INTELLIGENT USE OF ENERGY AT SCHOOL IUSES

Energy efficiency in industry

Student handbook

Intelligent Energy Europe

Official Partner

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About this handbook and IUSES

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Copyright notes

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Preface

Energy is everywhere! It's what makes things happen, what makes things move. It's what gives us light and heat. It's what we use to travel, to cook our food, to keep our food fresh, to make our food.

About this Handbook

This handbook, Energy Use in Industry is part of the course called Intelligent Use of Energy at School. This course is aimed at helping students learn the basic principles of energy efficiency. It is one of three handbooks besides the Handbooks on Energy Use in Transport and Energy Use in Buildings.

This handbook will introduce you to what energy is, and how it works, especially in industry. It will explain many of the terms used in energy, the different sources of energy, how electricity is generated, and how energy is used in industrial operations.

One of the main purposes of this course and this handbook is to show how we can make energy better, cleaner, produce it from more renewable sources and also how we can better manage it especially concerning the reduction of waste.

How the Handbook is organised

This handbook is intended to present information to you in an interesting and interactive way and includes many different types of information such as text, pictures, graphs, definitions, tips, important points etc. It also contains many different activities, exercises, questions and things to do. Here is a quick overview of what each section is about.

Chapter 1: Introduction to Energy

This section is made up of Chapters 1 and 2 and it will introduce you to what energy is and what it means. It will explain some of the definitions of how energy is measured - which measuring units are used and also what they mean. The meaning of "Power" will also be explained. It will also show that industry and society are dependent on the large scale use of energy where human energy itself is not enough.

Chapter 2: Sources of Energy

This section explains where energy comes from. The main types of energy we use are fossil fuels like oil, coal and gas which are non-renewable and can only be used once. Their emissions make a significant contribution to the change of climate. Other energy types, from renewable sources like the sun, wind or the sea, go on and on and do not cause global warming. We may also produce energy from resources maybe nowadays considered as "waste materials". Therefore we get energy from many different sources, some much better and cleaner than others. We outline trends in energy use and the significance of industry.

Chapter 3: Transforming Energy (energy carriers & industry use)

This section explains that energy is often converted into transportable fuels (via oil refining) or into electricity (using power plants). Sometimes we produce both electricity and useful heat. We look at the overall demand for energy in a country, showing that industry is one major user, comparable with transport and households. Finally, we introduce the idea of energy intensity.

Chapter 4: Energy management

This Chapter describes how an energy management system may be applied in industry. A similar approach may be adopted by a school to provide a structure for its energy management. This approach may be adopted by small as well as big organisations!

Chapter 5: Case study from paper industry

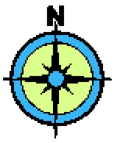
Chapter 5 presents the process for the manufacture of paper. This has been chosen as an example that illustrates the energy processes in industry. We have also provided instructions on how students may make their own paper, to provide opportunities for teachers to demonstrate particular aspects.

Some of the icons and tips in the handbook

In this handbook we have tried to break up the information for you into manageable and interesting chunks. It's not all just page after page of text (yawn!). So whenever we have things like a definition, an activity, a learning objective, an important note or a reference etc. we will mark it with an icon.
Watch out for these icons:

Definition: this is to indicate a definition of a term, explaining what it means.

Notes: This shows that something is important, a tip or a vital piece of information. Watch out for these!



Learning Objective**:** These are at the beginning of each chapter and they explain what you will learn in that chapter.

Experiment, Exercise or Activity: This indicates something for you to do, based upon what you have learned.

Web link: This shows an internet address where you can get more information

Reference: This indicates where some information came from.

Case Study: When we give an actual example of an industry or a real situation.

Key Points: this is a summary (usually in bullet points) of what you have covered, usually at the end of a chapter

Question: this indicates when we are asking you to think about a question, especially at the end of chapters

Level 2: this marks an in-depth section

Coming next: this is at the end of each chapter and tells you what's coming up next.

Chapter 1: Introduction to Energy

Learning Objective: In this Chapter you will learn:

- What energy is and what it means
- A brief overview of some of the main problems with energy use, their sources and how we consume them

What is energy?

As we already said, energy is all around us and without it we could not live. We use it every day, in many different ways. The food we take in contains energy; the paper this is written on took energy to be produced; the light you are reading it by is also energy.
But where does all this energy come from? And what are we doing with it? Are we using it wisely or are we wasting it needlessly? What are we going to do when all the coal and oil runs out? This is only one of the questions we will try to answer in this handbook.
We also need to think about what the conversion and usage of this energy causes? Ever heard of climate change? Greenhouse gas emissions? These are serious problems for the whole world now and energy production is one of their main causes. But it does not need be this way – there is a better way to produce and use energy and we will be learning about these and other issues while we go through this handbook.

Definition: Energy is usually defined as the capacity to do work. The amount of energy something has is the amount of work it can do.

Problems with Energy

Emissions from fossil fuel based energy production and use are the number one cause of climate change. The extraction and use of these fuels also causes pollution and we have to keep in mind that we are running out of these fossil sources. This means that security of supply is very important nowadays – we are very dependent on oil and coal especially.
Implementing renewable energy and energy efficiency measures are the best ways to reduce this damage to our planet. This is important in every day life, but also in industry and business.
Energy efficiency in industry, or complete self-sufficiency through renewables, not only leads to a better environment, but can also increase a business's profitability. This occurs through reductions in energy costs and overall increases in process efficiency. We'll learn more about these potentials later.

Sources of Energy

Nature provides us with numerous sources of energy, including solar radiation from the sun, flowing water (hydro), ocean waves, wind or the tide. Energy also comes from fossil fuels (including coal, oil and natural gas). These sources can be classified also as renewable and non-renewable. Renewable energy resources are derived in a number of ways:

- gravitational forces of the sun and moon, which create the tides;
- the rotation of the earth combined with solar energy, which generates the currents in the ocean and the winds;
- the decay of radioactive minerals and the interior heat of the earth, which provide geothermal energy;
- photosynthetic production of organic matter (biomass);
- and the direct heat of the sun (solar).

These energy sources are called renewable because they are either continuously replenished or, for all practical purposes, are inexhaustible. Non-renewable energy sources include the fossil fuels (natural gas, petroleum, shale oil, coal, and peat) as well as uranium (nuclear). Fossil fuels are both energy dense and widespread. Much of the world's industrial, utility and transportation sectors rely on the energy these non- renewable sources contain.

Energy Consumption

According to the International Energy Agency (IEA), the worldwide energy consumption will on average continue to increase by 2% per year. This yearly increase of the energy consumption leads to a doubling in every 35 years.

Energy consumption is loosely correlated with economic performance, but there is a large difference between the energy used in the most highly developed countries and the poorer ones. Did you know that an average person in the United States uses 57 times more energy than a person in Bangladesh?

The US consumes 25% of the world's energy (with a share of global productivity at 22% and a share of the world population at 5%).

Note: The most significant growth of energy consumption is currently taking place in China, which has been growing at 5.5% per year over the last 25 years. In Europe the growth rate was only about 1%.

Question: What do these four pictures indicate? Write one paragraph on each picture in relation to energy.

Key Points: The key points from this chapter are:

- Energy is important to our lives but maybe we are taking it for granted
- Energy production and consumption is causing huge damage to the planet and we need to stop that damage.
- Energy comes from many sources the older ones (oil, coal etc.) are running out and renewable sources are the only perspective to secure energy supply in the future.

Web links

International Energy Agency (IEA): http://www.iea.org

European Environment Agency: http://www.eea.europa.eu/themes/energy

Coming next: In the next section we will define power, explain the measuring units of energy and power, and do some exercises.

Energy and Power

Learning Objective**:** In this Chapter you will learn:

- The main measuring units of energy and power and how to apply them
- From an experiment how energy can be converted from one form to another

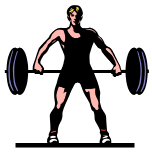
Definition: Power is the rate at which work is done or the rate at which energy is converted from one form to another, e.g. from chemical energy (coal) to electrical energy in a "power" station and from electrical to mechanical energy in a motor.

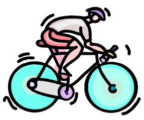
Units of Energy and Power	
Joule (J) - A unit for measuring thermal, mechanical and electrical energy. Since energy is the ability to do work, one joule (J) is the work done when a force of 1 newton acts for a distance of 1 meter in the direction of the force. It is also equal to the work done when a 1 ampere current is passed through a resistance of 1 ohm for 1 second.	**Watt (W)** - A unit of power, equal to the transfer of 1 joule of energy per second. **Multiples of units:** since a joule and a watt are quite small, we often speak in terms of 1000's of joules – a kilo joule (kJ), millions of joules (MJ) or billions of joules (GJ). Similarly we speak in terms of kilowatts (kW), megawatts (MW) and gigawatts (GW).

Human Power

But what do watts and joules mean in reality? How many do we use in our own bodies? And is that enough for us to live the way we do?

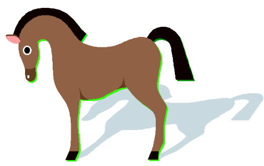
An Olympic weight lifter might achieve 1500 – 1800 W but only for a while less than a minute.





A top-class Tour de France cyclist might achieve a work output rate of 500 W for several hours. A person sitting will use about 100 W for basic body metabolism: breathing, thinking, etc.

"Horsepower" is an old unit of measurement that has several definitions but is typically equal to 745 W – so a horse was (optimistically) thought to be able to deliver 745 W.



But, in reality, human or horsepower are not enough for us any more, given the way we live. These are tiny amounts in comparison to what we need to produce our electricity, run our factories, power our transport etc. That's why we need our oil, coal, gas, wind and solar energy so much.

Units of Energy and Power	
Kilowatt hour (kWh) is a unit of energy or work, usually associated with electrical energy, but also used to describe other energy forms. If energy is used at the rate of 1000 joules per second (i.e. 1000 W) for the duration of 1 hour, 1 kilowatt hour of energy has been used. For example, if a 100W incandescent bulb is left lit for 10 hours, it will consume 1 kilowatt hour (100W x 10 hours = 1000 Wh = 1 kWh). It is also equal to 3.6 million joule.	**Tonne of Oil Equivalent (toe) -** This is a conventional standardized unit of energy and is defined on the basis of a tonne of oil having a net calorific (heating) value of 41868 kJ, otherwise approximately 42 GJ. This unit is useful if different fuels are being compared and large quantities are required. 1 toe = 11.630 MWh

Exercise – Experiment: In this experiment we will:

- consider how energy can be converted from one form to another (from electrical to thermal);
- carry out a simple energy balance;
- and assess how "big" a joule or watt really is.

When water is placed in an electric kettle, the electrical energy is converted to thermal energy, raising the temperature of the water. The specific heat capacity of a substance is the amount of energy needed to change the temperature of 1 kilogram of the substance by 1 degree Celsius (or Kelvin (K), if you prefer, since difference in temperature, whether expressed as degrees Celsius or Kelvin is the same). It has units of J/kg K. The specific heat capacity for water is approximately 4180 J/kg K. If a kilogram of water at 20°C is heated to 60°C, it needs 167,200 J, calculated from: 1 kg x 4180 J/kg K x (60-20) degrees K. This is 167.2 kJ, so you can see that a joule is not a large quantity of energy!
For this experiment you need:
Water, a weighing scale, an electric kettle, a thermometer, a plug-in wattmeter and a timer.
Here's what to do:
1. Fill a known quantity of water into the kettle and measure the temperature of the water.
2. Start timing when you switch on the kettle and measure the power drawn by the kettle in watts.
3. When the kettle switches off, stop timing and carefully (hot water may cause burns!) measure the water temperature.
4. Calculate the energy input by using the reading from the wattmeter and the heating time.
5. Using the known mass of water, the measured temperature rise and the specific heat capacity of water, calculate the heat gained by the water.

Question: Do they balance, if not, why not?

Note: Though the energy conversion in the kettle may be very efficient, the electricity may have been produced in a fossil fuel power station, with an efficiency of less than 50 % see later!

Questions:

1. If a hard-working individual can produce 200W of energy output on average, how many joules of work can a human produce in an average working year? What is this value expressed in kWh?
2. Your wattmeter may have the capability to determine how many kilowatt hours of energy are used for a particular task. If so, see how much energy is needed to wash a quantity of clothes, or dishes?
3. Steam systems are commonly used in industry, because, to evaporate water you have to provide the latent heat - which is released when the steam condenses. Latent heat is the amount of energy in the form of heat released or absorbed by a chemical substance during a change of state (i.e. solid, liquid, or gas), or a phase transition. What is the latent heat of 1 kg of water (at atmospheric pressure) and how does it compare with the sensible heat required to raise the temperature of liquid water through 80 degrees Celsius?

Definition: Latent heat is the amount of energy in the form of heat released or absorbed by a chemical substance during a change of state (i.e. solid, liquid, or gas), or a phase transition.

Key Points: The key points from this chapter are:
The units of energy and power are joule and watt respectively, but their values are very small, so we use multiples of these as our normal measures.
The energy we use daily far exceeds the capability of our own human energy output.

Web links:
International Energy Agency (IEA) website: *http://www.iea.org*
European Environment Agency: *http://www.eea.europa.eu/themes/energy*

Coming next: We will next learn where the energy for our society comes from, how it is converted and distributed, before considering where it is used in industry.

Chapter 2: Sources of Energy

Learning Objective: In this Chapter you will learn:

- The main sources of energy, both renewable and non-renewable
- How the use of renewable energy is growing

Primary energy is energy that has not been subjected to any conversion or transformation process. Primary energy includes non-renewable energy contained in raw fuels e.g. coal, crude oil, natural gas, uranium and renewable energy, e.g. solar, wind, hydro, geothermal.

When we look at the trends in supply of the individual energy sources, we see that there has been an overall increase in energy supply globally in the last 35 years. Within this overall growth, gas and nuclear energy took larger shares of the total supply, with a proportional reduction in the use of oil. Europe is still heavily dependent on fossil fuels. Between 1990 and 2005, the share of fossil fuels in total energy consumption declined only slightly from around 83 % to 79 % (see Figure 1 below). In the first 10 years of this period, gas became more widely used for power generation, with the proportion of coal decreasing. This resulted in a major reduction of air emissions. Since 1999, the use of coal has recovered, due to concerns about security of gas supply and gas price rises.

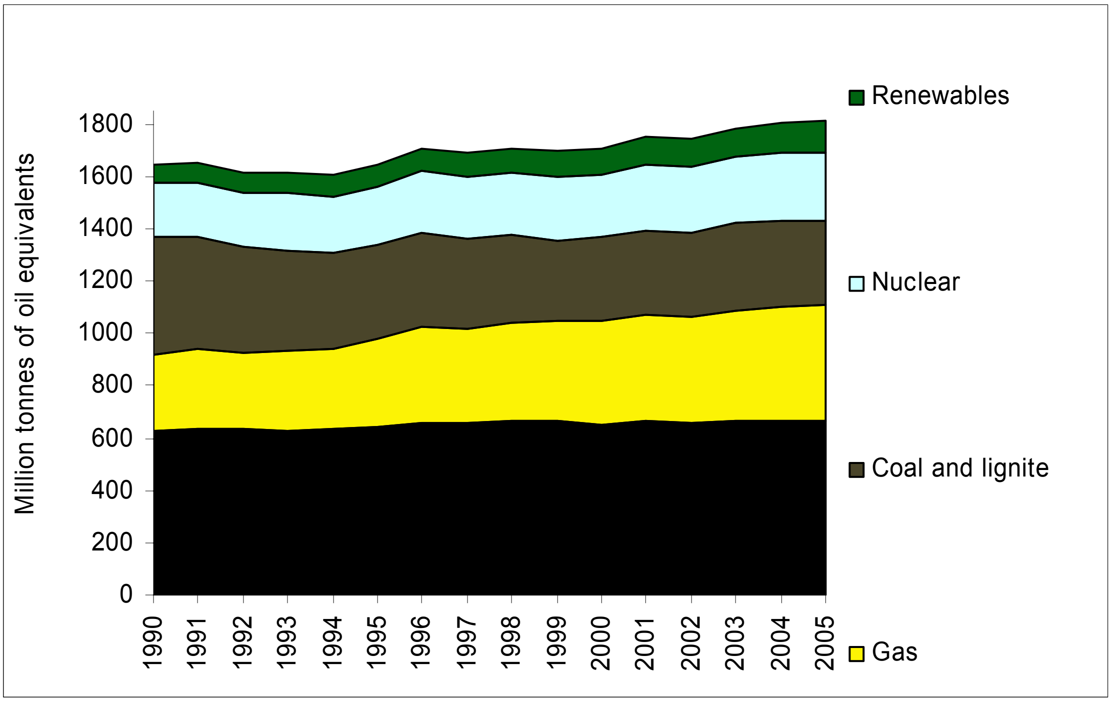


Fig.1 Total Primary Energy Consumption by Fuel, EU-27 Source: EEA, Energy & the Environment, 2008

In this period, renewable energy has the highest annual growth rate in total primary energy consumption, with an average of 3.4 % between 1990 and 2005. Biomass and waste have been the sources demonstrating the largest growth, as shown in Fig 2.

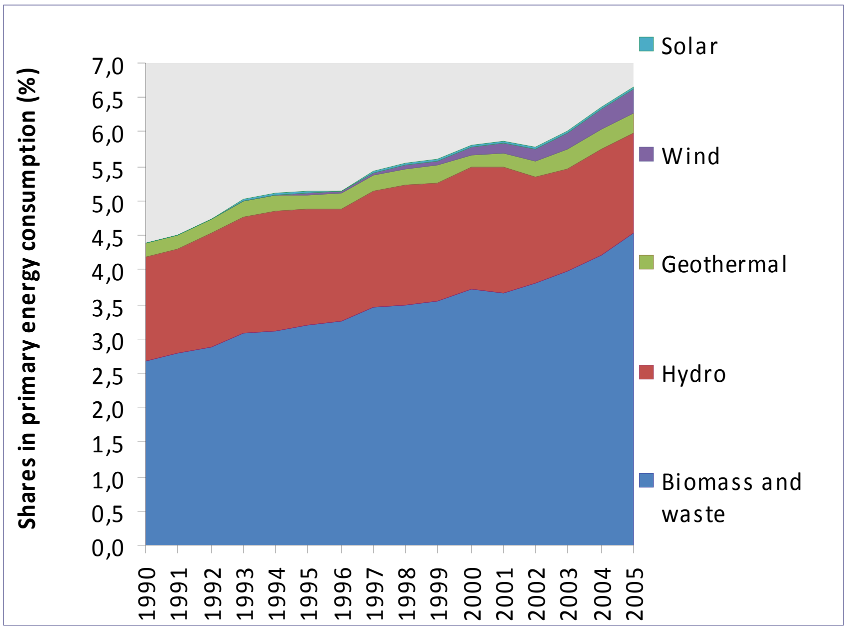


Fig.2 Contribution of Renewable Energy Sources to Primary Energy Consumption in the EU-27 Source: EEA, Energy & the Environment, 2008

Different countries obviously use different quantities of primary energy, depending on their population, energy intensity of their industry, climate, etc. Figure 3 shows the primary energy consumption in the partner countries in 2006, expressed as tonnes of oil equivalent.

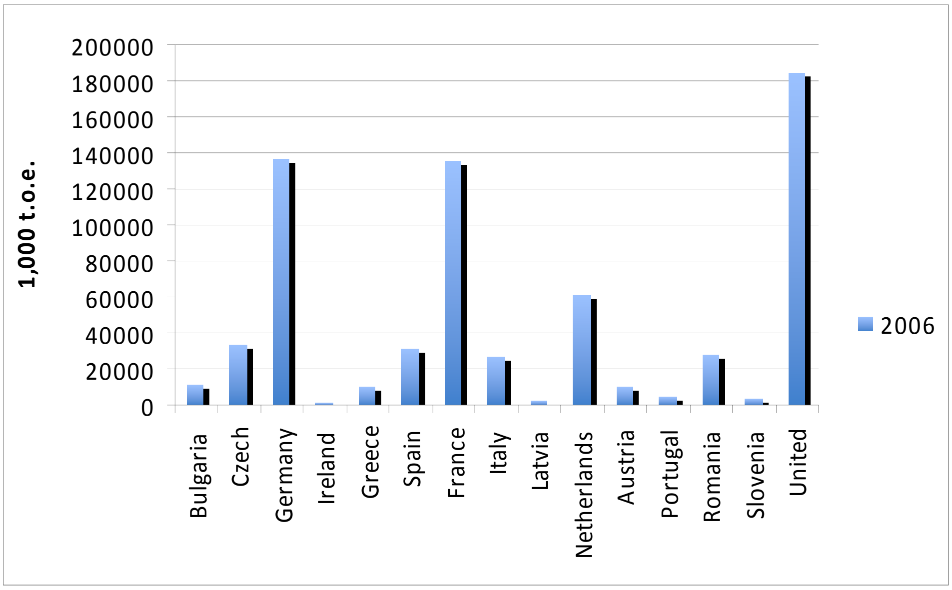


Fig.3 Primary Energy Production in Partner Countries 2006, (in 1,000 t.o.e) source: Eurostat website

An interesting insight can be gained by examining the energy mix in different countries. Within the EU-27, using 2005 data, 79% of our energy came from oil, gas and coal with shares of 36.7 %, 24.6 % and 17.7 % respectively and just over half (54%) of these imported. In figure 4, the total energy consumption in each country is represented as 100%, and this 100% is then shared between the different energy sources.

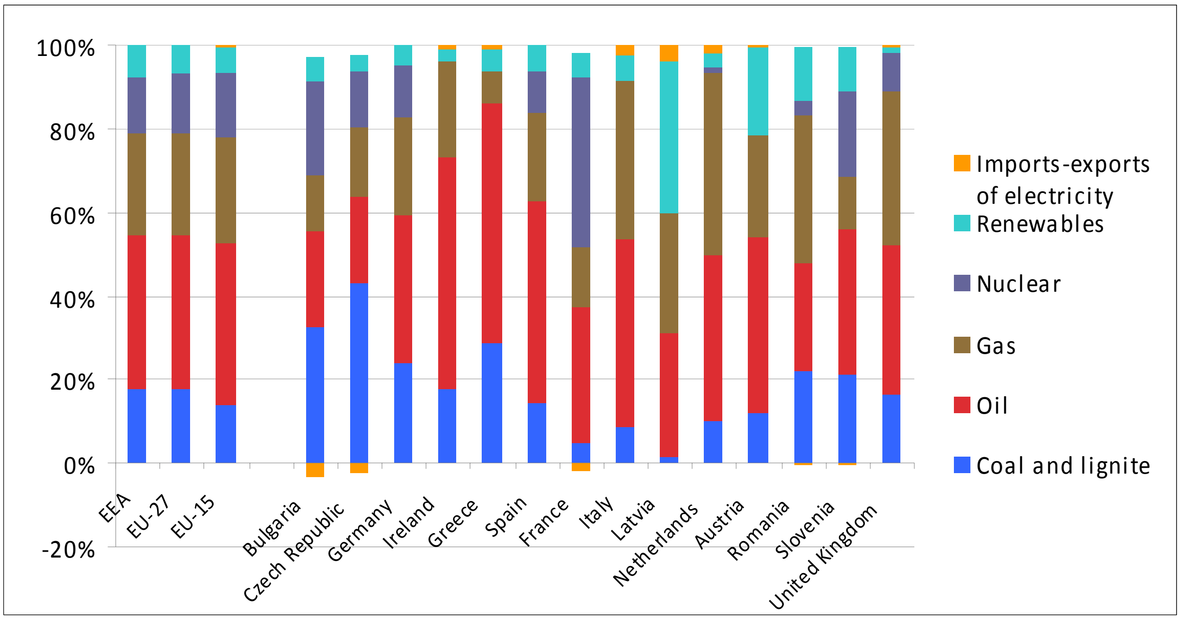


Fig.4 Share of total Primary Energy consumption by fuel by partner country in 2005: Source: EEA, Energy & the Environment, 2008

The following Figure 5 shows the source of the primary energy and the final destination for energy consumption for the EU-27. Nearly a quarter of the primary energy consumed is lost in transformation and distribution. The energy sector itself consumes just over a further 5% in its own operation. From this figure we can see the relative importance of the different energy sources and the sectors than consume energy, with industry directly accounting for less than one-fifth of energy demand.

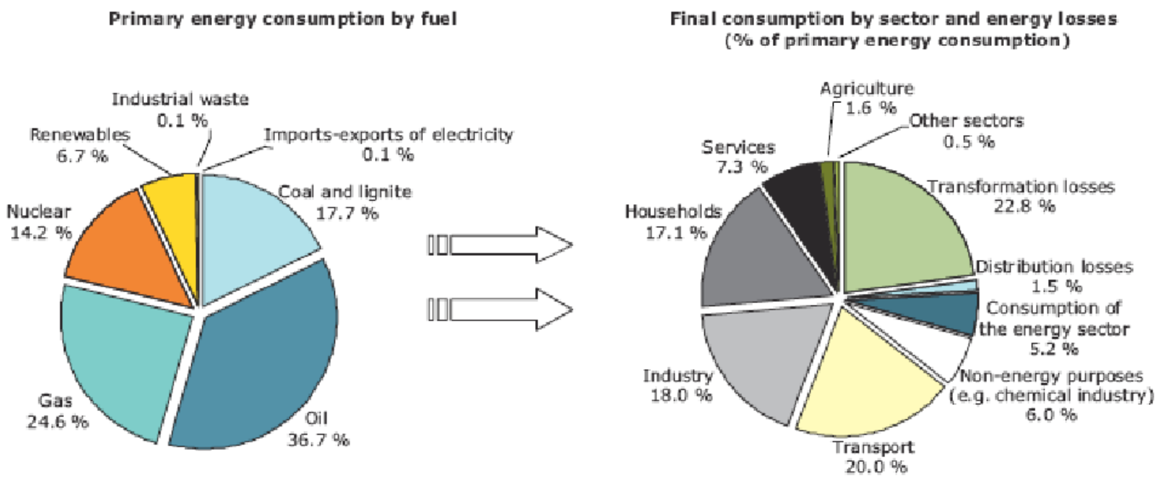


Fig.5 Structure of the efficiency of transformation and distribution of energy from primary energy consumption to final energy consumption, EU-27, 2005. Source: EEA & Eurostat

Final energy consumption in EU-27 industry fell by about 11% between 1990 and 2005. Much of this happened in the economic recession of the early 1990s as can be seen in Fig 6. As well as improved efficiencies, there has been a shift to less energy-intensive industry and to a service based economy within the EU. Though this may reduce energy consumption within the EU, we should still consider ourselves as indirect users of this energy and producers of greenhouse gases and other pollutants, if we use products that are now manufactured outside the EU.

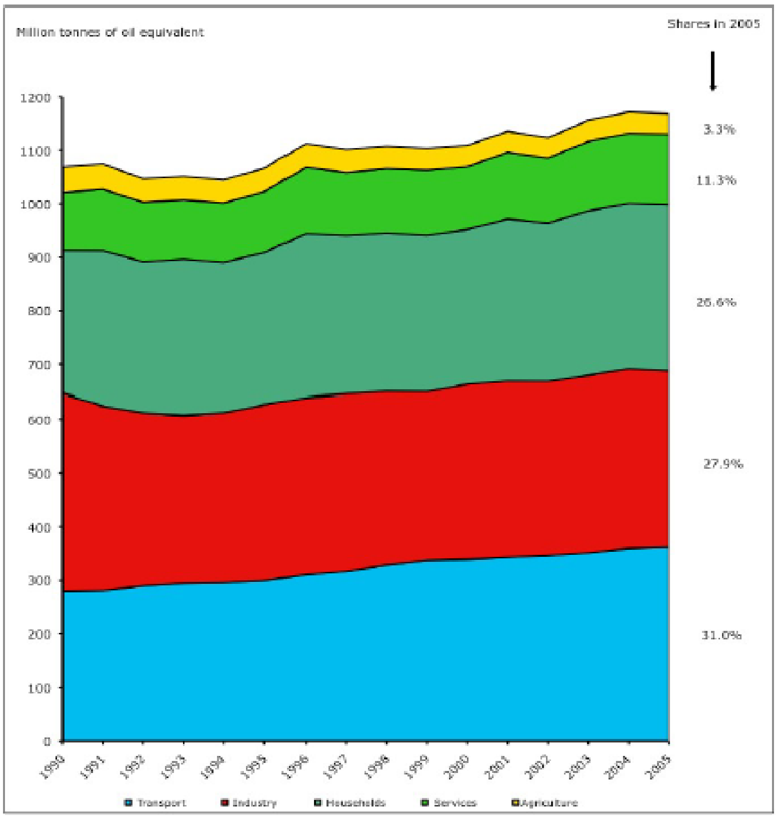


Fig.6 Final Energy Consumption by Sector. Source: Eurostat, EEA

Problems With Non-Renewable (Fossil & Nuclear) Sources Of Energy

We produce carbon-dioxide when we burn fossil fuels, contributing to climate change. In addition, depending on, the burning conditions, the exhaust gas cleaning equipment that is used and especially the composition of the fuel, we may produce smoke and gases that lead to acidification. Fossil fuels are a limited resource and often located far distant from Europe.

Problem	**Solution**
Finite resources	There is no escape from that, coal, oil and gas are limited. We may explore the deep sea, Arctic and Antarctica for more fossil fuels, but at greater financial and ecological cost.
Security of supply	As well as being limited, we rely on shipping and pipelines to transfer fossil fuels from around the world to us. Political uncertainty can result in losing access to these resources.
Greenhouse gas release	There are plans to develop technologies that will capture emitted carbon dioxide and store it, but there are uncertainties about the technical feasibility, the costs and the risks of storage.
Polluting emissions	Expensive gas cleaning equipment, fuel preparation and sophisticated burning control have been successful in reducing pollution in Europe – but at a price.

All of these solutions have their own problems, so an increase of efficiency and the intensive usage of energy from renewable sources is a major goal for future.

Peak Oil: Current consensus among the 18 recognized estimates of supply profiles is that the peak of extraction will occur in 2020 at the rate of 93-million barrels per day (mbd). Current oil consumption is at the rate of 0.18 ZJ per year (31.1 billion barrels) or 85-mbd. However there is widespread concern that we have reached “peak oil” where the rate of new discoveries is not enough to satisfy our growing demand. (source: www.peakoil.com)

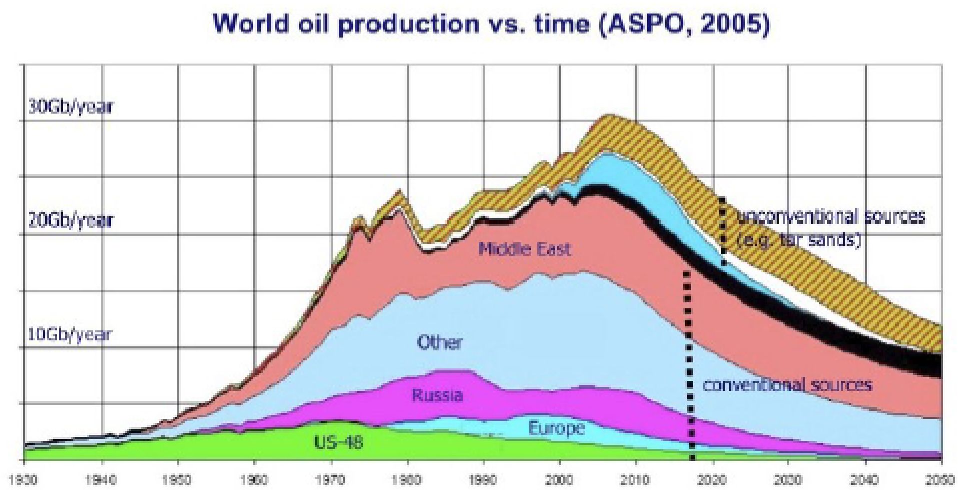


Fig 7 World Production vs. time (source: ASPO, 2005)

Peak oil is the midpoint of global hydrocarbon production.
In 1956 M. King Hubbert, a geologist for Shell Oil, predicted the peaking of US oil production would occur in the late 1960's. Although derided by most in the industry he was correct. He was the first to assert that oil discovery and therefore production would follow a bell shaped curve over its life. After his success in forecasting the US peak this analysis became known as the Hubbert's Peak (source: www.peakoil.com).

Renewable Energy

According to the International Energy Agency (2007), renewable energy accounted for 13.1% of the world's total primary energy supply in 2004, with biomass (79.4%) and hydro (16.7%) the principal sources. The 'new' renewable energy sources – solar, wind and tide – make up less than 0.1% of total primary energy supply. In its Alternative Policy Scenario (policies driven by concerns for energy security, energy efficiency and the environment, under discussion but not yet adopted, that could curb growth in energy demand) the IEA (2007) predicts that by 2030 renewables will remain at around 14% of global energy consumption, but its share of the electricity mix will increase from 18% to 25% (source: http://www.iea.org/weo/2007.asp).
In Europe, Renewable energy has the highest annual growth rate in total primary energy consumption, with an average of 3.4 % between 1990 and 2005 though the current usage shows a wide variation across countries, as shown in the following Figure 8:

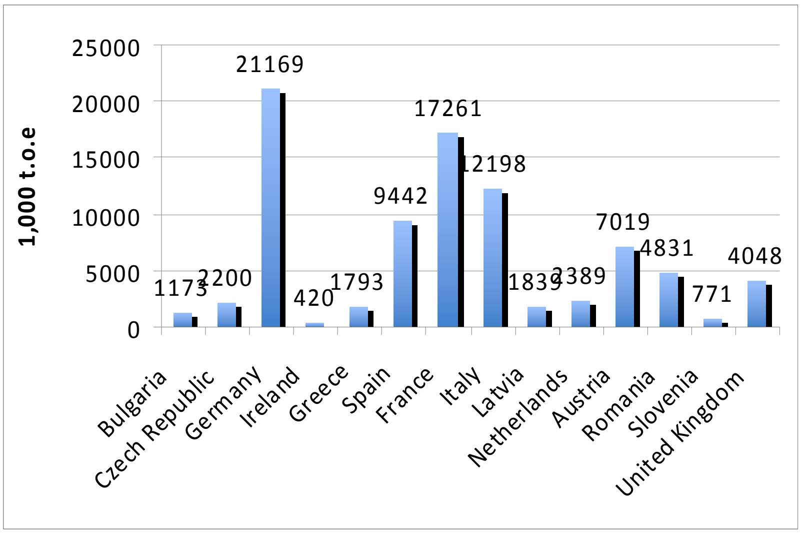


Fig. 8 Renewable energy Primary Production in 2006 (biomass, geothermal, hydro, wind and solar in 1,000 toe): Source: Eurostat website

Use Of Renewable Energy In Industry

Hydro-Power

Water mills were one of the first examples of using renewable energy, capturing the energy of moving water to drive machinery. Later, electricity generation became the normal practice. A pumped storage hydroelectric power plant is a net consumer of energy but is a technology to store electricity that is generated but surplus to needs at particular times. Water is pumped to a high reservoir during the night when the demand, and price, for electricity is low. During hours of peak demand, when the price of electricity is high, the stored water is released to produce electric power. Since many renewable energy sources are variable, this is a useful technology to store large quantities of energy.

Wind Energy

Again, wind mills were common to drive machinery, but now it more normal to see wind turbine "farms" generating electricity. Offshore groups of turbines are interesting because of the reduced "land take" and improved consistency of winds. Occasionally an industry may have a few wind turbines if they have available land.

Solar Energy

Relatively small scale applications of photovoltaic (PV) cells have become common, particularly for isolated pieces of equipment, and thermal solar collectors are used to produce small proportions of heating needs. Large scale applications are rare, involving arrays of parabolic mirrors to concentrate the sunlight onto a pipe containing a heat transfer fluid, such as oil, which is then used to boil water, which turns a generator to produce electricity.

Marine: waves and tidal currents

With the exception of offshore exploration and navigation lights, this application is confined to business generating electricity or developing the technology. Tidal barrages e.g. Rance in France, capture the energy of water flowing in and out of coastal inlets. The rise and fall of water level between the tides provides potential energy that may be captured. The marine currents that move the vast quantities of water may also be used to drive underwater turbines, capturing the kinetic energy, e.g. Strangford Lough in Northern Ireland. The wind-induced motion of waves may be converted into mechanical energy, which can, in turn, be converted into electrical energy for transmission to end-users. Much research is underway on this topic.

Geothermal

Geothermal energy is often associated with hot springs, geysers and volcanic activity, for example in Iceland or New Zealand. In 1904 the first dry steam geothermal power plant was built in Larderello in Tuscany, Italy. The Larderello plant today provides power to about one million households. Geothermal, or "ground-source" heat pumps are systems that use electrically driven machinery to extract heat from the few metres of soil nearest the surface. Operating like refrigerators, they use the very large thermal mass of the ground to provide the basic heat input, whose temperature is increased by the heat pump circuit to a level where it can be used for heating. Their use is mainly confined to domestic applications.

Biomass

Plant material may be grown specifically for its use as an energy source, either via combustion to produce thermal energy, or via a transformation process to gaseous or liquid fuels or to generate electricity. Biomass is often considered a "carbon-neutral" energy source, because the carbon released during combustion has previously been absorbed during the plant's growing. If crops are replanted there is a possibility of achieving a closed cycle, though consideration may need to be given to methane emissions from decomposition of plant matter. The dedicated planting of trees for use as a fuel source has been applied for centuries and their modern use is an extension of this tradition. Biomass has the advantage over other renewable energy sources that it can be stored, but there has been much criticism that growing plants for fuels diverts land from food production, leading to food scarcity and higher prices.

Waste to Energy

Waste material can be used to provide either thermal or electrical energy. Biodegradeable waste in landfills will naturally produce "landfill gas" which may be combusted, typically to generate electricity, though heat is also produced and usually lost. Sewage, sewage sludge, animal slurries and biodegradable wastes from breweries, abattoirs and other agro-food industries may be biologically decomposed ("anaerobically digested") to produce a methane-rich fuel. Combustible municipal, commercial and industrial waste, e.g. packaging, may be burned in an incinerator or cement kiln to produce heat or electrical energy. Many industries, other than agri-food, e.g. paper making, furniture making, will produce substantial biodegradeable or combustible material which may be used as an energy source. However, in all these cases, it should be considered if waste material represents inefficiency in the process that would be better if it was reduced, and although the material may be similar in nature to renewable energy sources, if the material is not replanted it represents a release of carbon. Valuable materials should be removed from waste before combustion and care has to be taken to ensure pollution does not arise from air emissions or liquid effluents.

Questions:
What are the most common energy sources in your country? Determine the distribution between non-renewable and renewable sources, and then into the various renewable sources and fossil fuels. How does this compare with other countries in Europe? How does this compare per capita with other EU countries (group exercise with each group in the class assigned a country). Use the weblinks below as starting points for data.

Key Points: The key points from this Part are:

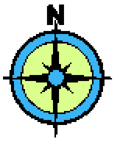
- The EU is still heavily dependent on fossil fuels (causing concerns about greenhouse gas emissions), and much of these are imported (raising issues about security of supply).
- There is considerable potential and interest in renewable energy, but much remains to be implemented.

Web links
The Environmental Information Portal: http://earthtrends.wri.org/searchable_db/index.php?action=select_variable&theme=6
European Environment Agency: http://themes.eea.europa.eu/indicators/
Eurostat, Environment and Energy Homepage: http://epp.eurostat.ec.europa.eu/portal/page?_pageid=0,1136239,0_45571447&_dad=portal&_schema=PORTAL

Coming next: In Chapter 3 we will learn next how this primary energy can be converted into energy carriers such as electricity, or more convenient fuels such as diesel or bioethanol.

Chapter 3: Transforming Energy & Industry Use

3.1 Transforming Energy (Energy Carriers)



Learning Objective: In this Part you will learn

- How primary energy is transformed into more useful forms: liquid fuels and electricity
- How significant industrial energy consumption is in the context of total energy consumption
- What are the main energy carriers and users of energy in industry

Energy types and carriers

The following diagram Fig.1, illustrates the ideas of primary energy, transformation, secondary energy and final use.

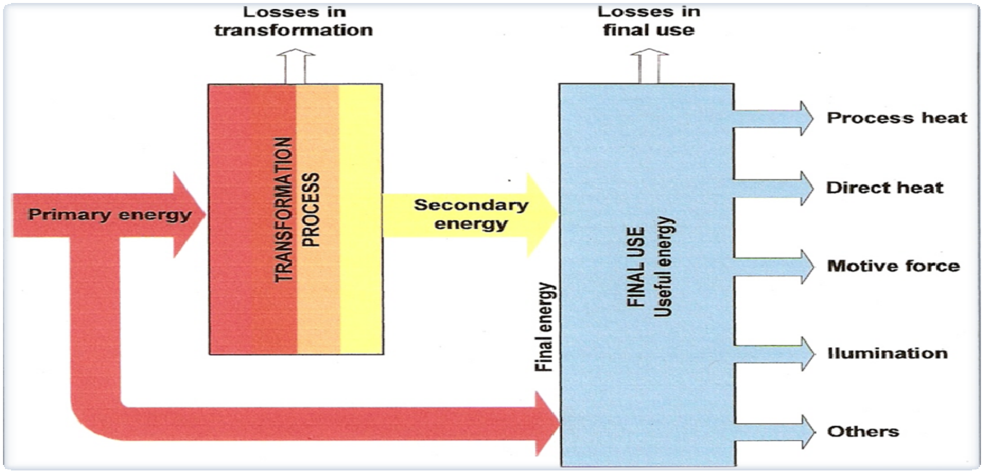


Fig.1 Diagram showing the transformation of primary energy (e.g. coal or wind) to secondary energy (e.g. electricity) and final use in heating, lighting, motors etc. Source: EU BREF on energy efficiency

It can be difficult to transmit primary energy in its natural form. Primary energies are converted in energy transformation processes to more convenient carriers of energy: secondary energy. Electricity is the most common example, being produced from coal, oil, natural gas, wind, hydro, etc, in an electricity power station. The convenience of electricity as an energy carrier has resulted in our developing an extensive "grid" to distribute electricity from centralised generating stations. The use of renewable energy has promoted a more distributed, or dispersed, generation of energy, so transformation of primary energy into secondary energy that can be relatively easily distributed is demanding more sophisticated distribution systems.

Electricity can be transported, but storing it is not so convenient. Liquid fuels, in contrast, are easily stored and transported. Crude oil can be refined into the range of fuels we are familiar with: diesel, petrol, etc. They can be converted into thermal energy e.g. heating our buildings, or be further converted into mechanical energy, e.g. transportation. However, we must remember that refining and transportation themselves consume energy.

As we will see later, an industry may convert electricity or fuel into another energy carrier such as compressed air or steam. Final users of energy may use either primary or secondary energy for purposes such as process heating, providing motion, lighting, etc.

Fuel Production

The principal liquid fuels are made by fractional distillation of crude petroleum oil (a mixture of hydrocarbons and hydrocarbon derivatives ranging from methane to heavy bitumen). Typically medium and light fuel oils (kerosene and diesel) are used in industry in heating and raising steam. Petrol (gasoline) and diesel are the main road and rail transport fuels. Liquefied Petroleum gas (LPG) is gas, liquefied under pressure, for storage and transportation, for use as a heat source or transport.

Liquid "biofuels" may also be produced from biological sources. Biological material, either specially grown or as process waste, may be biochemically converted to fuels such as methanol, ethanol, methyl esters ("biodiesel") or methyl ethers. There have been attempts to gain these fuels from specially grown crops ("agrofuels"), but there is now considerable debate ("food or fuel") about the desirability of this – see the transport handbook for more discussion.

Electricity Production

Electricity can be produced from renewable sources: wind, hydro, solar, biomass and geothermal, but the majority is produced by combustion of fossil fuels or nuclear reaction, as shown in the following Figure 2 for EU-27 production. The proportion of gas use in the EU has increased because of its clean-burning properties, but concerns about security of supply and rising prices are on-going issues.

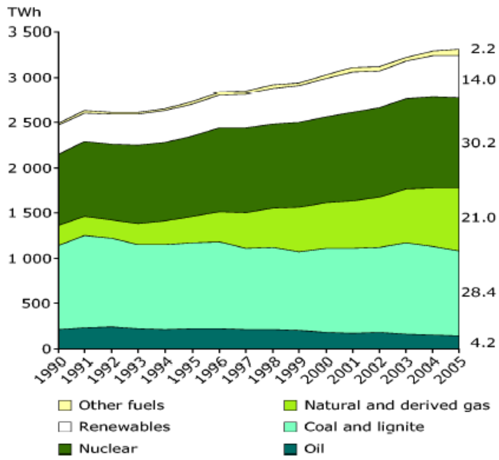


Fig.2 Electricity Production by Fuel, EU 27. Source: EEA website

The contribution of renewable energy to electricity production in individual countries is shown in Figure 3 below, showing that many countries have room for improvement!

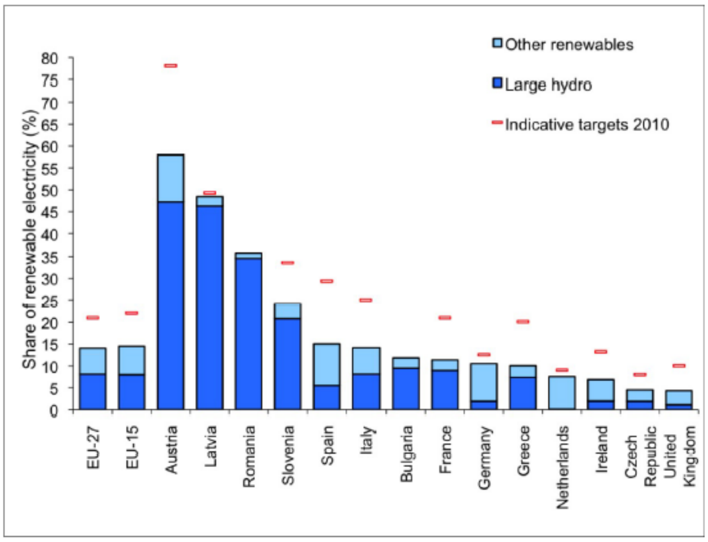


Fig.3 Share of renewable electricity in gross electricity consumption (%) 1990-2005 and 2010 indicative targets for Partner countries and EU: Source: EEA, Energy & the Environment, 2008

Most electricity generating stations are designed to produce only electricity. Typically fossil fuel is combusted to produce heat energy. Nuclear power is a nuclear technology designed to extract usable energy as heat, from atomic nuclei, via controlled nuclear fission reactions. In turn this heat energy converts liquid water to pressurised steam which drives a turbine, producing mechanical (rotational) energy. This rotation causes relative motion between a magnetic field and a conductor, and electrical energy is produced. After driving the turbine, the steam is now at a lower pressure and is condensed by using external cooling, before being returned as condensate back to the process to make steam again.

A critical aspect of this operation is that the overall efficiency may be low: 40% - 50%. Heat is lost via the exhaust combustion gases going to atmosphere, heat losses from the building and equipment, but most importantly, the heat that is transferred to the cooling system when the steam is condensed. This cooling is essential, and in summer conditions in Europe, some power stations have had to reduce output because of cooling limits. A further 5% - 10% of the energy is lost in transmitting the electricity through the grid distribution system.

Combined Cycle Power Plants

A combined cycle plant is power plant with gas as fuel that is first burned to drive a gas turbine, after which the exhaust gas is used to produce steam. While more efficient, use is largely confined to newer generating plants with access to gas supplies, though other fossil fuel sources, e.g. coal, can be gasified and used in this technology. The overall heat balance is shown in the following figure:

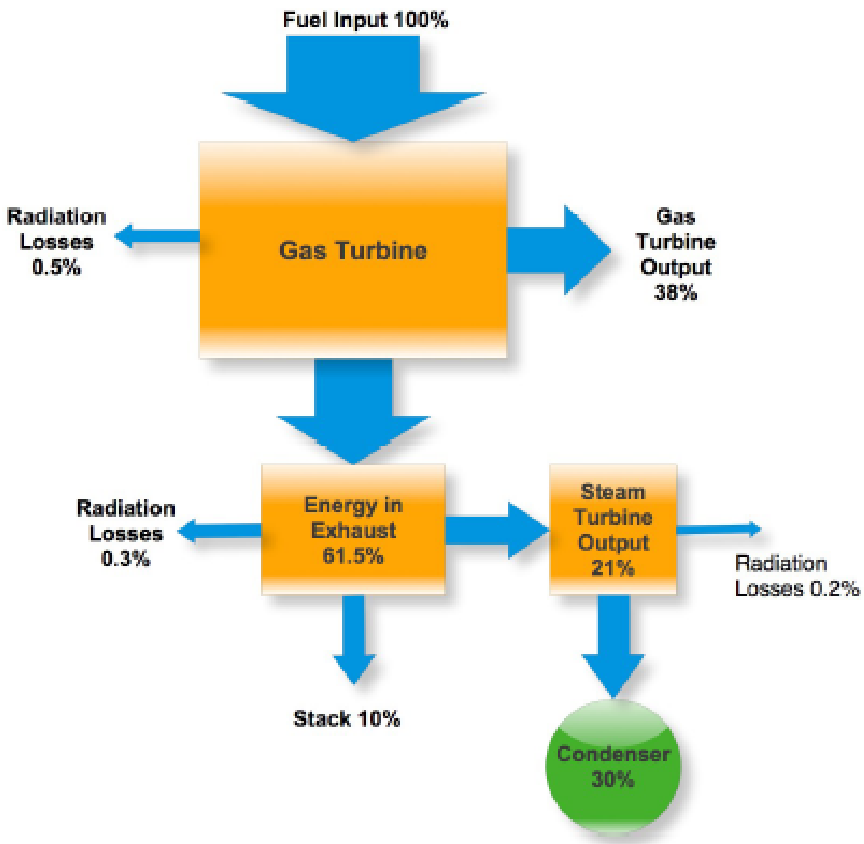


Fig.4 Energy Distribution in a Combined Cycle Power Plant (Source: Progress in Energy and Combustion Science 33 (2007) 107–134)

Combined Heat & Power (Cogeneration) Plants

Combined heat and power (CHP) plants are plants which are designed to produce both heat and electricity – also known as "cogeneration". CHP plants may be autoproducers (generating for own use only) or they may sell heat to adjacent industry or households via a district heating system as well as exporting electricity to the grid. Major energy efficiency is achieved by using CHP plants, since efficiencies of less than 50% for electricity-only plants are raised to over 75% for CHP plants as shown in Figure 4, but as can be further seen from Figure 5, the use of such systems is limited in many parts of Europe.

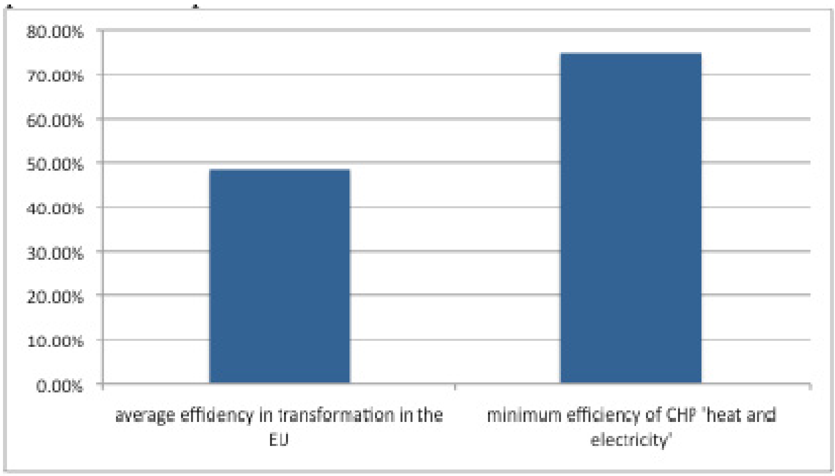


Fig.5 Efficiency in the transformation of energy. Source EEA website

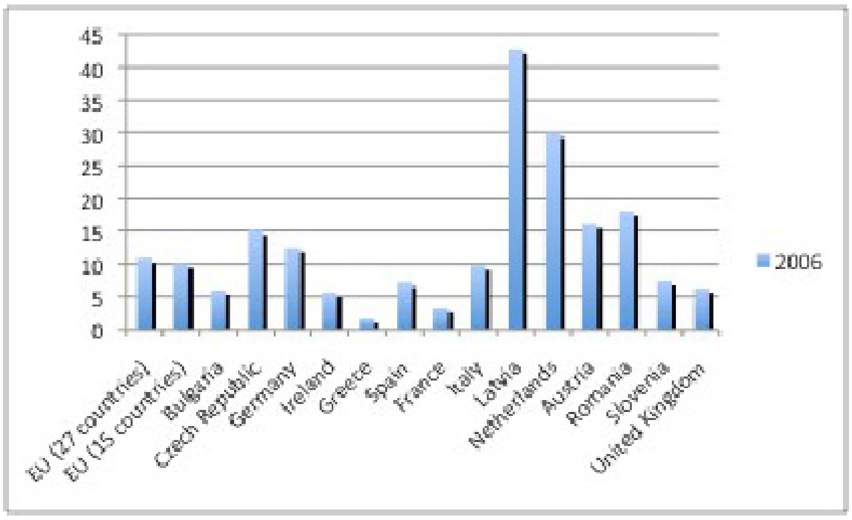


Fig.6 Percentage Share of Combined Heat and Power in Gross Electricity Production in 2006. Source: Eurostat website

Questions:

- What are the most common energy sources for electricity production in your country?
- How much electricity (in total GWh and as a % of total) is generated from renewable sources in your country?
- How does this compare with other countries in Europe?

National Energy Balances And Energy Intensity

Energy Balances

Case Study: A National Energy Balance

Consider the following diagram that illustrates the energy flows in Ireland in 2005. This type of diagram is called a Sankey diagram. The width of the arrows in the diagram is proportional to the magnitude of the energy flow. The primary energy provided has to match the energy consumed. A few observations can be quickly made: Ireland is heavily dependent on fossil fuels, with no nuclear and little renewable energy. Most of the energy is consumed by transport, the energy demand of the industry is comparably low.

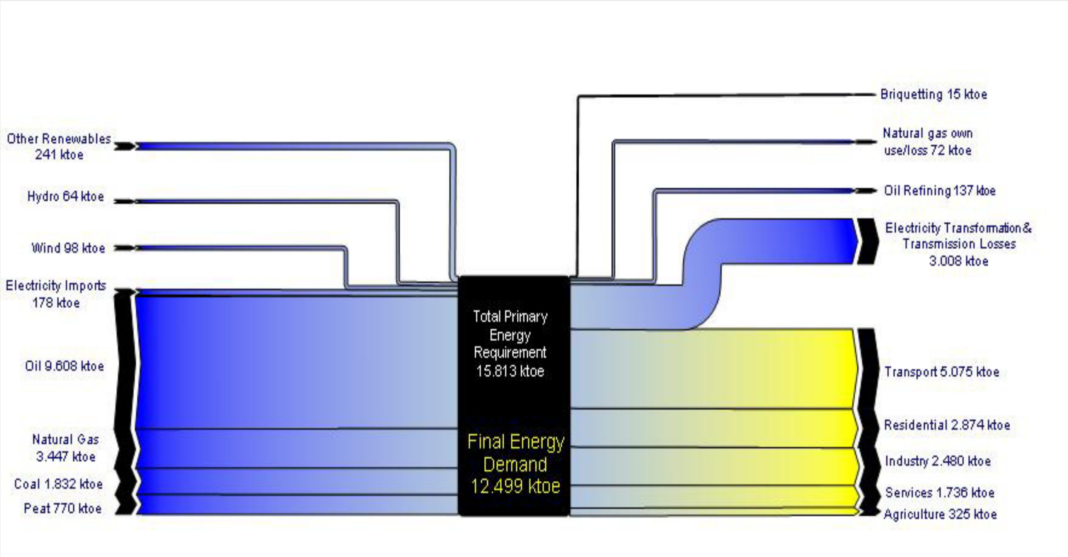


Fig.7 Energy Flow in Ireland 2005. Source: Energy efficiency in Ireland, Sustainable Energy Ireland, 2007

Questions:

- Obtain similar data for your country and draw the corresponding Sankey diagram.
- What fraction of energy is sourced from non-renewable sources?
- What % of primary energy is lost in transformation?
- What is the % figure for energy consumption in industry in your country?
- Calculate the energy used per person (energy intensity) in your country?
- Knowing the fuel mix, what is the carbon intensity (quantity of carbon used per person)? You will need additional information on the carbon amounts associated with oil, gas and coal.
- How do these compare with the EU average?

Hint: Look it up on the Eurostat- website.

Energy Intensity – What Do The Numbers Tell Us?

Energy intensity is a measure of total energy consumption in relation to economic activity. Total energy consumption in the EU-27 grew at an annual rate of just over 0.8 % in the period from 1990 to 2005, while Gross Domestic Product (GDP – an economic measure) in constant prices grew at an average annual rate of 2.1 % during the same period. As a result, total energy intensity in the EU-27 fell at an average rate of -1.3 % per year. This apparently positive outcome is shown in the following figure 8:

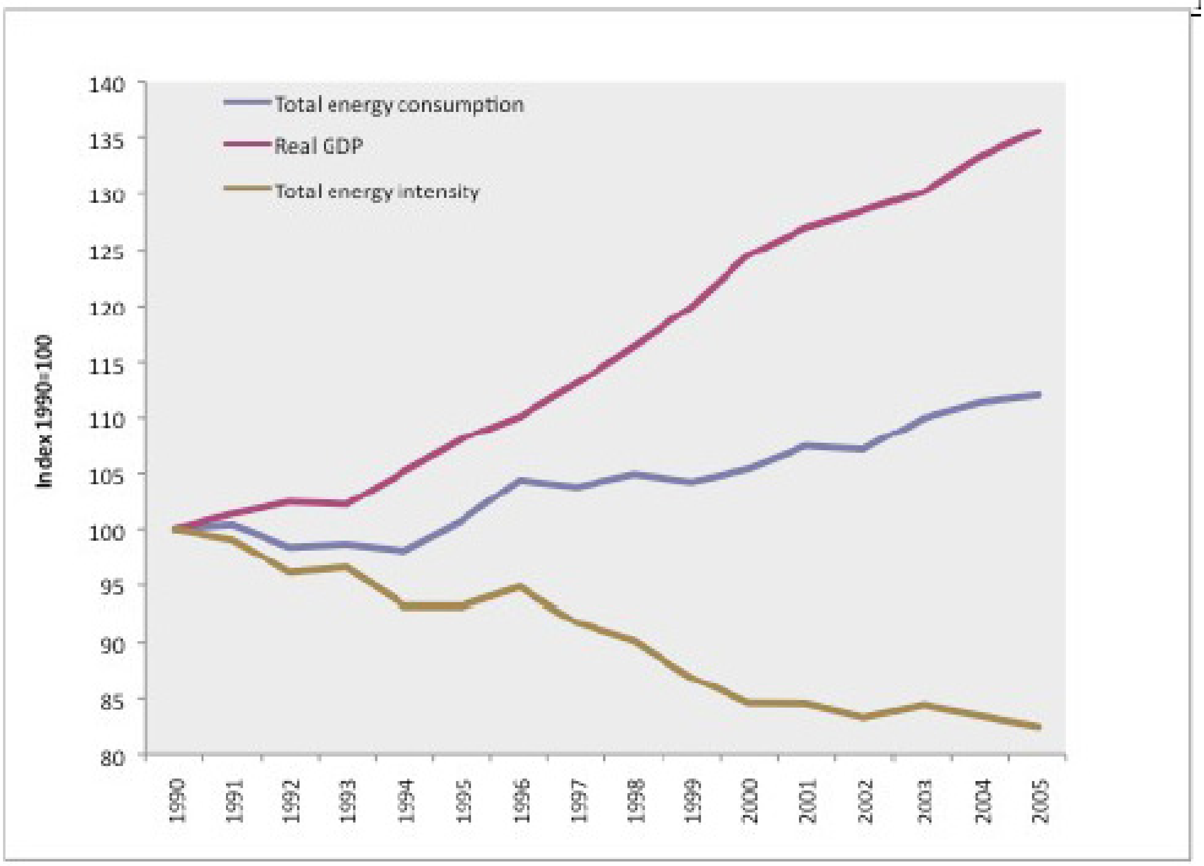


Fig.8 Total energy intensity in the EU-27 during 1990-2005, where 1990=100. Source: European Environment Agency and Eurostat

However, we have to realize that the increase of 0.8% per year in energy consumption accumulated to an overall 12% increase in energy demand. In economic terms, we may be more efficient by using less energy to produce an economic output, but the pressure on the environment has still increased. To get a better picture of the impact, we must consider the fuel mix in use and how this varies from country to country and in particular the reliance on non-renewable resources. This gives rise to a measure known as the "carbon intensity" or "carbon footprint" that reflects the amount of carbon emitted per head for each country. However, we must always be careful in using statistics.

Exercise: Consider the following figure, (Fig. 9) that presents total national energy consumption. Redraw this based on population i.e. energy consumption per head of population.

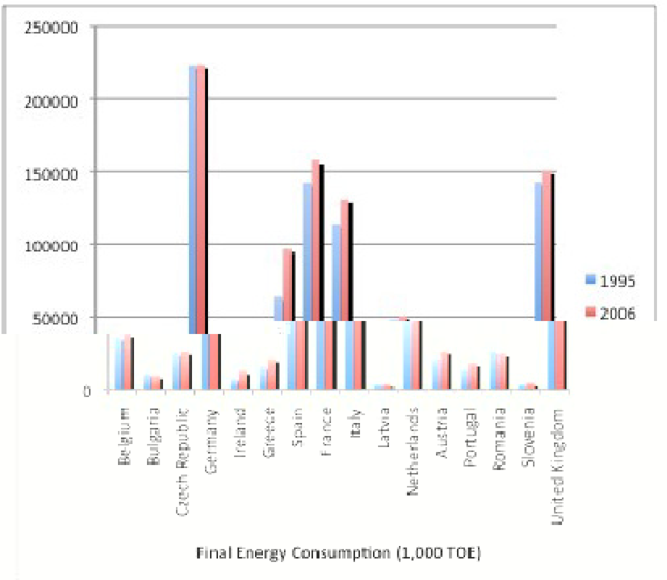


Fig.9 Final energy consumption in partner countries in 1995 and 2006 (source Eurostat website)

	1995	2006
Belgium	36037	38165
Bulgaria	11409	10028
Czech Republic	25067	26251
Germany	222795	223062
Ireland	7910	13037
Greece	15838	21454
Spain	63690	96642
France	142257	157779
Italy	113897	130654
Latvia	3814	4201
Netherlands	47736	50835
Austria	21015	26753
Portugal	13789	18544
Romania	26693	24706
Slovenia	3948	4945
United Kingdom	142633	150565

Table.1 Final energy consumption (1,000 t.o.e.) in partner countries in 1995 and 2006. Source data for Fig 9. above. (source Eurostat website)

This data may not reflect the energy behaviour of individuals, but rather the nature of industry, transport practices as well as household consumption in the country and particular economic features.

Weblinks :
European Environment Agency: http://themes.eea.europa.eu/indicators/
Eurostat, Environment and Energy Homepage:
http://epp.eurostat.ec.europa.eu/portal/page?_pageid=0,1136239,0_45571447&_dad=portal&_schema=PORTAL

Coming next: We will learn next how energy is consumed by industry as a share of the total energy consumption and broadly for which purposes this energy is used.

3.2 End Uses of Energy in Industry

The major energy end uses are:

Thermal	Electrical
Furnaces	Motors
Heating	Pumps
Cooling	Fans
Refrigeration	Conveyors
Baking	Crushing, grinding, milling
Drying	Machining, Forming, fabrication
Space heating and cooling, including ventilation	Vacuum systems
	Lighting

Table 1: The major energy end uses

More than 85% of electricity used in industry is supplied to electric motors. These convert the electrical energy into mechanical energy, driving pumps, fans, conveyors, compressors, etc. Motors are often running for many hours and they last for several years, so properly specifying high efficiency motors and ensuring that they are well operated is important to minimise electricity consumption.

Lighting is another significant electricity consumer in industry. Changes can easily be made to reduce consumption: these include ensuring that lighting levels are appropriate for the task and installing lighting systems that deliver more useful light per unit energy input.

Refrigeration circuits use a fluid which cools by drawing away the latent heat it needs to evaporate. Usually, this fluid is then pressurised and condensed for reuse. The energy to pressurise the fluid is normally provided by electricity via an electric motor.

Fans and blowers provide air for ventilation and industrial process requirements. They extract the air from buildings and draw in fresh air from outside. Air conditioning units, which use refrigerant gases, are also used to control temperature and humidity in a building.

Operation of boilers

Learning Objectives**:** In this chapter you will learn:

- What a boiler is
- Where the losses are
- How you can avoid losses and improve efficiency

Definition: A boiler is a vessel that uses heat to produce hot water or steam. Typically, a fossil fuel will be used as the energy source. If the boiler is very small, electricity may be used.

As you learned earlier in an exercise, steam contains the latent heat needed to evaporate the water, and is a more concentrated carrier of heat that a hot liquid. Steam can be used for heating (including evaporation and distillation) and also to drive mechanical equipment such as steam ejector vacuum systems, centrifugal compressors and steam turbines which can drive machinery or could be used to generate electricity. After the steam has condensed, it is normally returned to the boiler to avoid losing water and the residual heat in the water.

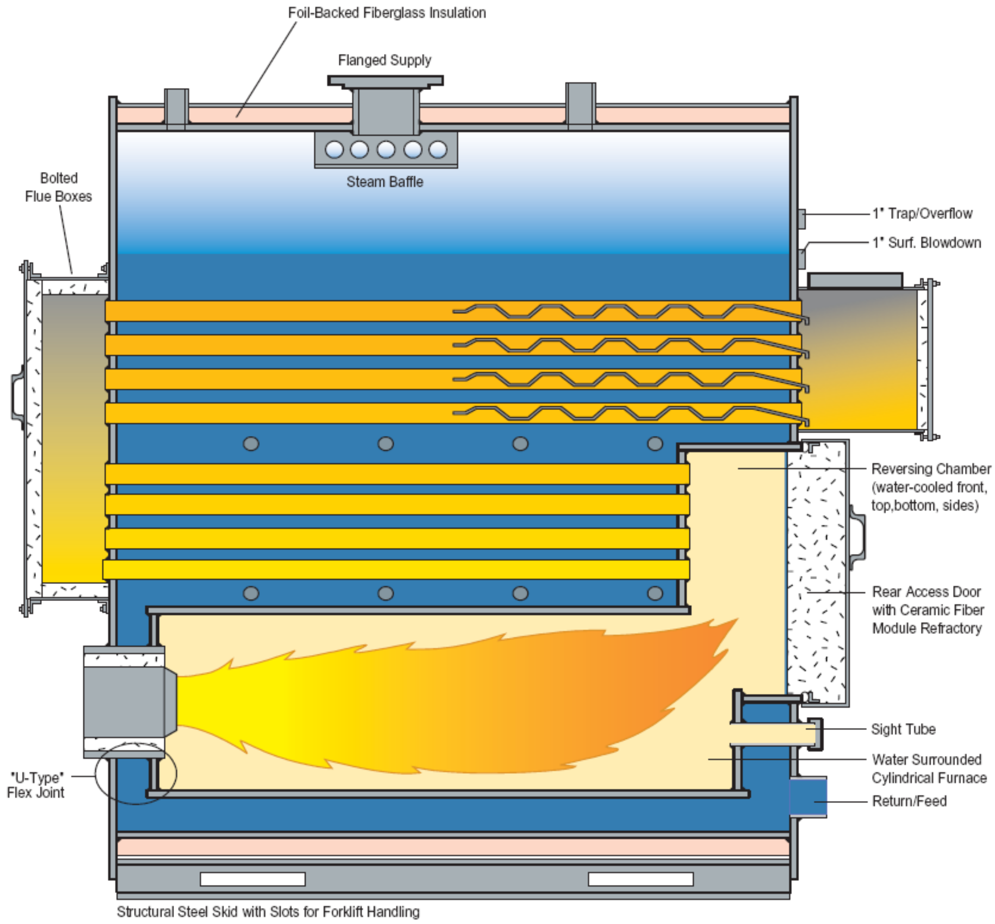


Fig. 1: Cut-away-view of a gas oil boiler [1]

The main categories in the energy efficiency improvement drive are the following:
In Figure 1 you can see the energy flow of a boiler. The main losses are in the flue gas. Radiation and convection as well as the heat loss in blow down are arranged between 3-4%.

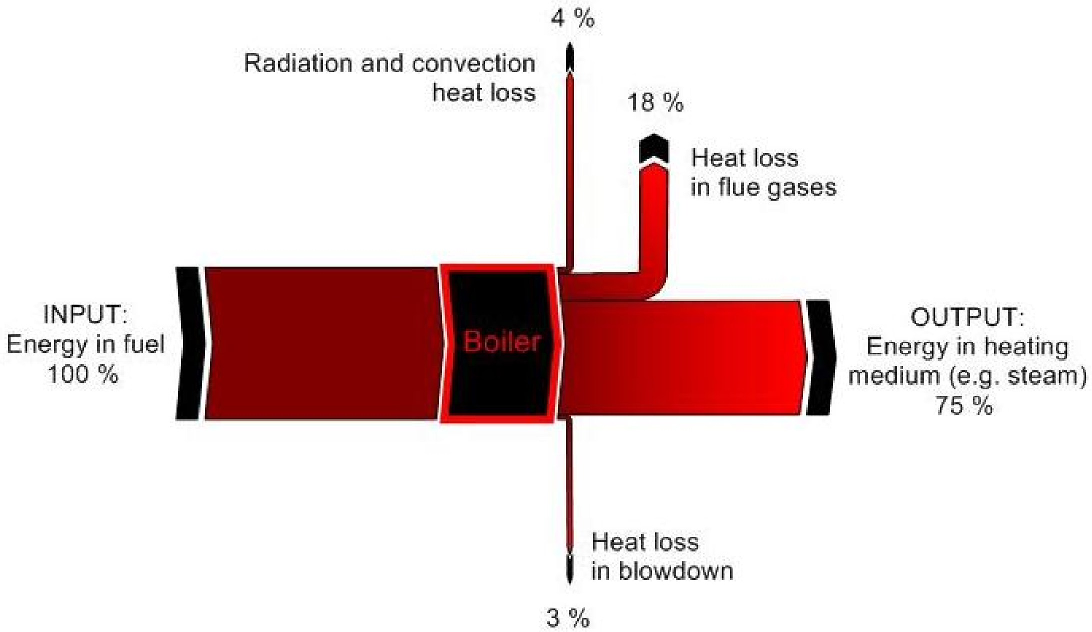


Fig. 2: Typical Energy Balance of a Boiler/Heater (made with SankeyEditor by STENUM) [2]

Boiler efficiency improvement program

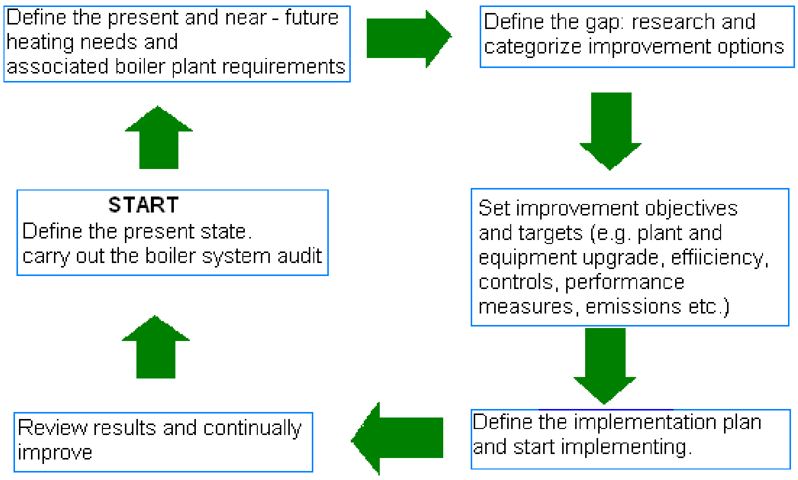


Fig. 3: Boiler Efficiency Improvement Program [2]

A systematic approach to improve energy efficiency of boilers - rather than unsystematic improvements - involves a few simple steps, as shown in Figure 3.

However important the economic, efficient operation of the boiler system, it should not be examined in isolation. The following should be checked for further energy-saving and energy-reclaim opportunities:

- the heating needs and energy efficiency aspects of heat-consuming processes, products and equipment; and
- the heat distribution systems (such as steam and condensate).

Heat and energy losses in a boiler system can be reduced in several ways. Some, such as combined heat and power generation (cogeneration), are sophisticated and complex; others can be easily implemented and offer good payback.

The main priorities to improve the energy efficiency are the following.

- Lowering the system's steam pressure or water temperature
- Avoiding leakage
- Keep the boiler clean. Except for natural gas, practically every fuel leaves a certain amount of deposit on the fireside of the tubes.

Note: Remember, one millimetre of scale build-up can increase fuel consumption by two percent.

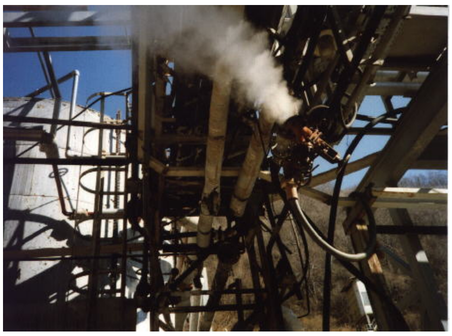


Fig. 4 Steam leakage

- Keep unwanted air out
- Blowdown water - dollars down the drain
- Even treated ("demineralized") boiler feedwater contains small amounts of dissolved mineral salts.
- Maximize hot condensate return
- A steam and condensate system must be properly designed to eliminate water

hammer and reduce losses and maintenance.

Flue gas

Note: A 20°C (36°F) reduction in flue gas temperature will improve boiler efficiency by about one percent.

Recent examples: A chemical plant is saving $500,000 per year by checking for, and replacing, all leaking steam traps. A plywood plant reduced its steam load by 2700 kg/h (6000 lb./h) by upgrading its piping insulation.

Questions:
Where are the main losses in a boiler system?
Which possibilities may improve the efficiency and avoid losses?

Exercise:
1.Most probably your school has a boiler to heat water and for heating in winter. Check with the caretaker if you can visit the boilerroom, maybe during summer when the boiler is cleaned or maintained. Check the control of the boiler, the gauges and have a look at the fireroom, the tubes and the stack.
2.Think about an excursion to a company. Try to find answers for the further questions:

- What is the exhaust gas temperature?
- What is the pressure of the steam (in bar)?
- Who are the consumers of the steam? Distance between consumer and boiler?
- Are the tubes insulated? Are there any evident leaks?
- How much energy is put in the boiler? On the basis of Fig. 2: *Typical Energy Balance of a Boiler/Heater*, you will be able to calculate the losses.

Fans and blowers

Learning Objective: In this chapter you will learn

- That there are three simple criteria which show you if a motor is still efficient
- About a procedure which helps companies to improve the energy consumption of their motors
- About important energy saving ideas for a pipe system by showing you an example

Energy-Efficient Motors

The relevance of measures is checked by a simple analysis. As a reference the so-called "Life Cycle Costs" are used, which is the total of costs for investment, servicing and maintenance and the costs for energy throughout the useful life of the motor of 10 to 20 years.
In the so called 1-2-3-Test, three criteria are important: the age of the motor, the hours of operation per year and the average efficiency.

Criteria 1: Age of the motor. The year of production can be read from the identification plate or asked from the producer (for him the model number is important).

Criteria 2: Rated Power. Read from the identification plate as well.

Criteria 3: Hours of Operation. The energy consumption may be calculated by the technical support or by reading the operation hour counter.

Procedure: You assign a value between 1 and 5 for each of the age, the rated power and the hours of operation using Table 2. The relevance of measures for the inspected motor are established by calculating the sum of the three values:

Table 2: 1-2-3 Test (motor efficiency)[4]

Age of the motor				
Up to 5 years	Up to 10 years	Up to 15 years	Up to 20 years	> 20 years
1	2	3	4	5

Rated Power				
> 1500 kW	Up to 1500 kW	Up to 500 kW	Up to 150 kW	Up to 50 kW
1	2	3	4	5

Hours of operation (per year)				
Up to 2000 h	Up to 3000 h	Up to 4000 h	Up to 5000 h	> 5000 h
1	2	3	4	5

Motor in the ranking														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Let the motor run					Look closer at the motor				Change is absolutely essential					

Results according to Table 2

Red area: If the score is over 10 a quick change of the motor is recommended

Yellow area: If the score is between 6 and 10, one should take a close look at the motor.

Green area: If the score is below 6 no measures will be necessary.

Saving energy on electric drives does not happen by merely changing the motors for new, more efficient ones. With this measure only a small part of the potential can be realised

The following procedure is advisable to optimize the energy consumption:

Step 1: Analysis of the consumption.

This step is the most important stage for saving the maximum of energy. Take a close look on the demand of the process, discuss and identify the relevant process parameters with the persons who are responsible for the process. Then identify the variation of the consumption required by the process in a discussion or by taking a measurement. Measurements can be taken even if the process hasn't been optimized yet, because the relative variation will have to be the same after the optimisation - unless the analysis shows that the process itself is not the best and the process concept should be changed.

Step 2: Analysing the machine which provides the medium

The process medium can be: steam, compressed air, water, etc. Questions to be asked include: Is the size of the machine appropriate to the consumption or is it oversized? In case of oversizing, the machine (pump, ventilator, compressor, etc.) runs in part-load, which leads to a reduced efficiency.

Step 3: Right control of the machine

The requirement of the media varies in actual process conditions so the handling of the machine has to be adapted optimally to the effective requirements. As a rule this is a frequency controlled drive for pumps, blowers, and compressors.

Step 4: Optimisation of the electric motor

There are three important rules for this step: a) ideal adaption of the size of the motor to the effective power requirement, b) the efficiency of the motor has to be at maximum and c) the control has to be adapted to the characteristic of the consumption.

Basic description of a pipe system

The basic description of a system can be done using the following data of name plates, technical datasheets or by simple measurements. In most companies most of these data can be collected by employees:

1. list of the 50 biggest pumps (by rated power)
2. function of these systems
3. power consumption of each of these pumps
4. range of operation (during a day/week)
5. annual hours of operation and resulting annual energy consumption
6. specific problems and maintenance requirements

Example: pipe system

A pump system requires that 50 m^3/h of water are pumped through a pipe of a 100 meters length. Assuming a diameter of 2 inch the resulting power demand is 24 kW. If the diameter is increased to 4 inches the required demand is reduced to 5 kW. The reduced velocity within the system results in significant energy savings and also in a reduced wear. Thus maintenance and lifecycle costs of the pump system are reduced.

Experiment

Think of an excursion to a company and you will find several electric motors (do not forget water pumps and the pump for the heating water).

Here is an interesting experiment for you:

- List the number of equal motors/pumps.
- List the capacity of each motor/pump (look at the characteristics of the machine for kW)
- List the operating hours (multiply the operating days with the operating hours per day) of each motor/pump

Table 3: As an example this table showing data from the premises of a car dealer may be usefull:

Component	Number of items	Capacity per component [kW]	Total capacity [kW]	Operating hours	kWh
auto lift	2	2.2	4.4	182	800.8
compressor	1	4	4	1600	6400

Questions: True or False:

- If the score on the 1-2-3 Test is between 6 and 10, everything is alright and you don´t have to do anything.
- Listing the consumption [kWh] per consumer is essential.
- Comparing the capacity of the component with the capacity which is actually needed is essential.
- Buying a new motor every year is absolutely necessary.
- One important criterion is the “Label of the component”. Only the biggest and most expensive motors are the best

Compressed Air

Learning Objective: In this chapter you will learn
- What compressed air is and where it is used
- Where the main losses are
- How you can improve the compressed air system

Usually compressors are driven by electric motors, but very large compressors may be driven by steam or gas turbines and small, portable, compressors may be driven by petrol or diesel. Compressors are inefficient items of equipment, and up to 90% of the energy provided can be lost as waste heat. The compressed air is stored in a tank, which acts as a reservoir or “buffer” supplying a network of piping that is maintained above atmospheric pressure and to which the tools are connected.
In Fig. 5 you can see the sources of losses. Only 5% of the total energy is stored in the pressurised air. 95% of the energy is converted into heat (also mechanical losses ultimately become heat).

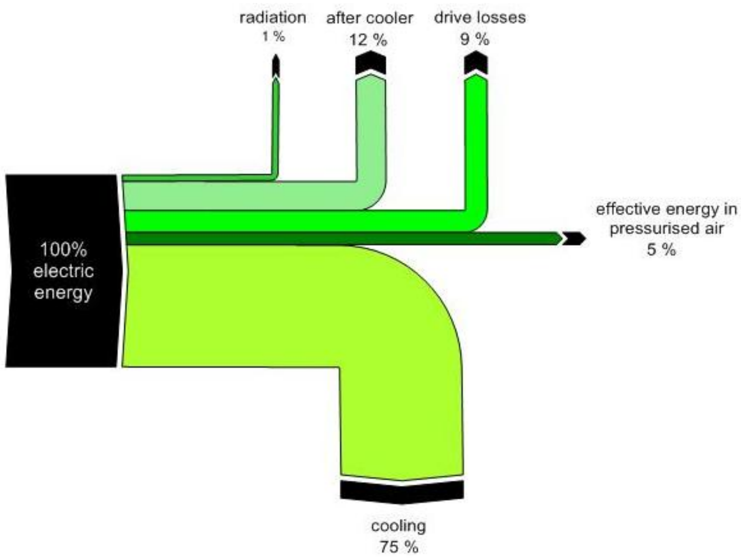


Fig. 5: Energy balance of a compressor (made with Sankey Editor by STENUM)[3]

The potential savings by optimising a compressor system are shown in Figure 6.

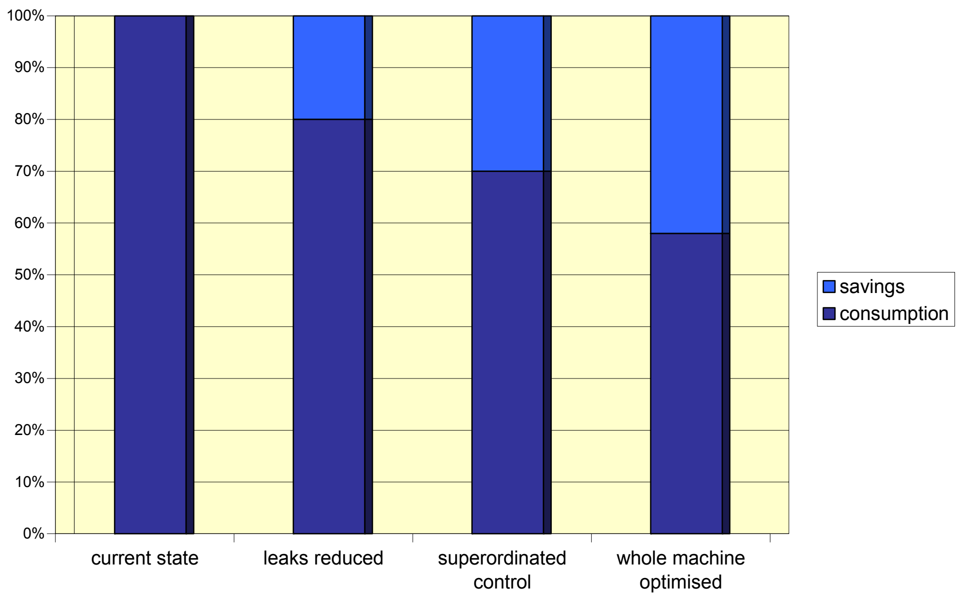
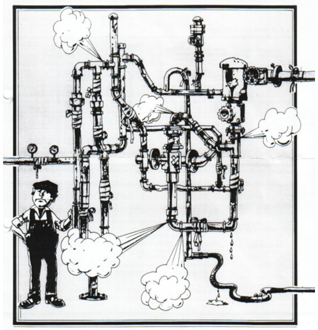


Fig. 6*: Energy savings – compressed air system [3]*

The following procedure helps to minimize losses from compressed air systems. It consists of four steps:

1. Avoiding leakage



One of the most fundamental ways in which the efficiency of any compressed air installation can be improved is by reducing leakage. While every effort should be made to keep a compressed air system leak-tight, all systems will have some leakage. There are however, several ways of reducing opportunities for leaks:

- Where to look for leaks

Condensate traps, fittings and pipework, flanges, manifolds, filters, cylinders, flexible hoses, instrumentation, tools and drainage points.

2. Don't generate at a higher pressure than necessary - the higher the pressure, the more air that will escape through a given-size hole.

3. Don't keep your whole system pressurised during non-productive hours just because a few items of machinery require a constant supply of compressed air.

Do isolate parts of the system that require air at different times. Isolation valves can be operated manually or automatically using simple control devices like time switches or interlocks, or they can be controlled using your building energy management system, if you have one.

4 Heat recovery

As much as 80-93% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a properly designed heat recovery unit can recover anywhere from 50-90% of this available thermal energy and put it to useful work heating air or water.

Table 4: Energy losses by leakage, using an electricity cost of € 0.06 per kWh [5]

hole diameter mm	air leak		loss of energy		costs	
	6 bar l/s	12 bar l/s	6 bar kWh	12 bar kWh	6 bar €	12 bar €
1	1,2	1,8	0,3	1,0	144	480
3	11,1	20,8	3,1	12,7	1.488	6.096
5	30,9	58,5	8,3	33,7	3.984	16.176
10	123,8	235,2	33,0	132,0	15.840	63.360

kW x 0,06 € x 8.000 operating hours/year

Exercise:

Think about an excursion to a (nearby) company with a pressurized air system (e. g. a paintshop, a joiner). Make a list of the tools which use pressurized air.

Can you identify any leaks?

Use the table (Table 4) to estimate the cost of electricity for the leaks?

Does the company use heat recovery?

Can you estimate the potential for heat recovery? Refer to Figure 5: Energy balance.

Cooling and Heating Fluids

Water (hot and cold) is the most commonly used thermal fluid in cooling and heating. Other thermal fluids include glycol (a water, alcohol mixture used in cooling), and oil (mineral or silicone for cooling and heating). The benefit of thermal fluids, other than water, is that they offer a greater operating temperature range. They can be cooled to below zero degrees Celsius without freezing and heated up to greater than 100° Celsius without starting to boil (or increasing pressure in a closed-loop system). These properties are of benefit in industries where the temperatures encountered are outside the 0° to 100° Celsius range.

Efficiency Improvements
The heating/cooling process can be made more efficient throughout the following actions:

- Regular scaling and de-fouling will reduce pumping losses.
- Energy recovery from thermal fluids may be utilised elsewhere in the process.
- Lagging pipes reduces heat losses

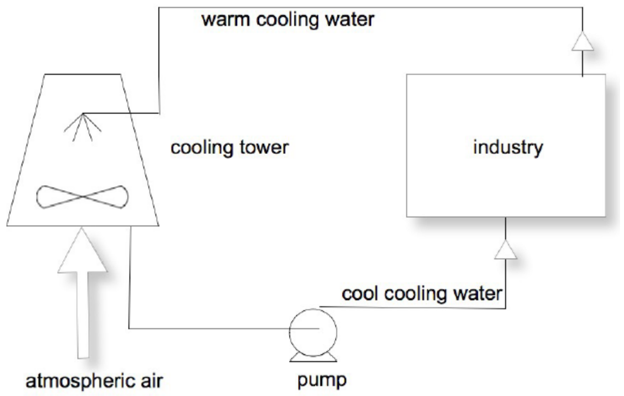


Fig. 7 Closed Loop Cooling System

References:

[1] Meilner Mechanical Sales, Inc. *www.boilersource.com*
[2] Dockrill P., Friedrich F., *Federal Industrail Boiler Program*, Natural Resource Canada, CANMET Energy Technology Centre, 1 Haanel Drive, Nepean ON K1A 1M1, *Boilers and Heaters: Improving Energy Efficiency*, Catalogue No: M92-299/2001E, 2001
[3] Initiativ Energieeffizienz in Industrie und Gewerbe *www.industrie-energieeffizienz.de*
[4] Top Motors *www.topmotors.ch*
[5] Heat Recovery with Compressed Air Systems *www.compressedairchallenge.org/library/factsheets/factsheet10.pdf*

Web links:

www.topmotors.ch
www.compressedairchallenge.org
www.boilersource.com

Key Points: The key points from this Part are:

- Power plants that generate electricity alone are relatively inefficient, at less than 50% efficiency
- Plants that produce useful heat as well as electricity are much more efficient
- Renewables still account for a small, but growing, proportion of electricity production.
- Energy consumption by industry is an important share of your country's energy consumption.
- Energy is used in many different ways in industry for many different purposes

Chapter 4: Energy Management

Learning Objectives: In the following chapters you will learn

- What an energy management is, why it is used and how it works.

Companies of all kinds are increasingly concerned with achieving and demonstrating environmental performance by controlling the impacts of their activities, products and services on the environment.

To be effective they need to be conducted within a structured management system that is well integrated within the organisation.

International Standards are intended to provide organisations with the elements of an effective management system that help organisations achieve environmental and economic goals.

A system of this kind enables an organisation to develop a policy, establish objectives and processes to achieve the policy commitments, take action as needed to improve its performance. The companies have to stick on the standards otherwise they will not get a Certification.

The overall aim of a management system is to support quality, environmental protection and socio-economic needs.

Definition:

ISO 9001: Quality management
ISO 14001: Environmental management
ISO 16001: Energy management

ISO 9001: Is an international Standard which sets standards that assure that customers get the quality they expected.
ISO 14001: An Environmental Management System is a set of processes and practices that enable an organisation to reduce its environmental impacts and increase its operating efficiency.
ISO 16001: The overall aim of this standard is to help organizations establish systems and processes necessary to improve energy efficiency. This should lead to reductions in cost and in greenhouse gas emissions through the systematic management of energy.

But why should a company implement a management system?
In Figure 1 you can see the answer – there are several points which argue for the implementation of a management system.

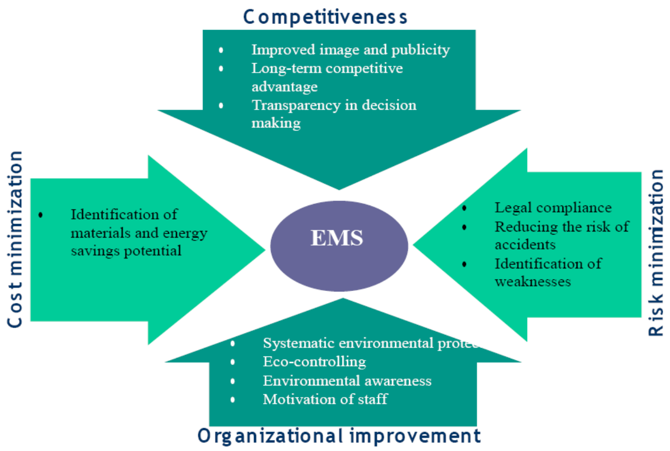


Fig. 1: Benefits of a management system for companies [1]

Note: On the whole all management systems consist of only a few important elements which are almost equal.

We will deal with these steps in the following parts of this handbook.
Let us turn our attention to energy management.

Goals of an energy management system

The goal of the implementation of an energy management system is to result in improved energy performance.

The organization shall periodically identify opportunities for improvement and control their implementation. The rate, extent and timescale of this continual improvement process is determined by the organization in the light of economic and other practical circumstances, such as size of the organisation, energy intensity of its activities, changes in production.

Note: Some important questions for the company are:

- Which energy carriers are used? (electric energy, natural gas, coal etc.)
- Which energy carrier predominates?
- Is a part of the used energy backed by alternative energies? (electric energy, wind or solar energy, biomass, geothermal energy etc.)
- How big is the daily/annual demand of energy?
- How does the energy get to the location? (communal mains power supply, own pipeline e.g.: natural gas, truck or ship e.g.: carbon or kerosene)
- How big are the daily/annual costs for energy?
- Which regions of the concern consume the energy? Which region needs energy the most?
- What is the share of the cost of energy on total operating cost?
- How did the energy costs change during the last years?
- Are energy questions essential for the location?
- Which plans has the company for the future energy supply?
- How big is the energy demand for the production? Parallel, what does the further energy demand (e.g.: lighting, heating, cafeteria etc.) look like?

Exercise

Try to answer these questions for your school! Talk to the caretaker and interview your principal, asking these questions.

Elements of an energy management system

In Fig. 2 you can see the main steps of an energy management system:

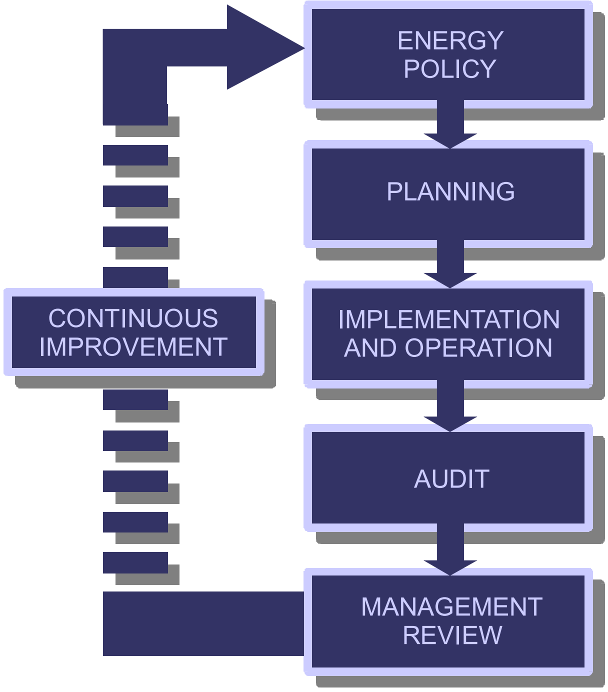


Fig. 2: Energy Management Cycle

The aim of an energy management system is to improve energy efficiency and not to fall back to the old inefficient behaviour in the future. This should lead to reductions in costs and green-house gas emissions through systematic management of energy. The full requirements for an (energy) management system are defined in international standards (ISO 14001, ISO 16001).

The following parts will deal with the single steps of the management system in detail.

Exercise:
Try to find documents concerning ISO 14001 or EMAS on the internet

Questions:

- Have you ever considered how much paper you use during only one single day at school or at home?
- Discuss how you can avoid paper consumption? How can these ideas be organized into one programme for the whole school?
- Which electricity consumers are in your school?
- Which management systems do you know? What is the content of them?

Energy policy

The energy policy is a written statement that the company wants to save energy, to improve the company continually and to ensure legal compliance.
This corporate energy policy should take the form of an official, publicly available statement of the organisation's commitment to achieve energy management objectives and to reduce energy related emissions.

Case Study:

STAR PAPER MILLS LIMITED
SAHARANPUR-247001 (U.P.) INDIA
Ph. 0132-2727731-35 (5 LINES) 2731731-35 (5 LINES) FAX : 0132-2726283
E-mail: starsre@starpapers.com, Web: www.starpapers.com, GRAM: "STAR"

15.12.2001

ENERGY POLICY

Star Paper Mills Limited, Saharanpur is committed to the cause of Energy Management and reduce its Energy Consumption by adopting the following measures.

1. To improve process, operation and maintenance with a view to reduce energy consumption.
2. To reduce wastages and improve productivity to minimise unit energy consumption.
3. To reduce consumption of coal by looking for options to generate steam through agriculture residue and other solid wastes generated in the plant.
4. To create awareness through training /seminars among all employees to conserve energy.

For STAR PAPER MILLS LIMITED

(Arun Bhambri)
Vice President (Technical)

Regd. Office :
27, Biplabi Trailoka Maharaj Sarani,
Kolkata-700 001
Gram : "SAFEST"
Ph. : 2242-7380-83 (4 LINES)
Fax : 033-22427383
E-mail : spmlcal@cal3.vsnl.net.in

Delhi Office :
301-303 Emca House, 23/23B, Ansari Road,
Darya Ganj, New Delhi-110 002
Gram : "STARMILL"
Ph. : 23273203, 23273206, 23273307, 23286589
Fax : 011-23273119
E-mail : starsre@ndf.vsnl.net.in

DUNCAN GOENKA

Fig. 3: Energy policy (Star Paper Mills Limited) [2]

Note: The policy has to:

- be available in written form
- be signed and finally issued by the top-management
- provide a framework for the definition of environmental objectives
- be updated
- be communicated to all employees
- be accessible to the public

Questions

- How should an energy policy be structured?
- Search for paper producing companies (in your area) in the internet.
- Are these enterprises certified according to ISO 14001 or ISO 16001?
- Does the company present an environmental/energy policy on the webpage?
- Try to find a (energy/environmental) policy of the enterprise(s)?
- Does your school have a policy (e. g. related to waste minimization, water conservation or energy reduction)?

Planning

Note: Planning considers the following aspects:

- environmental aspects
- legal and other requirements (laws, decrees, individual acts of law, voluntary agreements and obligations, customer requirements, requirements from other interested parties and consideration of these requirements);
- objectives and targets: Setting objectives and targets provides the means for transforming policy into action. The energy targets ensure that the company has defined success criteria so that progress towards improved energy efficiency can be measured.

A successful energy management is based on good planning:

Fig. 4: Important steps for the planning

The Input – Output analyses (material flow analyses and energy analyses) lead to the goals and the goals lead to the measures. It is important that the procedures are reviewed (***Fig. 4: Important steps for planning***).

Transparency regarding material flows gives a basis for sensitisation and the creation of awareness. Tools like input/output analyses, material flow analyses and energy flow analyses build the basis of an information system that allows you to determine the efficiency of material and energy flows and the effectiveness of measures. This makes them a valuable tool in measuring the actual improvement of environmental performance.

Input - Output

The first step in the initial analysis is the identification of areas of significant energy consumption. In Figure 5 you can see an overview of input and output in industry.

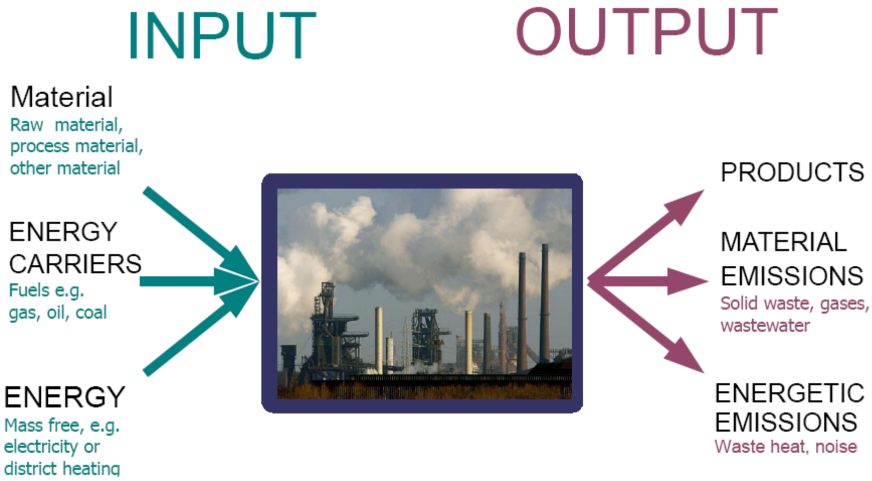


Fig. 5: Principle of Input – Output analyses

Initially the company needs an idea about the quantity and the nature of energy consumption. The energy review shall include past and present energy consumption.

The degree of detail depends on the size of the organisation and the energy consumption, but should as a minimum include energy inputs (electricity, oil, natural gas or other) and final use estimations (drying, pumping, air-conditioning, lighting, or other).

Trends in energy use over previous years should be reviewed and form the basis for setting targets. Information which is already available should be used in the review, e.g. energy bills, meter readings, building management energy reports or other existing information.

Often the biggest opportunities for improved energy performance will result from no-cost housekeeping measures i.e. training personnel to turn off equipment when not in use, promotion and awareness of energy performance in personnel's work practices, etc.;

The company should update the review annually. Reviews should, where possible, be based on actual measurements. Account should be taken of changes of the organisation, e.g. expansion of production, plant modifications, changes of the organization, staff qualifications and job descriptions etc.

Trends in energy consumption over the previous years should be analysed.

Case Study: An example of an annual review of a paper mill (M-real Stockstadt GmbH)

Input

Raw materials and auxiliary agents		Operating materials			
Total wood supply	**459 786 fm**	Petrol	4 487 l	Coal	910,1 GWh
Portion round wood	404 390 fm	Diesel	214 507 l	Thick lye	538,1 GWh
Portion chips	55 396 fm	Motor gas	29 139 kg	Bark and rejects	78,8 GWh
PEFC-certified	75,5 %			Recyclings	18,2 GWh
FSC-certified	3,8 %	**Fresh water**		Biogas	0,0 GWh
		Process water	15 181 962 m³		
Total pulp	**258 026 t**	Municipal water	53 937 m³	**Total electricity**	**418,315 GWh**
Own pulp (integration)	85 567 t	Cooling water	10 493 074 m³	Portion own production	297,147 GWh
External pulp	172 459 t			Portion external electricity	121,168 GWh
		Energy			
Chemicals		**Fuels in total**	**1 923,3 GWh**	**Total power consumption**	**417,780 GWh**
Pigments and fillers	133 504 t atro	Fuel oil S (1 %)	24,3 GWh	Process	365,972 GWh
Binders	16 890 t atro	Fuel oil S (2,8 %)	13,5 GWh	Own power plant consumption	51,808 GWh
Other chemicals	62 999 t HW	Fuel oil S in total	37,8 GWh		
		Neutral gas Energy Production	280,0 GWh	**Total steam consumption**	**2 174 378 t**
Packaging material	**2 041 t**	Neutral gas Process	60,4 GWh		
(without pallets and shells)		Neutral gas in total	340,4 GWh	**Total compressed air**	**91 059 (1 000 Nm³)**

Output

Products		Wastewater		Recyclings	
Total pulp	**143 929 t**	**Total quantity wastewater**	**15 181 962 m³**	**Total recyclings**	**61 433,0 t**
Pulp integration	85 567 t	CSB	4 862 t	Total therm. utilisation	23 736,9 t
Market pulp	58 362 t	BSB_5	248 t	Internal therm. utilisation	23 482,3 t
PEFC-certified	75,5 %	Total nitrogen	93,7 t	External therm. utilisation	254,6 t
		Total phosphor	12,5 t	Total utilisation	61 362,0 t
Total paper	**401 187 t**	Solid matters	167,4 t	Total disposal	139,6 t
Tauro (HFN)	201 040 t	AOX	0,911 t	Disposal landfill	58,6 t
EuroArt (HFG)	200 147 t			Special waste	143,8 t
PEFC-certified	65,3 %	**Air emissions**		Utilisation rate	99,8 %
		SO_2	391,5 t	Disposal rate	0,3 %
Energy		NO_x	799,2 t	Special waste rate	0,3 %
Power supply network	0 MWh	Dust	37,9 t		
Current to CWZ	535 MWh	CO_2 fossil	394 974 t		
Thick lye sales	53 275 t	CO_2 biogenous	200 441 t		

Fig. 6: Input - Output review [3]

Exercise: Try to make an Input – Output analysis in your school

- List the number of similar components (lights/beamers/computers/etc.)
- List the capacity of each component (look at the characteristics of the component for kW)
- List the operating hours (multiply the operating days with the operating hours per day) of each component
- Then ask your headmaster for the energy consumption of your school (e.g. per year). Compare the data you have calculated to the data of your headmaster. Are they almost equal or is there a big difference?
- Even if you didn't list all components that consume energy in your school you can tell the headmaster about how much energy is used by those components you worked out.

Goals

First of all the company has to set goals. These goals should be:

S pecific
M easurable
A mbitious
R ealistic
T erminated

The goal of the implementation of an energy management system is to result in improved energy performance.

The organisation shall periodically identify opportunities for improvement and control their implementation. The rate, extent and timescale of this continual improvement process is determined by the organization in the light of economic and other practical circumstances, as size of the organisation, energy intensity of its activities, changes in production.

Examples of goals include:

- actual energy savings within defined areas i.e. reduce compressed air losses by 10%;
- the introduction of new energy conserving technology (e. g. water flow reducers to reduce hot water consumption, heat exchanger in an air conditioning system to recover heat from the exhaust air, etc.) to reuse 20% of former heat losses
- training, awareness and motivation of employees to reduce hot water for cleaning by 20%;
- improving and expanding monitoring activities to reduce total energy consumption by 5%;
- establishing and implementing new procedures, work instructions etc. to reduce air losses by 10%

Measures

After setting your goals you are able to make decisions how you want to achieve that goals. The following table shows you an example for measures in a company:

Energy carrier	Goal	Measure
Electricity	Savings in compressed air system (180.000 [kWh/a])	Reduction of leaks - compressed air system
Electricity	Energy Savings: (50.000 [kWh/a])	Optimisation of lights
Natural gas	Optimisation of boiler system (480.000 [kWh/a])	Boiler Insulation of tubes Adjustment of the boiler
Natural gas	Reduction of natural gas for heating system (530.000 [kWh/a])	Heat recovery - compressor

Table 4: Example for goals and measures

Exercise:

- Concerning the enterprises you have identified in the earlier exercises: Do you find a list showing you their input materials and energy?
- Compare the energy consumptions of different enterprises.
- Is the list of energy aspects regularly updated?
- Make a table like in the example ***Table 4: Example for goals and measures*** that includes the goals and measures for saving energy. Rely on the components in your school.

Implementation and Operation

Top management should appoint a person responsible with authority for implementing the energy management programme. The management representative should also report to top management on the performance and results of the system.

Fig. 7: Organisational structure

Team

A central element of effective organisation is the team:

Work during implementation and later analysing the environmental effects, building awareness, generating options for improvement and implementing has some bearing on all of the company's operations. That is why it is better to appoint team members with the objective of covering the main operations. When selecting the team members make sure you cover the following areas:

- expert on law
- accountant
- chief technologist
- maintenance manager
- safety technologist

Exercise: Touch down on the moon

You are an astronaut shipwrecked on the moon. The craft that can take you back to earth is 300 km away. You have to decide which items you will take with you (matches, compass, life raft, signal rockets, stove, medication, water, iron ration, gun, ...):

- first individually (document your ranking)
- second as a result of a team discussion

Questions: Discuss the following questions:

- Who is responsible in your school for administration?
- Who is responsible for facility management?
- Who collects data on energy consumption, and reports them to the principal?

Communication, education, training

Effective communication is essential to ensure the success of the energy management system. Relevant and regular information enhances motivation and:

- Internal communication.

Internal communication helps employees to understand the organization's vision, values and culture. Communication may be oral or written, face to face or virtual, one-on-one or in groups. Clear and concise internal communication helps to establish formal roles and responsibilities for employees and maintain organization and clarity within an establishment.

The communication procedure should include the following:

a. who is responsible for internal communication about the energy conservation programme;
b. relevant information on the establishment, implementation and operation of the energy management system;
c. the means of communicating information (internal meetings, seminars, staff magazines, intranet, e-mail, information boards, etc.);
d. the way by which proposals from employees are reviewed and responded to.

- External communication

Communication with external parties is important for an effective environmental management system.

Documentation

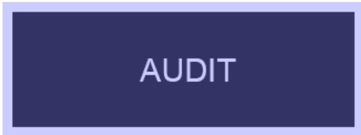
Documentation is necessary to describe and support the management system. The documentation should include all relevant operations and processes. It is a central point of reference for the implementation and maintenance of the overall system.

To monitor and control the impacts that certain processes or materials may have on the environment, procedures should be defined and made available for easy reference at all times. These documented procedures, which should be easy to understand and updated when required, will ensure the smooth functioning of the energy management system.

Exercise: Concerning the enterprises you identified:

- Is there a list of relevant know-how and experience of individual employees?
- Are there presentations on activities for awareness raising for energy conservation?

Audit



Do not confuse an audit with a management review. While the initial review 'kick starts' the management system, internal audits maintain its momentum.

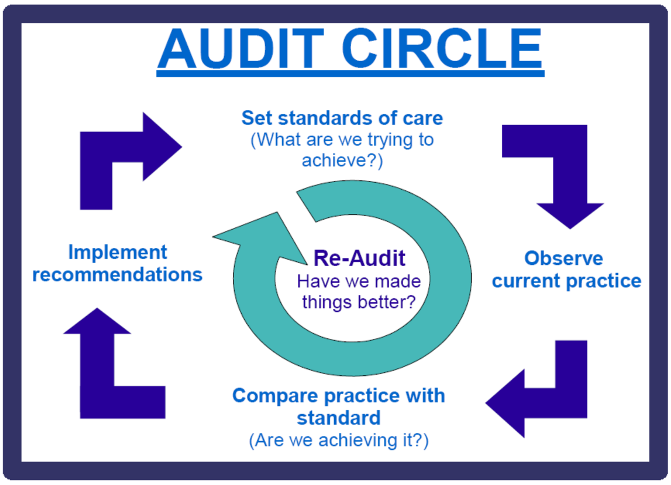


Fig.8: Audit circle [4]

Internal audits involve a systematic inspection and comparison of actual operating methods with the procedures specified in the EMS (environmental/energy management system) manual. The aim is to assess whether the EMS is operating correctly. On the one hand the audit should identify and highlight areas where the requirements of the EMS have been fulfilled; on the other hand it should detect non-compliances and suggest possible improvements. An audit may either focus on a procedure (e.g. emergency response) or on an area of operation or production line. The key to a successful EMS is commitment from all the employees. If employees are not committed, the system will be difficult to implement or maintain. Audits provide a valuable tool for gauging commitment within different parts of the company.

Note: The purpose of an internal audit is to carry out a systematic review of the energy management system and assess whether the system operates in accordance with the organization's own requirements

Frequency

The frequency of audits depends on the significance of the environmental aspects, but all procedures and areas should be audited at least once a year. The energy management representative is responsible for establishing the audit programme and communicating the results of the management system audits to top management on a regular basis.
Areas that require particular attention are: areas of high risk, areas where the company failed to meet legal requirements in the past.

Based on this information (areas of high risk, areas where the company failed to meet legal requirements in the past) an audit timetable is compiled indicating which areas or procedures are to be audited and when.

Management Review

MANAGEMENT REVIEW

The final step of implementing the management system is the management review.
Consider:

- Is the management system practical, operational and effective?
- What achievements has the business made?
- What are the reasons for any deterioration or improvement?
- Is the organisation complying with legal requirements?

The review should be based on relevant documents, such as the management audit report. Depending on the results of the review the policy or specifications of the management system may need to be revised. How often you make these revisions is up to you.

Exercise:
Presentation:
Congratulations: Now you know the main steps of an EMS.
Use the exercises and questions you did before. Based on them try to make a presentation which includes goals and measures which help saving energy in your school.

Key points: A management system consists of 5 main steps:

- Energy policy
- Planning: Input – Output analyses, goals, measures
- Implementation and Operation: Team, Communication, Documentation
- Audit
- Management Review

References:

[1] ISO 14001
[2] Energy policy (Star Paper Mills Ltd.) *http://www.energymanagertraining.com/banner/EMP2005_pdf/Star_Paper_Mills_EMP.pdf*
[3] M-real's Environmental Declaration 2007
http://www.m-real.com/ilwwcm/resources/file/eb7e914b0803b58/M-real%20EMAS%202007%20E_ENDI_08082007.pdf
[4] *http://www.southbirminghampct.nhs.uk/_services/rehab/Images/AuditCycle.jpg*

Web links:

www.sappi.com
www.m-real.com
www.iso.org
www.nsai.ie

Chapter 5: Efficient use of energy in the paper industry

Introduction

Who could imagine a world without paper? It is one of the most versatile and commonly used materials in our everyday life. Even in times of electronic communication and knowledge storage paper is still irreplaceable, not only in the field of education and information transfer but also for thousands of other products that we use every day.

Fig 9: Paper products.

The idea of papermaking had its origin about 2,000 years ago in China and became popular in Europe in the middle of the 13^{th} century [5]. In these times, fibres from mulberry bark, papyrus, straw or cotton were used as raw materials for paper manufacturing. The industrialization of paper production began only in the mid of the 19^{th} century and people started to extract the fibres of wood to use them as raw materials [1].
Energy has always played a major role for the production of paper. Early manufacturing always took place beside big rivers to ensure the water supply and the use of hydropower for operation of processes. The power of the sun and the wind helped to dry and to bleach the paper. The extensive use of fossil fuels began also with industrialisation of paper making. Today about 48% of the primary energy used in the European paper and pulp industry is generated from fossil fuels [22].

European paper facts[1] [22]

- Paper consumption in Europe increases on average by 2.6% per annum. The annual production capacity of European Countries is somewhat higher than 100 Million tonnes. Graphic papers account for about 48%, packaging paper grades for 40% and hygiene and speciality paper grades for 12% of the amount of produced paper.
- Germany is the most important paper producing country, followed by Finland, Sweden, Italy and France.
- The industry provides direct and indirect employment for more than 2 million people and comprises 1,200 pulp[2] and paper mills and 800 other companies in Europe.
- The European pulp and paper industry has an annual turnover of 79 billion Euros, i.e. 1.4% of the total European manufacturing industry`s turnover.
- The wood consumption of the CEPI – Countries in 2007 was higher than 119 million tonnes
- Pulp and paper manufacture is the world's fourth biggest primary energy using industry [17].

1 Facts for "Cepi Countries". Cepi stands for Confederation of European paper industries. Members in 2007: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, The Netherlands, United Kingdom.

2 Paper mainly consists of fibres from wood or recovered paper. The fibres are chemically or mechanically separated from the wood or any other raw material and are called "pulp".

More than half of the industry's heat and electric power is generated by the combustion of biomass - based fuels. Figure 10 demonstrates the share of primary energy[3] sources for the European pulp and paper industry.

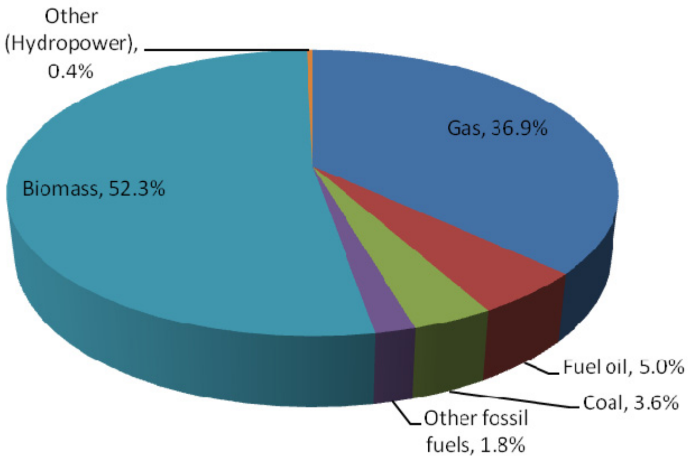


Fig 10: Share of primary energy sources [22].

Electricity, which is not self – generated but obtained from the grid, is produced from a variety of fuels. Figure 11 shows the ratio of fuels for electricity generation within the European Union.

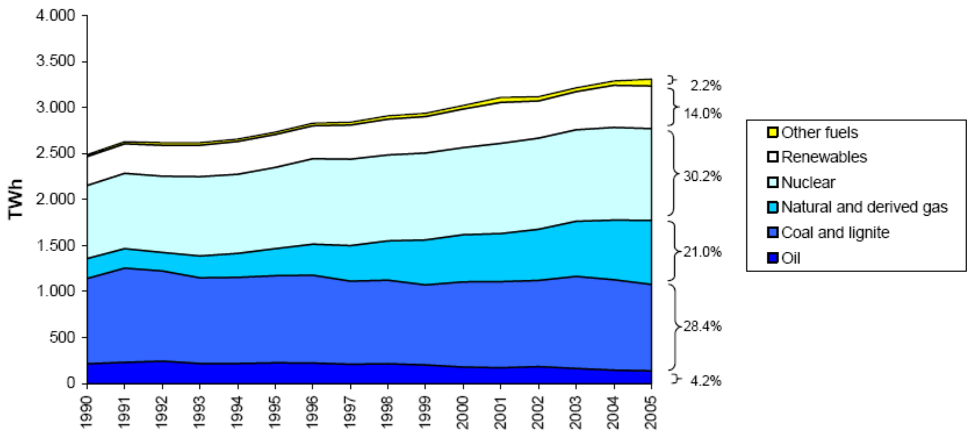


Fig 11: Annual electricity production in the EU – 27 by fuel [28].

"Renewables" in Figure 11 include electricity produced from hydropower, biomass- and biogas combustion, municipal waste combustion, wind energy, geothermal energy and solar photovoltaic power [28].

The production of paper and pulp contributes to severe impacts on our environment, as the process intensively uses wood, chemicals, water and has a very high demand for energy. In this context, this handbook describes paper manufacturing methods and gives an outlook on energy efficiency- and energy saving methods in the pulp and paper industry.

The Life cycle of paper

The power of the sun drives the pulp and paper eco cycle; it converts water, nutrients, solar energy and carbon dioxide to wood fibres in growing trees. The forest is a renewable resource of raw materials providing both wood fibres and biofuels for energy generation [19].

3 Primary energy is the energy embodied in natural resources before undergoing any transformation or conversions. Examples of primary energy resources are: coal, crude oil, natural gas, sunlight, wind, biomass, hydropower and uranium [33].

Figure 12 shows the basic steps of the paper life cycle.

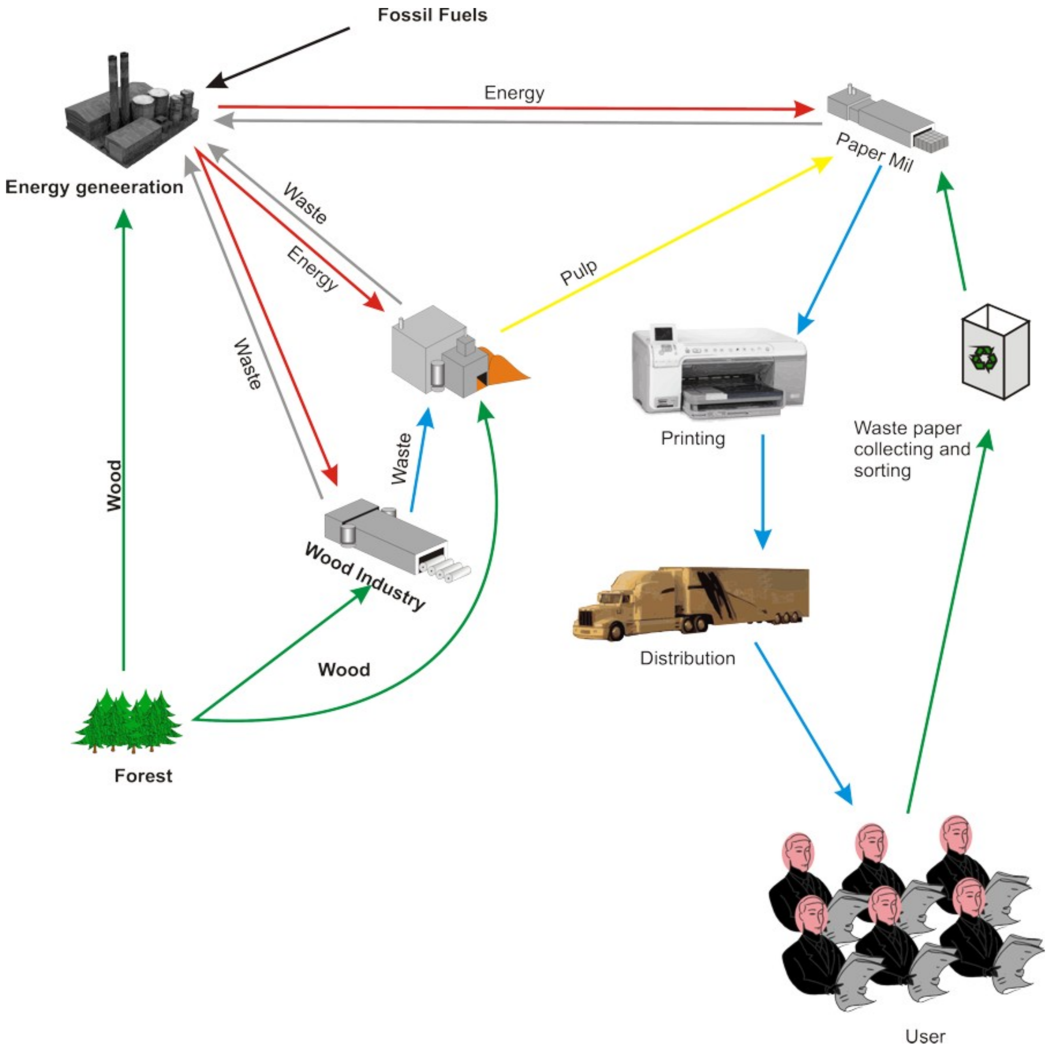


Fig 12: Life cycle of paper [31].

Wood, as well as by-products from the wood industry, are transported to the pulp mill where separation of the cellulose fibres from the other wood components takes place. The extracted fibres (pulp) are mixed with water and chemicals to be applied to the paper machine in the paper mill. Wastes from the wood industry and pulp- and paper mills are combusted in energy generation plants to save fossil fuels and reduce the amount of land filled waste. Waste paper is collected and sorted after being used and subsequently gets recycled to the production process [31].

Raw materials for the production of paper

Inputs of the papermaking process are fibres (pulp), chemicals, water and energy. Fibres, chemicals and water are mixed and form the "stock" that is applied to the paper machine [18]

Fibres

Different fibrous materials such as wood, non-wood plants or industrial sawmill wastes (primary or virgin fibres) and recovered paper[4] (secondary fibres) can be considered as raw materials for the production of paper. In the first manufacturing step the fibres are extracted from the raw material and the so called "pulp" is produced. This pulp is mixed with water and chemicals before it is applied to the paper machine, where the formation of the paper sheet takes place [3].

4 The industry favours the terminology "recovered paper" instead of "waste paper". [www.leo.org]

Wood

Wood is an organic material that consists of approximately 49% carbon, 44% oxygen, 6% hydrogen, less than 1% nitrogen and inorganic elements such as sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) and silicon (Si). These elements form macromolecules and thereby create the basic constitutes of wood: cellulose, hemicelluloses and lignin. The flexible cellulose fibres are bonded together and made rigid by the lignin [6]. Figure 13 shows the simplified principle of the cellular composition of wood.

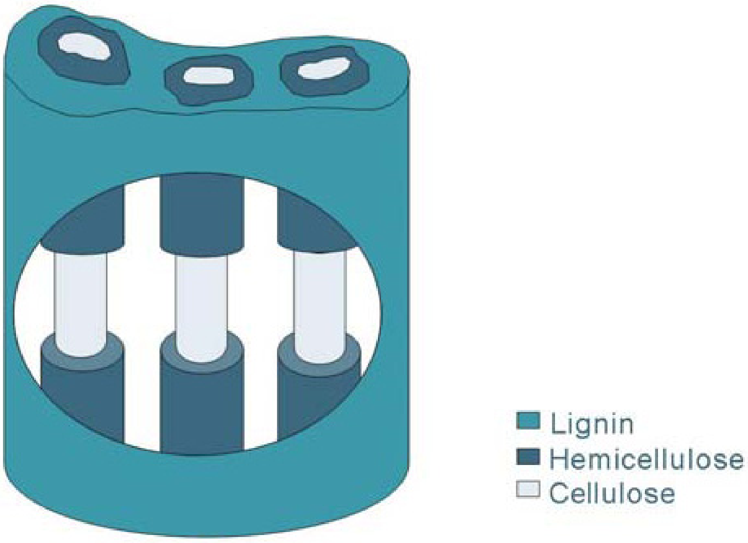


Fig 13: Simplified principle of cellular composition of wood [16].

For manufacturing paper, only the cellulose fibres can be used. They have to be separated mechanically or chemically from the other wood components.

Fibres from softwood trees, such as spruce, fir and pine are longer and coarser than hardwood fibres. Softwood fibres make the paper resistant to stretching and tearing, whereas hardwood fibres lead to a smoother surface of the paper sheet. Since softwood contains more lignin than hardwood, more chemicals and energy are necessary to separate the desired fibres from the other wood components [18].

Non-wood plants

Non-wood plants such as grass, flax, and hemp as well as agricultural residues, for example straw and sugar cane, are important raw materials for virgin fibre production in countries like China and India [19, 20].

Recovered paper

In 2006, 56% of the paper and board consumption in Europe was recycled. Newsprint and cardboard are the main products that are manufactured out of recovered paper [19].

Chemicals

Chemical substances such as fillers and coatings can account for up to 30% of the total stock. The addition of fillers, for example calcium carbonate (chalk) and kaolin, makes the paper more opaque, more resistant to aging, contributes to a smoother surface and increases its flexibility. Several process steps in pulp production such as dissolving lignin from virgin wood fibres, cleaning and bleaching also require the addition of chemicals [1].

Water

The most important raw material component is water. It is necessary for cleaning, cooling, steam generation and works as binding “agent” to form hydrogen bonds between the fibres within the paper sheet. Paper making processes can require 10 to 100 litres of water per kilogram of produced paper. Modern paper mills use water loops and circulation systems to minimize the fresh water demand [3].

Energy

Most paper mills have their own plants for the generation of electricity and the production of steam. Today, self generation of energy accounts for almost 60% of the total energy use in the European pulp and paper industry. Hydropower, natural gas, fossil fuels, wastes and biomass fuels, as well as energy that is recovered within the production process, are transformed to steam and electricity to run the process [18]. To give an example, Figure 14 shows the simplified energy flow sheet of an Austrian paper mill.

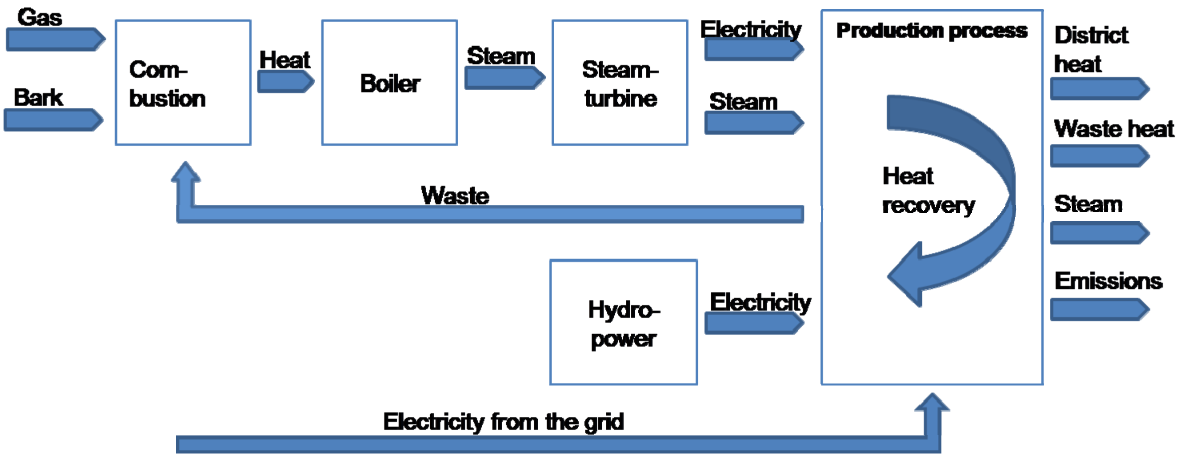


Fig 14: Energetic flow sheet of the UPM paper mill in Steyrermühl, Austria [14].

Natural gas, bark and waste from the production process are combusted to produce heat. This heat is used to make steam that drives a steam turbine which produces electricity. Excess steam from the turbine is used for heating purposes in the production process. Heat recovery systems also contribute to the energy supply of the paper mill. In this paper mill, a hydropower station also delivers electricity and the remaining demand is covered by the grid [14].

Paper mills use energy in form of steam for heating and drying purposes (for example in the paper machine) and electricity to run the different machines and motors. Energy costs are in a range of 15 – 25% of the total production costs [27].

The energy demand for the production of one tonne of paper is in a range of 3-5 MWh, this is the average amount of energy that is consumed by an European household within 3 months[5]. Due to these economical reasons it has always been a key task for the paper industry to reduce the primary energy demand and to enforce the efficient use of the generated steam and electricity. Especially the combustion of wastes from the production process and biomass fuels such as bark, wood residues and other residues from forestry operations contribute to a reduced use of fossil fuels and to a sustainable input of resources.

Above that, heat recovery installations throughout the manufacturing process reduce the total demand for energy generation and in this way also the amount of CO_2 and other emissions [19].

5 Source: www.aee.or.at; The average energy consumption per year (including all electrical consumers and the heating system) is approximately 20,000 kWh

Pulp production and preparation (
Extraction of fibres out of the raw materials. Fibres can be extracted mechanically (see Thermo mechanical pulp) or chemically (see Chemical pulp) from wood or mechanically from recovered paper. Screening, cleaning, and bleaching of the extracted fibres.

Paper machine
The pulp is made to paper

Production process of paper

Papermaking can be divided in two basic steps that transform the raw materials into the final product. [3, 20]:

- Pulp production and preparation systems

When wood logs are used as fibre source, it is first of all necessary to debark the logs. Generally log debarking happens in a rotating drum where the bark is separated from the wood by friction. The bark can be combusted for energy generation [4]. This so called "biomass combustion" reduces the demand of fossil fuels and the amount of waste from the process [2]. In a pulp mill the cellulose fibres of the wood logs are separated from all the other wood components and a mass of individual fibres is assembled. In case of an integrated pulp- and paper mill, pulp production and paper manufacturing happens at the same plant, otherwise the pulp is dried and pressed to bales for the use in any paper mill worldwide [19].

- Chemical pulp

In chemical pulping a combination of heat, chemicals and pressure breaks down the lignin in the wood so that it can be washed away from the cellulose fibres [18]. For this purpose the debarked wood logs are washed and chipped. Screening removes oversized chips for reprocessing. Sawdust can be combusted together with bark and other residues [2]. In chemical pulping the wood chips are "cooked" with a so called "cooking liquid" (white liquor) containing sodium hydroxide ($NaOH$) and sodium sulphide (NaS).
Under the influence of these chemicals and process temperatures from 155 to 175 °C, the lignin and part of the hemicelluloses are dissolved out of the wood, so that only the desired cellulose fibres remain.
The extracted fibres (pulp) contain "black liquor", a mix of spent pulping chemicals and lignin. By washing processes the black liquor is separated from the pulp and collected in a chemical recovery system, where approximately 70% of the energy input to the cooking process and more than 90% of the chemicals are recovered [2]. Initially, pulp has a brownish colour. Depending on the desired brightness and purity qualities of the paper, the pulp has to be bleached in order to remove more of the remaining lignin and other impurities. Chlorine / chlorine compounds, ozone / oxygen in different forms and hydrogen peroxide can be used as bleaching chemicals. Due to negative environmental impacts of some chlorine containing compounds, there are environmental objections against their use and most modern paper mills use chlorine – free processes [1].

Fig 15: Bleached chemical pulp [34].

Figure 16 illustrates the most important mass and energy flows of chemical pulp production.

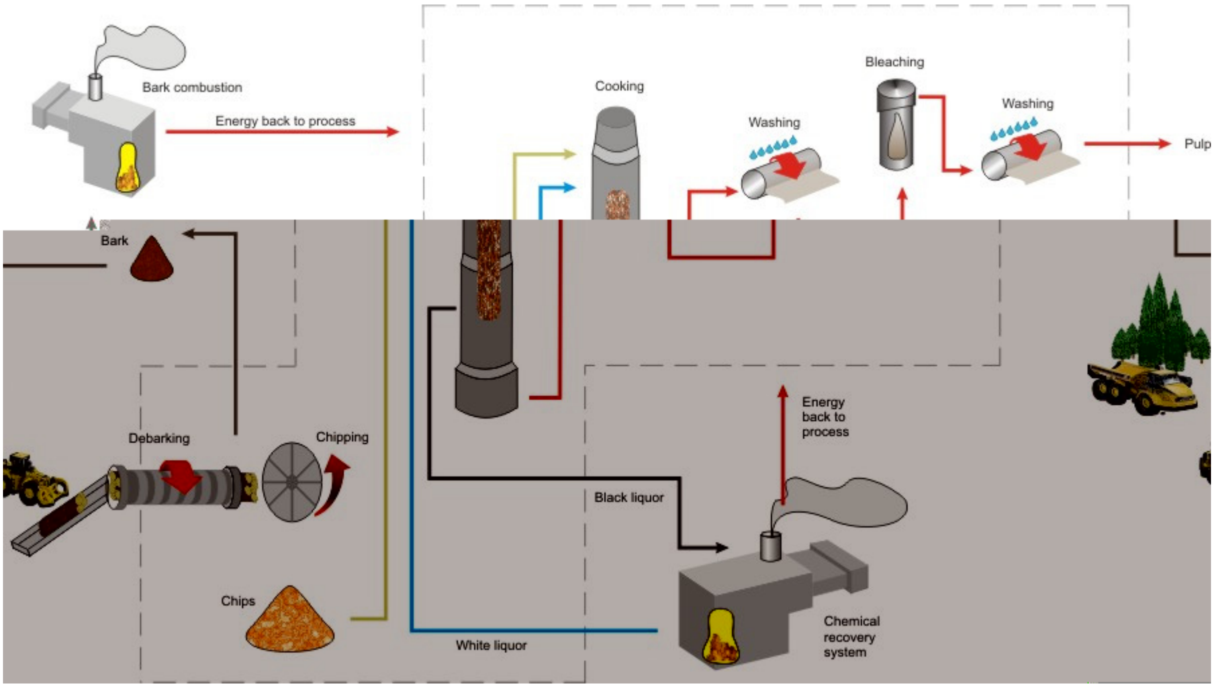


Fig 16: Flow sheet of chemical pulp production [31]

Chemical and Energy recovery system
In the recovery system, water is removed from the black liquor by evaporation; the remaining thickened liquor is led to a recovery boiler. The organic wood components in the black liquor (lignin and other wood components) have high energy content and are combusted to produce steam. The used pulping chemicals are collected at the bottom of the recovery boiler and are recycled to the process [18].

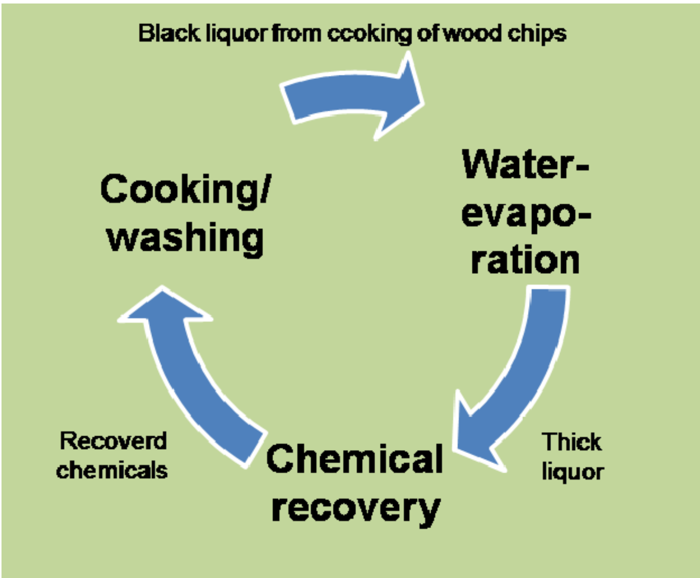


Fig 17: Flow sheet of the recovery system [4].

- <u>Thermo - mechanical pulp (TMP)</u>

Thermo-mechanical pulping uses heat and mechanical energy to extract fibres out of the wood. Wood chips are impregnated with steam to moisture the materials. Subsequently fibres are ground out of the chips by a rotating machine (refiner). The simplest design of such a refiner ba-

sically consists of two discs, rotating against each other.
The rotating energy of the refiner releases a lot of steam from the wet wood chips. This "waste steam" or "TMP steam" is separated from the wood fibres and led to the energy recovery system. The fibres are then screened to remove oversized particles from the stock, cleaned and bleached to achieve the desired pulp qualities [4]. Figure 18 shows the overall flow sheet of thermo-mechanical pulp production.

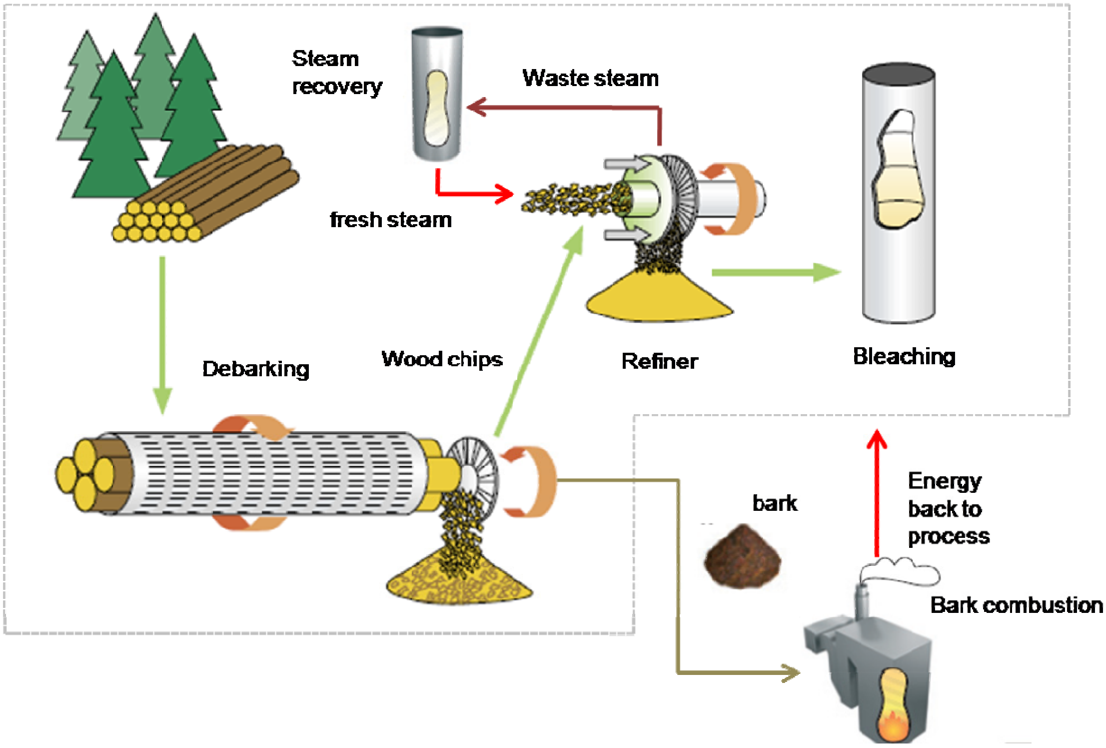


Fig 18: Flow sheet of TMP production [31].

<u>Energy recovery system</u>

The steam that is lead to the energy recovery system contains a lot of impurities (e.g.: turpentine, volatile organic oils) so that it cannot be directly used for heating in the process. Therefore the hot steam is applied to a heat recovery boiler to heat fresh water and to produce new steam for impregnation of the wood chips.

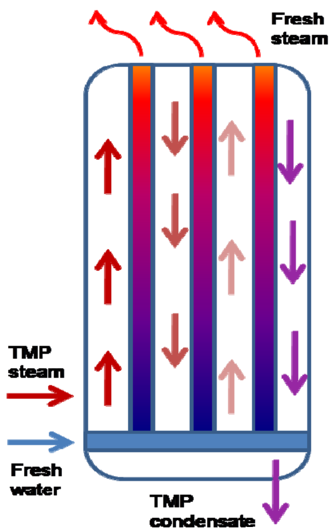


Fig 19: Heat exchange between TMP steam and fresh water [12].

The TMP steam circulates through the recovery boiler and heats the fresh water. Thereby it finally condenses and is withdrawn at the bottom to be lead to the effluent treatment system. With recovery boiler operation, 60–70% of the energy that is necessary to run the refiner can be recovered in the form of fresh steam [12].

- <u>Pulp from recovered paper (Paper recycling)</u>

In order to save raw materials and energy, paper can be recycled reusing the fibres of the paper instead of fresh fibres from wood. For this purpose, different recovered paper grades have to be prepared by the stock preparation system to be applied to the paper machine [3]. Figure 20 shows one possible flow sheet for recovered paper processing.

A pumpable suspension is produced from the input material in a vessel filled with water and recovered paper. This so called "pulper" breaks down the recovered paper into its fibres by dissolving it in water [3]. Ink particles and impurities such as foils, textiles, plastic bags, stones, staples or wood pieces are separated from the suspension before it can be applied to the paper machine [18].

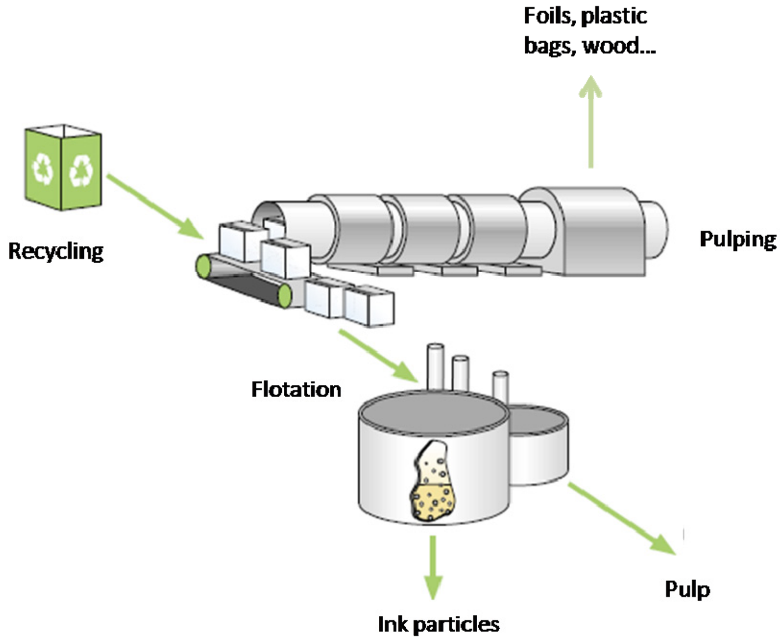


Fig 20: Paper manufacturing from recovered fibres [31].

The impurities that are removed during the recycling process (rejects) can be combusted for energy generation purposes [19].

- Recycling vs. incineration

Recycling of paper contributes to a sustainable production; however it is always necessary to bring fresh fibres from the forest into the paper cycle. Waste paper contains lots of broken and destroyed fibres that cannot be reprocessed any more [7]. At each cycle of reprocessing, 10–20 % of the fibres become too small for reuse and have to be replaced [17].

Paper that cannot be reprocessed any more can be combusted together with other domestic wastes in municipal incinerators. The paper positively influences the incineration process since it burns easily and therefore reduces the demand for supplementary fossil fuels [17]. Combusting one tonne of waste paper substitutes approximately 600 liters of oil [22].

Since municipal incinerators commonly generate energy, for example steam for district heating systems and electrical power to the grid (Figure 22), the incineration of waste paper that cannot be recycled or used in other materials any more is a way of recovering energy.

Fig 21: Crane for waste handling [25].

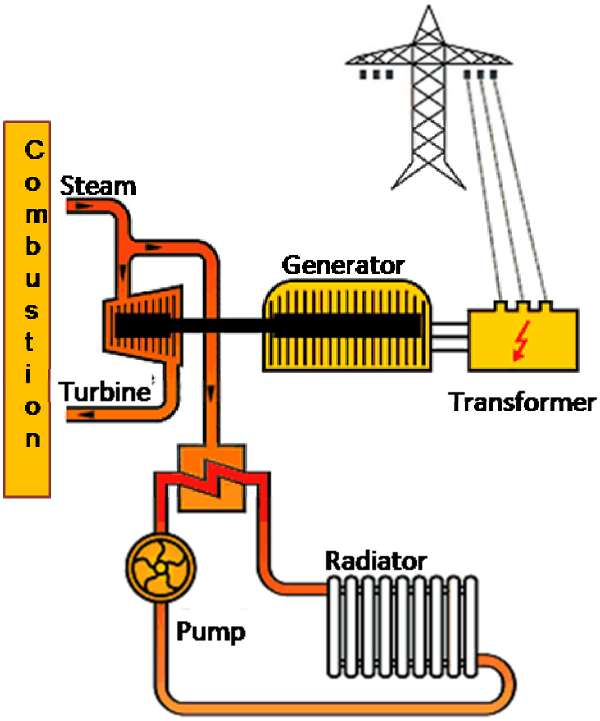


Fig 22: Energy output of waste incineration [26].

Paper recycling vs. fresh fibre use

The environmental impacts of paper production are numerous; this chapter will illustrate the most basic and commonly known influences of pulp and paper manufacturing on the environment.

Despite the many different paper grades and the various production processes for pulp and paper, several European and US American experts claim that paper that is manufactured from recovered fibres is less harmful to nature than paper produced from virgin fibres. [9, 10, 19, 25, 26]

Table 1 shows the different environmental impacts of the production process of 1 tonne paper from primary fibres (Scenario A) compared to one tonne from secondary fibres (Scenario B). Serious impacts on the environment are:

- Greenhouse gases: such as carbon dioxide (CO_2) and methane (CH_4) contribute to climate change by trapping energy from the sun in the earth's atmosphere [24];
- Particulates: small particles (< 10 µm) that are dispersed into the atmosphere during combustion can cause asthma and other respiratory illnesses or even cancer when inhaled [24];
- Sulphur dioxide: SO_2 results from combusting sulphur containing fuels (coal, oil) in boilers and leads to air pollution problems like acid rain or smog [24];
- COD: The Chemical Oxygen Demand (COD) value indicates the amount of persistent organic substances in the effluent water [24];
- BOD: The Biochemical Oxygen Demand indicates the amount of oxygen consumed by micro-organisms when degrading organic material in the effluent. Discharging effluents with high BOD contents can result in the reduction of dissolved oxygen in the water and adversely affect fish and other organisms [18];
- AOX: Adsorbable organic halogens: are an indirect measure of organic chlorinated compounds, some of which are toxic [24];

Table 1: Comparison of environmental impacts between paper produced from fresh fibres and paper produced from recovered paper [8, 9, 24].

	A: 100% fresh fibres	B: 100% recycled fibres
Raw materials		
Wood	2,200 kg	-
Used paper	-	1,100–1,300 kg
Minerals (e.g.chalk)	100 kg	25 kg
Chemicals (e.g. pigments, fillers)	230 kg	130 kg
Water	30,000-100,000 L	10,000-20,000 L
Energy consumption		
From combusting wood residues	3-4 MWh	
From combusting process waste		0.5-1 MWh
Additional (e.g.: fossil fuels)	0.5-1 MWh	1-2 MWh
Total	3.5-5 MWh	1.5-3 MWh
Emissions to water		
COD	5-50 kg	2-10 kg
BOD	1.8-2.1 kg	1.6-2 kg
AOX	<0.5 kg	<0.5 kg
Emissions to air		
Greenhouse gases (CO_2 equivalents)	1,200-2,500 kg	900-1,400 kg
Particulates	4-5 kg	2.5-3 kg
Sulfur dioxide	10-12 kg	9-11 kg

Regarding energy efficiency of the paper cycle, fibre recovery is less energy consuming than producing paper from virgin fibres. However it is likely that greater external inputs of energy from fossil fuels are involved in recycling processes since manufacturing processes that use virgin fibres, use a lot of wood as alternative fuels. One tonne of paper produced from recovered fibres consumes approximately 2 MWh i.e. 40% less energy than paper produced from fresh fibres [23]. This is the amount of energy that an average European Household spends in one and a half months[6].

If one takes a closer look at CO_2 emissions, the average saving potential is 700 kg per tonne of recycled paper compared to paper produced from fresh fibres. Assuming that an average car on European streets emits 160g of CO_2 per kilometre, one could travel for approximately 4,400 kilometres to emit the same amount of carbon dioxide.

- Combustion of wastes from the production process

Data from Germany's paper industry show that in 2001 35% of solid waste (bark and wood residues, all kind of rejects) was used for energy generation, 18% were composted or biologically treated, 41% were reused as raw material in other branches of industry and only 6% came to final disposal at landfills. The importance of combusting waste from the production process increases due to high costs for fossil fuels, stricter environmental legislation and high landfill costs

6 Source: www.aee.or.at: The average energy consumption per year (including all electrical consumers and the heating system is approximately 20,000 kWh)

[3]. The pulp and paper industry is the largest producer and consumer of alternative fuels such as sawdust, bark and other wood residues [19].

Generation of steam and electricity

In the production of paper and pulp, several process steps such as the dryer section of the paper machine use steam for heating purposes. Steam is generated by heat exchange between hot off-gases from combustion processes (combustion of fossil or alternative fuels, chemical recovery process) and fresh water [12]. *Figure 23* shows the basic principle of steam generation.

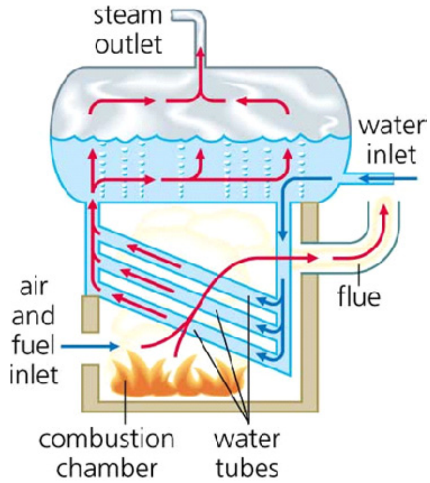


Fig 23: Simplified principle of steam generation [15].

The steam moves a turbine; its heat energy is converted to mechanical rotation energy. The shaft of the turbine is connected to a generator that transforms the mechanical rotation energy to electricity. Steam that exits the turbine is led to the paper making process for heating purposes.
In the steam consuming points it releases its energy into the process by condensing. The condensate is pumped back to the boiler to be vaporized again. This process is called a cogeneration steam cycle (combined heat and power generation) and is illustrated in *Figure 24* [11].

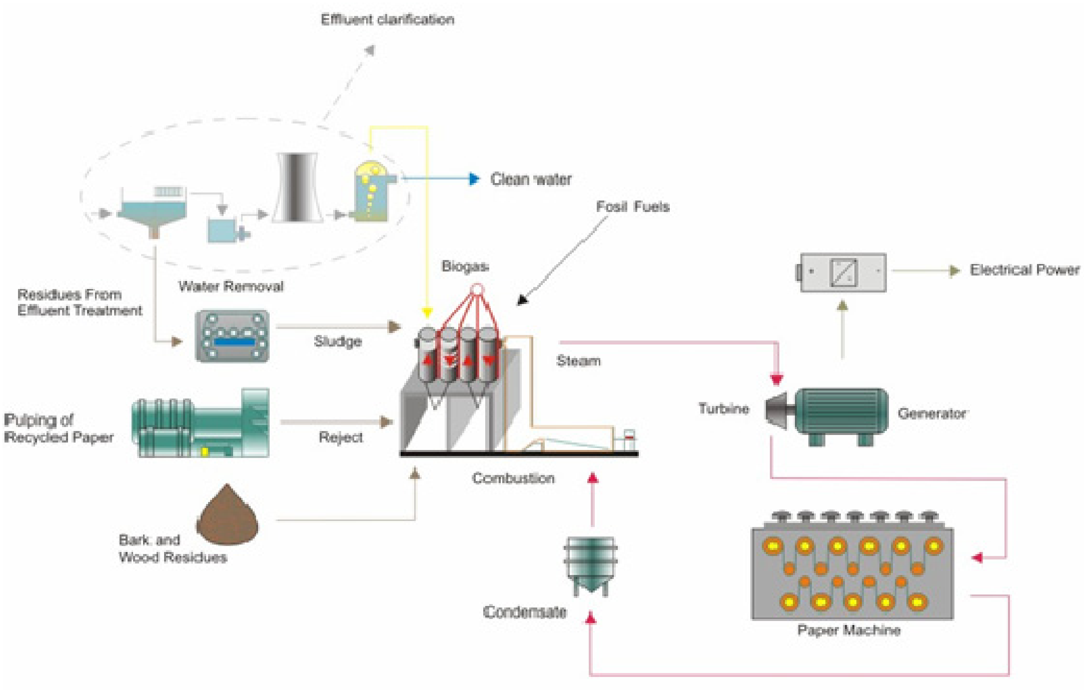


Fig 24: Flow sheet of waste combustion for steam and electricity generation [10].

Sludge and biogas[7] from effluent treatment and rejects from the pulping process are co-combusted together with bark, other wood residues and fossil fuels [10]. Biological treatment, either in plant or in municipal treatment plants, is today's standard for waste water from paper mills. The specific waste water volume of modern paper mills is about 10 – 12 L/kg paper [3].

Operation of cogeneration systems to ensure energy efficiency

Cogeneration is the simultaneous generation of electrical power and heat in one single, integrated system (combined heat and power generation). With waste heat from electricity generation, drying or heating in subsequent process steps is achieved. Thus, the amount of waste energy is reduced and fuels can be saved. This means that the overall efficiency of cogeneration processes is higher compared to conventional separate electricity and steam generation [29].

The efficiency (ŋ) of a process can be calculated as the ratio between the power output of a system (usable energy output i.e. useable thermal power, net electric output) and the energy content brought to a system (energy input i.e. net calorific value)[8] [13].

$\eta = P_{use}/P_{in}$; P_{use} = useful energy (i.e.: power, heat); P_{in} = Energy input

Cogeneration is recognised as a key technology to save energy and in this way to reduce emissions of carbon dioxide. Up to 25% of energy savings are possible to be achieved with cogeneration installations [19]. Figure 25 shows the energy efficiency advantage of heat and electricity cogeneration compared to separate power generation and steam boiler operation [29].

When separate electricity generation is processed, approximately 31% of the fuel energy can be converted into net electric power output, the rest of the energy input is lost as "waste heat" of the power plant. Typical boilers for steam production convert 80% of the fuel input into useable thermal power. If for example a paper mill requires 30 units of electricity and 45 units of steam, 154 units of fuel are necessary to operate the process. The overall efficiency can be calculated: [29]

$\eta = P_{use}/P_{in} = (30+45)/154 = 0.49$

η = 49%

A cogeneration process uses the waste heat from the electricity generation step and therefore requires less energy. Only 100 fuel units are necessary to supply 30 units of electricity and 45 units of steam to a paper mill, therefore the efficiency is much higher [29].

$\eta = P_{use}/P_{in} = (30+45)/100 = 0.75$

η = 75%

7 Biogas is a mixture of methane (55 vol-%), carbon dioxide (44 vol-%) and other gaseous components (1 vol-%) that is produced by microorganisms, digesting organic material under anaerobic (oxygen deficient) conditions Biogas is created for example in moors, swamps, landfills, and waste water clarification processes [32].

8 Net calorific value: Quantity of heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to remain as a vapor. [30]

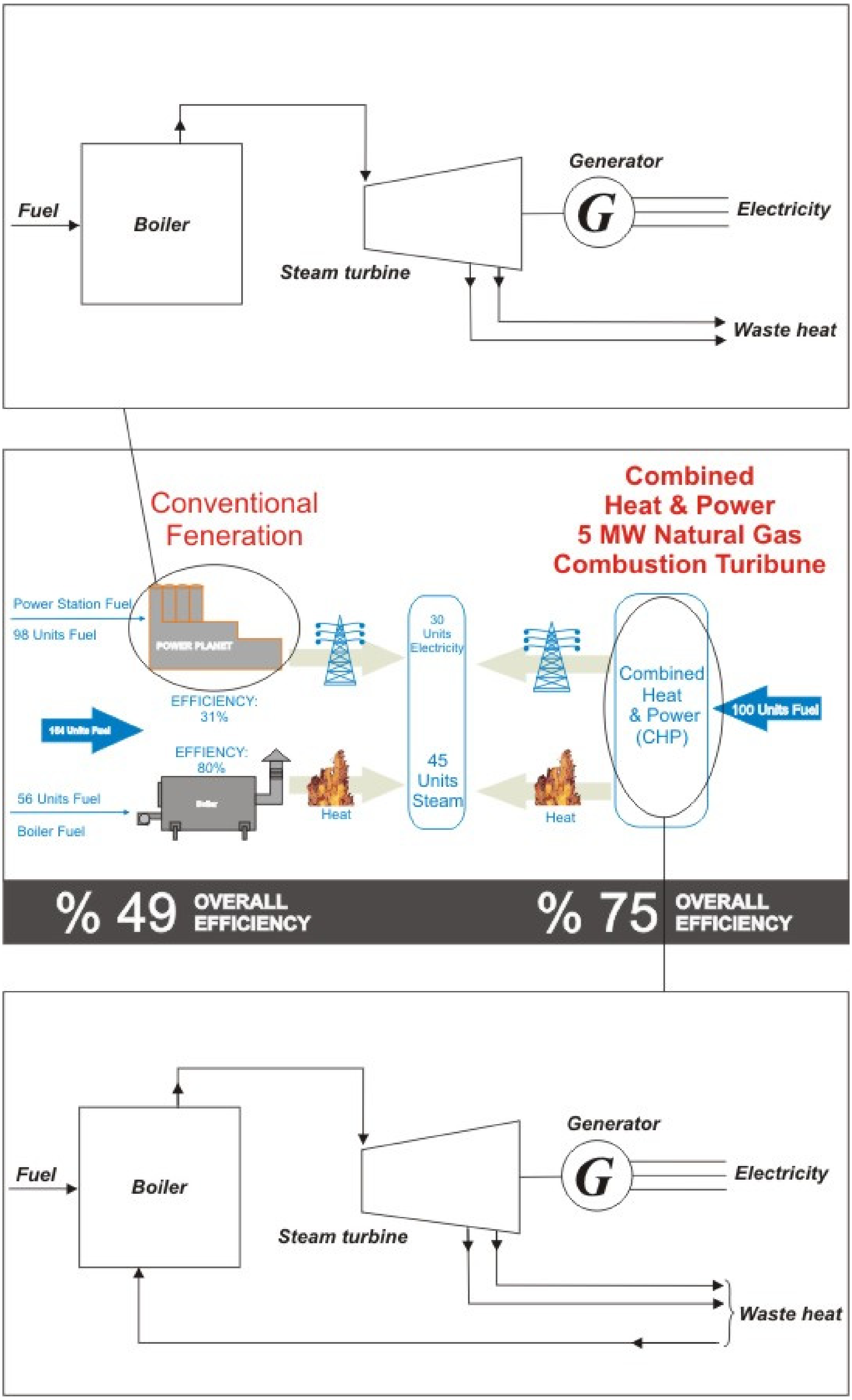


Fig 25: Overall efficiency of cogeneration (beneath) compared to separate generation of steam and electricity (above) [13, 29].

Sheet formation on the Paper machine

This is the final step of the paper production process. Figure 26 shows the basic components of a paper machine. There are five main sections: the headbox (where pulp and other components are applied to the paper machine), the wire section, the press section, the dryer section and the end group [3].

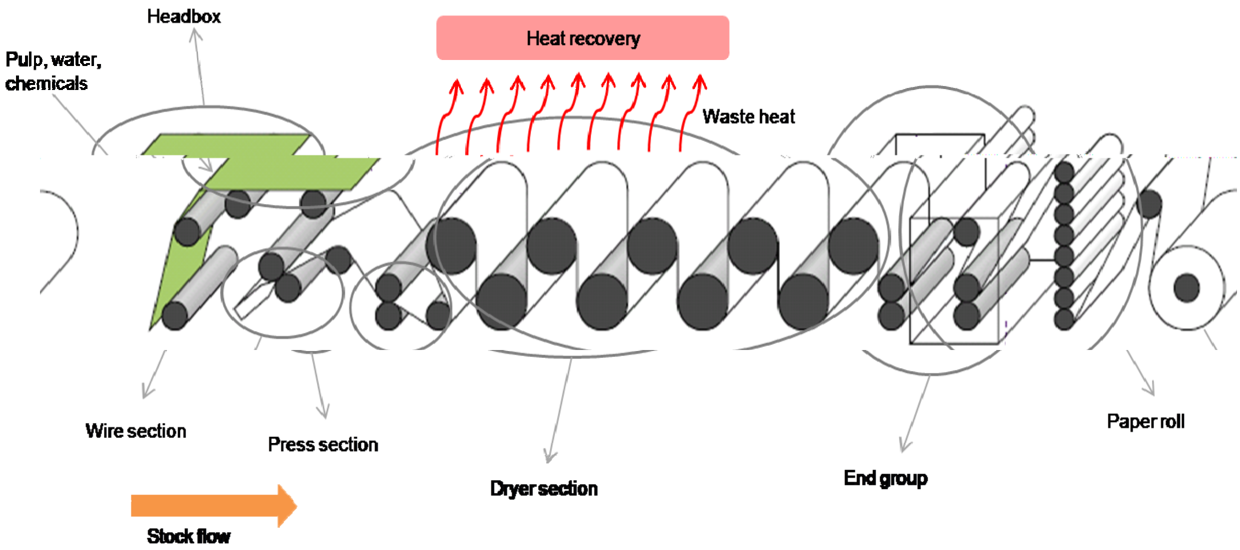


Fig 26: Operation principle of a paper machine [31, 2].

At the “headbox” the suspension of pulp, water and chemicals (fillers, pigments) is distributed across the machine. The water content of the suspension is 99% [2].
In the wire section water is removed from the suspension by different rolls and vacuum boxes to increase the solids content to 20% [3].
Dewatering of the fibre slurry is continued in the press section by compression of the paper web between metal rolls. The content of solids is increased to 50% [3].
Steam heated cylinders are used in the dryer section to evaporate the remaining water of the stock [3]. Chemical bonds are formed between the fibres and the final paper sheet is created [18].
Figure 27 shows the simplified operation principle of the dryer section.

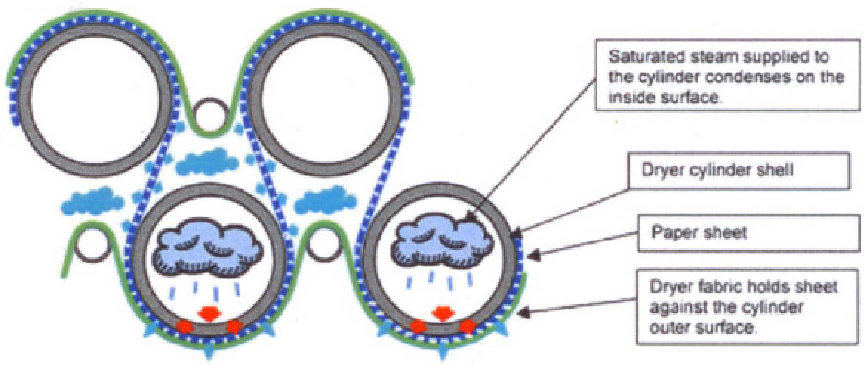


Fig 27: Dryer section principle [20].

For energy efficient operation of paper machines, heat recovery systems are installed above the dryer section. The hot, steam containing, exhaust air from the dryer section is collected and re-used for heating purposes within the paper machine [2].
The “end group” transfers additional pigments or other chemicals to the paper sheet, if neces-

sary. Coating colour is applied and the paper's surface gets glazed [3].The finished paper is wound to large rolls that can be up to 10 m long and can weigh 25 tonnes. [21]

Fig 28: Paper roll [23]

Note: : Paper saving tips

Never forget that you have a responsibility for the environment and the planet that we live on. By using resources and products in an responsible way, everyone can contribute to make the Earth a little more worth living.

- Reduce your paper consumption
  - Only print e-mails and documents if really necessary
  - Print your documents double sided
  - Don't throw away one side printed documents that you don't need any more – use them to make notes
  - Whenever possible use thin paper
- Use products made of recycled paper
- Collect your waste paper and throw it into the proper collection box

Example: Calculation:

A paper mill has a net energy consumption of 2.4 MWh per tonne of produced paper.

a. How much primary energy (fuel energy) input is necessary to run the production process when separate heat and power generation with an overall efficiency of 49% is operated?

$\eta = Q_{use}/Q_{in}$

$Q_{in} = Q_{use}/\eta = 2.4\ \text{MWh}/0.49$

$Q_{in} = 4.9\ \text{MWh}$

b. How much energy (fuel energy) input is necessary when heat and power co-generation with efficiency of 75% is operated?

$\eta = Q_{use}/Q_{in}$

$Q_{in} = Q_{use}/\eta = 2.4\ \text{MWh}/0.75$

$Q_{in} = 3.2\ \text{MWh}$

c. If in case a) and case b) all the energy would be generated by combusting natural gas, how much of it can be saved by cogeneration compared to separate heat and power generation ? The net calorific value of natural gas is approximately 10 kWh/m³.
Difference between cogeneration and separate heat and power generation:
4.9 MWh – 3.2 MWh = 1.7 MWh
1,700 kWh/10 kWh/m³ = 170 m³
170m³ of natural gas can be saved per tonne of paper when cogeneration is operated.

d. Complete the reaction equation for the combustion of natural gas
$CH_4 + O_2 \rightarrow CO_2 + H_2O$
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

e. Assuming that natural gas would only consist of CH_4, how many grams of CO_2 can be saved per tonne of paper when cogeneration is operated? The combustion of 1 m³ of CH_4 emits 1 m³ of CO_2 to the atmosphere. The molar mass of CO_2 is 44 g/mol
1 mol = 22.414 l
1 m³ = 1,000 l/22.414 l/mol = 44.6 mol
44.6 mol/m³ * 44 g/mol = 1,962.4 g/m³
170 m³ * 1,962.4 g/m³ = 333,608 g

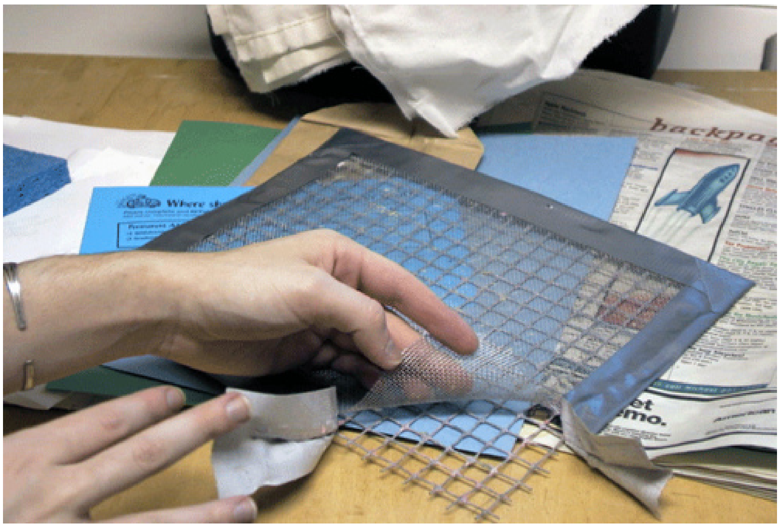
Experiment: Make your own paper!

From the Internet: http://www.flickr.com/photos/bzedan/sets/967347/; 14.12.2008

You need: paper, a blender, a vat (for example a kitty litter box), some old newspapers, a fan, water, a sponge, an old sheet, some adhesive tape, 1 piece of a fly screen (40x30cm), a screen made of wire (40x30cm); aperture size: 2x2cm, a multimeter

Make your "felts": cut the sheet into pieces of 50x40cm.

Make your screen: This is the simplest and cheapest version you can make. Both types of screen can be found at a hardware store.

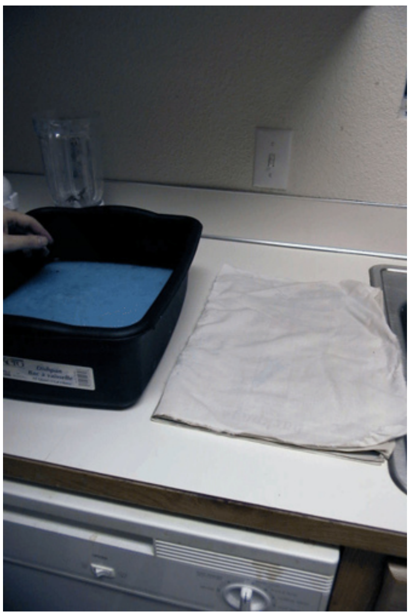


Fill the blender about 2/3 full of water. Let the water temperature be between tepid and bathwater warm.

Start tearing up or cutting your paper. Ideally, your bits of torn paper should be around 2x2 cm square.

Put the paper into the blend and mix it well (at least for three minutes). You can calculate the energy that is necessary for mixing: **Q=P*t.** P can be measured with your multimeter.

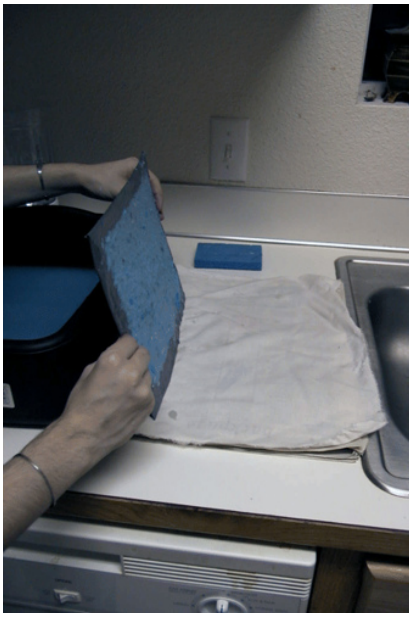
Add your pulp to the vat. Mix three blenders of pulp to one blender of water. This will make a nice soup, not too thick, not too watery.



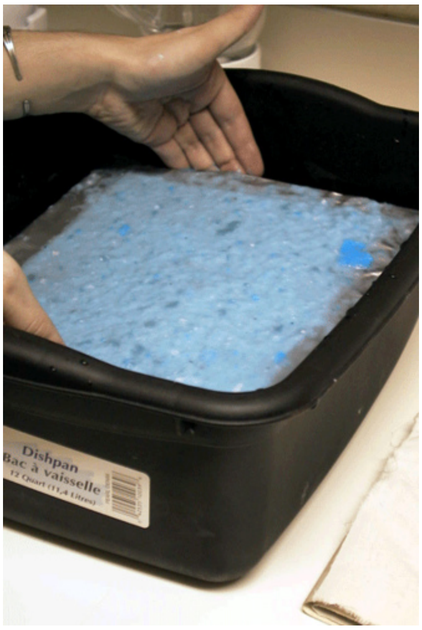
Prepare your space. Next to the vat, lay down some newspaper. Lay a 'felt' above the newspaper. Have the rest of your newspaper and 'felts' nearby.

Mix up your pulp and water by stirring your hand around in it.

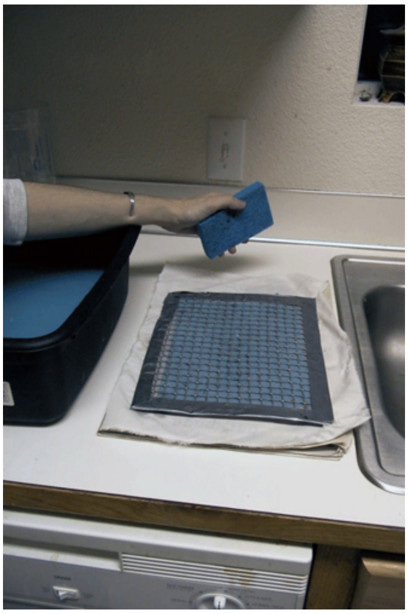
Put your screen into the pulp. Once your screen is in the pulp, shake it back and forth just a little, evening and settling the pulp along the screen. Continue rocking/shaking the screen as you pull it up out of the vat. If you mess up, just flip the screen over and tap it against the water in the vat, the pulp will fall off.

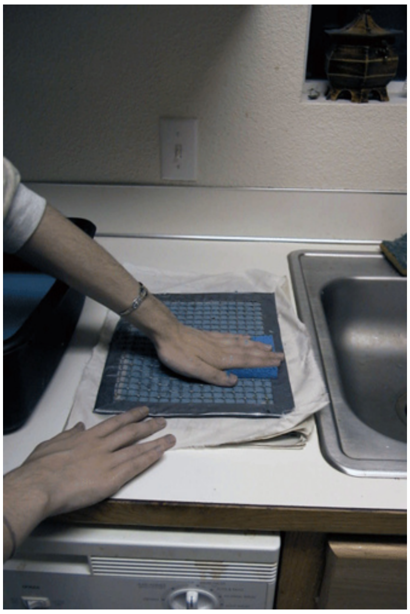


With your sheet formed, tilt your screen to drain the excess water out. When it's only dripping intermittently, you can couch it.

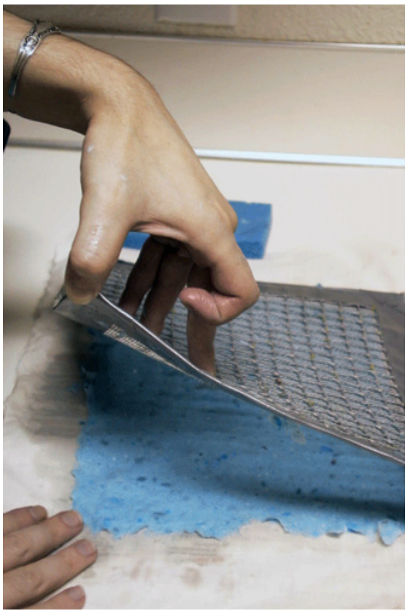


This is "couching". Line up your screen on your 'felts' and flip it over. The water in the screen should hold the paper to your screen enough for you to do this.





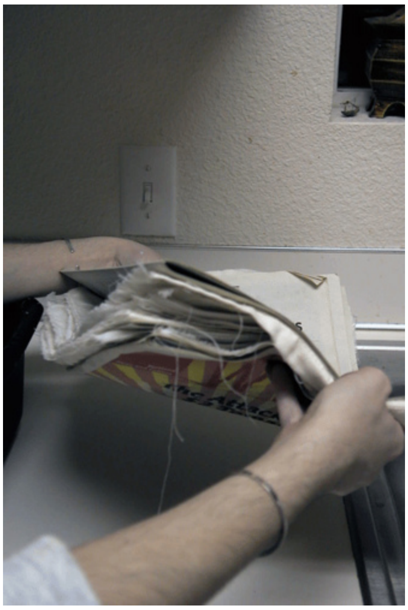
Soak up more water with your sponge through the back of the screen. Move around, paying attention to the edges



Starting from a corner, pull your screen off the paper. If it will not let go, plop it back down and soak up more water with the sponge.

Cover your paper with another 'felt'. Then some more newspaper, above that put one more felt and you are ready to go again.

After three to five sheets, you'll find that your paper is getting thin. Time to add more pulp.



When you're done making sheets, top off your pile with another 'felt' and some more newspaper. The result is called a "post".

Time for the press. On some floor you can clean easy or don't care about, lay down your post and put your board on top

Stand on it, centering yourself on the post. Hang out for a while, a few minutes is enough

Now you can remove your damp paper, and let it dry in a well-ventilated place, or you can keep it on the felt. REMEMBER: always pull from the corners and gently. Hang your 'felts' out to dry, recycle the newspaper. Paper is tough, but be nice to it when you are removing it from the 'felts'.

If you dry your paper with a fan you can calculate the drying energy: **Q=P*t.** P can be measured with your multimeter.

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