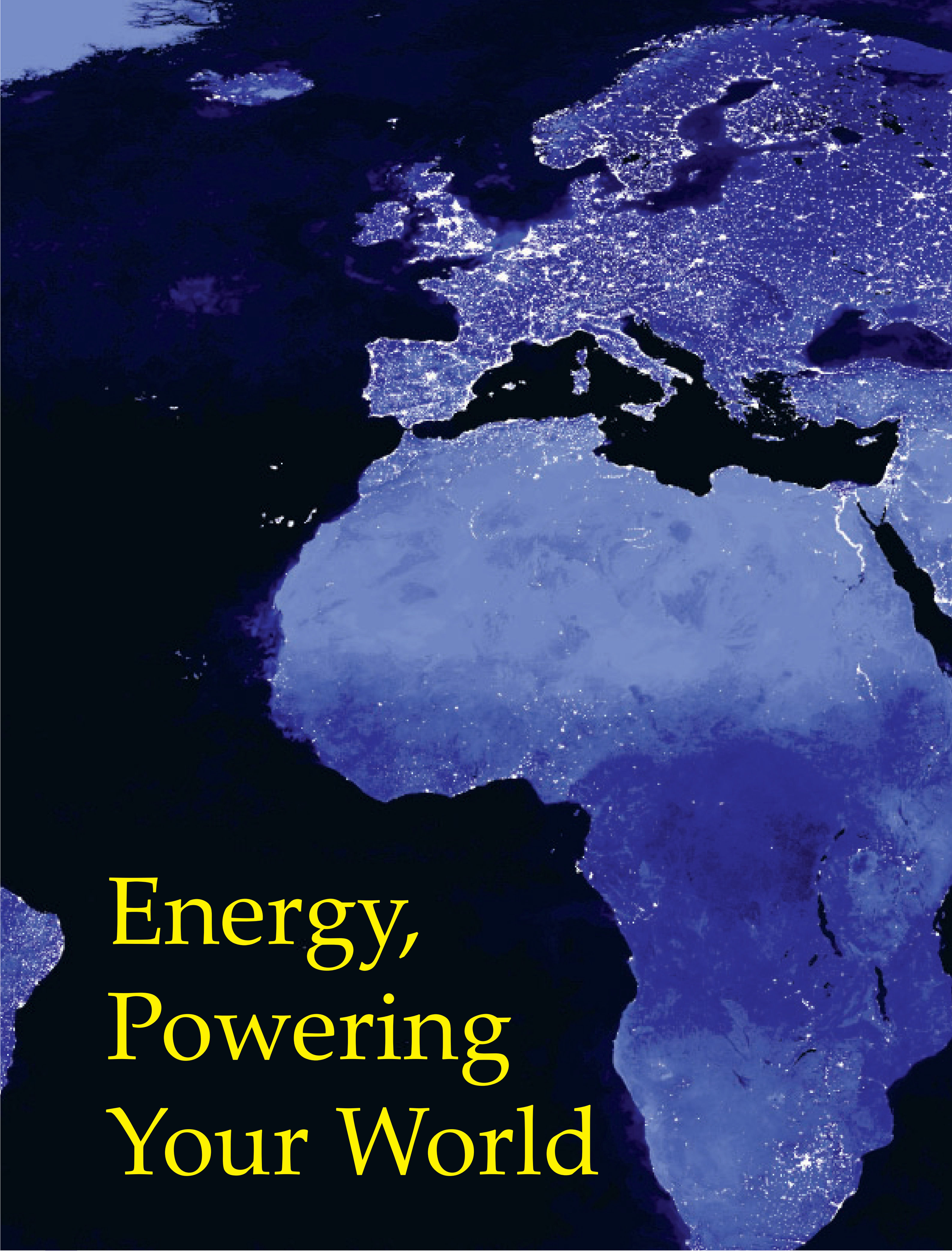

Energy, Powering Your World

PREFACE

This booklet is part of the 'Couldn't be without it!' educational project from EIROFORUM, a European initiative to bring information from Europe's top research institutes to schools and universities. 'Couldn't be without it!' aims at explaining the relationship between research and technologies which school students consider they can't do without, like computers, mobile phones, stereo installations, etc.

'*Energy: powering your world*' focuses on energy. Energy in our daily lives, the ways we use it, where it comes from, and how we will deal with our energy needs in the future. The future of energy starts today: important decisions need to be taken, and much research has to be done to guarantee our energy supply in the years to come, and to limit the damage done to the environment and our health. This booklet presents several aspects related to energy. The aim has been to supply teachers of 15-18 old students with material useful to them in their teaching.

All chapters include boxes which highlight detailed information, conclusions at the end of each chapter, exercises for the students and lists of web sites where more information about a particular subject is available. All web links are selected for their educational qualities and contain either information useful for school students or provide further information for teachers.

Cover picture: Earth's city lights at night. The picture was composed from photos made by satallites. Courtesy NASA

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We would like to thank Chris Warrick, Jennifer Hay and Niek Lopes Cardozo for helpful comments. We hope that this booklet provides the reader with useful educational information about the dynamic world of energy. The authors and the contributors warmly welcome any suggestions or comments leading to the improvement of this booklet.

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Table of contents

1 An introduction to energy

Energy is so normal to us, we hardly notice it. When we take a hot shower in the morning, we use energy. To wash we need soap and a towel, which were 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 for cooking, to get your own water at a well, to walk 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 we use (including electricity, petrol for transportation, etc) using muscle power only, we would need 100 people working for us, or about 10 strong horses. All day long, every day of the week. The power that flows through the wall socket in your house has the strength of many horses.

We take the abundance and availability of 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, and what the effects are for 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. If you have studied physics, you may know that even mass is a form of energy. We say that energy is present in energy sources, like wood, wind, food, gas, coal, and oil. All these different forms of energy have one thing in common - that 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 capacity to do useful work.*

Some energy services

Transportation
Light
Hot water
Cooking
Air conditioning
Manufacture of products
Sound
Clean water
Telecommunication
Computing

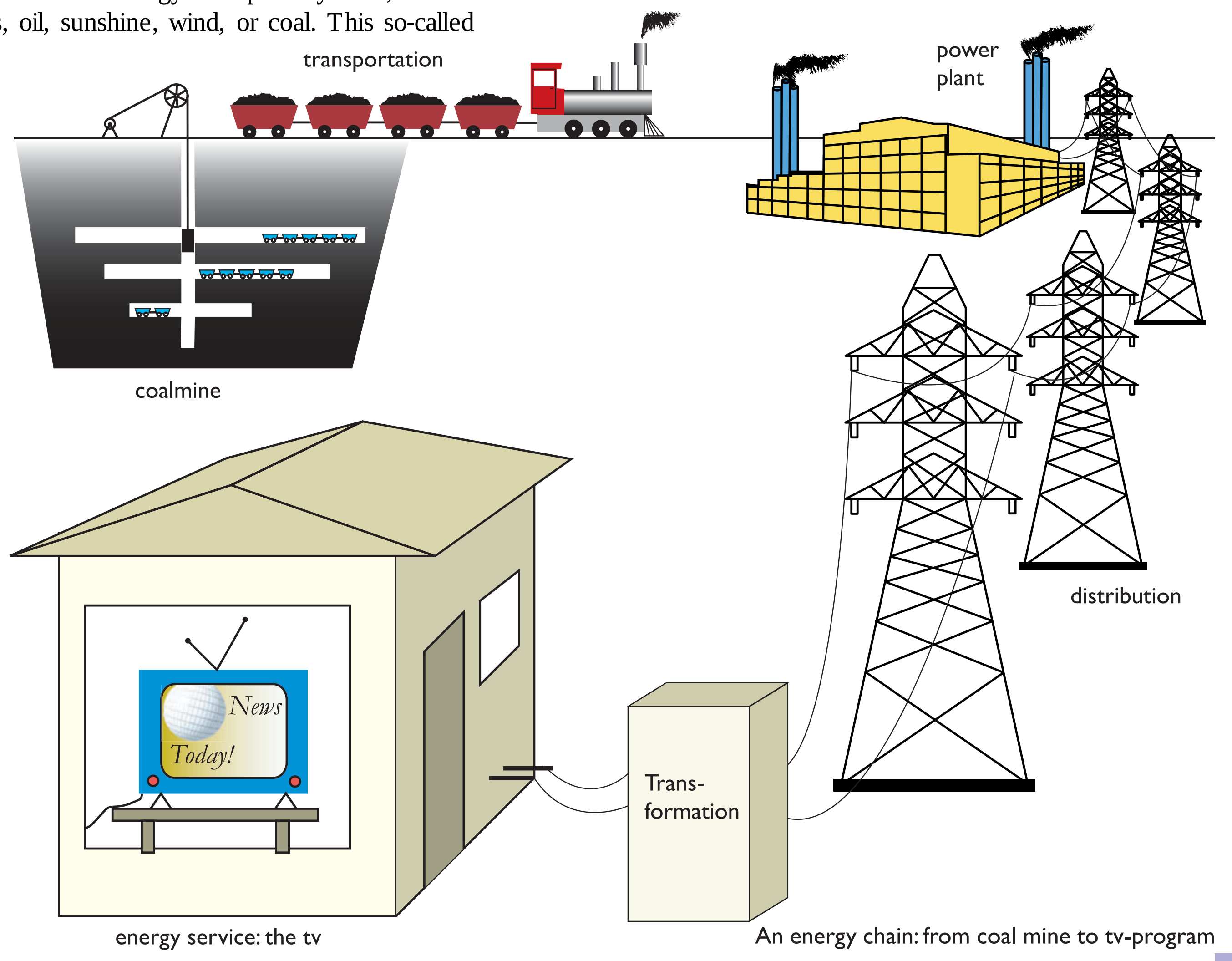
Energy is important to us because we use it to do the things we need, which we call *energy services*. Among the energy services are cooling and refrigeration, space heating, food-processing, water-cleaning, using mobile phones, driving a car or motorbike, making light and sound, the manufacture of products, 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 it come from?

Normally, we don't think very often about what happens beyond the wall socket or gas 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, there are chains of technologies that provides the energy.

The energy chains starts with the collection and extraction of energy in its primary form, such as gas, oil, sunshine, wind, or coal. This so-called *primary energy* is not of much use to us yet. The next step is to convert it into so-called *final energy*, such as electricity or petrol. Then it is necessary to transport, distribute and deliver it to the users. Finally, equipment like light bulbs, TV's, stoves and vehicles turn the final energy into *useful energy*, 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 activities need fuel or electricity. The energy chains are consequently very large: coal mines, oil platforms, pipes, distribution of coal and oil over the earth by large ships, power plants, transmission lines, gas stations, and much more. All together these energy chains 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 can hardly do without, like hot water, transportation and telecommunication, need energy. In his long history, mankind has often found new sources of energy and learned to use them to increase his well-being and comfort. Let's have a look at the history of energy.

Crossing the oceans using wind energy

Ancient times

Mankind learned to control fire long ago, perhaps as long ago as 500,000 years before Christ. In these 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, iron age and bronze age – derive from the ability of people to use energy to make metals and to manufacture tools and weapons.

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.

Present day use of animal power in India

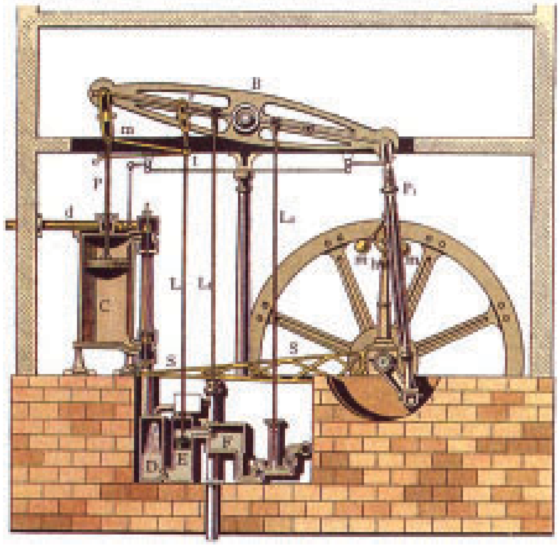
Another early source of energy, still used today, is animal power. Horses, oxen, camels, donkeys, elephants – their power can be used for transportation, farming, and to drive machines for grinding grain and pumping water. In the developing world, animal power is still used for many purposes. Animals have different characteristics: while oxen are very strong and useful for ploughing the fields, horses are faster, and are better suited for transportation. And human power was used as well: Roman warships that were used in 260 BC 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 on the Nile River, and several centuries before Christ, windmills were used in China to pump water. Around A.D. 600, windmills were used in Persia to grind grain.

The power of falling water 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 Archimedes used a large mirror to set Roman warships on fire during the attack of Syracuse (around 240 BC).

Of the fossil fuels, coal has the longest and most varied history. People in China used coal as early as 3000 years ago, and there is evidence that Romans in England used coal for cooking in A.D. 100-200. In 1298, the famous explorer and traveller Marco Polo published a book about his travels in China, in which he reports about “large black stones which ... burn away like charcoal.” For centuries now, it has been one of our most important fuels.



James Watt’s steam engine

Energy in the 1600’s

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 in England had become a booming business, and coal was exported around the world. Although English cities became very polluted by all the coal burning, the English preferred to put up with it, as they needed their wood for making charcoal. Charcoal was needed in large quantities for iron smelting, and the processing of other metals. Wood was also used in large quantities to build naval warships.

The first energy crisis in history started in 1630, when charcoal, made from wood, started running out. Coal from coal mines could not be used for this purpose, as it contained too much water and sulphur, which made it burn at a lower temperature. Large parts of the woods in Sweden and Russia were turned into charcoal, to solve this problem. Around 1700, people learned a way to remove the sulphur from fossil coal, so they could use it for metal production as well.

Energy in the 1700’s

By this time, most of Europe and especially England had cut down most of their forests. As they came to rely on coal for fuel, the demand for coal grew quickly. Another reason for this was the invention of the steam engine by Thomas Newcomen in 1712, which was used to pump groundwater out of deep coal mines. Before, the water in coal mines had to be hauled out by a horse, using a bucket attached to a rope, which was very inefficient. 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: moving energy. With this new invention, machines could be powered by coal, while 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 first battery, which gave the world its first steady supply of electrical energy. Volta's name is still used today: the wall socket in our homes supplies electricity at 230 or 110 Volts.

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

In the 1800's 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, people depended on the power from wind and water to power factories, which were certainly not available everywhere at any time. Energy slowly became to be seen as a resource that was available when and where it was needed.

The invention of electricity

Electricity was discovered by a Greek philosopher named Thales, who lived 2500 years ago. He noticed that when he rubbed fur to a piece of amber, the amber would attract small pieces of light material, such as feathers or lint. The Greek word for amber is "electron", hence the word "electricity". Today we know that this attractive force is caused by static electricity.

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 horsepower machine, which could do the work of twenty horses. Watt worked out how much each company saved by using his machine rather than 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.

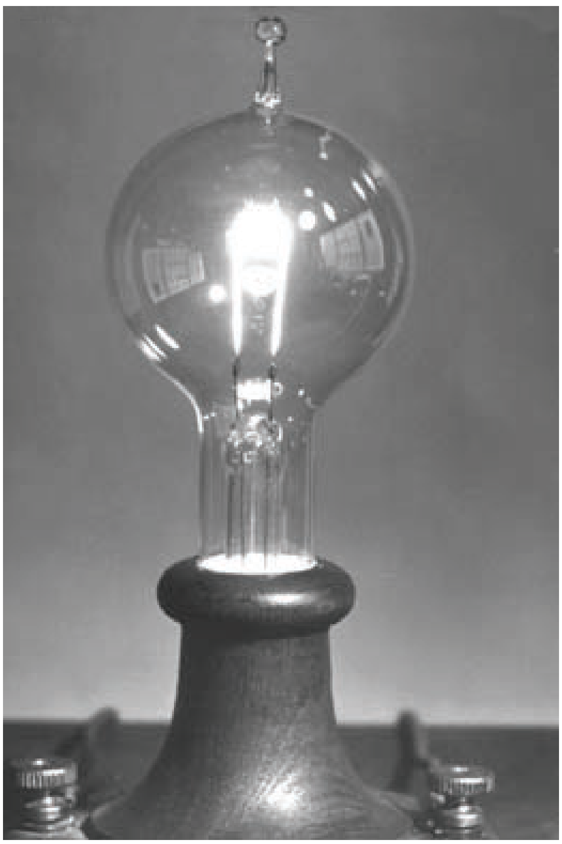
In addition to powering factories, the steam engine was put to other uses as well. In 1804, the first steam locomotive was built, and in 1807, the first steam boat. At the same time, coal gas (gas that is released when coal is heated) was discovered, and used to light factories. Coal oil (a liquid released when coal is heated almost to burning point), which is now called kerosene, was discovered, and in 1807 was used to light the streets of London.

A steam locomotive

During this age, the steam engine was improved and grew much more powerful still. By the end of the 19th century, a steam engine provided the power equal to that of 6000 men.

In the mid 1800's, the construction of small dams to generate electricity from hydro power began, and at the end of the 1800's, people experimented on generating electricity by windmills.
Solar power was first developed by the French 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.

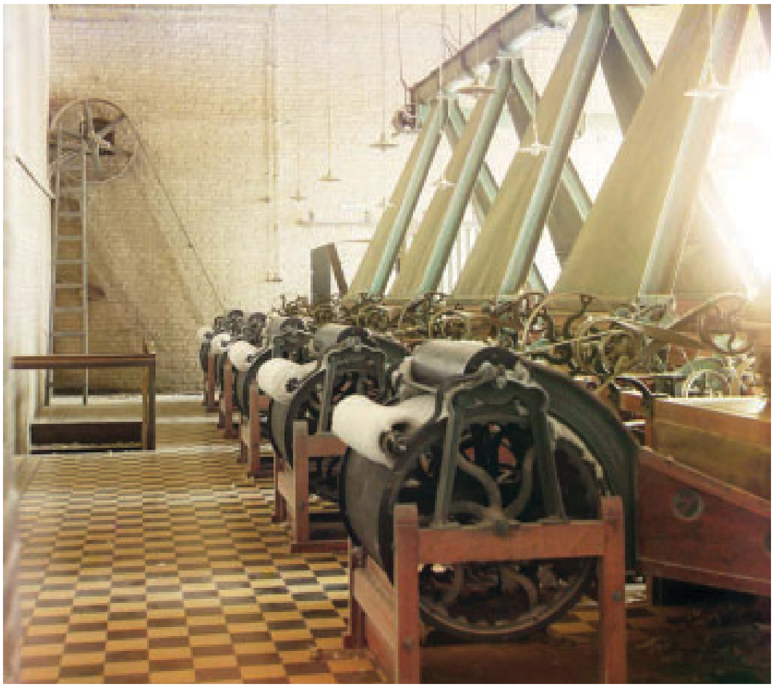
In 1859, the first petroleum was pumped out of the ground in Pennsylvania in the USA. For long the petroleum had been a nuisance, contaminating wells for drinking water. For a while it was sold as medicine, but people quickly realised its usefulness for heating and lighting. Before long, people learnt how to refine oil to make petrol and diesel oil, which were used to power a new invention: the combustion engine.



Thomas Edison's first electrical lightbulb (1879)

Steam power

In the 1800's, many factories sprang up that were powerd 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 figure below this driving belt is visible in the background.



A cotton mill powered by steam

ENERGY IN THE 1900'S: THE AGE OF THE COMBUSTION ENGINE

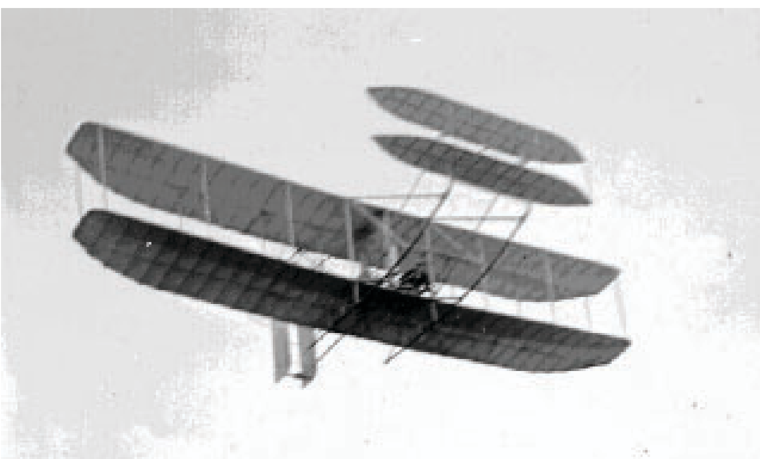
With the new fuel petrol available, the French inventor Etienne Lenoir invented the first practical "internal combustion engine" which uses burning petrol to drive a piston in the engine. The German inventor Nikolaus August Otto made a better one 16 years later. In 1885, the German engineer Benz took 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 automo-

Gottlieb Daimler's first four-wheeled automobile (1886)

bile, powered by a combustion engine. Of course, they were still very expensive, and it primarily became a rich man's toy.

But that quickly changed. In the United States, Henry Ford figured out how to make a lot 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



The first powered airplane of the Wright brothers (1903)

machine, inventing the first airplane to run on fuel. At 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 in energy.

In the middle of the 20th century, during and after the Second World War, people discovered how to use the power inside the atom. Lise Meitner, a German 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, an Italian physicist designed and built the first nuclear fission reactor in the United States of America, and 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, where the nuclei of small atoms fuse together and release lots of energy. In the 1950s scientists started to research how to harness on earth this source of energy, which uses the hydrogen in ordinary water as its fuel.

The energy use in this century 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. We have also learned that energy comes at a price.

In 1973, Arab oil producing nations stopped supplying oil to western nations and America for political reasons. Overnight, the prices of oil tripled. This led to a large energy crisis, in which cars lined up at gas stations to buy petrol. 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 41$ (85 of today's dollars), while the current price is about 28$ per barrel!

In 1979, the Three Mile Island nuclear power plant (USA) suffered a partial meltdown 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 crises that people felt. The even more serious and frightening nuclear accident of Chernobyl in 1986 caused many people to change their minds about using nuclear energy as an energy source.

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

Another problem is that energy is not available to everybody. Around two billion people, one-third of the world population, does 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 increases very rapidly. By the year 2050, it is expected that there will be ten billion people on earth, compared with the six billion now, and they will all need energy. People in developing countries will start using as much energy as we do. For these reasons, it is expected that in 2050 our energy demand might be four times what it is today. If we keep making energy the way we do now, using mainly fossil fuels, our environment would suffer badly. Eventually, fossil resources would become more expensive and finally run out, although this is still very far away.

And modern solutions…
When fossil fuels are burned, the greenhouse gas CO_2 is released. But there is a way to intervene: catch the CO_2 when it is formed, and put it in an empty natural gas and oil fields. This technique, which is 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

Pollution takes many forms: oil drums in the antarctic

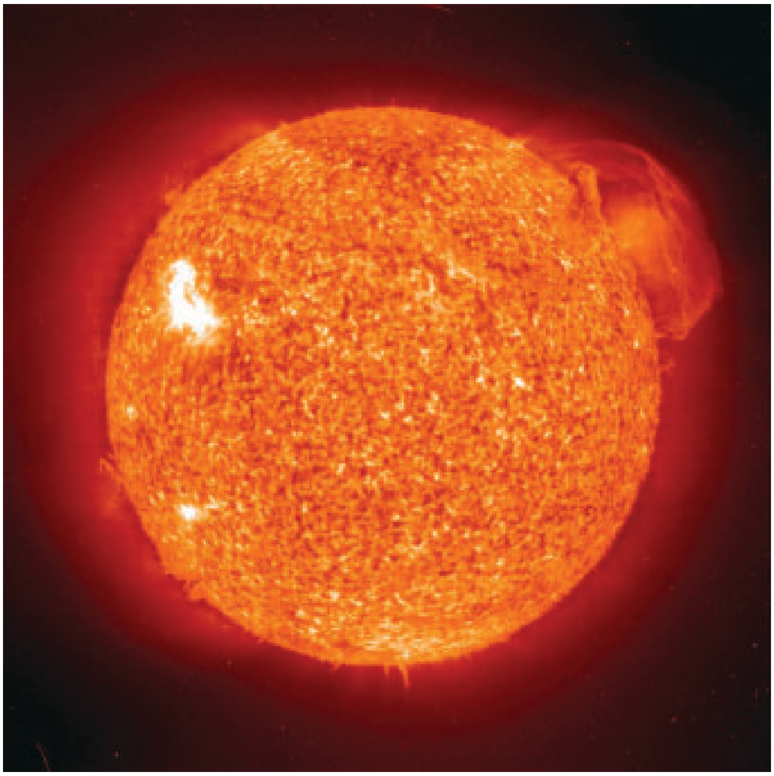
Generating electricity from the wind

that is put back in. Research is 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*.

New technologies to harness renewable energy sources such as solar, wind, and biomass, are actively researched and start to develop, although at present they account for less than 1% of our energy use. It is hoped that around 2050 they may provide much more.

A lot of 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 emission-free and safe energy around 2050, mainly fuelled by substances extracted out of the water in the oceans. At the moment, national and international research programs are carried out worldwide to develop this source of energy here on earth.



Fusion power gives the sun it's energy. Scientist try to harness this energy source on earth

Electricity from the sun using solar panels

Summary

- Energy has been used since the earliest history: from 500,000 BC until today.
- Large-scale use of charcoal and coal started already in the 1600's.
- The invention of the steam engine in the 1700's introduced a revolution: for the first time thermal energy could be converted into motion.
- In the 1800's, the steam engine started the Industrial Revolution. It was also the century in which electricity was discovered.
- The 1900's introduced the era of the combustion engine, mass production, airplanes and nuclear energy.
- Since the 1970's people have become aware of how much the modern world depends on energy, and that using energy has environmental consequences. As a consequence, renewable sources are now being developed.

On the Web

>>>

www.energy.ca.gov/m+pco/history.html

Gives a timeline of mayor energy inventions.

www.eia.doe.gov/kids/milestones/

Milestones in the history of energy.

library.thinkquest.org/20331/history/

History of energy and much more. Pages developed by students.

www.energyquest.ca.gov/story/

General site on energy made by students.

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3 THE ENERGY WE USE

We use different forms of energy, like gas, electricity and petrol. Can't we perform every energy service we need with 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 the things we want to do with energy: heat things up (houses, food, water), cool things down (food, rooms), produce and manufacture things and materials (industrial use), transport things (cars, trucks, ships, trains, planes), and everything else (make music, light, 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 use heat also for cooking, taking a hot bath or shower. We use cold fridges and freezers to prevent our food from decaying, and to make cold drinks. In industry, heating and cooling are used for many processes as well.

Air transport needs a lot of kerosene

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 carried out with electricity. Think for example of a water heater and an electrical oven. However, this is normally much more expensive than using fossil fuels, and it is only used for relatively small amounts of heat.

Most cooling appliances such as freezers, fridges and air conditioners run on electricity, although there are also fridges that run on gas. The freezer and fridge at your home probably are the largest consumers of electricity.

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 big portion of the railway system (and similar systems such as trams and metro).

Electricity is also used to drive electrical motors, which are used in factories, pumps, fans and many other applications. In your home, you'll probably find twenty to forty electric motors driving all kinds of things. For instance, each fridge has one pump, a microwave oven uses two motors (one for the fan, the other for the rotation plate), your stereo set probably contains seven little electric motors, your computer might have eight of these, and a video recorder has at least two of them.

Industrial Use of Energy

The manufacture of the products we use everyday, and the materials that were used e.g. to build our houses, cost a large amount of energy. Factories burn fuels to produce heat and power. Apart from the usual fuels and electricity, industry uses a large variety of less commonly used fuels, like wood chips, bark, and wood waste material from the production of paper, coal briquettes, coke oven gas, and others. Manufacturing processes require large quantities of steam, which is produced in boilers using the combustion of fuels.

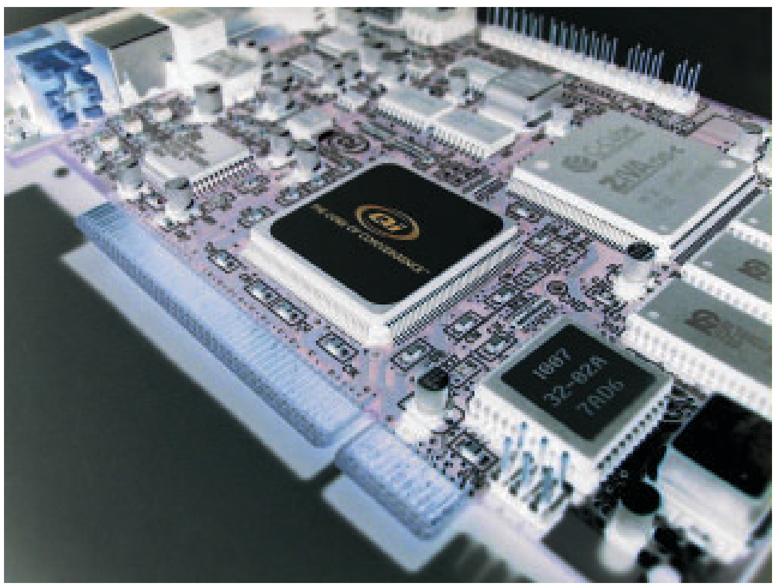
Other applications

Many more services at home require some use of energy and the devices designed to provide them rely only on electricity. When you surf over the internet or type your homework, your desktop needs electricity. If you want to enjoy some music or to see your preferred TV program, you need electricity. Cleaning rooms, wash and dry laundry, ironing: all require electricity. Sometimes electricity is even used to cut bread, to squash oranges and to clean one's teeth. Also personal security is linked to electricity, to open the main entrance, to speak over the intercom, to run an alarm device.

Electricity is the most flexible form of energy: it can be used for virtually any application. No noises or gasses are produced at the place where electricity is used. You don't need a tank of fuel to power your computer or stereo, it is there the moment you need it and in the form you want to have it. You could say that everywhere you would like to use energy when you are not moving, electricity will do the job, unless it is not possible, or cheaper to combust oil, gas, or coal on the spot.

But there are some disadvantages too. The central generation of electricity means it has to be distributed over the country in order to bring it to your house. This causes an average loss of energy of 10%, and needs a large and expensive distribution system. Electricity is also quite hard to store in large quantities. You need large, heavy batteries to store a reasonable amount of electrical energy. As you have to take these batteries with you on a vehicle, transportation doesn't work very well on electricity. Of course, trains solve this problem by having their own power lines, which act like very long extension cords!

Electricity is the most flexible form of energy



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

How to measure energy

Energy comes in many forms: we use electricity for light, cook on gas, 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 do we measure energy?

We say that energy is the *capacity to do work*. Energy is measured in joules (J), and 1 joule is the amount of energy needed to lift a mass of a hundred grams over one meter. So, if you lift an apple one meter, you need one joule of energy to do it. And we can go on: for two meters, you need 2 joules, and to lift 1 kg 1 meter, you need 10 joules. One joule is not very much energy, so we usually talk about kilojoules (1000 J = 1 kJ), or megajoules (1,000,000 J = $1 \cdot 10^6$ J= 1 MJ). 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. A banana contains roughly 180 kJ, and a chocolate bar contains about 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

Table 1. Energy present in food (source: Food and Nutrition department, Singapore).

Food	Portion size Quantity	Weight (gr)	Energy (kJ/gr)	Energy (kJ)
Butter / margarine	1 dinnersp.	15	466	31
Peanut butter	1 dinnersp.	15	378	25
Peanuts	1 tablesp.	30	718	24
Milk chocolate	2 pieces	40	890	22
Potato chips	1 packet	35	785	22
Chocolat cake	1 wedge	55	1054	19
Pork chop	one	85	1184	14
Apple pie	2 slices	85	1105	13
Hamburger	1 serve	100	1121	11
Bread, plain	1 plate	60	647	11
Chicken, Roasted	1 scoop	90	815	9
Nasi Goreng (fried rice)	one	400	3242	8
Ice Cream	1 plate	45	374	8
Boiled egg	one	50	311	6
Rice, plain cooked	1 plate	200	1092	5
Cow's milk (whole)	1 glass	250	945	3.8
Yoghurt (naturel)	1 cup	200	716	3.6
Cola	1 can	285	491	1.7
Banana	one	90	176	1.9
Apple	one	150	223	1.5
Carrot	one	65	97	1.5
Orange	one	150	181	1.2
Watermelon	1 wedge	200	130	0.6
Cucumber	5 slices	40	25	0.6

To be precise

The formula for calculating how much energy you need to lift a mass is Energy = Mass x Acceleration of gravity x Height, or $E = mgh$. On earth, g equals 9.81 m/s^2, so to lift 100 grams of mass (which is 0.1 kg) to a height of 1 meter, you need $E = 0.1 \cdot 9.81 \cdot 1 =$ 0.981 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 with one degree centigrade. One calorie equals 4.19 joule. Often a larger unit, the *kilocalorie* or *kcal* is used: 1 kcal = 1000 cal = 4190 joule.

Unit of Energy	Symbol	Equivalent amount of joules
Kilojoule	K	$1{,}000 = 10^3$
Megajoule	MJ	$1{,}000{,}000 = 10^6$
Kilowatt-hour	kWh	$3{,}600{,}000 = 3.6 \cdot 10^3$
Ton of Oil Equivalent	Toe	$4.187 \cdot 10^{10}$
Calorie	Cal	4.190

Table 2. Commonly used units of energy

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 40 minutes, or sleep for 6 hours. Table 1 shows the food content of many foodstuffs.

Power

Apart from energy, we also encounter *power*. Power is the amount of energy used 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. Most appliances such as TV's or microwave ovens indicate how much power they use. A microwave oven, for example, uses 1000 Watts, and a clock radio about 10 watts.

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 5000 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 $5.124 \cdot 10^9$.

How much is a thousand watts, or ten watts? 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, weighing 50 kg, runs up three flights of stairs, which is a height difference of roughly 10 meters in total. For this, she needs 5000 joules (50 kg x 10 meter x 10 joules per kg per meter). If she does this in 20 seconds, she has used 5000/20 = 250 watts during those 20 seconds. Linda will probably be quite tired.

The Ton of Oil Equivalent

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

Food contains a lot of energy: these three peppers in total contain about 300 kilojoule.

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. This means it takes about 13 people to power a microwave oven!

The horsepower

The horsepower is still used to express the strength 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 powerful car has about 200 – 300 horsepower!

Energy and power are often used in the same sense, but they mean something very different. Power is a measure for how *quickly* energy is used. If you use 10 joules in 10 seconds, or 10 joules in 10 seconds, then in both cases the *energy* you have used is the same. 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 was smaller.

Energy in your home

Energy comes to our homes in different forms. The one we are most accustomed to is the energy from the wall socket: electricity. Electrical energy is supplied by the source of the electrical current, such as a battery or an electrical generator. In most homes, electrical power is purchased from a power company, which has several large electrical generators. The energy produced by the generators travels to individual homes through power lines. The unit of energy sold to households is 1000 watts during one hour, which is called the *kilowatt-hour*, or kWh for short.

Units of Power

1 kW= 1000 watt

1 kilowatt-hour = 1000 watts during 1 hour = 3.6 MJ

1 horsepower = 746 watt

How much energy is 1 kWh? Well, 1000 watts for 1 hour equals 1000 joules per second x 60 minutes x 60 seconds = 3,600,000 joules. And for this you pay about 11 Eurocents, at least in the Netherlands (how much do you pay for 1 kWh in your country?). Let's say you hire a first-class athlete to make this much energy for you, for example on a

What to do with 1 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 Celsius
- Run an average car with an electrical engine for 1.6 km.
- Play a stereo for 20-30 hours
- Let an energy saving fluorescent light bulb of 18 watts burn for 55 hours

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

bicycle driving a generator. An athlete can generate 300 watts for several hours, so it will take him about three hours of hard work! And you will have to pay him a lot more than 11 Eurocents, probably.

Apart from electricity, energy also comes to our houses in the shape of fossil fuels such as gas, oil, petrol and coal. Gas and oil are used for cooking and to heat homes in winter. Petrol 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 use on camping sites for example. Petrol can be bought at tank stations. 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!

How much energy do you use?

Every day we use energy, but how much exactly? It depends on where you live, on how you live and on what you do. As we talked about kilowatt-hours as a unit to measure energy, let's see how many kilowatt-hours we use in a month. Most appliances have a label that says how much power they need. A television, for example, takes about 180 watt, and an electric toaster takes about 1000 watt.

Of course, if you want to know how much energy you use, you also have to know *how long* you use an electrical device. For example, an electrical clock of 5 watts that is on for a whole month takes about 4 kWh per month, while a toaster of a 1000 watts, which is only on for two hours every month, takes only 2 kWh per month! So small devices, which seem harmless in their energy demand, can sneakily take up quite a lot of electricity. Table 4 lists the energy need of many household devices, how long they are used on average, and how much energy they use per month.

Form of Energy	Cost per Unit	Energy content per unit in kWh	Cost per kWh in Euro
Electricity	1 kWh ~ 0.11 Euro	1	0.11
Natural Gas	1 m^3 ~ 0.11 Euro	10	0.01
Gasoline	1 litre ~ 1.1 Euro	8	0.13
Battery	1 AA penlight ~ 1 Euro	0.001	900

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

Table 4. Energy needs of household appliances (continued next page).

Appliance	Watts	Hours per month	kWh per month
Air conditioner (room)	750	120 - 720	90 - 540
Water heater (family of 4)	3800	98 - 138	375 - 525
Dehumidifier	350	120 - 720	42 - 252
Clothes washer	500	7 - 40	33 - 196
Fridge-freezer (600 l)	500	150 - 300	75 - 150
Clothes dryer	5000	6 - 28	30 - 140
Water bed heater	400	150 - 300	60 - 120
Dishwasher	1300	8 - 40	20 - 102
Refrigerator (450 l)	300	190 - 300	56 - 90
Electric Heater (portable)	1200	30 - 90	30 - 90
Humidifier (portable)	100	80 - 540	8 - 54
Computer	200	25 - 160	5 - 32
Television	180	60 - 440	5 - 35
Microwave oven	1300	5 - 30	5 - 30
Coffee maker	900	4 - 30	4 - 27
Ceiling fan	60	15 - 330	1 - 20
Lighting (single lamp)	60	17 - 200	1 - 12
TL tube (120 cm)	50	10 - 200	0.5 - 10
Hair Dryer	1000	1 - 10	1 - 10

Appliance	Watts	Hours per month	kWh per month
Fan (portable)	115	18 - 52	2 - 6
Stereo	30	1 - 170	0.03 - 5.1
Vacuum cleaner	800	2 - 6	2 - 5
Electric toaster	1000	2 - 5	2 - 5
Clock	5	720	4
Fluorescent lamp (60 watt equiv.)	18	17 - 200	0.3 - 3.6
Drill	300	3 - 7	1 - 2
Toothbrush	10	1 - 2	0.01 - 0.02

Table 4. Continued from the previous page (Source NB power, France)

How to read energy bills and the electricity meter

The energy bill states how much kilowatt-hours of electricity and how much gas were used over a certain period. To see how much electrical power you use at a certain *moment*, you can look at the electricity meter. Often, an electricity meter has a disk that you can see spinning around. The more power you use, the faster the disk spins. You can see how much kilowatt-hours you have used on a numerical display. In the same way, you can see how much gas you use from the gas meter. In this way, you can measure your energy consumption per hour, per day, per week, etc.

Which devices take a lot of energy? From the table we see that the refrigerator, the freezer, air conditioning, space heating and electrical water heaters use a lot of energy. In other words, all the devices that have something to do with heating or cooling. Table 5 lists the energy use of a typical household. From the table, you can get an idea how much electricity you and your family use every year. The European average 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 bills! On the energy bill, you can find how many kilowatt-hours of electricity you and your family have used in a year or in a month. You can compare this value to the European average, and to the numbers in table 5.

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

Item	Average consumption (kWh per year)
Air conditioning / space heating	1400
Boiler (hot water)	1060
Freezer	480
Dish washer	440
Fridge	363
Light	300
Washing machine	290
Electrical oven / cooker	230
TV	220
Others (VCR, hair dryer, stereo, vacuum cleaner, etc.)	70

Table 5. Average yearly energy use of household appliances.

Stand-by power

Many electrical devices are never completely off, but are in stand-by. This stand-by mode takes energy: An average house uses about 100 watt of power for electrical devices on stand-by. Try it in your own house!

In table 6, the electricity use of countries in Europe is listed. As you can see, there are large differences between different countries. There are several reasons for these differences. Norway, for example, is a country that is very thinly populated, and it would therefore be very expensive to make a gas grid next to the electricity grid. Moreover, Norway has a lot of cheap hydro electric power. For this reason, people in Norway use electriciy for just about everything, including house heating. This takes a lot of electrical power.

If you divide your household's yearly electricity use by the number of people in your household, and multiply by the number of people in your country, you can estimate the yearly electricy use of households in your country. Does the value you get agree with the one from table 6?

Primary energy use

Up to now, we have just talked about how much electricity we use. We also use gas for heating and cooking, cars, trains and planes use petrol or other fossil fuels, factories use energy to make their products, and materials to make things from. So let's see how much 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 meters 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 41,868 megajoule, and it is the average heat content of one ton of crude oil (equivalent to the volume of about 7.5 oil barrels).

Country	Population in millions	Total electricity consumption in housholds in billion kWh per year	Electricity consumption per person in kWh per year
Norway	4.5	33.60	7467
Sweden	8.9	41.86	4703
Finland	5.2	18.49	3556
Belgium	10.3	23.49	2281
Switzerland	7.3	15.58	2134
France	60.0	126.98	2116
Denmark	5.35	10.23	1912
United Kingdom	60.0	110.47	1841
Ireland	3.85	6.51	1691
Luxembourg	0.44	0.70	1591
Austria	8.15	12.91	1584
Germany	83.0	131.28	1582
Czech Republik	10.2	14.07	1379
Netherlands	16.0	21.40	1338
Bulgaria	7.7	10.12	1314
Greece	10.6	13.49	1273
Slovenia	2.0	2.38	1190
Spain	40.0	45.47	1137
Slovakia	5.4	5.70	1056
Italy	57.5	60.70	1056
Hungary	10.0	9.88	988
Portugal	10.1	9.53	944
Poland	38.7	20.81	538
Romania	22.4	7.88	352

Table 6. Electricity use in households. Norway, Sweden and Finland use cheap hydro power, which they use for house heating as well. Belgium, Switzerland and France use a large amount of nuclear fission power. The average number of persons in a European household is 2.6.

From primary energy to electrical energy

To generate electrical energy, you need primary energy like coal, gas, wind or sun. In the case of the fossil fuels, which still generate most of the electrical energy, fuel is burned to make steam, which is used to power a steam turbine. The steam turbine powers an electrical generator. Not all energy present in the fossil fuel is put into electrical energy: a large amount is lost as waste heat. The part of the energy present in the primary fossil fuel that is put into electrical 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 electrical energy, so the *efficiency* is 33%. This means that to generate one joule of electrical energy, you need about 3 joules of fossil fuel.

The energy consumption and losses of energy transformation in power plants, refineries, coke ovens, and the losses in transmission and distribution, mean that we actually use much more energy then the total final energy consumed (for example the electricity in our house). When we use 1 kWh of electrical energy, which is 3.6 MJ, the primary energy needed to provide that amount of energy is almost 10 MJ, or about three times as much.

When we talk about *primary energy*, we mean the energy in its raw form, which will partly be transformed into electricity, partly turned into for example petrol for transportation, and partly used directly for heat or industrial processes. Instead of listing the numbers per country, we will now look at Western Europe as a whole, and compare the values to other regions in the world. In table 7 you can see how much primary energy is used in different regions of the world, and how much it is per person.

How do these numbers compare to the average electricity consumption of households? In the figure below the use of primary energy is shown for the case of the Netherlands. Clearly, the household energy use is just a small fraction of the total energy use. The energy used for generating electricity for households, is just 7% of the total energy use. This figure is not representative for Europe, as the Netherlands use a lot of gas for heating. The European average is about 10%. So only 10% of all the primary energy we use in Europe goes into making electricity for households, the rest is used elsewhere.

Table 7. Total primary energy use in toe per year in different regions of the world. OECD stands for *Organisation for Economic Co-operation and Development*, and includes the following countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Country	Population in millions	Total primary energy use in million toe	Primary energy per person per year in toe
Europe (OECD)	519	1746	3.4
USA	273	2270	8.3
Brazil	168	179.7	1.07
China	1254	1088.3	0.87
India	997	480.4	0.48
Africa	775	490	0.63
World	5921	9774	1.65

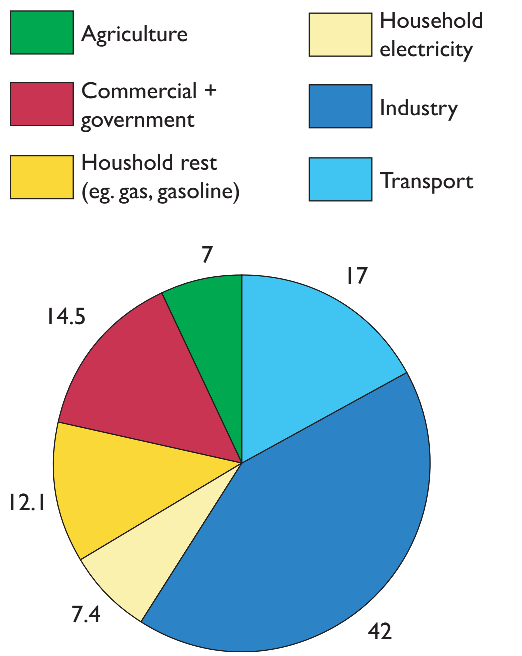


Figure 1. Primary energy use in the Netherlands. The amount of primary energy used for electricity generation is just 7.4% of the total amount used. The percentages are indicated in the figure. (source ECN, 2001)

Manhattan at night, New York, USA.

Children in Benin, Africa. People in the USA use 25 times as much energy as people in Africa.

Where does all this energy go? Mainly to industry, public services and transportation. The factories that make the products we use need a lot of energy. And the transportation of people, products, raw materials, etc., takes a lot of energy too.

From the table you see that in Western Europe, one person uses 4.2 tons of oil equivalent per year. How much is that? The energy content of 4.2 tons of oil is about $1.7 \cdot 10^{11}$ joule. If you were to use muscle power only, how many people would you need to generate this much energy? An average person can generate about 50 watt continuously, which is $1.57 \cdot 10^{9}$ joules in a year (working all day and night, all days of the week, all weeks of the year). So you need more than 100 people to generate the energy each of us uses. Each on of us would need a 100 'energy slaves' to generate his or her energy.

What about the rest of the world? Energy use varies enormously around the world. From table 7, you can see that in the USA, people use about 25 times as much energy as people in India and Africa.

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 spend, 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 steams 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 10% 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 about 50% of the energy or more 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 longer, too.

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. On top, the exhaust of the plane is very bad for the environment.

At the moment, many industries try to use production methods that use less energy. Smart production processes re-use heat that was lost through the chimney in earlier times. Biological 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.

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 8 you can see the embodied energy in megajoules per kilogram of 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. An average house may easily embody up to 900,000 megajoule! Can you make an estimate of how much energy your house embodies?

Table 8. Energy embodied in common construction materials (Source, CSIRO, Australia)

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

Some industries use more energy than others. There are six industrial sectors that are the biggest consumers:

- Power plants, oil refinery and coal tranformation processes require large amounts of energy to transform energy in the form that is needed.
- Iron and Steel: the reduction of iron ores into metal is energy intensive, as well as the production of steel.
- Chemicals: basic chemicals used elsewhere in industry, plastics and synthetic fibres, and final products like drugs, cosmetics, fertilizers, et.
- Paper and allied products: for the manufacturing of pulps from woods or other cellulose fibres, and for the manufacturing of paper and final products (i.e. napkins, etc.).
- Non ferrous metal industries: for the melting and refining of metallic materials (copper, steel, aluminium) from ore or scrap. It includes also the manufacturing of the final metal products, such as sheets, bars, rods, plates, etc.
- Non metallic materials, such as cement, glass, and all forms of bricks require a lot of energy in special ovens.

In general, the industry of a country uses a large share of all the primary energy that is used. In the Netherlands, for example, the industry uses 42% of the primary energy.

Summary

- Energy services can be divided in heating and cooling, transport, and everything else.
- All energy forms are expressed in Joules (J).
- Power is the rate at which energy is produced or consumed, expressed in watt (W), which is equal to joules per second (J/s).
- Electrical energy is usually expressed in kilowatt-hours (kWh).
- Heating and cooling use most of the energy at home.
- Different regions of the world use very different amounts of energy.
- If energy had to be generated by human power, you would need 100 people to generate the energy for one person.
- The primary energy used for the generation of electricity is just a small part of the total primary energy used.

Things to do

- What would one day without electricity look like?
- Identify the energy content of five food products at home. How long would you be able to run, ride your bike or sleep with these amounts of energy?
- Look up how the oil crisis in the 1970s developed. Which measures were taken by the government of your country from that time onwards?
- Write down today's meter readings for gas and electricity use at home and the ones 1 week later. Calculate the weekly gas and electricity usage and compare this with your friends (take into account the number of people living in each family).
- What other energy saving techniques or habits then already discussed can you think of? How much energy per month would you save with these measures?
- Write a brochure which stimulates people to save more energy. What would be your slogan?

On the Web

>>>

www.iea.org

The site of the International Energy Agency, where information and statistics on energy are available.

www.iiasa.ac.at

Non governmental organization that performs studies on environmental, economic, technological and social issues.

www.eia.doe.gov

Official energy statistics from the US Government.

www.ase.org/educators/

Energy efficiency in schools.

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4 The sources of energy

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

The present total world consumption of energy amounts to 10 billion tons of oil equivalent. It is supplied by oil, coal, natural gas, nuclear fission and renewable sources like hydro-energy, wind, solar, non-commercial fuel like firewood, etc., as shown if figure 2. Fusion energy does not generate energy yet, but one day it may be one of the largest sources of energy. In this chapter, we have a look at all these different sources of energy.

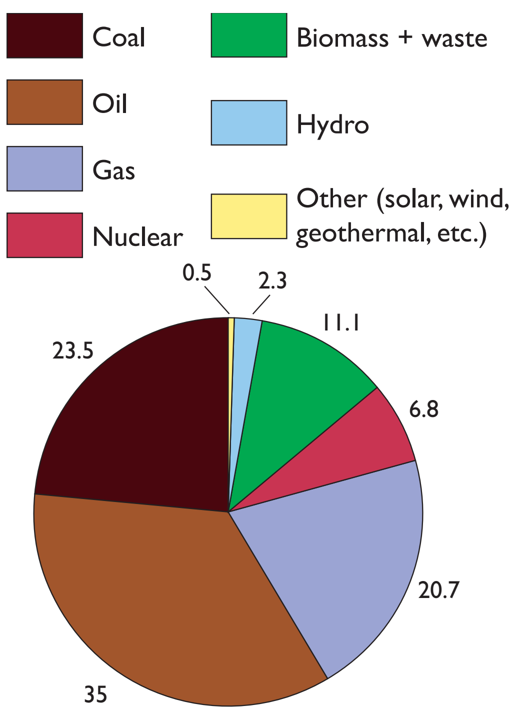


Figure 2. The primary energy sources. Coal, oil and gas together make up 80% of the primary energy. New renewable sources like solar, wind and geothermal energy make up 0.5%.

Energy from fossil fuels

Coal, oil and gas power most of the energy services around the world, in fact, they provide 80% of all the energy in the world. They are called fossil fuels because they have been formed millions of years ago. Fossil fuels have to be harvested by mining, which is a heavy and large-scale industry. They have been formed from prehistoric plants and animals that lived 300 million years ago. When these ancient living organisms died, they decomposed and became buried under layers of rock, mud and sand. Eventually, hundreds of metres of earth covered them. During millions of years the dead plants and animals slowly decomposed and formed the fossil fuels that we use today.

Different types of fossil fuel were formed depending on what animal and plant debris were present, what conditions of temperature and pressure existed when they were decomposing and how long the material was buried.

Oil

Oil keeps your country moving. Almost the entire transportation fleet – cars, trucks, trains and airplanes – is powered with fuels made from oil. Lubricants made from oil keep the machinery in the factories running. Also fertilizer, used to grow food, is made from oil. It is quite likely that the toothbrush you used this morning, the plastic bottle that holds your milk, and the plastic ink pen that you write with are all made from oil. Many medical substances are also made from oil.

Oil (and natural gas) was created from organisms that lived in the water and were buried under ocean sediments. Oil exists underground as tiny droplets trapped inside the open spaces, called “pores,” inside rocks. The pores and the oil droplets 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.


Often, oil has to be pumped from the ground

Natural gas

Natural gas is made up mainly of methane (CH_4), a compound that has a carbon atom surrounded by four hydrogen atoms. Methane is highly flammable and burns almost completely. There is no ash and very little air pollution. Natural gas is colourless and in its pure form, odourless.

For most of the 1800s, a type of gas made from coal (a mixture of carbon monoxide, CO, and hydrogen, H_2)was already used as a fuel for lamps to light city streets. In 1885, Robert Bunsen invented a burner that mixed air with gas. The "Bunsen burner" is still used today to provide heat for cooking and warming buildings.

Today, natural gas provides one-fifth of all the energy used in the EU. 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 your house.

The advantages of gas are that it is easy to transport by pipeline from one place to another 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 for a variety of chemicals.

Coal

Coal is the most plentiful fuel in the fossil family and it 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 formed from the dead remains of trees, ferns and other plants that lived 300 to 400 million years ago.

Different kinds of coal exists, with different properties. Anthracite, which is very hard, gives much 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*, which has even lower heat content, is used. Some coals contain hardly any sulphur, others contain 5% of sulphur or more.

Fossil coal is burned in power plants to produce electricity. If your family uses an electric stove, you use about half a ton of coal a year. In case your water boiler is electric, you use about two tons of coal a year. An electric fridge counts for another half-ton a year. Even though you may never see coal, you use several tons of it every year!

How we use fossil fuels

We use oil, coal and gas mainly for transport, space heating, fuel to make electricity, and as a raw material, as shown in figure 3 on the next page.. Oil can be refined into a number of transport fuels, like petrol for cars, kerosene for airplanes, and diesel for trucks. Electricity is made in power


Oil barrels. Each day, we use 74 million barrels of oil worldwide.

plants, which are often powered by fossil fuels, mainly gas and coal, as shown in figure 4.

There are a number of problems with burning fossil fuels. First of all, combustion 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*. These problems are discussed in the next chapter.

We use a lot of fossil fuels. Each year, we consume an amount of fossil fuels that took nature one million years to form. Still, there are large resources of fossil fuels around the world, enough to satisfy our energy demand for at least another hundred years. However, there are two problems with our dependence on fossil fuels only. First of all, the environmental problems mentioned above. Secondly, 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 and US gas resources will have been used up.

How to make electricity

The main difference between fossil fuels and electricity is that fossil fuels are easy to store, and electricity is not. Fossil fuels can be stored close to where they are used, for example in the fuel tank of a car. Most of the electricity you use is generated a fraction of a second before it is consumed. Production and use of electricity need a power grid, which is a complex and fine-grained network of transmission, distribution and transformation facilities.

In general, a country has a number of large power plants, whose power ranges from 500 to 1500 MW. Most power plants are fuelled by coal or gas, or with nuclear fission power. The electricity is then distributed through power transmission lines.

Smaller electricity generating units are fuelled by diesel, which is made from oil. These are called *diesel generators*, they generate between 1 kW and 10 MW, and are easily transportable.

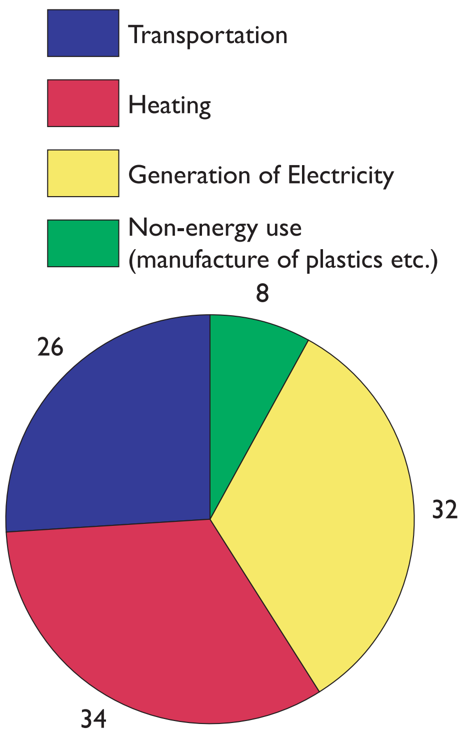


Figure 3. Use of fossil fuels for different purposes

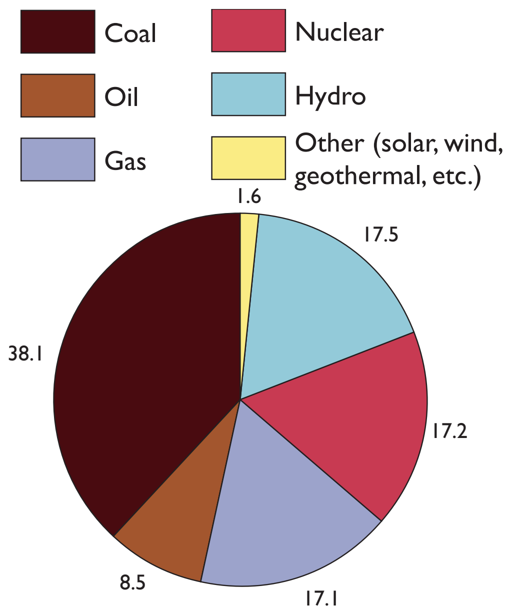


Figure 4. Energy use for generating electricity

In an electrical generator electricity is made by turning a magnet in a magnetic field. The changing magnetic field drives the electrical current. With the exception of solar cells and fuel cells (which are discussed in chapters 4 and 6), all ways of generating electricity in some way drive a generator of this type. For example, fossil fuels are used to heat water into steam, which can be used to power a steam turbine. The steam turbine then drives the electrical generator.

A gas turbine works in a similar way: when the gas is ignited and starts to burn, it expands. The expanding gas is used to power an electrical generator through a turbine. In addition, 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, we have a *Cogeneration Plant* or *Combined Heat and Power Plant*.

The heat released by nuclear reactions can be used in the same way. And in the case of a wind turbine, the spinning blades drive the electrical generator in the head of the mill. In the case of hydro power, the falling water is led through a hydro turbine, which drives an electrical generator. In this chapter, we will have a closer look at all these ways of generating electricity.

A lot of energy is lost going from primary energy like coal or oil to the final energy service, like light, or hot water. Of the primary energy, about 35% is transformed into electricity, the rest is lost as heat. In the distribution, another 10% is lost. Finally, the electricity is used for some energy service, where again energy is lost. On the next page, the situation is shown for a lightbulb.

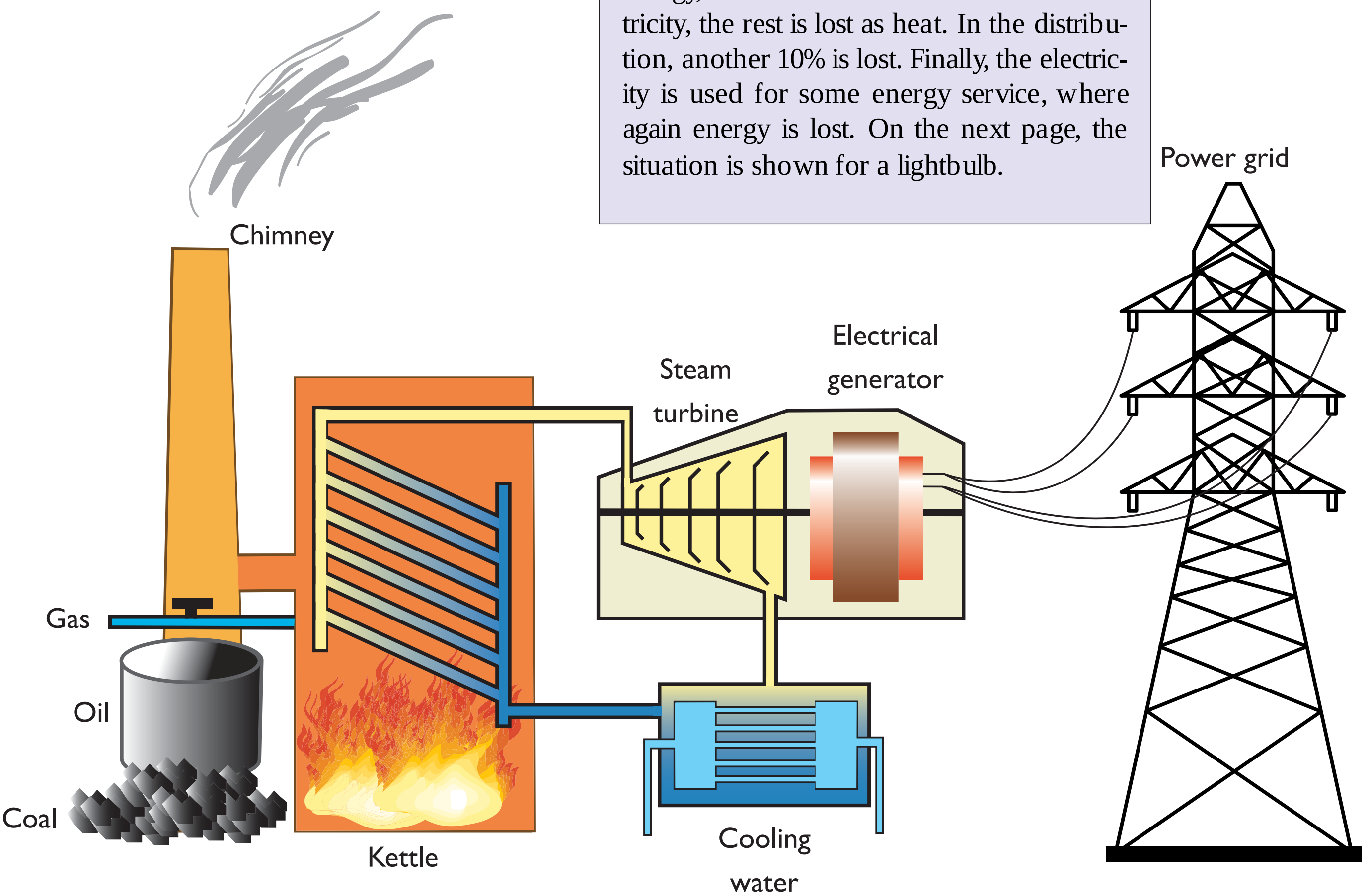


Figure 5. A power plant fueled by fossil fuel: coal, oil or gas. The fire in the kettle heats water to steam, which then flows through a steam turbine. The steam turbine powers an electrical generator, which produces electricity. The electricity is distributed through the power grid.

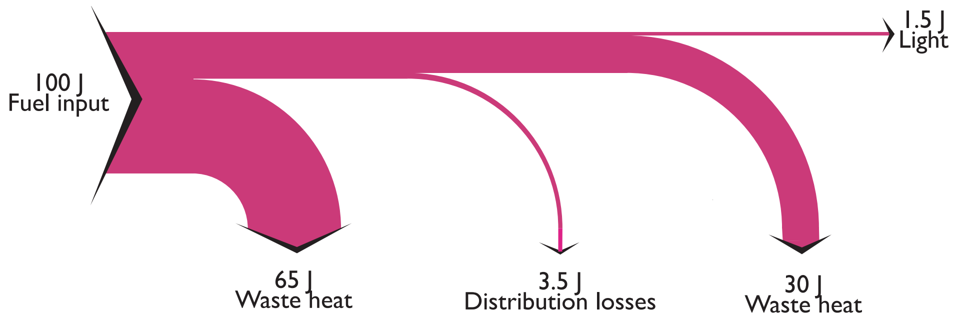
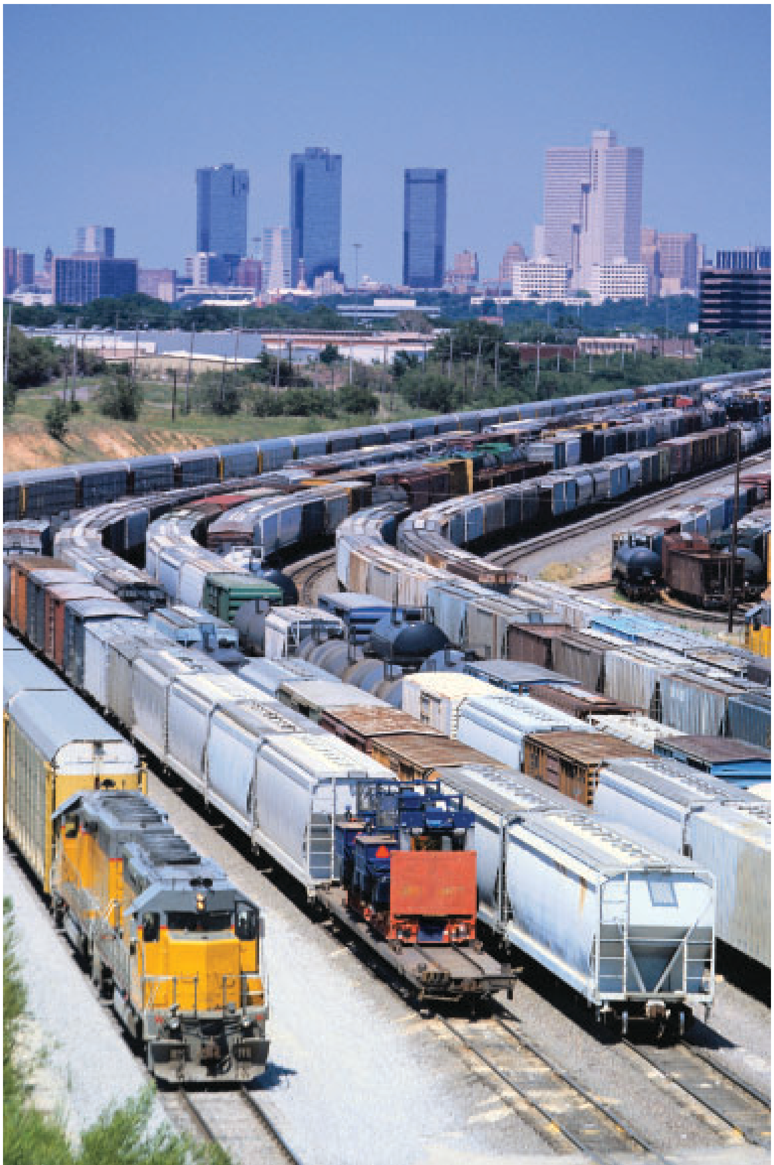


Figure 6. Energy efficiency from source to final use for a light bulb. Of the original 100 joule fuel input, 65 joules are lost as waste heat in the power plant. During distribution via the power grid, another 3.5 joules is lost. In the lightbulb, only 5% of the electrical energy is turned into useful light, which amounts to 1.5 joule. In the lamp, 30 joules of heat are produced. Fluorescent lights perform much better: instead of 1.5 joule, they transform about 25 joules (out of the 100 put in) into light.

Almost all transport depends on fossil fuels, mostly oil.



On the Web

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www.fe.doe.gov/education/

A site about coal, oil and natural gas from the US Department of energy.

www.actewagl.com.au/education/electricity/generation/fossilfuels.cfm

Electricity generation from fossil fuels.

www.eia.doe.gov/kids/non-renewable/nonrenewable.html

About fossil fuels.

www.ase.org/educators/lessons/fossil.pdf

High school lesson plans on fossil fuels.

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Nuclear fission

So far we have been dealing with fossil fuels and chemical combustion. In that case atoms rearrange themselves into new molecules in which they are more tightly bound, and energy is released. 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 which is set free in each individual process is millions of times larger, and the total amount of material passing through a power plant based on this principle is correspondingly thousands of times smaller.

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

Nuclear fusion is in a sense similar to chemical combustion: the fuel has to be brought to a high enough temperature to ignite. Then the reaction heat, if it does not leak away too rapidly from the source will itself be enough to maintain the temperature needed for the reaction. The big difference is the level of temperature needed: it has to be hundred of millions of degrees for nuclear fusion, compared to the hundreds or thousand degrees in chemical combustion.

Nuclear fission is different: it is maintained by a chain reaction. Every nucleus which splits produces also a number of neutrons – for the typically used reaction of Uranium-235, on the average about 2.4 – which each can again trigger the fission of another nucleus. Nuclear fission is already in widespread use, with nuclear power plants covering some 17% of the world's electricity demand. The material used for fission, uranium, is found underground in the form of uranium ore. 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. However, many countries have stopped constructing new nuclear power plants, because it has become clear that nuclear power has some serious problems as well.

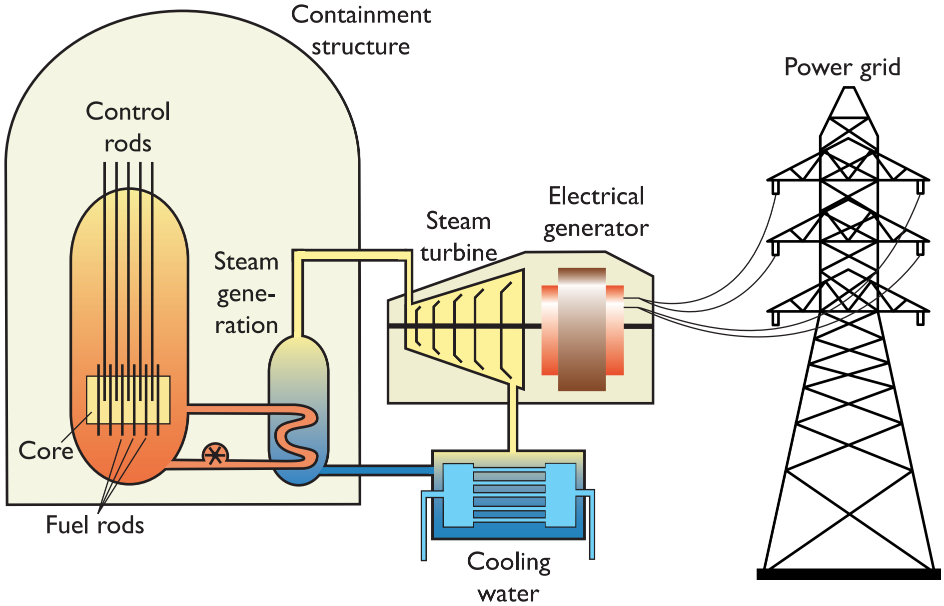
Einstein and nuclear energy

Einstein discovered that mass can be turned into energy, and the other way round. This is expressed in his famous formula: $E = mc^2$. In this formula, 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: 300,000,000 meters per second. The square of that number is a *very* large number. If you change 500 kilogram of mass into energy, you get $4.5 \cdot 10^{19}$ joules of energy, which is enough to cover the whole electricity use of the world for a year. If you want to generate that much energy with fossil fuels, you need 5 billion tons of coal! If you put that coal in a train, it would be long enough to wrap around the earth 14 times. That is the power of nuclear energy.

They arise essentially from the fact that the products of the fission reaction emit radiation and produce heat. Also the neutrons produced in the reaction can cause other atoms of the structure or the fuel to become radioactive. These materials have to be handled therefore with great care, and kept in a location where they cannot come into contact with human beings or the food chain 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

Nuclear power plant in Borssele, the Netherlands.

Figure 7. Principle of a nuclear power plant. Fuel rods containing uranium are placed in the core of the reactor. The hot fuel rods heat water, which is used to make steam through a heat exchanger. The steam is used to power a steam turbine. The reactor core is put in a containment structure for safety.

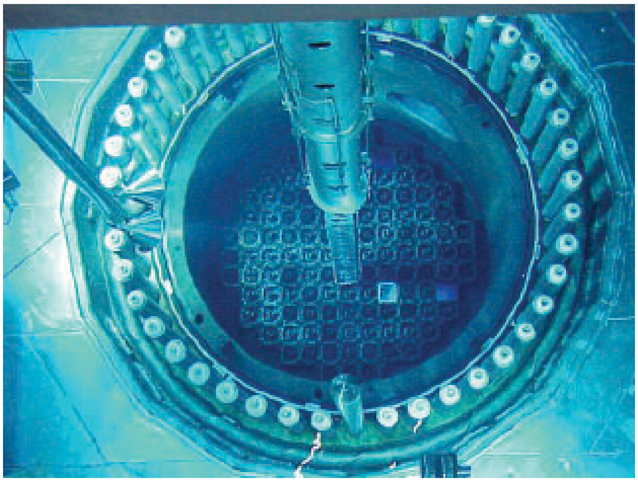


means that one has to provide cooling, even after the fission reaction has stopped and the power plant has shut down.

The design of modern fission power plants offers a very high level of safety against accidents like the escape of radioactive material to the outside. The principle employed is to use multiple, independent systems, which provide safe containment, even if one or two of them fail at the same time. An accident, like that of the Chernobyl reactor, where control over the nuclear reaction was temporarily lost, would not have been possible in any power plant in the western world.

Despite the present problems in public acceptance, fission energy is at present, besides hydro power, the only large CO_2-free source of electrical power. To reduce climate changes, whilst al-

Changing a fuel rod in the core of the reactor



On the Web

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www.nea.fr/

General site about nuclear energy. French & English.

www.world-nuclear.org/education/education.htm

Information on all aspects of nuclear energy.

www.nei.org/scienceclub/index.html

Including class projects, games, and links.

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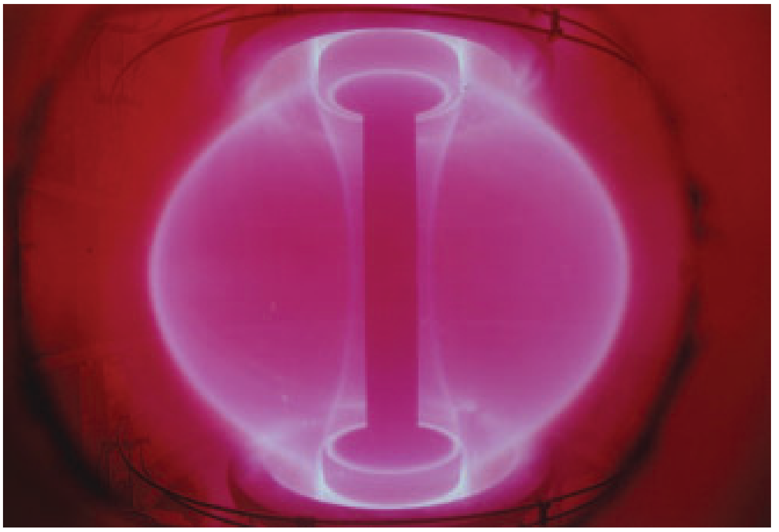
ternatives like solar, wind and fusion are not available, means nuclear fission will remain one of our most important large-scale energy sources. So it is definitely worth while trying to solve the problems of safety and waste, and to use the energy available from fission as best we can.



A fusion plasma.

Fusion energy

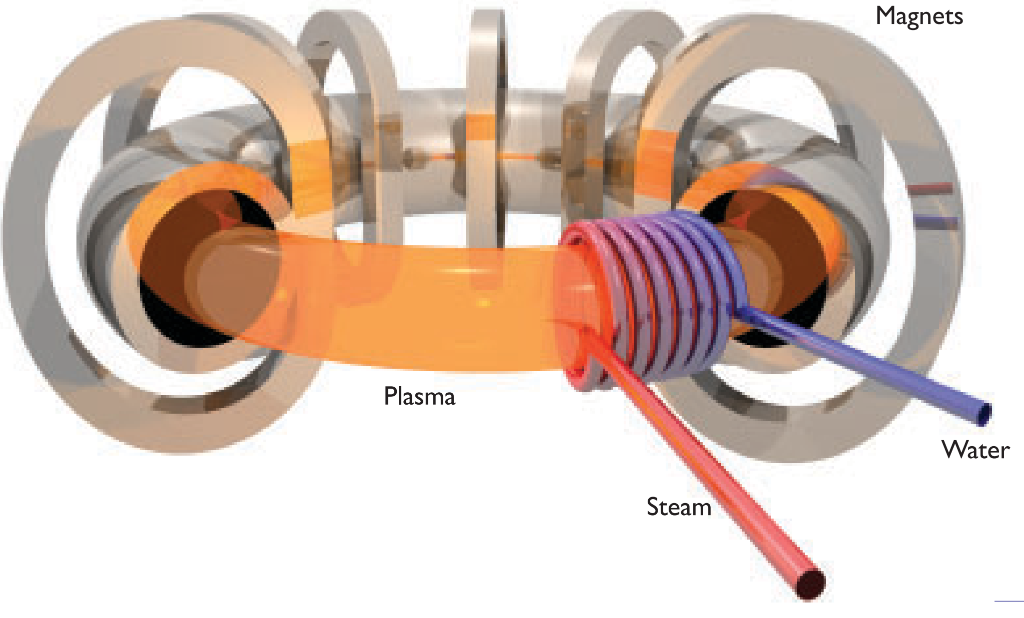
Nuclear fusion is the process whereby two atoms fuse together, and release lots of energy. Fusion is the energy source of the sun and the stars and is therefore the most common energy source in the universe. The sun burns up the lightest of the elements, hydrogen (600 million tons each second), which fuses to form helium. In the fusion process no pollutants are formed.

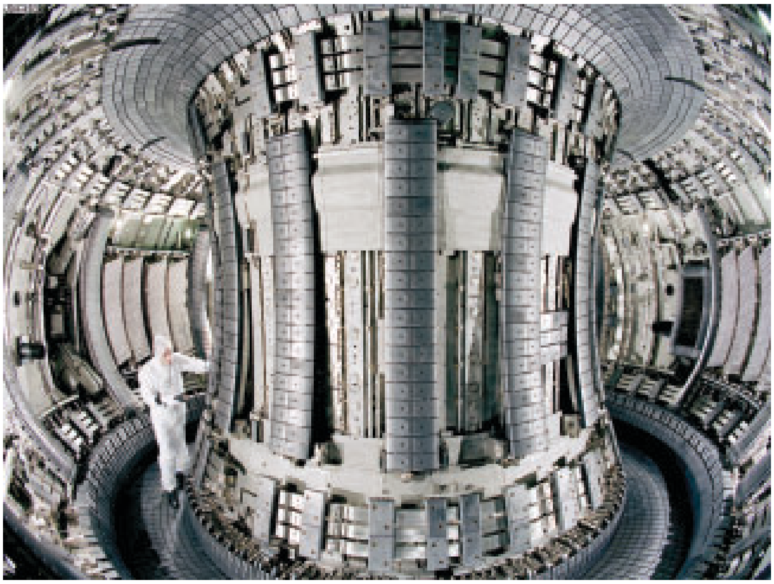
In a sense, all energy we use comes from fusion energy. Fossil fuels were once plants that grew using energy from sunlight. Wind is caused by temperature differences in the atmosphere, caused by the sun. Hydro-energy is powered by the evaporation of water, which is caused by the sun as well.

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

On earth, the fuels that will be used are deuterium and tritium, which are both so-called isotopes

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. D-shaped magnets around the mantle are used to control the plasma. Inside the mantle, water is circulated, which is heated to steam. The steam is used to power a steam turbine.





Inside the torus of a fusion reactor. The torus shown is part of JET (Joint European Torus), near Oxford, England. From the man inside, the scale can be guessed.

of hydrogen. Deuterium is available from ordinary seawater: about 0.0035% of water is deuterium. Tritium is made from lithium, a common metal. If the deuterium in a litre of seawater is turned into energy by fusion, it can cover the electricity usage of a household for two years! 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 to the world energy demand before the second half of this century. It is expected that in 2015 the next great scientific experiment in fusion, ITER, will be up and running.

Although there are no waste products from the fusion process, the internal structure of the plant itself becomes radioactive during its operation. At the end of the lifetime of a fusion plant, after about 30 years, those parts of the reactor have to be dismantled and stored at a safe location for about a hundred years, which is very short compared to the time the waste of nuclear fission has to be stored. After that time, the stored materials can be re-used, or stored away just like any normal waste.

On the Web

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www.itercanada.com/introduction/index.cfm

Fusion explained to a broad audience.

www.fusion.org.uk/index.html

General information about fusion.

www.efda.org/

The portal to the European Fusion Programme.

www.iter.org/

The new fusion experiment: ITER.

fusioned.gat.com/

Information on fusion with slide shows and video's.

http://www.jet.efda.org/

Information on the current largest fusion experiment in the world, JET.

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Hydro Power

Hydro electricity uses the energy in falling water to drive an electrical generator. In some countries with mountains, like Nepal, water from small streams is used to drive a generator, generating enough energy for one or more households. These systems can be as small as a 100 watts 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 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 dam, which is the largest hydro dam in the world, generates 9,000 MW and it has been in operation since 1984.

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

Renewable 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. And geothermal heat, the heat inside in the earth can be called renewable as there is so much of it, it will never run out as long as humans are around.

Some renewable sources, like sun and wind, are available in almost any place. The units that generate electricity from these sources are normally small, such as solar panels or windmills. 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.

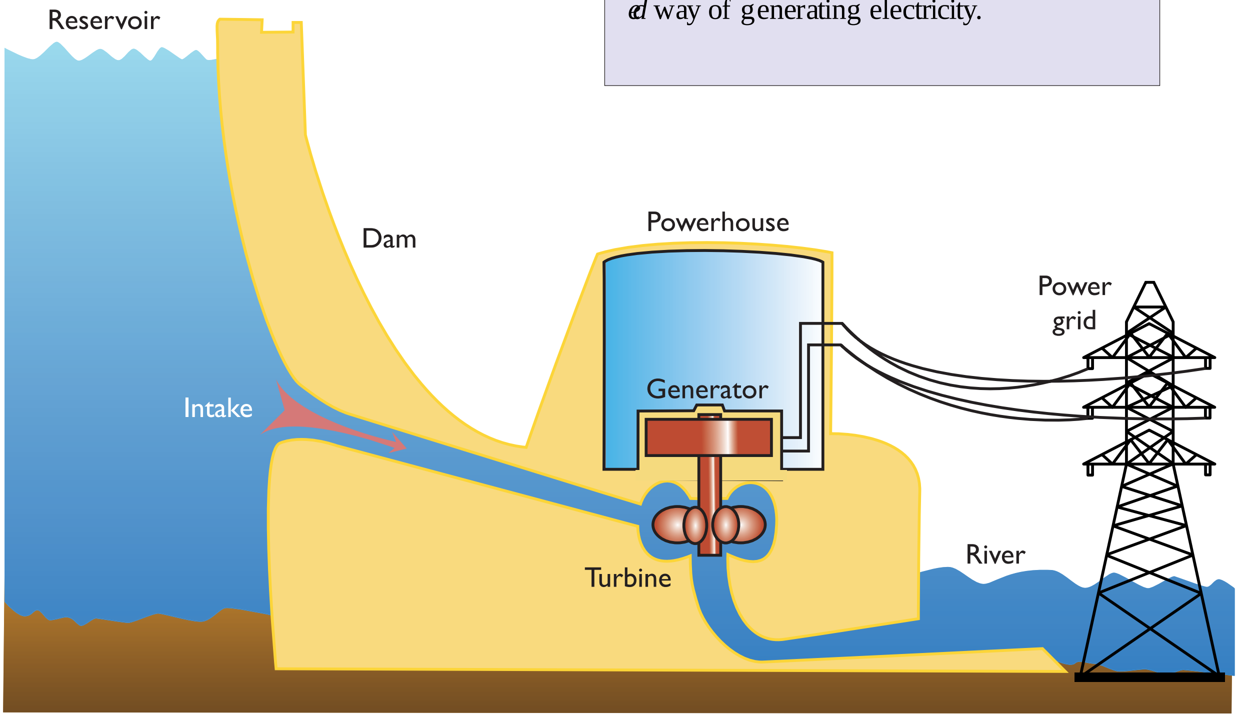

Figure 9. The principle of a hydro dam. Water from a reservoir is lead through a turbine, which generates electrical power.

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 have to 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. Also the threat of possible accidents to the dam has to be considered.

A dam placed in 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 18% 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.

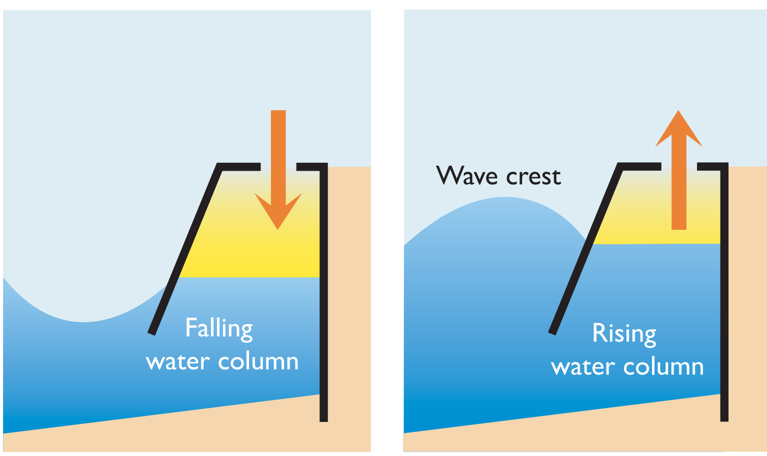

Figure 10. Power from the waves: a rising and falling water column compresses air, which is used to power a turbine.

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 1968. In 1984, a 20 MW tidal power plant started in the Novia Scotia bay, 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 windmill-like structures that generate electricity when water flows through 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 generate the energy.

On the Web

Hydro and ocean power

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www.eren.doe.gov/RE/ocean.html

American govenment site on energy from the ocean.

www.iclei.org/efacts/hydroele.htm

Hydro electricity fact sheet

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On the Web

Renewable energy sources

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www.eren.doe.gov/RE/ocean.html

American govenment site on energy from the ocean.

www.re-energy.ca/

One of the best sites about renewable energy. Includes hands-on instructions to built wind turbines, solar collectors and water turbines in the classroom.

www.soton.ac.uk/~engenvir/environment/alternative/hydropower/energy2.htm

A very complete site about renewable energy. Including a glossary and an explanation of how things work in practice.

www.nrel.gov/education/

Includes student and teacher programs.

www.infinitepower.org/lessonplans.htm

Includes lesson plans.

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A promising technique is to use a partially submerged concrete chamber built on the shore-line, with the bottom side open to the sea. Waves coming in 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 these types of constructions: on the Scottish island of Islay, a 500 kW generator of this type has been installed.

Energy from the sun using solar panels

Energy from the Sun

When the sun is shining, every square meter of area that is at right angles with the sunlight receives about 1000 watts. Averaged over the whole year, each square meter receives about 100-200 watts. 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 the 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 meter on the poles does not get as much solar energy as a square meter 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 from. 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 in an electrical circuit. Current type solar cells are made from silicon, and convert about 10% of the sunlight into electricity. In the Netherlands, this means that if you put a solar panel of one square meter on your roof, you can expect to generate about 120 kWh a year.

Rows of parabolic mirrors that concentrate sunlight on the tubes in the middle of the mirrors. Oil inside the tubes, which is heated by the concentrated sunlight, is used to generate electrical power.

At the moment, solar electricity accounts for less than 0.01% of the world's electricity use.

Normally, 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 lifetimes of 20 to 30 years. The main problem is that solar panels are still very expensive. A solar panel that delivers about 100 watts when the sun is shining vertically on the panel, costs about 400 Euro. To cover the average electricity demand of a household, which is about 4100 kWh a year, you would need about 35 square meters of solar panel (in Europe), which will cost around 14,000 Euro, and they will last about 20 to 30 years. The same electricity coming from a power plant now costs you about 450 Euro per year.

For this reason, people work very hard to make more efficient and cheaper solar cells. At the moment, solar cells are often used at places where it is very hard to get electrical power 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 often 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 electrical generator.

Another way of using solar energy is to convert it into heat, and to use the heat to warm up 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 very cheap, and you see a lot of so-called *solar collectors* on rooftops. Also swimming pools, which have to heat large quantities of water, sometimes use solar collectors.

On the Web

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www.wattsonschools.com/

Lesson programs, solar systems and an energy unit calculator

www.worldbank.org/html/fpd/energy/subenergy/solar/solar_pv.htm

A good site which shows how solar systems work in practice.

www.solarbuzz.com/Education.htm

A list to all kinds of educational material for students and teachers on solar energy.

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Energy from the wind

Since many centuries before Christ, windmills have been used to convert the power of the wind in mechanical energy. This energy was used for pumping water, grinding grain, or powering simple mechanical devices. Today, windmills are still used by farmers to pump up water in many countries. Another old application of wind energy 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 electrical generator. Wind energy currently generates only 0.3% of the world's electricity, but the capacity is growing. Wind turbines cover about 14% of the electricity demand in Denmark, and about 3% in Germany.

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 windmill, 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 windmills 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 that the electricity is generated very irregularly. If the share of wind and solar power grow, 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.

The capacity factor of wind turbines

Wind turbines come with a label that says how much power they can generate. For example, there are 750 kW turbines, and larger ones, 1.5 MW to 2.5 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", they use these figures.

The energy that is delivered by a wind turbine depends on the number of hours it can operate each year. This of course depends on the weather condition. In fact, averaged over a year, a wind turbine delivers about 20-30% of its potential energy output. The difference between the actual yearly energy and the theoretical maximum is called the *capacity factor*. So on average, a wind turbine of 1.5 MW delivers about 4200 MWh per year. So on average during the year, it is as if the turbine had power of about 300 to 450 kW, instead of 1,500 kW.

Wind turbines on a hill.

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

On the Web

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www.eia.doe.gov/kids/renewable/wind.html

A brief introduction to wind energy.

www.eia.doe.gov/kids/milestones/wind.html

Wind energy and history.

www.eia.doe.gov/kids/renewable/renewable_links.html#Wind

Links to wind energy sites.

www.windpower.org/quiz/index.htm

Wind energy quiz.

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Energy from biomass

Biomass is another word for organic matter. When used as a fuel, it includes lumber industry residues (wood 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.

Wood chips used for electricity generation

Organic material has stored sunlight 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 replenished for biomass energy purposes. These plants, such as fast-growing trees and grasses, are called *biomass energy feedstocks*, or *energy crops* for short.

On the Web

Biomass and geothermal energy

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www.nrel.gov/education/biomass.html

Extensive list of biomass related websites.

geothermal.marin.org/index.html

Including classroom and public information packages.

iga.igg.cnr.it/index.php

International Geothermal Association.

http://geothermal.marin.org/

Geothermal education office.

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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 meters deep. Water that is injected in the well (which can be simple rainwater) 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

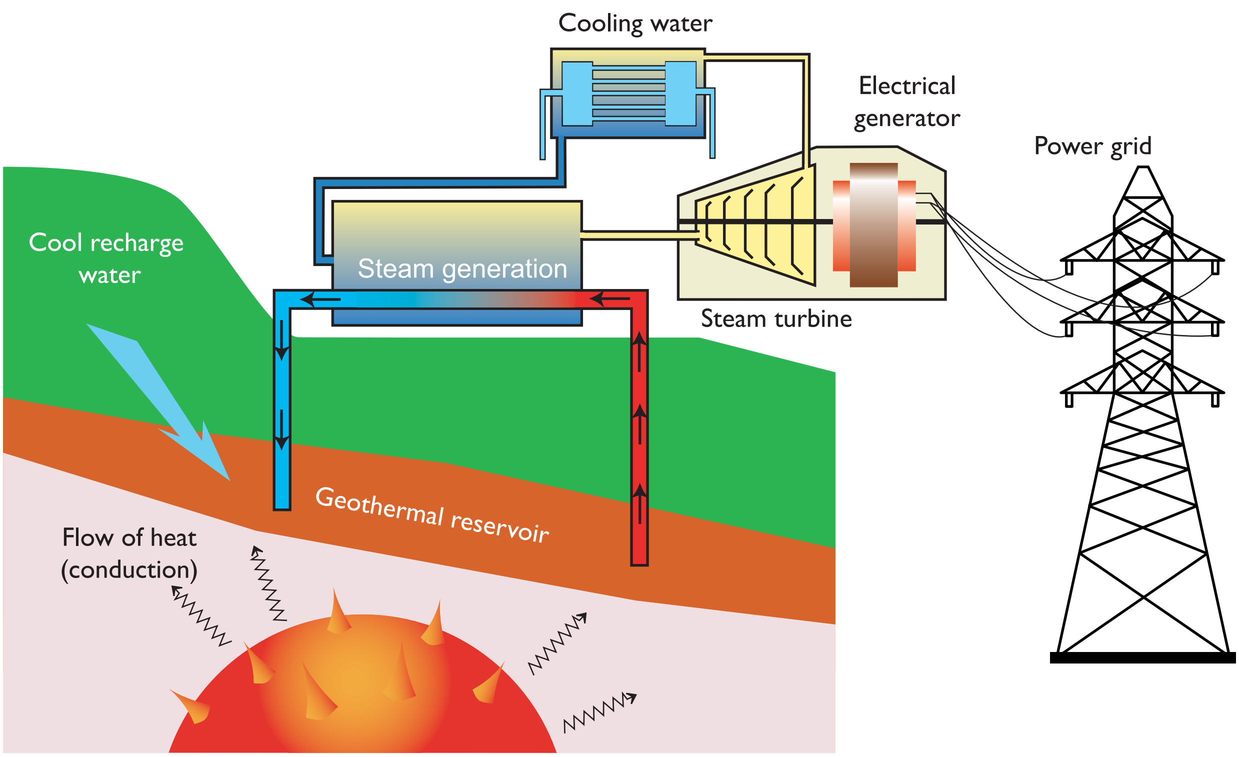

Figure 11. The principle of geothermal energy. The inner heat of the earth is conducted towards the surface of the earth. In deep wells, cold water is injected. In a production well, hot water is pumped up. The hot water is used to make steam, which is used to power a steam turbine.

Energy source	Fuel needed for a 1000 MW plant, during one year	For comparison
Biomass	2,000 km^2 of energy crop	3 times surface lake of Geneva
Wind	2,700 windmills of 1.5 MW (25% capacity factor)	486 km^2
Solar PV	23 km^2 of solar panel on the equator	2555 soccer fields
Biogas	20 million pigs	
Gas	1.2 km^3	47 Cheops pyramids
Oil	1,400,000 tons	10,000,000 oil barrels or 100 super tankers
Coal	2,500,000 tons	26,260 train waggon loads
Nuclear fission	35 tons of UO2	210 tons of Uranium ore
Fusion	100 kg D and 150 kg T	2850 m^3 of sea water and 10 tons of lithium ore

Table 9. Fuel requirements for different energy sources. In the table, the fuel use is shown for a 1000 MW power plant for one year (total output about 7000 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.

uses only geothermal power for its electricity. In the world, around 8,000 MW of geothermal electricity is generated, and another 10,000 MW of direct geothermal heat is used.

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

Comparing different energy sources

All energy sources discussed in this chapter have different characteristics regarding quantity and type of fuel, surface needed, and cost. In table 9, the fuel needs 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. This is caused by the fact that these energy sources are not very concentrated: the fossil fuels embody much more energy. Nuclear fission, and especially fusion, need the smallest quantitiy 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 guarentee clean and plentifull energy in the future.

Summary

- Oil, coal, and gas are the most important sources of primary energy. They provide 80% of all energy.
- Nuclear fission is a powerful and clean way of generating electricity. However, there are concerns about the safety of plants and waste disposal.
- Fusion energy is an inexhaustible and clean energy source that is currently under development.
- Hydro power provides electrical power on a large scale. However, new dams can have a severe impact on people and the environment. Most of the availble locations are already in use.
- Renewable energy sources are sources which constantly renew their energy.
- Biomass energy is used a lot in developing countries, especially in the form of firewood.
- Renewable energy sources like solar and wind generate clean energy, but currently their share of the world's energy is very small.

Things to do

- Try to visit a power plant and write a report about it.
- How would you design a solar collector to use the sun's heat for warming up water?

5 Energy, the environment, and health

The increasing production and use of energy can be dangerous to the environment. And to your health. Energy production is the biggest part of the negative impact humans have on the environment. When wood is burnt, many 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, which is released when any fossil fuel is burned, amplifies the greenhouse effect and causes the earth to warm up. People may have to move when large hydro dams are built, and forests may be cut down for firewood.

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

The household level

In western countries, there is not much pollution produced in homes. Most of us cook on electricity, gas or some fluid fuel, which is quite clean. However, about half of the households in the world depend on firewood and coal for cooking and heating. It is very hard 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 5-18 percent of the energy goes in the pot, the rest is wasted. What is more, incomplete burning of solid fuel produces a wide range of health-damaging pollutants, as shown in table 10.

This is no small thing. 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 the national burden of illness in developing countries. Of course, the risk of pollutants is the largest when people are near. The problem is that the dirtiest fuels are used exactly at times when people are present: every day, in the kitchen and in heating stoves.

Household energy use can be seen as an *energy ladder*, which at the lowest end has simple biomass fuels (dung, crop residues, wood), higher up are liquid fossil fuels like kerosene, then gas, and at the top the most modern form, electricity. Going higher up the ladder, the stoves that are used become cleaner, more efficient, and more controllable. In general, when alternatives higher up the ladder become affordable and available, people tend to move up the energy ladder, where they have access to more energy services, as shown if figure 13.

Where in ancient times all of humanity depended on wood, now roughly half of the global population has gone one or more steps up the ladder. The other half still depends on wood, or, where wood has become scarce, have been forced down the ladder to dung and crop residues. In some severe situations, people use the poorest-quality fuels such as shrubs and grass.

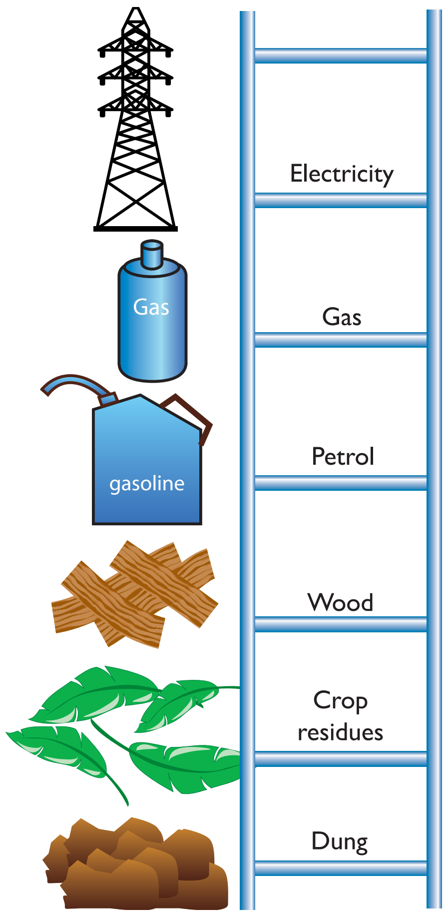

Figure 12. The energy ladder.

Substance	Concentration at 1 kg wood per hour mg / m^3	Standards set to protect health mg / m^3
Carbon monoxide	150	10
Particles	3.3	0.1
Benzene	0.8	0.002
1,3 - Butadiene	0.15	0.0003
Formaldehyde	0.7	0.1

Table 10. Indoor concentration of health-damaging pollutants from a typical wood-fired cooking stove. Mg/m^3 means milligrams per cubic meter. 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).

At the lower end of the ladder, people use more of their own energy, for example to gather wood. Fuel gathering at the lower end of the ladder is a major burden for women and children, because of the heavy loads and the long time it takes. For example, in developing countries women and children spend 9 to 12 hours a week on firewood collection. In Nepal, women spend even two and a half hours ever day collecting firewood (the men spend forty-five minutes).

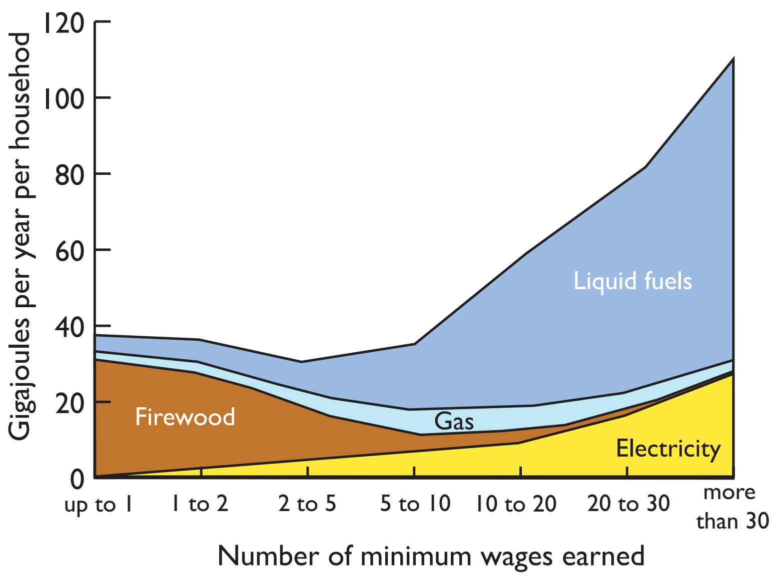

Figure 13. Average energy demand by income in Brazil, 1988. One minimum wage equals 50$. When people earn more, they tend to use more electricity and liquid fuels. (Source WAE, UNDP)

Poor people spend a large part of their time collecting the energy they need. This time cannot be spent in 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 poverty again, because you need to spend all your time in survival activities. This normally leaves very little time to do things that might get you out of poverty, like education, or production of goods to sell on the market.

The community level

Most of us are familiar with urban pollution. When looking over a city from a high point on a hot, windless day, you can often see a yellowish haze over the city. This is *smog*, a mix of small particles and exhaust gasses from car and motor engines. In some cities with a large car-fleet like Athens (Greece) or Los Angeles (California) people get lung-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 the ground level it is dangerous to human health. Ozone is produced when nitrogen oxides react with incompletely burned fuel from car and truck engines. Ozone can causes 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 meters measure carbon monoxide, nitrous oxides, and small particles.

Heavy traffic causes smog in large cities.

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 alternative 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 that is needed. They go into the mines for coal, go drilling for oil on the sea, cut wood or harvest biomass, and construct large hydroelectric dams. Harvesting energy is dangerous and heavy work, with 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 in the whole world (Source: WAE, UNDP). Energy comes at a high price!

The regional level

Another major environmental problem is acid rain, caused by sulphur dioxide released from burning coal and oil products, and nitrogen oxides. 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, for the Three Gorges hydro dam in China about two million people will be forced to move from their land, which will be flooded by the dam. In recent history, similar re-

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

settlement programs where in total some 40 to 80 million people were moved, have caused large social problems.

The global level

Some gasses in the atmosphere have the effect of forming a warm blanket around the earth, which is called the *greenhouse effect*. The gasses 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 greenhouse, but the glass stops the heat radiation that comes from the hot ground.

The greenhouse effect is a powerful effect: it keeps the earth 33 °C warmer than the earth would be without it. So without the greenhouse effect, the average temperature would be below the freezing point! Life on earth, including human, animal and vegetable life, could not exist without the greenhouse effect.

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

Not all gasses have the same effect in the atmosphere. Methane for example retains heat in the atmosphere 21 times more than carbon dioxide. So if you produce 1 gram of methane, and 21 grams of carbon dioxide, it has the same effect on the greenhouse-warming of the earth.

Cattle and methane

About 20% of the methane emissions in 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 food is used to make methane. The total effect of 1.3 billion cattle making 100 millions tons of methane each year can have an effect on the balance of greenhouse gases. Human related processes, from energy production to agriculture, produce about 60% of the world's methane. Ruminants produce approximately a third of that amount, or 20% of the world's total emission of methane.

Ruminating cattle release greenhouse gases.

Both carbon dioxide and methane disappear slowly from the atmosphere. CO_2 is eventually taken up by the oceans, and CH_4 is removed by chemical reactions in the atmosphere. This is a very slow process: it takes about a hundred years for a molecule of CO_2, and about 12 years for a molecule of CH_4. This has the very important consequence 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 go down. So it is like doing a large-scale experiment with the earth, while we are all sitting in the test tube.

The greenhouse effect may be fragile. In the last 150 years, we have burned a lot of fossil fuels, which have released huge quantities of CO_2 in the atmosphere. The production and use of energy causes two-thirds of all greenhouse gasses made by humans. As you can see in Figure 15, the CO_2- concentration in the air has risen by 30 pe cent since the Industrial Revolution. The CO_2 oncentration has fluctuated before in the past but never this fast. 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.

Units of concentration: ppm

To measure small concentrations of a substance, we use the unit *parts per million* (ppm). It simply measures 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.

What is the effect of all the extra CO_2? Since the late 19th century, the average temperature has risen 0.6 degrees Celsius. The 11 hottest years since 1860 have all occurred after 1983, and the sea level has risen by 10 – 25 centimetres in the last century. Mountain glaciers around the world have shrunk, and cloudiness and rain has increased around the world. It is expected that by the year 2100, the average air temperature could rise by 1.4 – 5.8 degrees Celsius and the sea level could

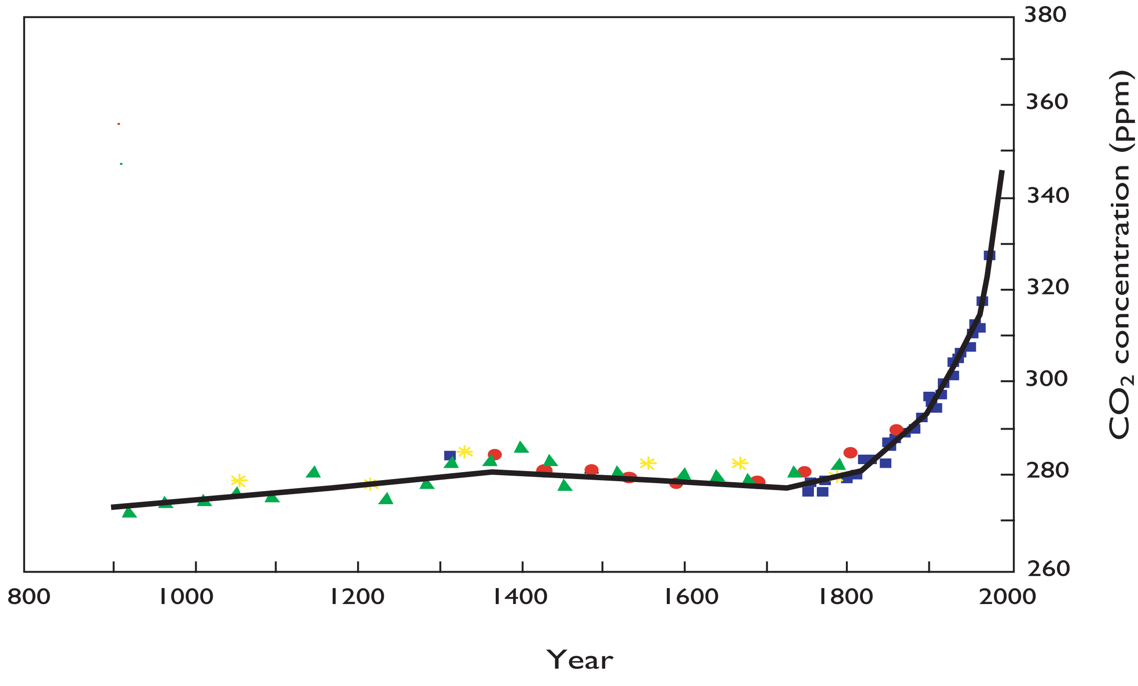

Figure 15. Increase in CO_2 concentration during the last 1200 years. Clearly, the concentration has started to increase dramatically since the use of fossil fuels started around 1800. The concentration is expressed in parts per million (ppm). The different colored points represent measurements from different sources. (Soure:F. Joos, 1996Europhysics News, 27, 6, 213-218 (1996))

increase by 0.09 to 0.88 meters, depending on the future scenario (source: IPCC, TAR). To put this number into perspective: the difference in average temperature between the last ice age thousands of years ago and the current time is just 6 degrees.

You might think that an average temperature rise of a few degrees is not so much of a problem, but actually it is. First of all, the rise in sea level caused by a few degrees temperature increase will already cause problems for many coastal areas. Secondly, the inland temperatures will change by much more than the average, and in general it is the *extremes* of the weather that become greater. And it is these extremes, like droughts, hurricanes and floods, which cause us the most trouble.

People expect that in the next 100 years, the CO_2 level may become double what it was before 1860 in the best case, and in the worst case, it may quadruple (source: WEA). If the CO_2 level quadruples to four times the pre-industrial level, the world will look quite different. 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.

What can we do about it? The only way to stop the harmful effects of extra CO_2 is to stop producing it, that is, to stop using fossil fuels or to capture and dispose safely of the CO_2 produced by burning fossil fuels. Obviously, that is not an option at this moment. But even if we want to let the CO_2 level stabilize at two times the pre-industrial level, that would mean that we have to cut our CO_2 production right now by two-thirds. And instead of decreasing, the CO_2 production is rising every year.

A global temperature rise will lead to a higher sea level

The Kyoto protocol

In the 1990's, scientists around the world started to warn people about the dangerous effects of greenhouse gas emissions. According to several studies performed in a number of countries, the rapid increase of greenhouse gasses in the atmosphere causes a small, but steady increase of the temperature of the earth. Special international panels and committees were created by the World Meteorological Organization (WMO) to discuss the problems, and they recommended urgent measures against this threat (IPCC, Intergovernmental Panel for Climate Change).

Since then, several initiatives have been taken to avoid the predicted catastrophic effects like 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)". In this document, the goal was formulated to achieve "stabilization of greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (anthropogenic means of human origin). Afterwards, this international treaty was signed by most countries, and has entered into

The Kyoto protocol (continued)

force, meaning that it is now obligatory for all countries.

During the United Nations Climate Change Conference in Kyoto, in December 1997, major industrial nations 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 by 5.2% (8% reduction for the European Union) of the 1990 levels between 2008 and 2012. This pact is known as the *Kyoto protocol*. (As it is part of another document, it is actually called the Kyoto protocol to the UNFCCC).

However, the Kyoto protocol is not obligatory until enough countries sign it (also called *ratifying* a protocol). The protocol becomes obligatory if signed by nations that together produced in 1990 55% of all the greenhouse emissions of the developed nations. Now, after five years, we are slowly approaching this target. The problem is that the USA have declared that they will not sign the agreement, and the USA alone accounts for 36% of all the greenhouse emissions of the developed nations.

Even if the Kyoto protocol is not ratified, many countries have decided that they should meet the target of 8% reduction anyway. At the moment, countries try to think of how these reductions can best be realized, and what the most practical methods of reduction are. Should we use energy more efficiently, or should we supply more electricity CO_2-free, for example using solar panels? Do we have to build more nuclear power plants, just because they don't emit greenhouse gasses? Should we invest in windmills or in fusion research, or in both?

As we only have one earth, we cannot afford to make mistakes

Energy options and the greenhouse effect

Not all energy sources produce greenhouse gasses. Solar panels, wind energy, and hydropower are all examples of energy sources that produce electricity, but no 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 for example, rotting plants produce methane, which is a very powerful greenhouse gas.

Can we generate all our energy without producing greenhouse gasses? Yes, but we will have to work very hard to achieve that stage. Solar and wind energy only play a very small role now, and it will take many decades and a lot of research before they will generate substantial amounts of energy. Eventually, they can only supply part of the electricity because they are intermittent. Clean fossil, the technique of putting CO_2 back in the ground, is still an experimental technique, and questions about the effects and risks in the longer term still have to be answered. Fusion energy doesn't work yet, and it will take some decades of research before fusion delivers a reasonable share of the energy mix. If we take the climate problems seriously, we will have to develop all clean energy sources, and we will have to do it quickly.

On the Web

>>>

unfcccc.int

Provides information on the United Nations Framework Convention on Climate Change

www.ipcc.ch

The site of the Intergovernmental Panel on Climate Change

www.arm.gov/docs/education/warming.html

A good site with translations in French, Spanish, German and Italian. It also provides exercises for students.

www.defra.gov.uk/environment/climatechange/schools/index.htm

Climate change information for 12 – 16 year olds students and their teachters.

hdgc.epp.cmu.edu/teachersguide/teachersguide.htm#lesson

Teacher's guide to Climate Change, including lesson material.

globalwarming.enviroweb.org/games/index.html

Global Warming Games.

www.climatechange.gc.ca/english/workroom/students/greenhouse.shtml

Special site for schools including possible actions and a workroom. English and French.

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Summary

- The production of energy can have dangerous effects on the household, community, regional and global level.
- The household level: smoke causes illness in developing countries
- The community level: Energy production is a dangerous job. Many people are injured or killed in mines.
- Also at the community level, energy use can cause smog above cities and the formation of ozone.
- The regional level: use of energy can cause acid rain.
- Globally, the greenhouse effect caused by carbon dioxide and methane is starting to have an discernable influence on the climate everywhere on earth.

Things to do

- What is your opinion about nuclear energy?
- How do you think we should stop global warming?
- Find out what your country does to stop pollution from energy production.
- Has your country signed/ratified the Kyoto protocol?

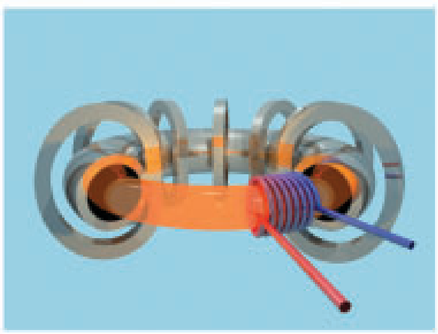
6 Thinking ahead: the energy of the future

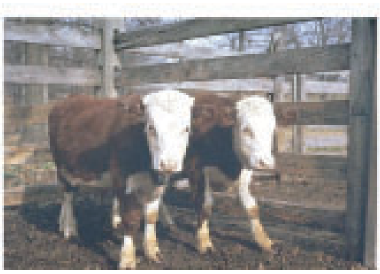
It is expected that in 50 years, the world energy use will be three times higher than it is today. This growth in energy use leads to two problems. The first is that we will slowly run out of easily obtainable fossil fuels. Although in total, there are enough fossil fuels to last us several hundred years, they are not spread evenly around the world. Almost 80 percent of the oil and gas is in the Middle East and in the former USSR. 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, 70% of all energy in Europe will have to be imported in 20 to 30 years from now. For many people it is a very worrying idea to be so dependent on other countries. For this reason, many countries are considering starting building nuclear fission power plants again, so they are less dependent on other countries.

A second problem is environmental damage. One of the fossil fuels that we have plenty of, is coal. But it is also very dirty to burn. So if large countries such as China and India remain dependent on coal, the local environment will suffer badly,






Our future energy system is determined by decisions we take today.

as it already does today. And CO_2 does not stay inside a country's borders, because of the greenhouse effect, CO_2 produced *anywhere* is our problem as well. On the other hand, if more nuclear fission power plants are going to be built, more nuclear waste will have to be disposed of, and this will also create problems.

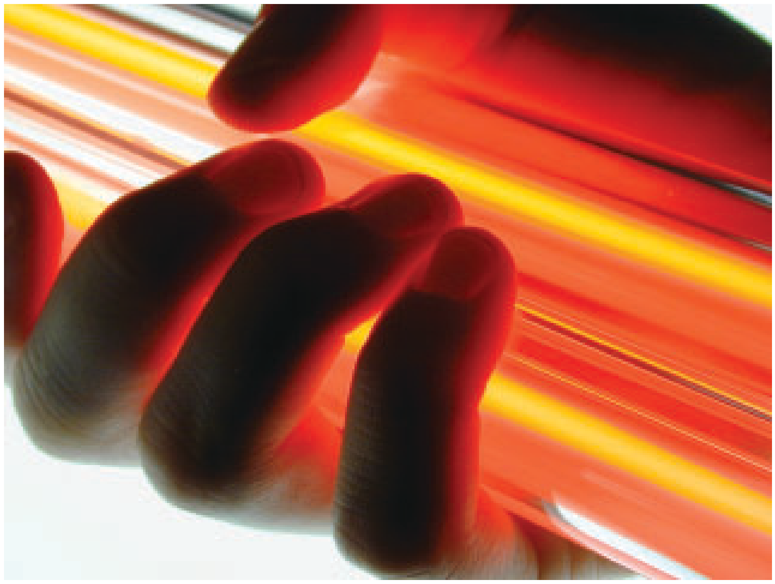
How to choose an energy source

Which energy source is most suitable for a given situation depends on many factors. Some energy sources, like coal, are cheap but if you don't have mines, you come to depend on foreign countries, and you emit greenhouse gasses. Other sources, like solar energy, are available throughout the world (at different prices, depending on climate conditions), but they are still very expensive, and take up lots of space. Let's see what factors determine the choice of an energy source for any country.

First of all: how much does it cost? The so-called *capital costs* are the cost for building the energy source in the first place: constructing a power plant, buying the solar panels. Power plants are very expensive, up to 1 billion Euro for a 1000 MW plant according to the US Department of Energy. But there are more 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*. This is normally about 0.03 Euro per kilowatt-hour, or a fraction of what you pay the energy company (the rest you pay is for the distribution network, taxes, etc.)

Apart from costs there are more factors, like the required *capacity*. If you need 1 kilowatt of power, you have many choices, including a small windmill, solar cells, or a diesel generator. But if you need 1000 Megawatt, for a city for instance, you will need to think of coal- or gas-fired power plants, or may be a nuclear fission power plant.

Then there are the environmental considerations such as the greenhouse effect: you may decide to generate your electricity CO_2-free, 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 lot 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 in all technology, *safety* is very important. If a hydro dam breaks, or a nuclear fission power plant has a bad accident, immediate evacuation of many people is necessary. You also don't want to stand next to a windmill losing its blades. Many people lose their lives in the mining of coal, in coal-dust explosions in power plants, and in oil-well accidents. Although there is no such thing as "safe energy" (that's like asking for petrol that doesn't burn), 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. Some sources, like nuclear fission, are best used for centralized energy ge eration, while others are more suitable for dece tralized, on–the-spot generation of energy. So it i important if a source is *centralized or decentralized*. Finally, if fuel has to be imported for a source, like oil, a country can become very dependent on

Energy source	Capital cost Euro per kW	Generating cost Euro per kWh	Common size power plant kW	Greenhouse gas emission gr. C equiv. per kWh	Land use km^2 per 1000 MW
Oil products	1,000	0.25	1 - 10,000	200	1
Coal	800 - 1,100	0.05	1,000 - 1,000,000	270	1 - 2.5 plus mines
Gas	300 - 600	0.035 - 0.050	1,000 - 1,000,000	180	1
Nuclear fission	1,00 - 1,500	0.05 - 0.08	250,000 - 1,000,000	6[1]	1 plus mines plus safety areas
Large hydro	1,400	0.05	10,000 - 20,000,000	20[1]	30 - 40
Solar PV	4,00 - 6,000[2]	0.25	0.01 - 10	25[1]	23
Wind	700 - 1200[2]	0.06 - 0.10	0.1 - 100,000	34[1]	490
Biomass	1,300 - 1,700	0.05 - 0.10	1 - 150,000	10[1]	2,000
Fusion	6,000[3]	0.05 - 0.10[3]	1,000,000-3,000,000	9[1]	1

Table 11. Characteristics of different energy sources. Sources: Energy Information Administration, SAGE project, NEMS.

1) Nuclear, solar, wind and fusion emit CO_2 during the construction and deconstruction. In the case of large hydro: recent research shows that some hydro dams generate greenhouse gases in the form of methane, from decomposing plants.
2) 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.
3) Fusion will become commercially available around 2050, therefore capital and generating cost are prognoses for that year. The capital cost depend on the type. (source EFDA, socio-economic research on fusion, 2001)
4) The safety hazards in the worst case scenario.

Energy source	Safety hazards[4]	Intermittent	Dependence on other countries	Centralized / decentralized
Oil products	small	no	high	both
Coal	small	no	high	centralized
Gas	small	no	high	centralized
Nuclear fission	evacuation	no	medium	centralized
Large hydro	evacuation	no	none	centralized
Solar PV	none	yes	none	decentralized
Wind	small	yes	none	decentralized
Biomass	small	no	none	decentralized
Fusion	small	no	none	centralized

	Situation I	Situation II	Situation III
Demand	1,000 MW	50 MW	1 kW
Budget	1,000 million Euro	150 million Euro	50,000 Euro
Greenhouse gas	< 250 gr C / kWh	< 100 gr C / kWh	< 50 gr C / kWh
Land use	< 100 km^2	< 50 km^2	< 100 m^2
Safety	No demands	small	small

Table 12. Three different energy demand situations. The first situation generates enough electricity for 2 million households, the second for 100,000 households, and the third for two households.

other countries. So the *dependence on other countries* is an issue as well.

In table 11 all the energy sources are compared using these nine factors. As you can see, depending on what you find important different energy sources can be suitable. Let's consider the three different examples shown in Table 12. Can you figure out which sources are most suitable for each situation? The solutions are printed at the end of this chapter.

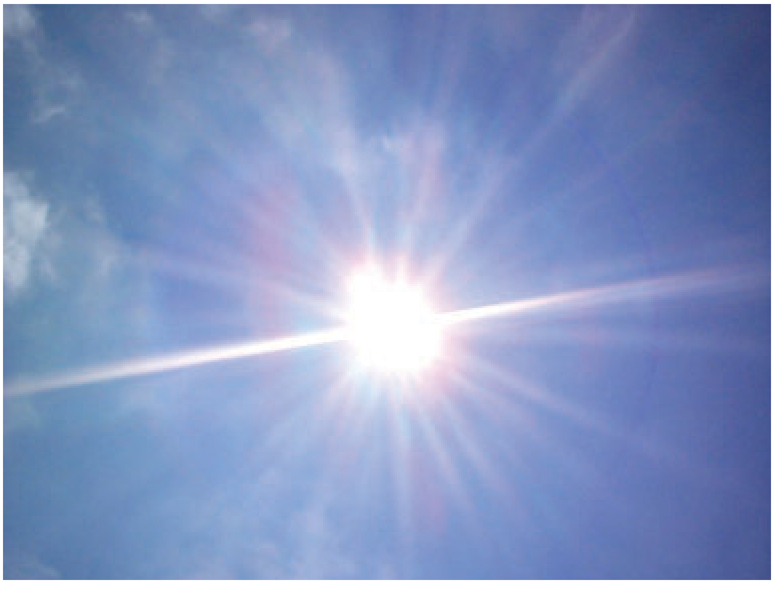
Sustainable energy

Apart from looking at each energy-demand situation separately, we can also consider the development of the energy system as a whole. How should it develop? Do we have to take action now, or can we wait until fossil fuels run out? In an ideal world, we would like *sustainable development*. Sustainability is defined as: "Meeting the needs of the present generation without compromising the ability of future generations to meet their needs " (Brundtland report, 1987).

We shouldn't use up more than our fair share, so to speak, and we should make it possible for the 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 it's social, economic and environmental dimensions. This we call *sustainable energy*. It refers to the production and use of energy sources in ways that respect long-term human well-being and ecological balance.

To reach this goal in the long run, we would preferably use only renewable energy sources: sources of which the energy never runs out. Among these sources are wind, water, solar and fusion energy. Although with fusion we actually burn fuel, it will never run out, as there is so much of it in the world's oceans.



Sustainable energy: clean and inexhaustible. Fusion scientists try to make a sun on earth.

Of course, at the moment we are very far of this ideal situation. According to the 1999 world energy balance produced by the International Energy Agency, only 17% percent of our energy comes from renewable sources (including non-commercial biomass like firewood), and 19% of our electricity. Most of the renewable energy comes from hydro energy, and the burning of waste materials, and most of the potential hydro energy capacity is already in use. At the moment, the growth of the world energy demand is ten times larger than the growth of the supply of renewable energy.

Keep up the growth?

At the moment the installed wind energy power is still very small, so it is easy to grow fast. If you have 100 windmills, and you want to add 35%, you have to built 35 extra windmills. But if you have 10,000 windmills, and want to add the same 35%, you have to build 3,500 extra windmills! It is easier to grow when the numbers are still small, and it is unlikely that the current fast growth can be maintained.

Let's go renewable?

Why don't we use much more renewable energy already? There are several reasons. The first is that the world is just starting to improve technologies that harness renewable energy which is available, in a way that is economically acceptable as well. Especially solar, wind and biomass energy are growing very fast: installed wind power has been growing by 35% every year for the last five years, however, it is unlikely that the present fast growth can be maintained (see box on this page).

The second reason is that despite many years of research and development, renewable energy technologies remain more costly than just burning fossil fuels. Of course, it is very hard to compete with a fuel that you can practically just pick up from the ground. But fossil fuels have many 'hidden' costs, such as the future costs of the effects of the greenhouse effect, and the medical costs of diseases caused by polluted air. If these costs are taken into account, the picture may change in favour of renewable energy sources.

Research in solar power.

A third reason is that especially wind and solar energy are so-called *intermittent* sources of energy, meaning that they do not deliver energy all the time. This means that you need back-up power, or a means of storing power for times when there is no sun or wind, which adds to the costs of these energy sources. Furthermore, sun, wind and geothermal sources are not spread evenly around the globe. Especially geothermal and wind are very site-specific.

Finally, renewable sources like wind, solar and biomass need a lot of land. If you take a windmill that can generate 1.5 MW, which has blades of 60 meters, you need 667 of them to reach the same output power of a 1000 MW power plant. In reality, you need 2700 of them, if you assume a capacity factor of 25%. To put the mills in, you need about 480 square kilometres of land. To get a 1000 megawatts of biomass power, you need 2000 square kilometres of land to grow energy crops!

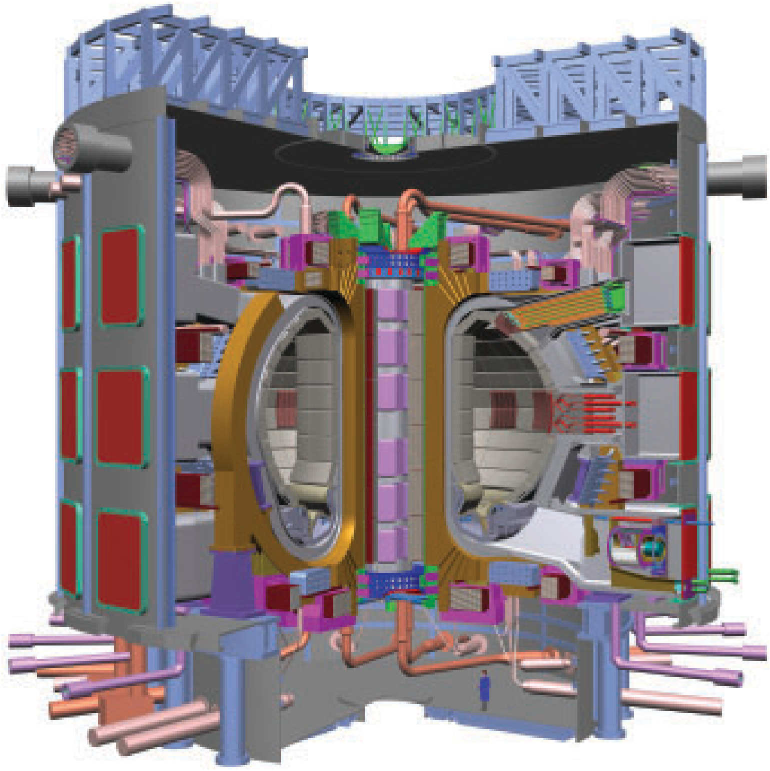
Present research for future energy options

In the future, we need all the energy options that are available to us. Currently, much 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 to improve existing commercial energy technologies. Public institutions like universities and research institutes funded by the government try to develop energy technology that is not commercial yet.

In the supply sector, coal mining companies try to reduce the mining cost, and to extract methane from coal beds or even to gasify coal directly in the mine. Oil and gas companies develop measurement techniques and software to improve the success rate of new drillings, try to enhance the amount of oil and gas taken out of a single well from 20-30% to 60-70% or more, inject steam in some fields in order to recover heavy oils too dense t flow out. Refining companies ha

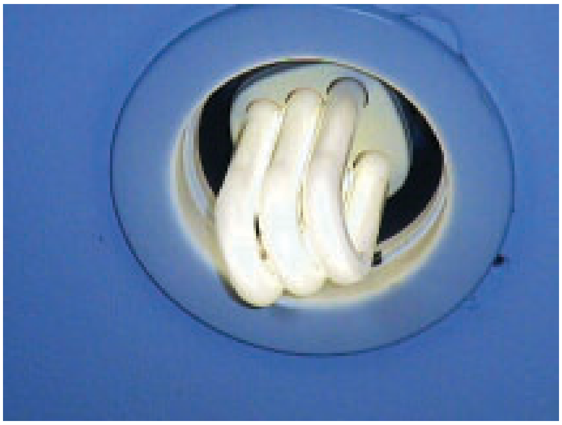
to reduce continuously the sulphur content of oi products, or the amount of harmful substances n petrol or the emission of other harmful org nic compounds. The suppliers of machinery to build power plants try to improve the efficiency of the components, and devise new ways to reduce pollution and to reduce costs. There is a large amount of research, both from companies and public institutions, to improve the performance of all kind of technologies that harness renewable energies, because their success would improve significantly our future energy perspectives.

In the transmission, distribution and delivery of energy to the final consumers research is aimed



The next experiment in fusion power, the ITER, will be finished around the year 2012. The little man in blue in the lower part of the picture shows the scale.

at improving the amount of energy that can be transported, reducing pollution and costs. For instance, some research is devoted to transport coal in pipelines in the form of coal-oil and coal-water slurry. To reduce the electric transmission losses, new super-conducting cables are under study. Other research tries to improve the stability of large national or regional electric networks.



Fluorescent lights use five times less energy than normal lightbulbs.

In the final use sectors the research activities are even more diverse. The efficiency of most energy devices is improving, from refrigerators, light bulbs, automobiles, motors to every kind of oven and boiler in industry. The list of RD&D (Research, Development and Demonstration) projects carried out in recent years in the main parts of the energy technologies systems is extremely long, with many successes.

Some of the energy sources that were mentioned in chapter four are still actively being researched. For example, there is a worldwide research program aimed at developing fusion energy, and great

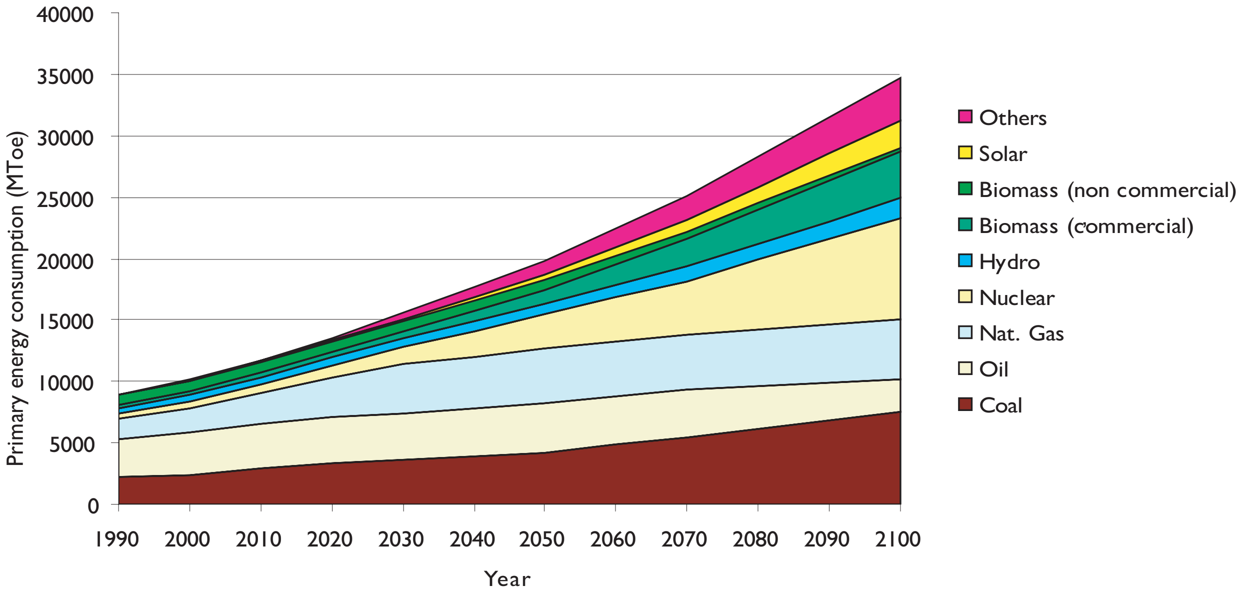


Figure 16. Energy scenario for the global primary energy consumption up to the year 2100. (Source: World Energy Council and IIASA, 1998, (middle scenario), see also www.iiasa.ac.at).

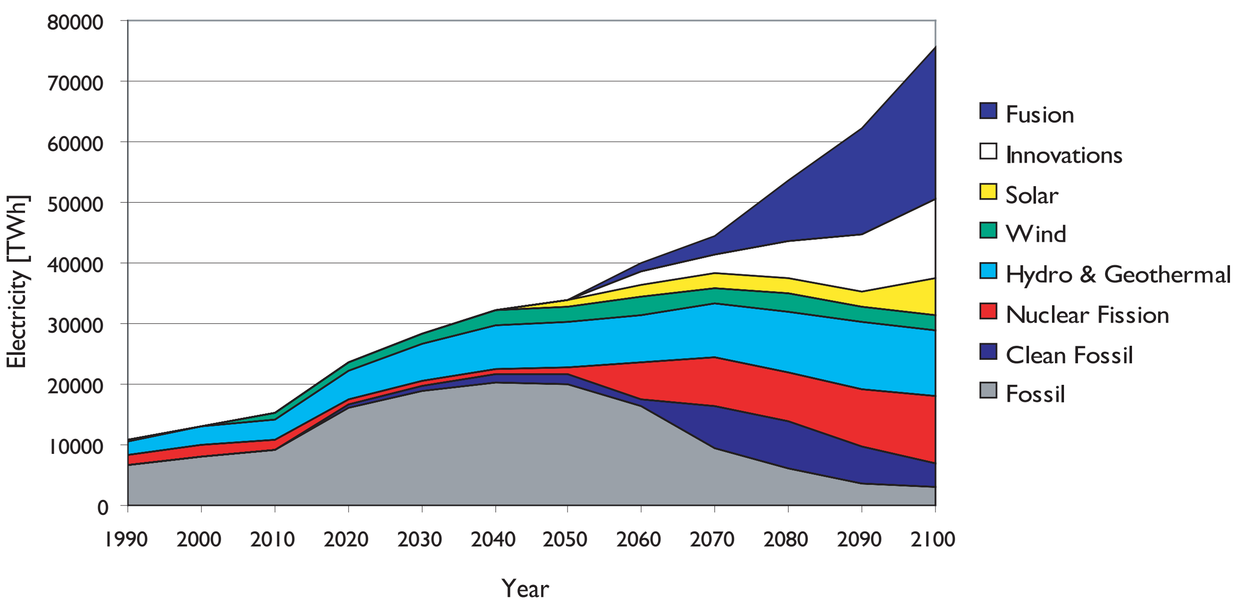


Figure 17. Energy scenario for the world electricity use up to the year 2100. Source: the Research Institute of Innovative Technology for the Earth, Tokyo, Japan.

progress has been made already. It is expected that fusion energy will be available in the second half of this century.

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 16 shows such a scenario, made by the World Energy Council (WEC). According to this scenario the world energy demand will triple during the next 50 years, mainly caused by the growth of the world population from the current 6 billion to 10 billion in 2050. Another cause is the economic growth and increased energy use of developing countries. In this scenario, the use of fossil fuels is expected to continue to grow at a slow pace. Around 2050, the share of renewable energy could be around 25%.

Figure 17 shows a different scenario, this time for the world electricity demand. Notice that in the second scenario, fusion energy is given a prominent place, while the WEC scenario does not. The Japanese scenario describes the following situation:

- After an increase in coal consumption, there will be hardly fossil fuels used anymore at the turn of the century.
- Clean Fossil will be coming up, but is under development during the first decades.
- Nuclear Fission will be applied more and more.
- Hydro & Geothermal will increase slightly but will then remain constant since all sites nature provides will be in use in the second half of the century.
- Wind will show a rather slow increase during the first decades and won't grow much further after that.
- Solar energy still needs a long time to grow.
- Wind will show a rather slow increase during the first decades and won't grow much further after that.
- Fusion will show a dramatic increase after 2050.

Full speed ahead

To take an example, suppose that we would like to have 10% of the world electricity demand covered by wind energy in the year 2050. As we have 0.3% now, we need one hundred times as much wind energy by 2050 (remember that the total energy demand in the world will probably triple). This means that every year, the number of windmills has to grow by 10% over the next 50 years. This growth speed is certainly possible now, as we do not have many windmills yet. But as the installed capacity grows, the 10% becomes a very large number of new windmills to be placed somewhere, every year: In the year 2049, we have to find a place for 60,000 extra windmills of 3 MW each. And that is just for 10% of the world's electricity…

Of course, these are just two possible scenarios, and things may turn out to be very different. 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 energy mix. Factories and power plants have to be built, research and development have to be done, people have to be trained.

Fusion power is often not taken into account in energy scenarios up to 2060 or so, as it is expect-

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 ed that fusion will not be available commercially before 2040 – 2050. After that time, fusion energy can form a considerable contribution in the reduction of the emission of greenhouse gases.

The energy carrier of the future: Hydrogen?

In the ideal case, we would like to use electricity for all purposes. 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 so much fossil fuels like petrol for transportation: petrol is easy to store, and contains lots of energy. 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 *energy carrier*, like electricity.

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 chemically reacted with a high efficiency, with zero emission (just water) where it is used. If hydrogen is made from renewable or nuclear sources, or from fossil fuel of which the CO_2 is captured, it would be possible to produce and use fuels with hardly any emission of air pollutants or greenhouse gasses.

A bus powered by hydrogen using fuel cells and an electrical motor.

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

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. To produce one kilogram of hydrogen, about 50 kWh of electricity are needed.

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 these two carriers. The concept of a hydrogen economy has been explored several times, the first time in the 1950's and 60's, where hydrogen was seen as a complement of a largely fission energy system, to store off-peak fission power. Later, it was explored as a means 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 the CO_2 that is released can be captured and stored in old gas or oil fields, or in deep subterraneous water layers.

So-called fuel cells turn hydrogen (and oxygen) into electricity at low temperature and high efficiency. Recently, rapid progress is made towards using fuel cells for transportation and power applications in industry.

Conclusion

All large-scale energy production systems have their problems and their merits. Fossil fuels emit greenhouse gasses and other pollutants, most hydro-capacity has already been used, and new hydro dams change the environment and have social costs. Nuclear fission power plants are emission-free but produce waste. Using fossil fuels often makes countries very dependent on other countries. Apparently, we cannot have the good without some of the bad. The best way is to have a diversified energy system, using all possible energy sources, so 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 thing to have is centralized energygeneration 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 such a big and important system. Our decisions now on which technologies to develop and support, will largely determine what the energy system looks like in 50 years time or longer. We have to provide the generations that come after us with the techniques they need to satisfy their energy demand. As there are so many uncertainties about the future developments, it is best to develop all available energy sources so that they come 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 away. The future of energy starts today.

On the Web

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www.eren.doe.gov/kids/

Renewables, energy efficiency, quizzes.

www.energyquest.ca.gov/index.html

A very good and interactive site with almost all energy subjects covered.

www.irish-energy.ie/energy_linked/subjects_geog.htm

Complete lessons about fossil and renewable energy subjects.

www.academyofenergy.org/intro.html

Including materials for students and teachers.

europa.eu.int/comm/dgs/energy_transport/index.html

Multilingual site with information about EU-policy on energy and transport.

europa.eu.int/comm/research/energy

The European Commission site for energy research.

Links for teachers:

www.nefl.org/educatorlinks.html

www.eren.doe.gov/education/

www.solarnow.org/links.htm

sln.fi.edu/tfi/hotlists/energy.html

dir.yahoo.com/Science/Energy/

An extensive list about all aspects of energy varying from sources to news and media about energy.

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Summary

- The continuous use of fossil fuels creates a burden for future generations, forcing us to think today about the world of tomorrow in terms of sustainable development and energy.
- Fusion energy might become one of the important energy sources in the future, but it still needs some decades of development.
- Although renewable energy sources are already available, several decades are also needed to bring these technologies to a mature state.
- The uncertainties of the future energy mix require us to develop all possible energy technologies to a mature state, starting today.

Things to do

- A class discussion or essay about how you think energy in the world should be produced and consumed fifty years from now. Try to focus also on developing countries.

Sources

The supplied data (all tables and all percentages relating to energy sources and consumptions) derive from:

- Energy balances of non-OECD countries (1999), International Energy Agency (IAE)
- Energy Balances of OECD countries (1999), IAE
- International Energy Annual (1999) – Energy Information Administration (EIA), DOE
- International Energy Outlook (2002) – EIA, DOE
- Energy and the challenge of sustainability (2000)— World Energy Assessment, UNDP
- F. Joos, 1996, Europhysics News, 27, 6, 213-218
- Energy research Centre of the Netherlands (ECN)

Solution to the exercise:

Exercise I:

- The electricity demand is 1 Gigawatt: oil, solar, wind and biomass are excluded.
- The budget for the plant is 1 billion Euro's, which corresponds with capital costs of 1,000 Euro/kW: coal, gas or nuclear are still optional.
- The C – limit leaves coal out.
- Land occupancy is not a problem for gas or fission.
- Depending on the safety considerations (e.g. whether there is room for safety areas), either a gas fired power station or a fission power station would be the solution.

Exercise II:

- The demand is 50 Mega watt: oil and solar are excluded.
- The budget is 150 million Euros to generate 50 Mega watt, this corresponds with 3,000 Euro / kW.
- The C – limit leaves coal and gas out.
- The safety hazard and the capacity exclude fission too.
- The available options are wind and biomass. The available land occupancy prevents 100% f the demand being covered by biomass only. Co sidering the budget and land occupancy, combination of 50% wind and 50% biomass will do the job. (Wind has higher capital costs, but occupies less land then biomass resulting in an optimum of these two options of 50 / 50)

Exercise III:

- The demand is only 1 kW, excluding coal, gas, nuclear and large hydro
- A budget of 50,000 Euro means 50,000 Euro/kW, leaving room for even solar.
- A C – limit of 50 gr. / kWh excludes oil.
- A land occupancy of 100 m^2 for 1 kW, corresponding with 100 km^2 / GW, leaves solar as the only option. Disregarding the surface area limit would probably result in a choice for wind energy, however, as it is much cheaper.

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