat to make hot water. The hot water can be used directly for a shower or a bath, or for heating buildings. This way of using solar energy is quite cheap, and you see a lot of these so-called *solar collectors* on rooftops. Also swimming pools, which have to heat large quantities of water, sometimes use solar collectors.

Energy from the wind

For many centuries, windmills have been used to convert the power of the wind into mechanical energy. This energy was used for pumping water, grinding grain, or powering simple mechanical devices. Today, windmills are still used by farmers in many countries to pump up water. Another old application of wind energy, and a popular one nowadays, is to use the wind to propel sailing ships.

In modern times, so-called *wind turbines* are used to produce electricity. A wind turbine consists of a large rotor that usually has three blades, which is driven by the wind. The rotor is attached to an electric generator. Wind energy currently generates only 0.3% of the world's electricity, but the capacity is growing. Wind turbines cope with about 20% of the electricity demand in Denmark, about 6% in Germany, and 5% in Spain.

Wind turbines have their problems too. Not everybody likes to see large numbers of wind turbines placed in the countryside. There are concerns that the large fast-moving blades are dangerous to birds. If you live near a wind turbine, you will find them noisy, and sometimes accidents can happen when a turbine loses its blades. For some of these reasons, people are planning to put more wind turbines out into the sea, where the wind blows more regularly and wind speeds are higher. On the other hand, the costs of building wind turbines in the sea are higher, as are the costs for maintenance and operation.

Another problem is that sometimes there is no wind. This situation can occasionally last many days, and may happen over a large part of Europe simultaneously. Another way of saying this is that wind power (and also solar power) is *intermittent*, which means that the electricity is generated very irregularly. As the share of wind and solar power grows, great care has to be taken to guarantee the stability of the electricity supply. In most cases, back-up systems fuelled by fossil fuels will be necessary. At the moment, research is carried out on different techniques for storing the intermittent wind and solar power.

Energy from biomass

Biomass is another word for organic matter. When used as a fuel, it includes waste from the wood industry (wood chips and sawdust), agricultural and food processing wastes, sewage and solid waste, and other organic materials. Biomass was one of the first sources of energy known to mankind, and it continues to be a major source of energy in much of the developing world. Something like 80% of the total energy demand in the developing world is covered by biomass energy, mostly in the form of firewood that is collected locally.

The capacity factor of wind turbines and solar panels

Wind turbines come with a label that displays how much power they can generate. Some turbines can generate 750 kW, larger ones can generate 1.5 MW or even 3 MW. This figure is the *peak output* (or *maximum capacity*) of the turbine, which is the amount of power the turbine generates when the wind is optimal. When people talk about the “”installed capacity of wind power”, this is what they are referring to.

The energy delivered by a wind turbine depends on the number of hours it can operate each year. This of course depends on the weather conditions, and in practice a wind turbine delivers about 20-30% of its potential energy output averaged over a year. The difference between the actual yearly energy production and the theoretical maximum is called the *capacity factor*. So on average, a 1500 kW wind turbine produces about 300-450 kW.

The same holds for solar panels, which are characterised with their so-called *peak power*, which is the power they produce when the sun is at right angles with the panel. Of course, this happens only around noon every day when it is sunny, and averaged over day and night and over the year, a solar panel produces about 10% of its peak power output. A solar panel of 100 watt peak power produces on average 10 watts.

Wind turbines on a hill.

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In organic material, sunlight is stored in the form of chemical energy. There are two ways of using this energy, the simplest being direct combustion. The dry biomass is burned and used to heat water to steam. A second method is called anaerobic digestion, which produces methane gas, also appropriately called *biogas*. The process is a kind of fermentation, in which bacteria break down the biomass into smaller components. The fermentation is anaerobic, which means “without oxygen”, and it generates heat. Landfills, where municipal waste is dumped, also create biogas that can be used as fuel.

When burned, biomass does release carbon dioxide, a greenhouse gas. But when biomass crops are grown, an equivalent amount of carbon dioxide is consumed through photosynthesis. The net emission of carbon dioxide will be zero as long as the plants continue to be replanted for biomass energy purposes. These plants, such as fast-growing trees and grasses, are called *biomass energy feedstock*, or *energy crops* for short.


© Mark Tiele Westra

Windmill in Nicaragua. Wind energy does not have to be high-tech: in many developing countries simple windmills are used for pumping water.

Oil from rapeseed can be used to produce biodiesel.


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Wood chips used for electricity production


© Warren Gretz (PIX DOE/NREL)

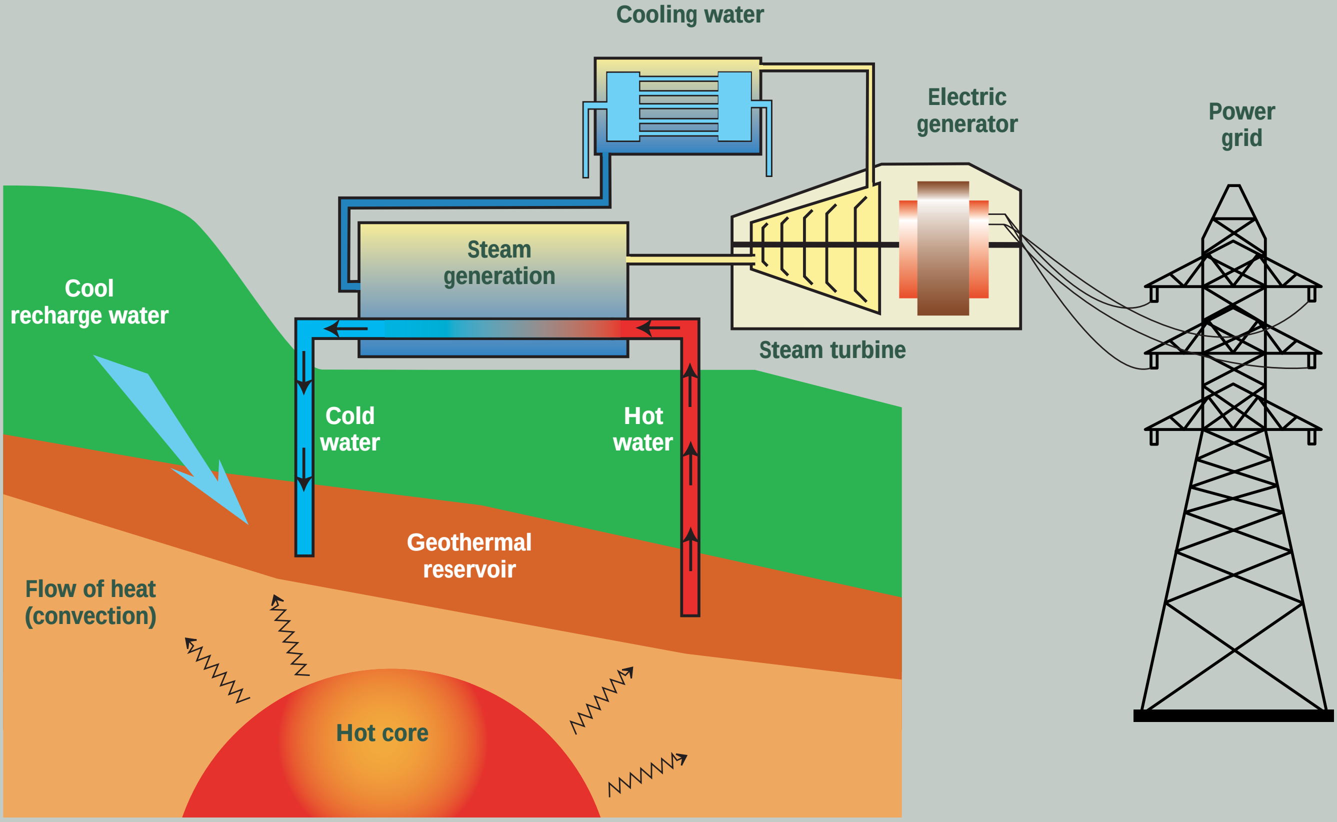
Geothermal energy

Geothermal energy derives from the Greek words *geo*, meaning 'earth', and *therme,* meaning 'heat'. The idea is to use the heat of the inside of the earth to generate electricity. The nucleus of the earth is red hot: about five thousand degrees centigrade. Sometimes, hot molten rock or magma comes to the surface during volcano eruptions. It is this enormous source of energy that geothermal plants try to harness for the production of heat or electricity.

If you dig a hole in the earth, the temperature rises about 17 to 30° Celsius per kilometre depth. A geothermal well can be up to 2500 metres deep. Water that is injected into the well is heated to steam, and can be used to generate electricity as shown in the figure below. Alternatively, the hot water can be used directly to warm homes and buildings.

Twenty countries around the world have built over 250 geothermal power plants. In the United States, geothermal power supplies the city of San Francisco with energy, and in El Salvador, 40% of the electricity comes from geothermal energy. Iceland uses only geothermal power for its electricity. In the world, around 8000 MW of geothermal electricity is generated, and another 10,000 MW of direct geothermal heat is used.

Figure 11.
The principle of geothermal energy. The inner heat of the earth is conducted towards the surface of the earth. In deep wells, cold water is injected. In a production well, hot water is pumped up. The hot water is used to make steam, which is used to power a steam turbine.



Of course, the right conditions to exploit geothermal energy in this form exist only in a very limited number of places around the world. For this reason, the total potential of energy production from geothermal energy is very limited. Once built, geothermal power plants provide cheap and clean energy. However, the initial construction of a geothermal power plant is expensive.

Another technology to mine heat from the earth uses hot rock found almost everywhere at some depth beneath the surface. This *hot dry rock* heat can be mined by injecting water in one well, which seeps through the hot rock to production wells nearby, where the water can go up again. At the surface, the heat that the water picked up is extracted, after which the water can be recirculated to mine more heat.

Production of browncoal in Germany. A coal-fired power plant of 1000 MW needs 2.5 million tons of coal every year

Table 8.
Fuel requirements for different energy sources. In the table, the fuel use is shown for a 1,000 MW power plant for one year (total output about 7,000 million kWh). Clearly, wind, solar and biomass need a lot of space. Fission and fusion stand out as they require only very modest amounts of fuel.

Energy source	Fuel needed for a 1000MW power plant, during one year	Approximate land use for a 1000MW plant (km2)	Comments
Biomass	30,000 km2 of woods	30,000	
Wind	2700 wind turbines of 1.5MW	490	
Solar PV	23 km2 of solar panels	23	placed in a country near the equator
Biogas	60 million pigs	600	pigs are held for food, energy is extra.
Gas	1.2 km3	1	
Oil	1,400,000 tons	1	10,000,000 oil barrels or 100 oil tankers
Coal	2,500,000 tons	1+ mines	26,260 train waggon loads
Nuclear fission	35 tons of uranium oxide	1+ mines	from 210 tons of uranium ore
Fusion	100 kg deuterium and 150 kg tritium	1+ mines	from 2850 m3 of sea water and 10 tons of lithium ore

Comparing different energy sources

All energy sources discussed in this chapter have different characteristics regarding quantity and type of fuel, the land surface they need, and their cost. In table 8, the characteristics and fuel requirements of a 1000 MW power plant powered by different energy sources are listed. From the table, we see that especially biomass, wind, and solar power need a lot of space, which is caused by the fact that these sources use energy that is not very concentrated. Fossil fuels carry a lot of energy per kilogram, and it is hard to compete with them. Nuclear fission, and especially fusion, need the smallest quantity of fuel of all.

Our energy sources are constantly changing. Behind the cables of the power grid lies a world of intense exploration, research, and development. Every day, hundreds of thousands of people work to harvest energy, such as coal, oil, and gas. And thousands of scientists develop new energy sources such as wind, solar, and fusion energy. New sources that are needed to guarantee clean and plentiful energy in the future.

5 Energy, the environment, and health

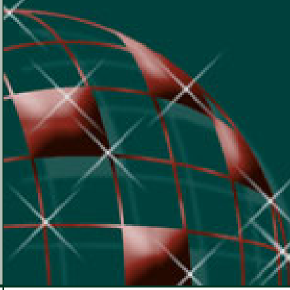
The increasing production and use of energy can be dangerous to the environment and to our health. The production of energy is a major part of the negative human environmental “footprint”. When wood is burnt, toxic fumes and small particles are formed, which are dangerous when inhaled. Sulphur dioxide that is released when coal or oil is burned, creates acid rain. Carbon dioxide, released when fossil fuels are burned, amplifies the greenhouse effect and causes the earth to heat up. People may have to be relocated when large hydro dams are built, and forests may be cut down for firewood, leading to soil erosion.

Health and environmental problems occur at four different levels. If I burn wood in my home, I inhale the smoke, but my neighbour doesn’t. That is the *household* level. The fumes of all cars in a city make smog, which everyone in the city has to inhale. That is the *community* level. Fine particles, sulphur dioxide and ozone can have effects hundreds of kilometres from their original source. That is the *regional* level. And finally the greenhouse effect, which heats the earth, affects us all. So that is the *global* level. We will have a look at each of these levels.

The household level

In western countries not much pollution is generated in the home. Most of us cook with electricity, gas or some fluid fuel, which are all quite clean. However, about half of the households in the world depend on firewood and charcoal for cooking and heating. It is very difficult to burn solid fuels in a clean way, because it is hard to mix them thoroughly with air in simple cooking stoves. In fact, only about 5 to 20 percent of the energy released by the burning fuel goes in the cooking pot, the rest is wasted. Added to that, incomplete burning of solid fuel produces a wide range of health-damaging pollutants, as shown in table 9.

This is no small matter. It is estimated that about two million women and children die prematurely every year because of the use of solid fuels, and that it causes about 5 to 6 percent of all illnesses in developing countries. The health risk of burning fuels for cooking and heating is high, because the fuels are burned in close proximity to people: every day, in the kitchen and in heating stoves in rooms.



Polluting substance	Concentration at 1 kg wood per hour (mg/m³)	Standards set to protect health (mg/m³)
Carbon monoxide	150	10
Fine particles	3.3	0.1
Benzene	0.8	0.002
1,3-Butadiene	0.15	0.0003
Formaldehyde	0.7	0.1

Table 9.
Indoor concentration of health-damaging pollutants from a typical wood-fired cooking stove. Mg/m3 means milligrams per cubic metre. The column on the right shows typical limits set to concentrations to protect health. There are dozens of other pollutants that are damaging to health present in wood smoke. (source: WAE, UNDP).

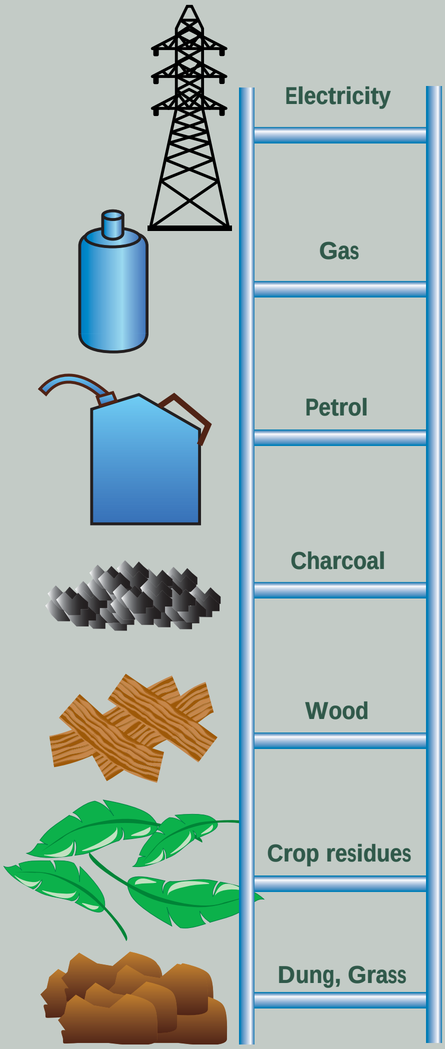


Figure 12.
The energy ladder.

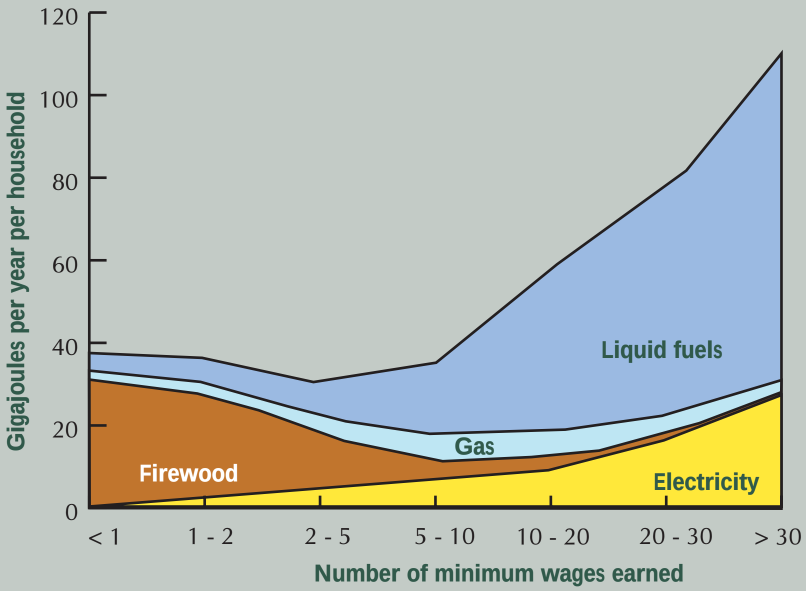


Figure 13.
Average energy demand by income in Brazil, 1988. One minimum wage equals 50$. When people earn more, they tend to use more electricity and liquid fuels. (Source WAE, UNDP).

Household energy use can be seen as an *energy ladder:* at the lowest end are simple biomass fuels (dung, crop residues, wood), higher up are coal, liquid fossil fuels like petroleum, then gas, and at the top the most modern form of energy: electricity. Going higher up the ladder, the stoves used are cleaner and more efficient. In general, when alternatives higher up the ladder become affordable and available, people tend to move up the energy ladder, as shown in figure 13.

In ancient times everyone depended on wood. Nowadays, roughly half the global population has moved one or more steps up the energy ladder. The other half still depends on wood, or, where wood has become scarce, has been forced down the ladder to the level of dung and crop residues. At worst, people use the poorest-quality fuels such as shrubs and grass.

At the lower end of the ladder, people use more of their own bodily energy and time – for example in gathering wood. Fuel gathering is usually a task for woman and children, for whom it is a major burden because of the heavy loads and the time involved. In developing countries it is not uncommon for woman and children to spend up to 12 hours a week on firewood collection. In Nepal, women spend up to 2.5 hours every day collecting firewood.

Poor people spend a large part of their time collecting the energy they need. This time cannot be used for producing things that can be sold, working on the land, or learning. This is called the *poverty trap*: once you are poor, it is very hard to get out of the poverty trap, because you need to spend all your time in survival activities.

Heavy traffic causes smog in large cities.

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The community level

Most of us are familiar with urban pollution. When looking over a city from a high vantage point on a hot, windless day, you can often see a yellowish haze hanging over the city. This is *smog*, a mix of small particles and exhaust gases from car and motor engines. In some cities with a large car-fleet like Athens (Greece) or Los Angeles (California, USA) people get respiratory problems from smog, and the concentrations of nitrogen oxides and ozone often exceed safety levels.

While ozone occurs naturally in the upper atmosphere where it creates a protective layer around the earth, at ground level it is dangerous to human health. Ozone is produced when nitrogen oxides react with incompletely burned fuel from car and lorry engines. Ozone can cause breathing problems, aggravate asthma, and cause inflammation of the lungs. It can also reduce the body's immune defence system, making people more susceptible to illnesses like bronchitis and pneumonia. Children and elderly people are especially susceptible to these health risks. In most large cities, the air quality is constantly measured. Apart from measuring ozone, these air quality gauges measure carbon monoxide, nitrous oxides, and small particles.

Sometimes, local authorities take strict measures to avoid air pollution. When the air pollution becomes too severe in Teheran, the capital of Iran, drivers are allowed on the roads only on alternating days, depending on whether their license plate starts with an odd or even number. In western cities like Milan (Italy) and Athens (Greece) similar measures are taken, sometimes stopping the traffic for a full day.

Other problems at the community level are related to the harvest of energy. In every community some people have to harvest the energy needed. They go into the mines for coal, go drilling for oil on the sea, cut wood or harvest biomass, or construct large hydroelectric dams. Harvesting energy is dangerous and heavy work, with a high risk of injury or illness. According to the International Labour Organization, about 10 million workers mine coal (approximately 0.3% of the global workforce). It is estimated that energy production and distribution causes about 70,000 to 300,000 deaths a year globally, and many more injuries. This is the price we pay for our energy.


© Adam Hart-Davis / DHD photo gallery

Acid rain can cause buildings, statues and bridges to deteriorate faster than usual.

Cattle and methane

About 20% of the methane emissions into the atmosphere come from animals like oxen, cows, and sheep. Cows can only digest some foods after a fermentation process, called rumination. During this process, bacteria in the cow's stomach produce methane gas. In a cow, around 2 - 12% of the energy from its food is used to make methane. The world-wide presence of 1.3 billion cattle making 100 millions tons of methane each year, has an appreciable effect on the balance of greenhouse gases. Human related processes, from energy production to agriculture, produce about 60% of the world's methane. Ruminating cattle produce approximately a third of that amount, or 20% of the world's total emission of methane.

Ruminating cattle release greenhouse gases.


© Ken Hammond (USDA)

The regional level

Another major environmental problem is acid rain, caused by sulphur dioxide and nitrogen oxides, both released from burning coal and oil products. Acid deposited by rainwater damages stone structures such as buildings and statues. If the ground cannot neutralize the acid, damage is done to plants and trees. Lakes can become too acid, which can lead to the death of fish populations. In time, whole ecosystems can be damaged.

But not only fossil fuels have large impacts. As already mentioned, the Three Gorges hydro dam in China will require about two million people to move from their land before it is flooded. In recent history, similar resettlement programs have caused large social problems.

The global level

Some gases in the atmosphere have the effect of forming an insulating blanket around the earth, which is called the *greenhouse effect*. The gases absorb part of the heat radiation from the ground, and send part of it back to the Earth. A greenhouse works in a similar way: the sunlight passes through the glass of the greenhouse, but the heat that comes from the hot ground inside cannot pass through the glass, and is trapped inside the greenhouse.

The greenhouse effect is very powerful: without it, the average temperature of the earth would be 33 °C colder, corresponding to a (very chilly) -20 degrees Centigrade! Life on earth, including human, animal, and vegetable life, could not exist without the greenhouse effect.

All the gases that contribute to this effect are called *greenhouse gases*. The gases in the atmosphere that contribute most to this effect are water vapour, carbon dioxide (CO_2), methane (CH_4) and N_2O. Carbon dioxide is released when wood, coal, gas, or oil are burned. Methane is released by rotting plants, mining, and cattle.

Not all gases have the same greenhouse effect in the atmosphere. Methane, for example, retains heat in the atmosphere 21 times more than carbon dioxide. So 1 gram of methane has the same greenhouse-warming effect as 21 grams of carbon dioxide.

Units of concentration: ppm

To measure small concentrations of a substance, we use the unit *parts per million* (ppm). It simply expresses how many particles of some substance are present per million particles, for example the amount of a toxin in food, or the amount of CO_2 in the atmosphere.

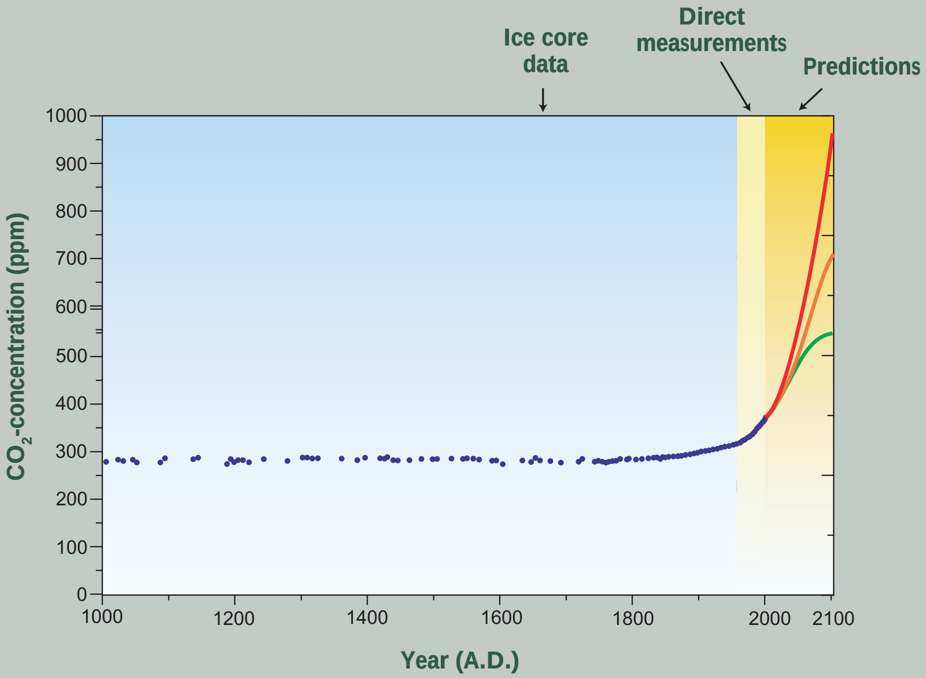

Figure 14.
Increase in CO_2-concentration during the last 1200 years. Clearly, the concentration has started to increase dramatically since the use of fossil fuels started around 1800.
The concentration is expressed in parts per million (ppm).

The International Treaty on Climate Change Mitigation

In the 1990s, scientists around the world started to give warnings about the dangerous effects of greenhouse gas emissions. According to several studies performed in a number of countries, the rapid increase of greenhouse gases in the atmosphere causes a small, but steady increase of the temperature of the earth. Special international panels and committees were created to discuss the problem, and they recommended urgent measures to meet this threat. The most important of these panels is the *Intergovernmental Panel for Climate Change* (IPCC), in which several hundred experts from over 100 countries across the world are involved.

Since the 90s, several initiatives have been taken to avoid the predicted catastrophic effects such as the global temperature rise, sea level rise, changes in rainfall patterns, etc. One of the most important initiatives was taken by the United Nations (which is the international organization aimed at maintaining peace and security, friendly relations among nations, and solving international economic, social, humanitarian, and environmental problems).

During the Earth Summit held in Rio de Janeiro (Brazil) in May 1992, most of the world governments approved a document called the "Framework Convention on Climate Change (UNFCCC)". Under this convention, governments promise to gather and share information on greenhouse gas emissions and launch national strategies to reduce greenhouse gas emissions. In the document, the stated aim was to achieve "stabilization of greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic

Both carbon dioxide and methane disappear slowly from the atmosphere. CO_2 is eventually taken up by the oceans, and CH_4 is broken down by chemical reactions in the atmosphere. This is a very slow process: it takes about a hundred years before a molecule of CO_2 is absorbed by the ocean, and about 12 years for a molecule of CH_4 to be broken down. So what follows is that whatever we do to the atmosphere now, the effects will be around for at least another hundred years! Even if we stopped producing CO_2 now, it would take a hundred years for the concentration to decrease. Our present use of fossil fuels and the consequent emission of greenhouse gases is like carrying out a large-scale experiment with the earth, with all of us sitting in the test tube…

A global temperature incease will lead to a higher sea level.

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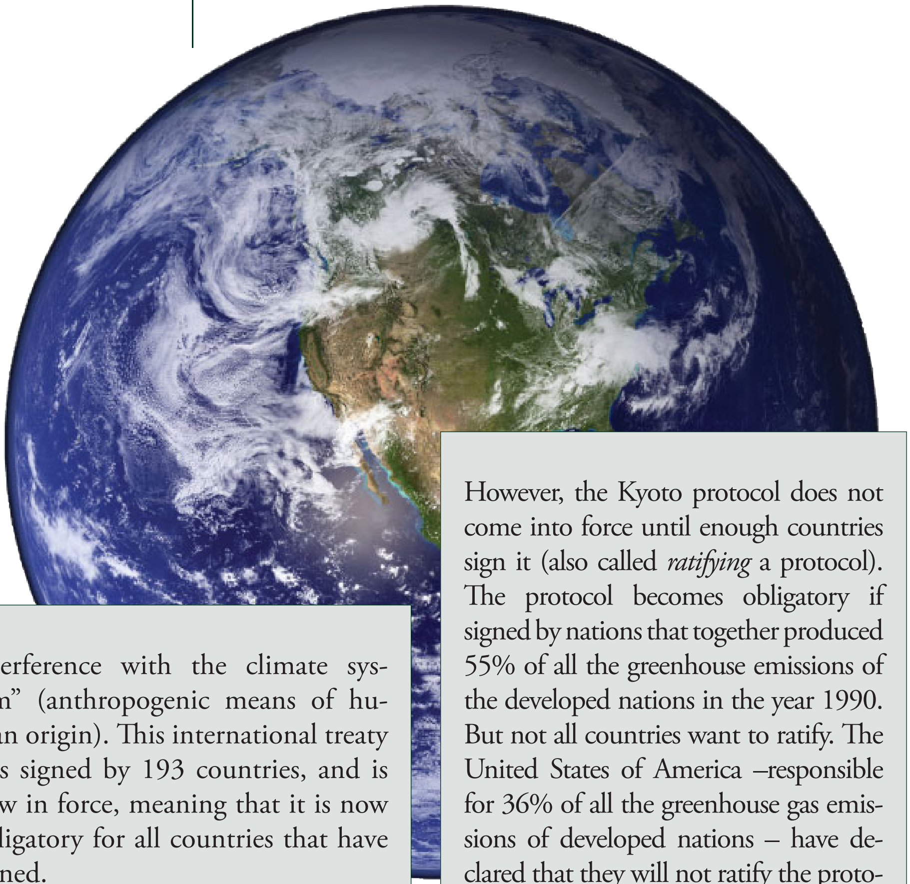

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interference with the climate system” (anthropogenic means of human origin). This international treaty was signed by 193 countries, and is now in force, meaning that it is now obligatory for all countries that have signed.

When they adopted the Convention, governments knew that it would not be sufficient to have a real effect on climate change. During the United Nations Climate Change Conference in Kyoto, in December 1997, major industrial nations therefore agreed to reduce greenhouse emissions. After long and difficult negotiations about how much, where, and when to reduce emissions, and who is going to pay for it, a pact was signed to reduce the global emissions of the developed countries. The goal was set that by 2012, the greenhouse gas emissions of the countries signing the treaty should be reduced by 5.2% compared to the emissions in the year 1990. This pact is known as the *Kyoto protocol.*

However, the Kyoto protocol does not come into force until enough countries sign it (also called *ratifying* a protocol). The protocol becomes obligatory if signed by nations that together produced 55% of all the greenhouse emissions of the developed nations in the year 1990. But not all countries want to ratify. The United States of America –responsible for 36% of all the greenhouse gas emissions of developed nations – have declared that they will not ratify the protocol, and for a long time, Russia held the same opinion. But in November 2004 Russia changed its mind, and ratified the protocol. After eight years of waiting, the Kyoto protocol finally entered into force in February 2005.

At the moment, countries are trying to work out the most practical methods of reduction. Should we use energy more efficiently, or should we supply more CO_2-free electricity, using solar panels for example? Do we have to build more nuclear power plants, because they do not emit greenhouse gasses? Should we invest in windmills or in fusion research, or in both? Or, perhaps, should we do everything we can think of, because the problem facing us is so large?

In the last 150 years, we have burned a lot of fossil fuels, which have released huge quantities of CO_2 into the atmosphere. As you can see in figure 14, the CO_2 concentration in the air has risen by 35% since 1800. The CO_2 concentration has fluctuated before in the past, but never this quickly. If changes occur over thousands of years, the ecosystem has a chance to adapt itself, but with this very fast change, ecosystems may not be able to adapt. This could lead to many species of animals and plants becoming extinct.

Does all this extra CO_2 have an effect on the global climate? In the last century, the average temperature has risen 0.6 degrees Celsius and the sea level has risen by 10 to 25 centimetres. The 10 warmest years since recording temperatures started in the 19th century, have all occurred after 1990. Mountain glaciers around the world have shrunk, and cloudiness and rain have increased around the world. It is expected that by the year 2100, the average air temperature could rise by 1.4 to 5.8 degrees Celsius. To put this number into perspective: the difference in average temperature between the last ice age – thousands of years ago – and today, is just 6 degrees. The sea level could increase by 9 to 88 centimetres.

You might think that an average temperature rise of a few degrees is not much of a problem, but actually it is. First of all, the rise in sea level caused by a few degrees temperature increase will immediately cause problems for many coastal areas. Secondly, the inland temperatures will change by much more than the average, and cases of *extreme weather* – floods, draughts, and hurricanes – will become more frequent.

Scientists expect that in the best case, by the end of this century, the CO_2 level may become twice as high as the level before 1800. In the worst case, it may become four times as high. If the CO_2 level quadruples to four times the pre-industrial level of 280 ppm, the world will look quite different. The sea level could rise about one metre, temperatures could go up locally by 15 to 20 degrees Celsius, and on the average about 6 degrees. There are enough cheap fossil fuels available to make this scenario become reality.

What can we do about it? The only way to stop the harmful effects of extra CO_2 is to stop producing it, which means to stop using fossil fuels, or, to capture and dispose of the CO_2 produced. Obviously, both options are impossible at this moment. But even if we want to stabilize the CO_2 level at twice the pre-industrial level, we will have to cut our CO_2 production by two-thirds within the next decades. And instead of decreasing, the CO_2 production is rising every year.

Energy options and the greenhouse effect

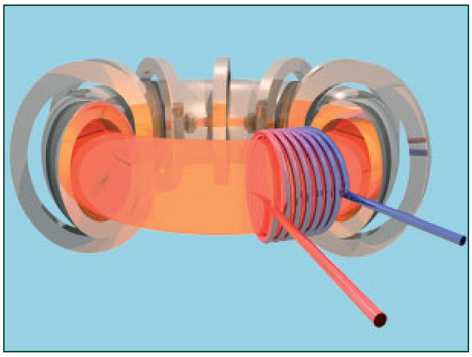
Not all energy sources produce greenhouse gases. Solar panels, wind energy, and hydropower are all examples of energy sources that produce electricity without making CO_2. But even that is not quite true. To make the materials for windmills or solar panels, energy is needed – which mostly comes from fossil fuels. And in the case of hydro dams, rotting plants in the water can produce methane, which is a very powerful greenhouse gas.

Can we generate all our energy without producing greenhouse gases? Yes, but we will have to work very hard to achieve that. Solar and wind energy only play a very small role now, and it will take many decades, a lot of research and development, and a lot of money, before they will generate substantial amounts of energy. New, safe types of nuclear power plants may provide part of the answer. The technique of putting CO_2 back in the ground has a large potential, but is still an experimental technique, and questions about the effects and risks in the longer term have to be answered. It will still take some decades of research and development before fusion power can start to deliver a reasonable share of the energy mix. If we take the climate problems seriously, we will have to develop all the clean energy sources, and we will have to do it quickly.

One of the consequences of climate change is more frequent violent weather conditions such as storms, droughts, and floods.

6 Thinking ahead: the energy sources of the future

We live in a world that has only just *begun* to consume energy. The rapid rise of the world population – from 6 billion today to 9 billion 50 years from now – combined with the rapid economic development of countries like China and India, push our energy needs to ever-increasing heights. During the next 50 years, mankind will consume more energy than the combined total in all its previous history. Figure 15 shows the development of global energy needs, for different regions in the world.



Our future energy system is determined by decisions we take today

With carbon emissions threatening our environment, the world needs a massive shift towards cleaner energy sources. New solutions are required to face the surging demand for energy, and to face the problems connected to the present energy system.

Current problems

It is expected that in 50 years, the world energy use will be at least twice as high as today. This growth leads to at least four serious problems.

The first one is that we will slowly run out of easily obtainable and cheap fossil fuels. Although there is enough coal to last another two hundred years, nature has not been so generous with oil and gas. Estimates by various groups place the peak of the world oil production – the moment in time after which world production of oil starts to decline – anywhere between 5 and 20 years from now. For gas, the peak will come about 20 years after the peak for the oil.

A second problem is that oil and gas reserves are not spread evenly around the world. Almost 80 percent of them are located in the Middle East and in the Russian Federation. So, if we remain dependent on fossil fuels, we will become very dependent on these countries. At the moment, Europe imports 50% of its energy, most of it in the form of gas, oil and coal. It is expected that, if no measures are taken, in 20 to 30 years from now Europe will have to import 70% of its energy. For this reason, many countries are considering options, such as wind power or nuclear fission, to make them less dependent on other countries.

A third problem is the damage to the *environment*. When coal, one of the most abundant fossil fuels, is burnt, a large amount of pollution is produced. So if large countries such as China and India remain dependent on coal (as they are now), their local environment will suffer badly, as it already does today. Moreover, CO_2, the gas responsible for the greenhouse effect, does not stay inside a country's borders and therefore it is a problem for the whole world.

The fourth issue is *energy poverty*: at the moment, some 2 billion people are still dependent on firewood for cooking and heating. Their lack of access to modern forms of energy is a major hurdle for their economic development. The oil price, which has seen a large increase in the last few years, is another hurdle. Rich countries can afford expensive oil, but poor countries cannot.

The goal of sustainable energy

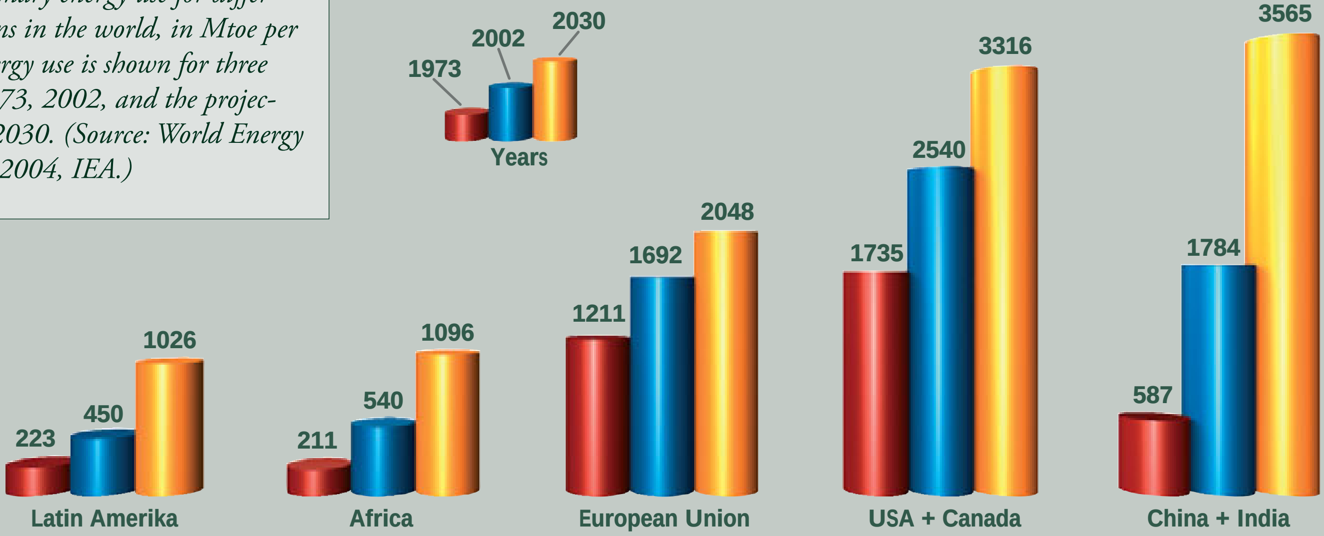
What is the goal that we should set for the development of the energy system? What do we want the energy system to look like in, say, 100 years from now?

In an ideal world, we would like *sustainable development*. When the term was first introduced (in the Brundtland report, published in 1987), sustainability was defined as: "*Meeting the needs of the present generation without compromising the ability of future generations to meet their needs*". In other words, we shouldn't use up more than our fair share of resources, and we should make it possible for future generations to meet their needs, for example by offering them as many sustainable energy technologies as possible to choose from.

What does the goal of sustainable development mean for energy production? We would like energy produced and used in ways that support human development over the long term, in all its social, economic and environmental dimensions. This is what we call *sustainable energy*. It refers to the production and use of energy sources in ways that respect long-term human development and ecological balance.

To reach this goal in the long run, we would prefer to userenewable energy sources: ones which never run out. Among those sources are wind, water, solar, and biomass energy. As the available fuels for fusion are abundant enough for millions of years of energy production, it can also be considered as a renewable source for all practical purposes.

Figure 15.
Total primary energy use for different regions in the world, in Mtoe per year. Energy use is shown for three years: 1973, 2002, and the projection for 2030. (Source: World Energy Outlook 2004, IEA.)



At the moment, a sustainable energy system is still a distant dream. According to the 2002 world energy balance produced by the International Energy Agency, only 14% percent of the world energy comes from renewable sources (including non-commercial biomass like firewood), and 18% of our electricity. At the moment, almost all of the renewable energy comes from hydropower, the burning of waste materials, and biomass. What is worse, the growth of the world energy demand is larger than the present growth of the supply of renewable energy.

Renewable sources

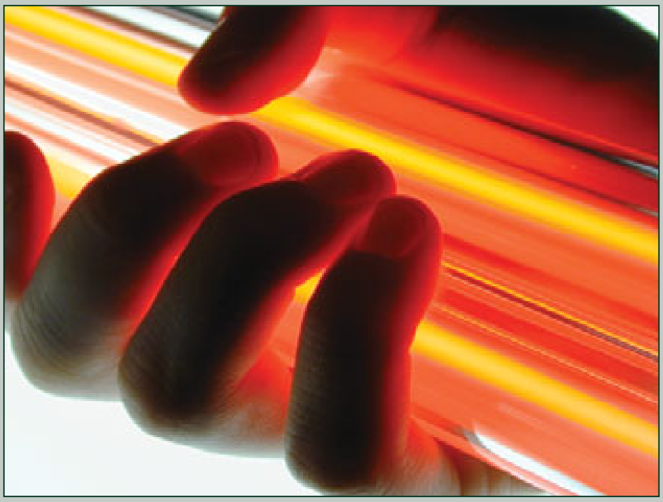
Why don't we use much more renewable energy already? There are several reasons. The first one is that the world is only just starting to realise the full scale of the energy problem, and the dangers of climate change. The sense of urgency required has been lacking until now. At the moment, solar, wind, and biomass energy are growing very fast, because many governments have actively started to promote the use of these sources.

The second reason is that, despite many years of research and development, renewable energy technologies remain more costly than fossil fuels. Of course, it is very hard to compete with a fuel that you can practically just pick up from the ground. We will have to get used to the idea that the availability of cheap energy is at an end, and we will have to pay more for our energy. We should bear in mind that fossil fuels have many 'hidden' costs, such as those of the greenhouse effect and the medical costs of diseases caused by polluted air. If these costs are taken into account in the price of electricity, the picture may change in favour of renewable energy sources.

The third reason is that wind and solar energy in particular are so-called *intermittent* sources of energy, meaning that they do not deliver energy all the time. This means that we need back-up power, or means of storing power for the time when there is no sun or wind. This increases the costs of these energy sources. Furthermore, sun, wind and geothermal sources are not spread evenly around the globe, and are very site-specific.

In addition, renewable sources like wind, solar and biomass need a large surface area. Say you cover an area of land in Northern Africa, which has an average input of solar power of 250 W/m^2, with solar cells that turn sunlight into electricity with an average efficiency of 14%. Then, allowing for the fact that the sun is shining at an angle, you need to cover an area of 30-40 square kilometres with solar panels to generate the same output power as a 1,000 MW power plant. Although this is certainly possible, the size of a large-scale renewable power plant should not be underestimated.

A second example: to get 1000 MW of biomass power, you need 2000 square kilometres of good farming land to grow energy crops. The production of fertilizers is energy-intensive and uses fossil fuels as a base, so the use of fertilizer to grow biomass needs to be minimized, which hampers production.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Moving to more efficient sources of light saves energy

How to choose an energy source

To make appropriate choices for the future, you need to know what your energy needs are. Different energy needs require different solutions. In this section, we look at the different aspects one has to consider in choosing an energy source. Energy sources are used to power industry and transportation, heat homes, and generate electricity. Here, we look at electricity generation only.

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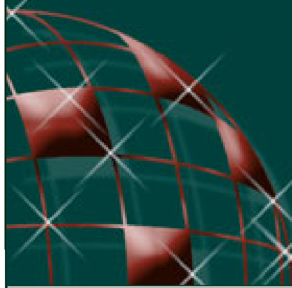
Research in solar power

The most suitable energy source for electricity production in a given situation depends on many factors. Some energy sources, like coal, are cheap. But if you don't have coal mines, you become dependent on foreign countries. Fossil fuels emit greenhouse gases, which result in climate change. Other sources, like solar energy, are available throughout the world (at different prices, depending on climate conditions), but they are still very expensive, and have a limited capacity. Let us see which factors determine the choice of an energy source.

First of all: how much does the electricity cost? The so-called *capital costs* are the costs for building the energy source in the first place: the construction of the power plant, buying the solar panels. These costs are expressed in euro's per MW of power. But there are additional costs: a power plant needs fuel, it needs people to operate it, and after its lifetime is over, it needs to be dismantled. If all these costs are added together, and divided by the total number of kilowatt-hours the power plant will produce during its lifetime, you arrive at the *price per kilowatt-hour*, also called the *generating costs*. For a coal-fired power plant, these costs are about 0.03 Euro/kWh. The price the consumer pays is much higher than that, around 0.12 Euro/kWh, because of the distribution costs, taxes, etc.

Apart from costs there are more factors, like the required *capacity*. If you need 1 kilowatt of power for a small workplace in Africa, you have many choices, ranging from a small windmill to solar cells, or a diesel generator. But if you need to power a large city, for which you need 1,000,000 kW (1000 MW), you will need to think of coal- or gas-fired power plants, or may be a nuclear fission power plant.



Energy source	Capital costs (Euro per kW)	Generating cost (Euro per kWh)	Range of power	Intermittent?	Dependence on other countries?	Centralized (C) or decentralized (D)?	Advantages	Disadvantages
Oil products	1000	0.25	1kW - 10MW	no	high	both	high energy content good distribution system easily tranported	promotes global warming creates political tension supplies will run out
Coal	800 - 1100	0.03	1MW - 1GW	no	high	C	large supply inexpensive easy to recover	global warming, acid rain expensive transportation system air pollution
Gas	300 - 600	0.03	1MW - 1GW	no	high	C	easy to transport easy to obtain relatively clean	global warming supplies will run out
Nuclear fission	1000 - 1500	0.05	250MW - 1GW	no	medium	C	no greenhouse gases waste is compact fuel is inexpensive	large capital costs long-term high-level waste potential nuclear proliferation
Large Hydro	1400	0.05	10MW - 20GW	no	none	C	inexpensive once dam is built renewable fuel	only available in some locations environmental damage downstream often needs extensive relocation of local people
Solar PV[1]	4000 - 6000	0.60	10W - 10MW	yes	none	D	renewable fuel potentially very large scale distributed	needs lare area of land currently very expensive not available everywhere
Wind[1]	700 - 1200	0.07	100W - 100MW	yes	none	D	renewable fuel distributed	needs large area of land needs energy storage highly climate dependent
Biomass	1300 - 1700	0.04	1kW - 150MW	no	none	D	renewable fuel	inefficient if small plants are used needs large area of land
Fusion[2]	6000	0.07	1GW - 2GW	no	none	C	no greenhouse gases abundant fuel supply only short-term waste	commercial plant is 35 years away large capital costs large units

Table 10.
Characteristics of different energy sources. Sources: Energy Information Administration, SAGE project, NEMS.
1) The capital cost quoted are for peak capacity. If the capacity factor is taken into account, wind becomes 3 - 4 times as expensive, and sun about 10 times.
2) The capital costs of fusion are estimates for the year 2050, when it is expected that fusion will come available on the market. (source EFDA)

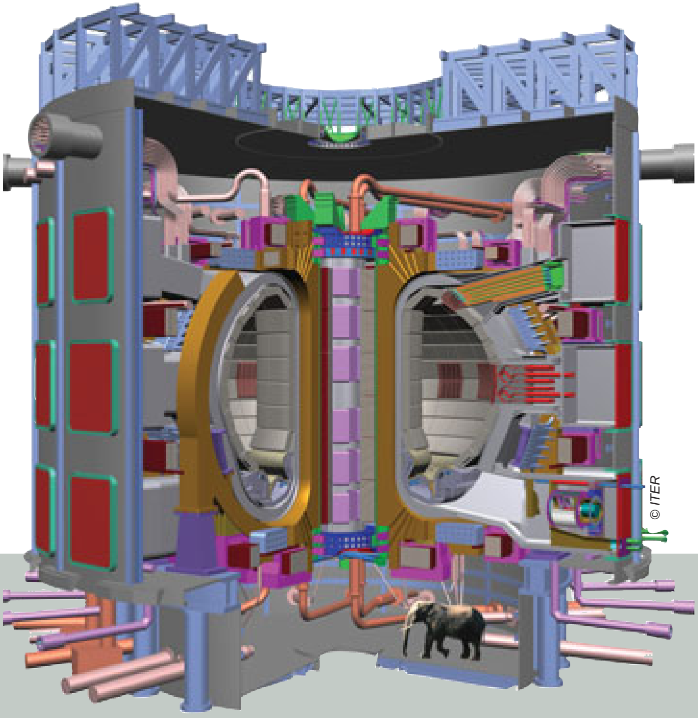
Furthermore, there are environmental considerations such as the greenhouse effect: you may decide to generate CO_2-free electricity, for example with nuclear energy, or clean fossil. So the *greenhouse-gas emission* is an important factor.

Also the *land use* may be important. If you decide to use biomass as an energy source, you will need a big area of empty land that can be used to grow energy crops. With an expanding global population, that may be hard to come by. The same holds for putting windmills in densely populated countries.

As with all technology, *safety* is very important. If a hydro dam breaks, or a nuclear fission power plant has a serious accident, immediate evacuation of many people is necessary. You also don't want to stand next to a wind turbine losing its blades. Many people lose their lives in coal mining, in coal-dust explosions in power plants, and in oil-well accidents. Although there is no such thing as "safe energy", some sources are more dangerous than others.

Renewable energy sources like wind and solar do not deliver energy all the time. This is the *intermittency* of a source. A large share of intermittent energy sources will require some form of energy storage, or back-up power. Some sources, like nuclear fission, are best used for centralized energy generation, while others are more suitable for decentralized, on–the-spot generation of energy. So it is important if a source is *centralized or decentralized*. Finally, if fuel (like oil) has to be imported, a country can become very dependent on other countries. So the *dependence on other countries* is an issue, too.

In table 11 all the energy sources are compared using these different factors. As you can see, depending on what your needs are, different energy sources can be suitable.


© ITER

The next experiment in fusion power, ITER, will be finished around the year 2015. The elephant in the lower part of the picture indicates the scale.

Fluorescent lights use five times less energy than normal, incandescent lightbulbs.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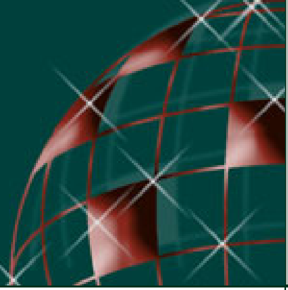


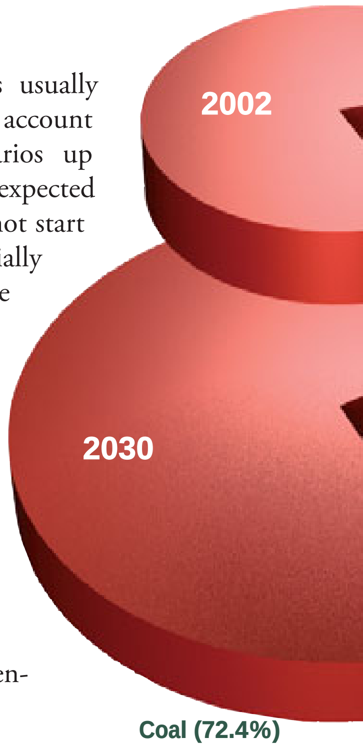
The future energy mix

People study possible future energy situations using so-called *energy scenarios*. Each scenario can be seen as one particular image of how the future could unfold. Figure 15 shows such a scenario, produced by the International Institute for Applied Systems Analysis (IIASA), together with the World Energy Council (WEC). Of course, this represents just one outlook on the future. Other organisations, companies and research institutes hold different views.

The IIASA/WEC study was published in 1998, and it presents six different scenarios, which have different assumptions about technological and economic development, and measures taken to protect the environment. The scenario presented here is the 'middle' scenario, which represents average technological developments and economic growth.

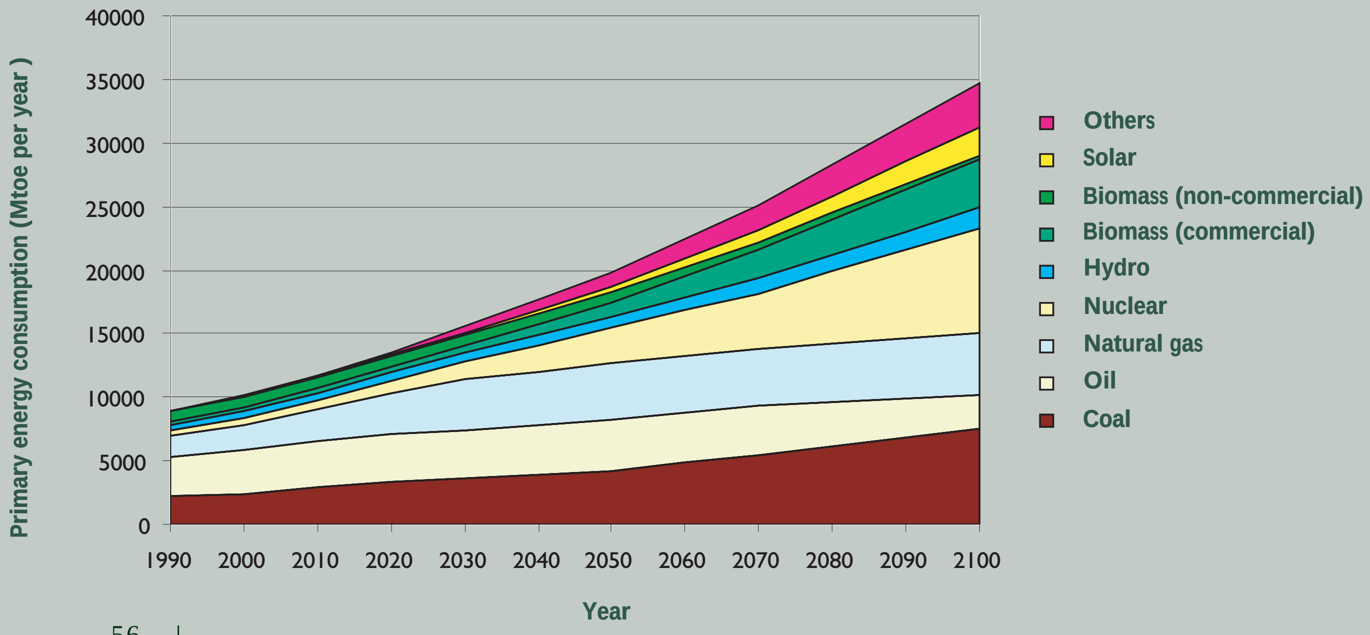
What makes their scenarios a little difficult to interpret is that they lump together various energy sources, such as wind energy, geothermal energy and waste. They also lump together nuclear fission and fusion under the name "nuclear".

Fusion power is usually not taken into account in energy scenarios up to 2050, as it is expected that fusion will not start being commercially available before 2040 - 2050. After that time, fusion energy can form a considerable contribution to the production of energy, and in the reduction of the emission of greenhouse gases.



From figure 16, we see that this scenario expects a large increase in the use of coal, gas, nuclear power, and commercial biomass. In 2100, solar power and the "other" renewable sources represent 16% of world energy according to this scenario. In the case of electricity production, this scenario expects a large increase in the fraction of renewables and nuclear energy.

Figure 16.
Energy scenario for the global primary energy consumption up to the year 2100. (Source: World Energy Council and IIASA, 1998, middle scenario).



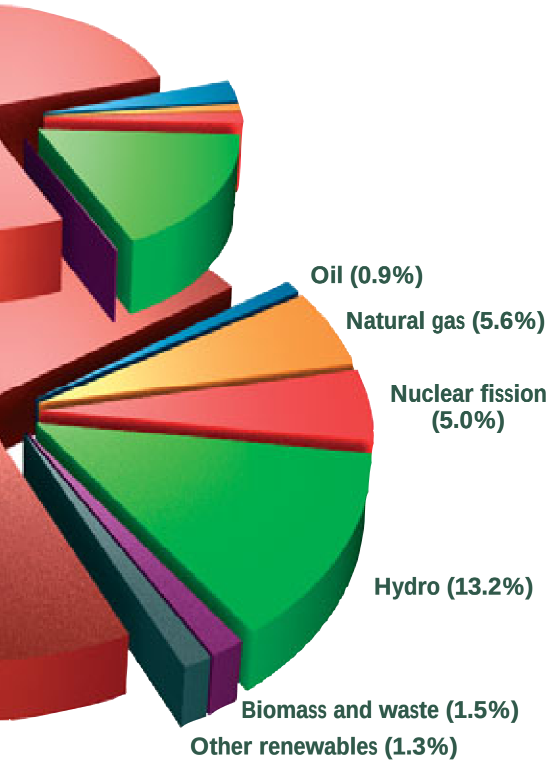


Figure 17.
Projected growth of electricity use in China over the next 25 years. The present use (1675 TWh in 2002), will probably grow to 5573 TWh in the year 2030. Most of this growth will be realised by coal-fired power plants.
(Source: World Energy Outlook 2004, IEA)

Of course, this is just one possible scenario, and things may turn out to be very different. It is very hard to predict 50 years into the future, let alone 100 years. One thing we do know for certain is that changing the energy system is a very slow process. If a new technology is discovered for generating energy, it takes up to 50 years before the source has a reasonable share of the global energy mix. Factories and power plants have to be built, research and development have to be carried out, and people have to be trained.

To illustrate the speed of the growth, figure 17 shows the projected increase of electricity use in China over the next 25 years. Chinese energy planners think that most of this growth will be realised by coal-fired power plants.

Energy research

In the future, we will need all the energy options that are available to us. Currently, a lot of research is aimed at developing new energy sources, improving existing ones, and improving the efficiency with which we use the energy. Private companies in developed nations spend a lot of money improving existing commercial energy technologies. Public institutions like universities and research institutes funded by the government try to develop energy technologies that are not yet at a commercial stage.

Full speed ahead

To give an example of the size of the required developments, suppose that we want to have 10% of the world's energy demand met by wind energy in the year 2050. If we expect the total energy demand in the world to double by that time, we need roughly 22.000 Mtoe of energy in 2050, which is equivalent to 920 EJ (1 EJ = 10^{18} joule). A windmill of 3 MW with a capacity factor of 33% produces 3.1 $\cdot 10^{13}$ J per year. So if we want to cover 10% of the world energy demand with wind, we will need close to 3 million windmills in 2050, which means we have to build 7 windmills every *hour* for the next 50 years.

And that is just to supply 10% of the world's energy. From this example, it is clear that we will need to develop all possible clean energy sources as soon as possible, as there will be no single solution to the world's energy needs.

If our energy system will become more sustainable or not will depend on how much money we are willing to spend for a clean and healthy energy system.

The companies that supply the primary energy, such as coal and oil companies, try to get more energy out of the ground using improved technology. Coal companies try to extract methane (the primary component of natural gas) from layers of coal, or even to turn coal straight into gas underground. Oil and gas companies try harder to find new wells, by using advanced measurement techniques and computer models. They also try to get more oil and gas from existing wells, by a variety of techniques like injecting steam or CO_2. Another field of active research is CO_2 storage: to avoid emission to the atmosphere, the CO_2 produced while burning fossil fuels can be put underground in old gas fields or water layers.

The companies that refine the crude oil into fuels like gasoline and kerosene, constantly try to reduce the amount of sulphur and other harmful substances in their products. The companies that build power plants try to improve the efficiency of the plant, and to reduce pollution. A lot of companies and public institutions, like universities, try to improve the technology for capturing renewable energy such as wind and solar power in ever cheaper and more efficient ways.

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A bus in Amsterdam, powered by hydrogen, a fuel cell, and an electric motor.

In the different sectors where energy is used, research activities are even more diverse. The efficiency of most energy devices is improving, from refrigerators, light bulbs, automobiles, and motors to every kind of oven and boiler used in industry. The list of energy research, development and demonstration projects carried out in recent years is extremely long, with many successes.

Some of the energy sources that were mentioned in chapter four are still actively studied. For example, there is a worldwide research program aimed at developing fusion energy, and great progress has already been made. It is expected that fusion energy will become available commercially around 2040.

The energy carrier of the future: hydrogen?

In the ideal case, we would like to use electricity for all purposes because it is easy to transport and clean to use. However, we have already seen that electricity has a number of disadvantages, most of all that it is hard to store. That's why we use fossil fuels like petrol for transportation: it is easy to store and contains lots of energy in a small volume. So for the future, we would like to have a substance that is easy to store and transport, contains lots of energy, is pollution and carbon free, and can be efficiently turned into power where we need it. What we want is an efficient and clean *energy carrier*.

Several possible fuels have been proposed for this goal: methanol, ethanol, special synthetic liquids such as dimethyl ether made from natural gas or coal, compressed natural gas, and hydrogen. Of these, hydrogen offers the greatest potential benefits. Hydrogen can be made from a wide variety of primary energy sources, like natural gas, coal, oil, biomass, waste, sunlight, wind, fission, and fusion power. Hydrogen can be burned or used in a fuel cell, with zero emission (just water) when used. Fuel cells turn hydrogen (and oxygen) into electricity at low temperature and high efficiency. Recently, rapid progress has been made towards using fuel cells for transportation and power applications in industry. If hydrogen were made from renewable or nuclear sources, or from fossil fuel with CO_2 sequestration, it would be possible to produce and use fuels with hardly any emission of air pollutants or greenhouse gases.

It is important to stress that hydrogen is not a new energy source: it is just a convenient intermediate form of energy. We first need energy to make the hydrogen out of water by electrolysis or some other chemical reaction. The production of one kilogram of hydrogen requires about 50 kWh of electricity.

The use of hydrogen as an all-round energy carrier leads to the concept of a *hydrogen economy*. In a hydrogen economy, the two main energy carriers are hydrogen and electricity, and the whole energy system is organized towards them. The concept of a hydrogen economy has been explored several times, first in the 1950s and 60s, when hydrogen was seen as a complement of an energy system largely based on nuclear fission, to store off-peak fission power. Later, it was explored as a mean to store the intermittent energy from renewable sources, or to build a second energy grid complementary to electricity. Recently, the idea is to make hydrogen from fossil fuels, and to capture the CO_2 released in the process and to store it in old gas or oil fields, or in deep subterranean water layers.

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A small fuel cell powering a laptop. The thin cilinder contains the hydrogen.

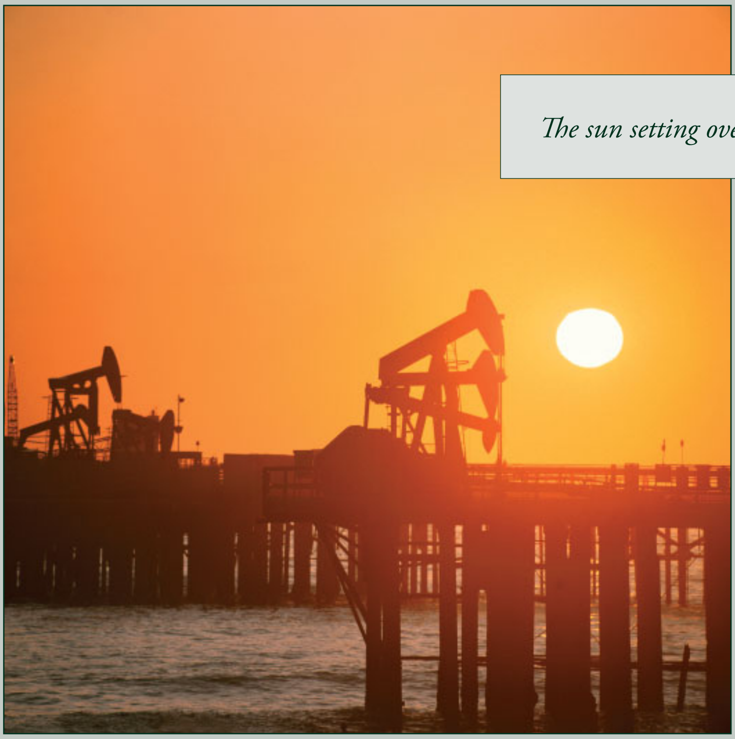
Conclusion

All large-scale energy production systems have their pros and cons. Fossil fuels emit greenhouse gases and other pollutants, new hydro dams change the environment and have social costs, biomass needs a lot of surface area. Nuclear fission power plants are emission-free but produce nuclear waste. Using fossil fuels often makes countries very dependent on other countries. It seems we cannot have the good features without some of the bad ones. The best way is to have a diversified energy system, using all possible energy sources, so that the risks and negative impacts of all sources can be limited.

There are other reasons for a diverse energy mix. For urban populations, the best approach is to have a centralized energy generation in the form of power stations of a 1000 MW or more, combined with a strong power grid. On the other hand, rural societies are better served with small, decentralized sources of energy such as wind or solar power.

The energy system changes only slowly, because it is very large. Our decisions now on which technologies to develop and support, will largely determine what the energy system will look like in 50 years or more. We have to provide the generations that come after us with the techniques they need to satisfy their energy needs. As there are so many uncertainties about future developments, the best approach is to develop all available energy sources so that they become available when they are needed.

Research in renewable energy sources, safe and clean ways of using fission power, and new sources like fusion energy are all needed to guarantee our energy many years from now. The future of energy starts today.



The sun setting over an oil field.

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