# Chapter 6. Conventional energy

The waterfalls at Trollhättan

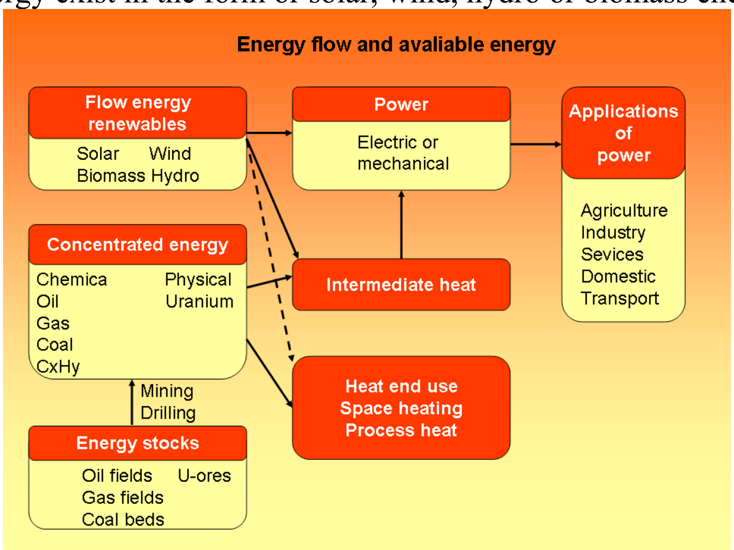
# Chapter 6

## *6.1 Introduction*

In this chapter we will discuss the energy consumption per individual in various countries. The mean power consumption on Earth is around 2 kW per individual. However, there are large differences between highly industrialized countries as the US, where the consumption lays around 12 kW, whereas the corresponding figure is 400 W in India. The power of a man is around 20 W. One realizes that there has to be large technical efforts and energy resources to keep the society and the energy consumption going. Large efforts have also to be done in order to reduce the consumption and to increase the efficiency of different energy systems.

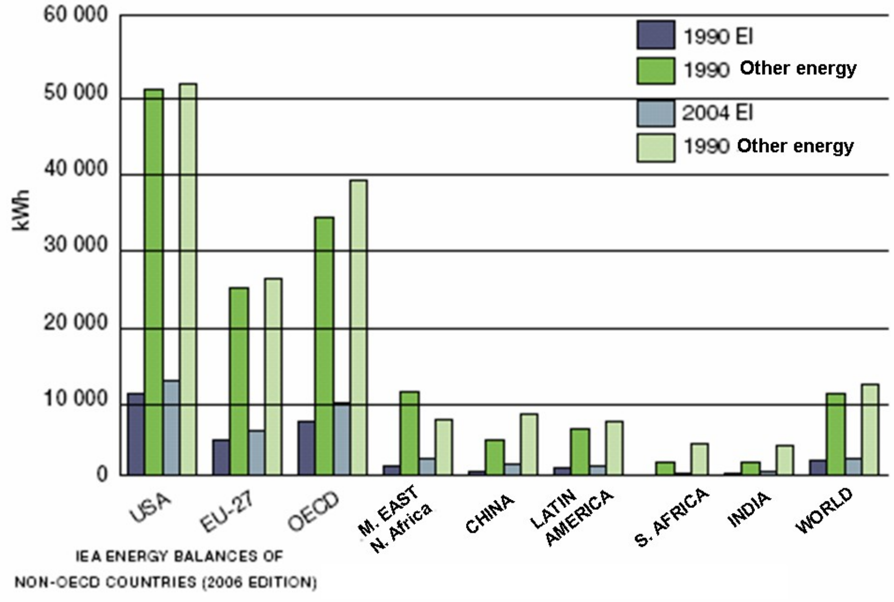
### *6.2 Energy*

In the picture below we see the Classification of energy flow as well as available energy or exergy. There are several both chemical and physical energy that is concentrated as oil, gas, coal, methane as well as uranium that can be converted to heat or electric or mechanical (cars) in both industry, transport or as domestic use. The concentrated energy comes from mining or drilling where the energy stocks can be found as oil or gas fields, coal beds or uranium ores. The renewable energy exist in the form or solar, wind, hydro or biomass energy.

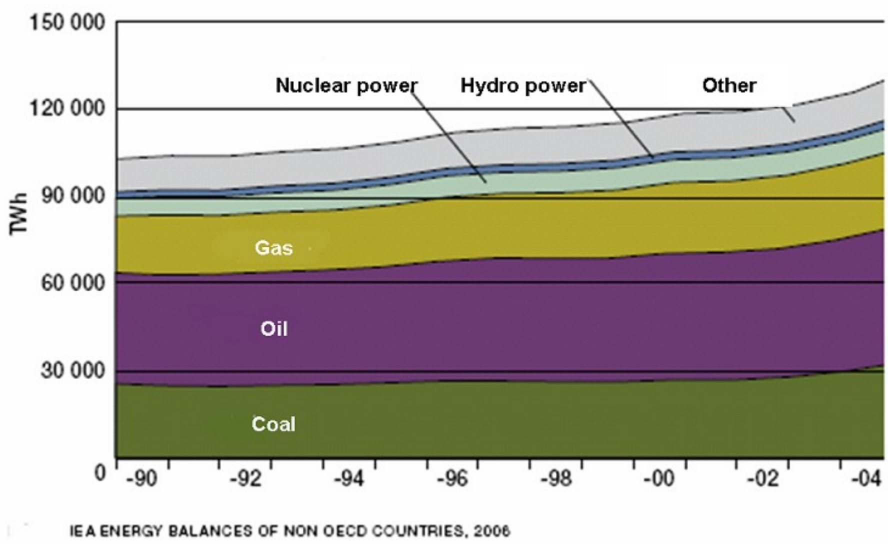


### 6.2.1 Energy consumption Worldwide

We can first start discussing the energy consumption per inhabitant. Often, one uses the energy unit *1 toe (tonnes oil equivalent) = 11.63* MWh = *41.9* MJ. In our part of the World (EU) the consumption reaches almost 4 toe, while in Africa and Asia, the consumption still is low, below 1 toe.

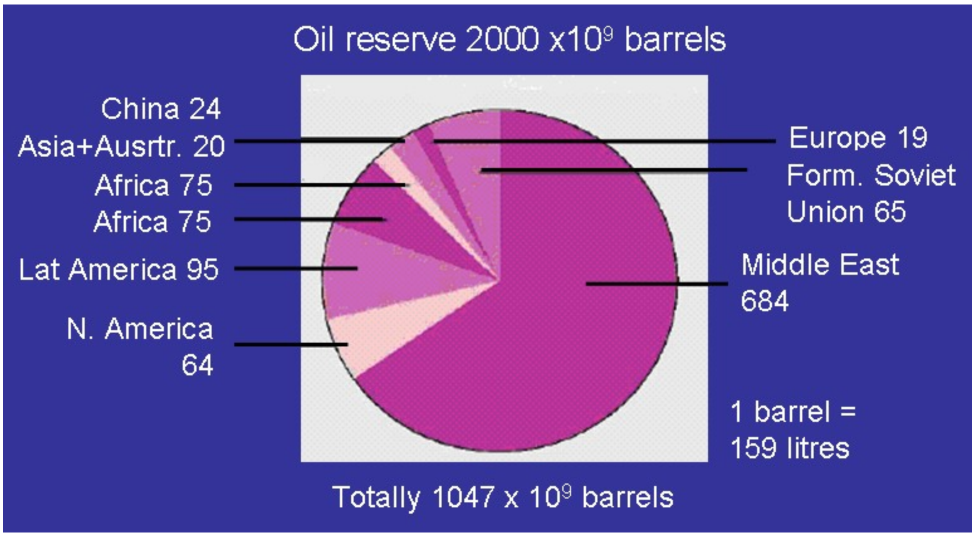



We can continue to look at the commercial energy consumption worldwide and in the figure below we see that the total consumption is increasing. If we look at the year 1966 the consumption was 4000 toe and in 1994 this amount has doubled to 8000 toe. The dominating energy consumption is due to oil, gas and coal. The contribution from waterpower and nuclear power is just around 400 toe, i.e. some 10% of the total energy consumption.




### 6.2.2 Oil consumption

Let us study the world oil consumption and estimates of the oil reserve. Worldwide one gives the amount of oil in barrels, where *1 barrel = 159 litres*. The assets of the Earth are shown in the figure below. The oil is unequally distributed over the Earth. The largest oil assets are of course found in The Middle East as shown in the figure.



From Energimyndigheten (www.energimyndigheten.se )

According to optimistic prognoses, the oil reserve is around $2000 \times 10^9$ barrels of oil that can be used as for now. Already almost 90% of the World's oil is supposed to be detected up to now. However, World consumption of oil today is around $6.3 \times 10^7$ barrels/day.

**Example**

How long will the oil last if the consumption is $6.3 \times 10^7$ barrels/day and the total amount is $2000 \times 10^9$ barrels?

**Solution**

It will last $t = \dfrac{2000 \times 10^9}{6.3 \times 10^7 \times 365}$ years = 87 years

One can also assume that the oil consumption will increase by some percentage annually due to the growing economies all over the World.

**Example**

Suppose the oil consumption will increase by a factor $k$ annually. How long will it then take to reach the oil reserve limit?

**Solution**

Let us use a mathematical series to do the calculation. Let the amount of the first year be $f_0$. Introduce an increase in consuming by a factor $k$ annually, then, after the first year we will have consumed $f_0 + f_0 k$.

The sum of this mathematical series is $\Sigma = f_0 \dfrac{k^n - 1}{k - 1}$ if the consumption takes $n$ years.

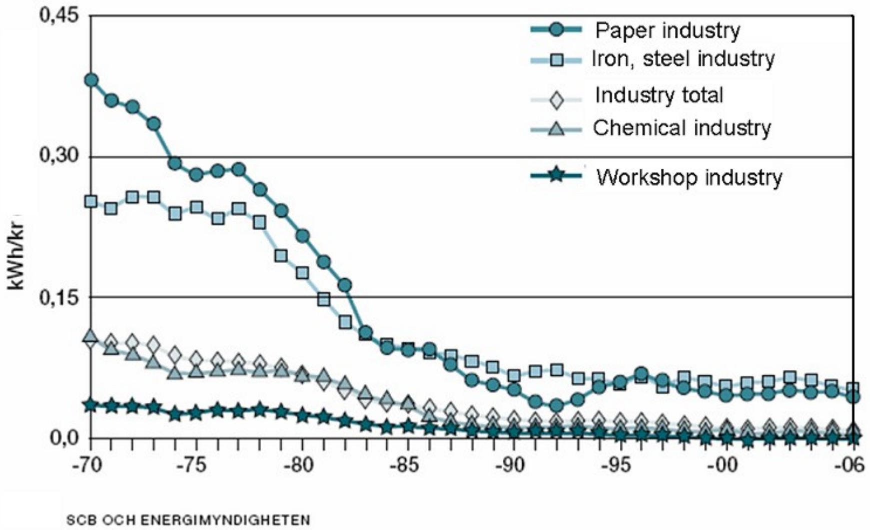
We really don't know the annual increase, but we could check with 5% and see how long time it will take. Equation:

$$2000 \times 10^9 = 6.3 \times 10^7 \frac{1.05^n - 1}{1.05 - 1} \Rightarrow 1.05^n - 1 = \frac{2000 \times 10^9 \times 0.05}{6.3 \times 10^7 \times 365} \Rightarrow 1.05^n = 1 + 4.349$$

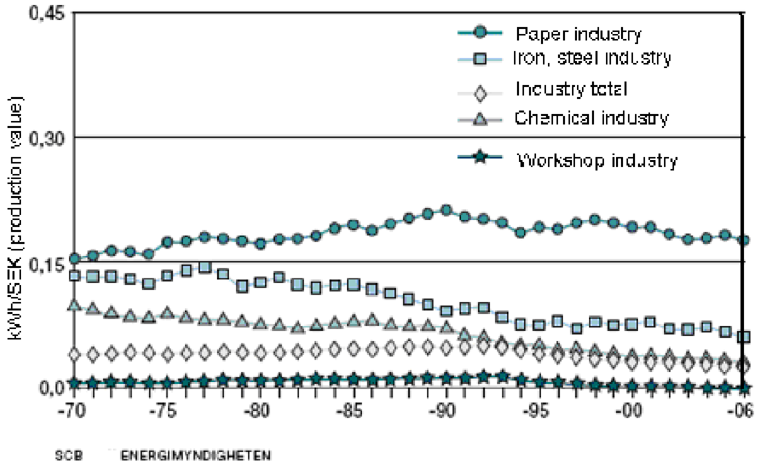
$$\Rightarrow n \log 1.05 = \log 5.349 \Rightarrow n = 35 \text{ years}$$

So, the situation seems to be quite troublesome. One realizes that we have to use other forms of concentrated energy, than just oil for heating, for transport and for cars. Recent messages in the newspapers claimed that the consumption of oil in China had increased by almost 10 %, far above our calculations.

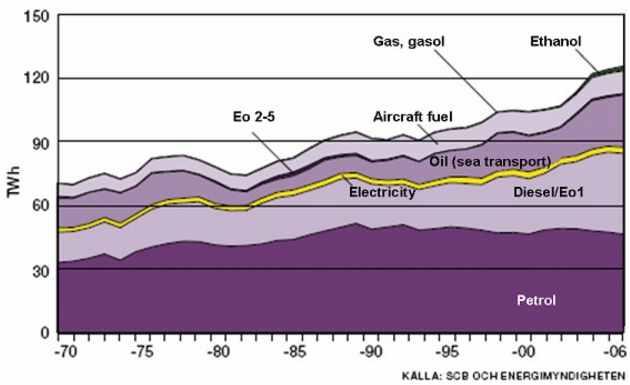
### 6.2.3 Energy consumption in the industry



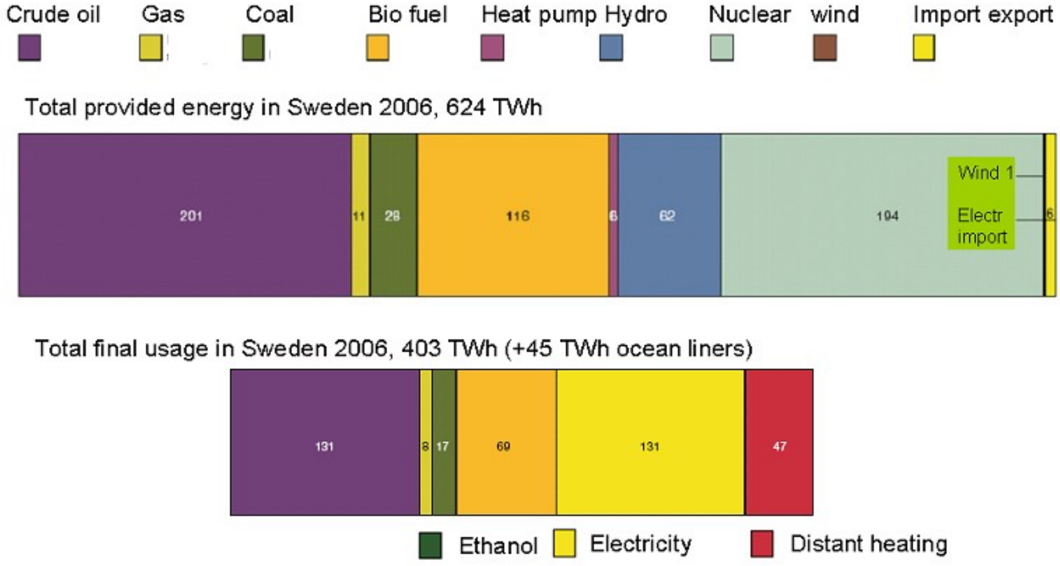

In the above figure, the total consumption of oil in the industry is shown between the years 1970 to 2006, where the prices of oil is set to the year 2000 in the unit kWh/SEK. Although there has been a growth in the industrial production, all fields of the industry show a significant reduction in the use of oil. In the figure below, one sees the electricity consumption of the industry in the prices of the year 2000.



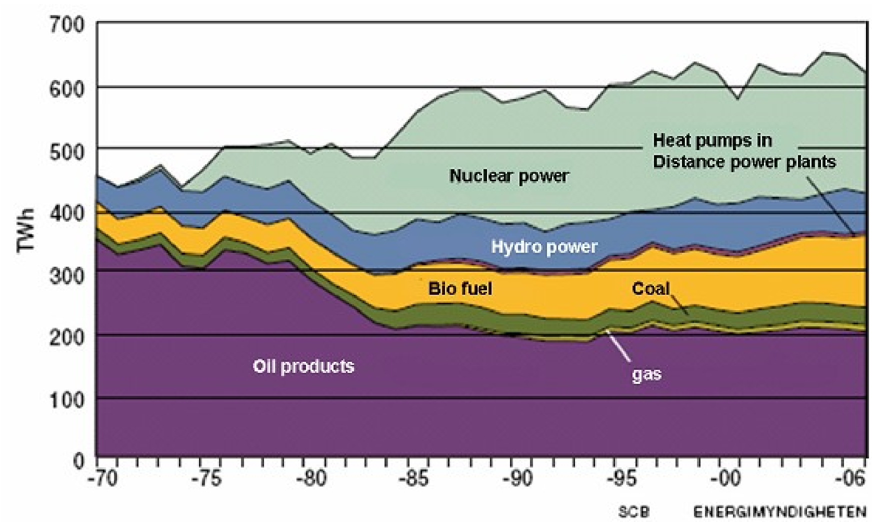

One can also consider these graphs as a measure of the cost efficiency of the industry. Since 1970 the electricity consumption has been reduced by almost 60 %. When studying the industry we can also look at the transport sector and the energy consumption is shown below.



If we now study the total production and usage of energy in Sweden we end up with the following diagrams showing both provided energy and used energy.



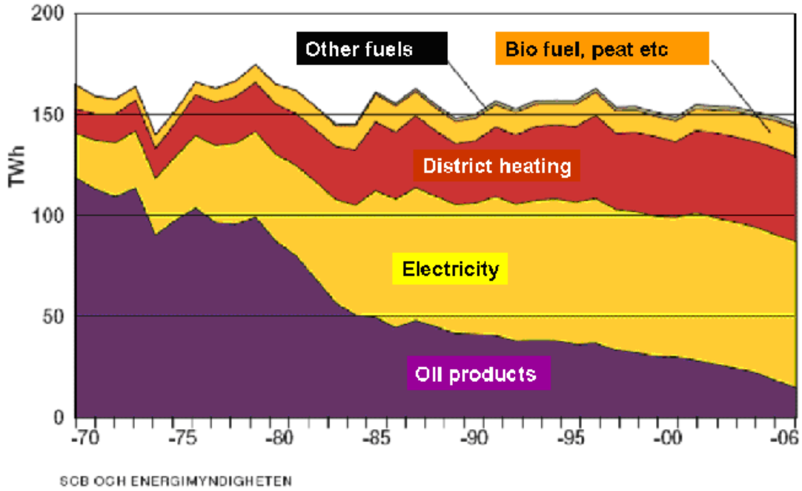

The total provided energy is around 624 TWh, where part of this energy is converted to other energy carriers, such as electricity and distant heating. Some of the energy usages disappear in transports on the seas.
In the picture below we can study the energy supplies of Sweden during 30 years.




The total energy support to Sweden in 2006 was 624 TWh, which includes an import of electricity of 6 TWh. As we have seen earlier, oil and nuclear power were the main parts followed by bio fuel and hydropower. Since 1970 however, the usage of oil and other oil products has decreased by more than 40 %, whereas the electric energy based on hydropower and nuclear power has increased by almost 140 %. Also the supply of bio power has increased and so more than 170 %.

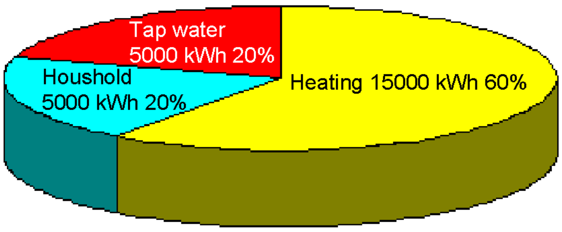
### 6.2.4 Energy consumption for housing

Let us look at the energy usage concerning *housing and services* in Sweden during 1970 to 2006. One sees in the diagram below that there is a significant drop in oil product usage, which already has lead to a remarkable decrease in carbon dioxide emission. Since1990 the usage of electricity, based on hydro and nuclear power is dominating, though district heating has grown to about half the size of the electricity used for heating. Still bio fuel plays a minor role.

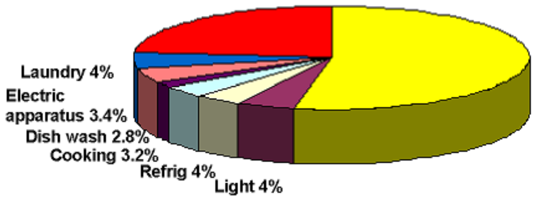



**Energy consumption in a house**

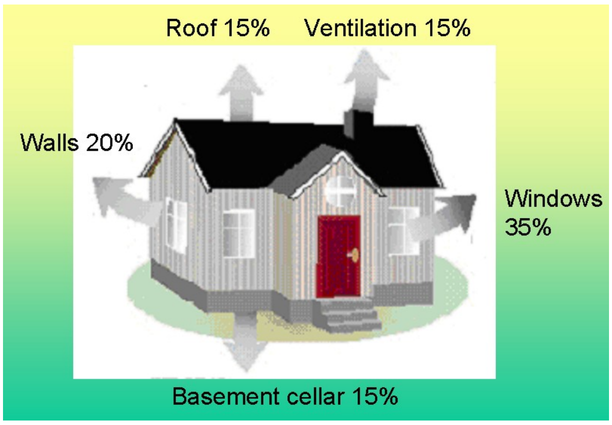
When we look at a small standard house or villa, the total energy consumption annually is around 25000 kWh, and is shown below, where the major part comes from heating the house:



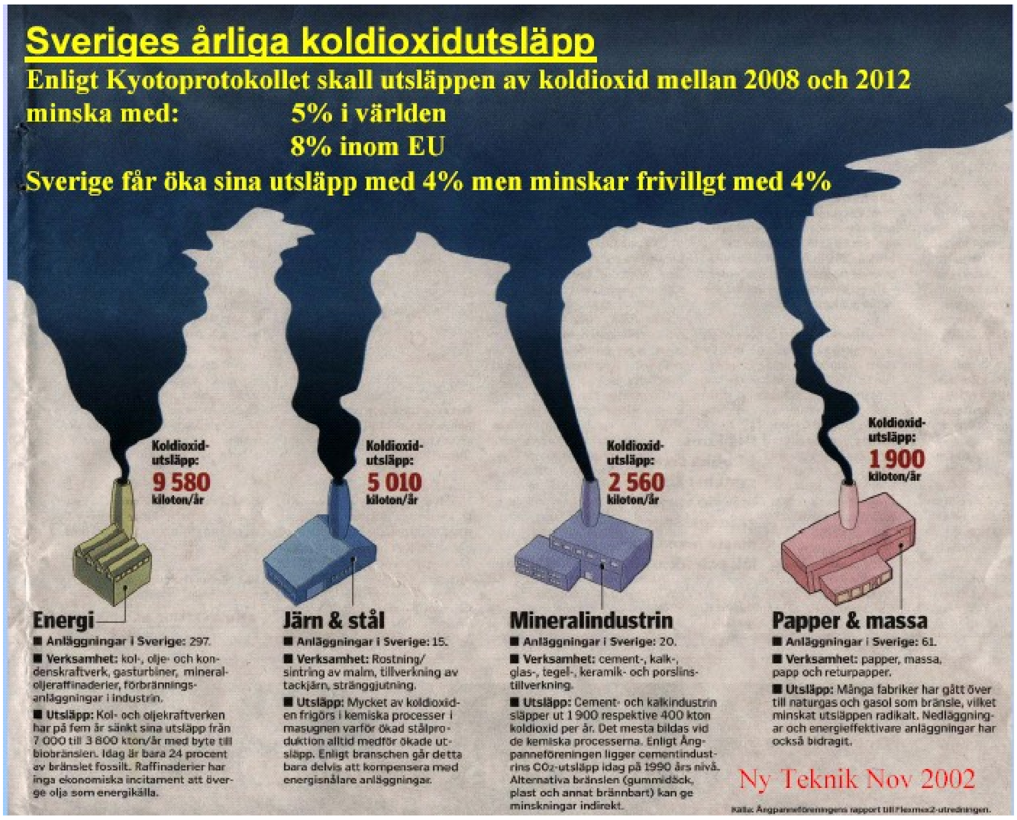

Let us look in detail on the household consumption that is around 5000 kWh altogether. Of the total consumption we have.



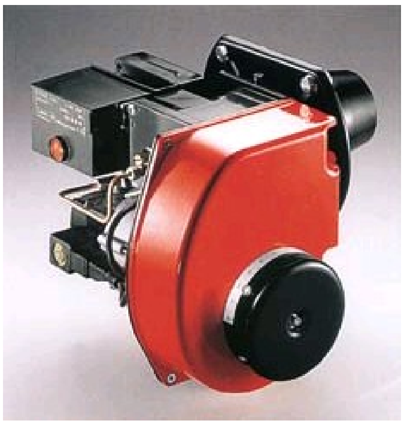

When heating a house, the energy takes its way through the roof (15 %), the walls (20 %), windows (35 %), through ventilation (15 %) and through the basement and cellar (15 %) in the following way.



The picture below (Ny Teknik 2002) shows the carbon dioxide exhaust from different areas, such as Energy plants, Iron and steel industry, metal industry and paper industry. According to the Kyoto protocol, the reduction of carbon dioxide worldwide should be reduced; in the World as a whole at 5 % and within EU at 8 %. Sweden is aloud to increase its exhaust by 4 %, but agrees to decrease it with 4 %.




### 6.2.5 Oil burners for heating houses



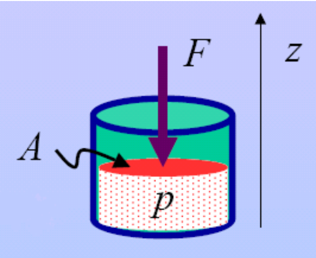
An oil burner consists of an electrical motor connected to a fan, and an oil pump. The fan is blowing air to the burner, and the pump pumps oil from a reservoir to the entrance hole of the burner, where the oil is mixed with air. In order to maintain the fire, a photo detector controls the fire, and if something goes wrong, and the fire faints, it gives a signal to a transformer that gives a distinct spark for ignition of the system. The high voltage is around 15 kV. The oil consists of small droplets around 0.1 mm in diameter. Normally the pressure is around 10 bar before entering the chamber.

The oil is normally preheated to around 70C° making its density lower and also its viscosity. The so-called environmental oils have normally a higher ignition point why it is necessary to preheat them.

### 6.2.6 Heat engines

Basic Thermodynamics can be found in Chapter 10. Below are found the formulas needed to do calculations on Heat engines, refrigerators etc.

Mechanical work can be described by: "*Work = force x distance*" or with




$$dW = -F \cdot dz = -\frac{F}{A} \cdot A \cdot dz = -p \cdot A \cdot dz = -p \cdot dV$$

Here $dW$ stands for the work, $dz$ is the distance, $F$ is the force, $A$ is the area and $p$ the pressure.

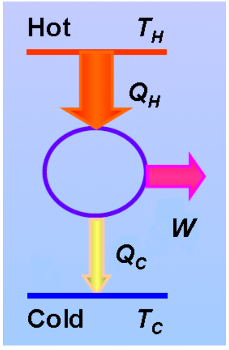
**Heat** is described by $Q = cm(T_2 - T_1) = cm\Delta T$

Here we have a system (gas, liquid etc) where the temperature changes from $T_1$ to $T_2$ or by $\Delta T$.

If we have a system (gas, liquid etc) it can have a so-called internal energy $U$. It can be the energy of the vibrating or rotating molecules of the gas.
In words the law can be written: ***Change in internal energy = Heat supplied to the system + Work done on the system*.**
The energy conservation law can in thermodynamics be written as:

$$dU = dQ + dW$$

This is the so-called *First law of thermodynamics*.



This figure describes how a heat engine works. The heat flows from the hot reservoir towards the cold reservoir thus performing work we can use: $W = \Delta Q = Q_H - Q_C$

The heat $Q_H$ flows from the hot reservoir with temperature $T_H$, and goes into an apparatus that converts heat to mechanical work W. The apparatus produces a heat loss equal to $Q_H$ at a temperature of $T_C$. The mechanical work $W$ comes out of the apparatus.

The *thermal efficiency* is denoted by $\eta$ and we define $\eta = \frac{useful \quad output}{required \quad input}$ and with the formulas:

$$\eta = \frac{W}{Q_H} \leq \left(1 - \frac{T_C}{T_H}\right)$$

The so-called *Carnot efficiency* $\eta_{Carnot} = 1 - \frac{T_C}{T_H}$ is the maximum efficiency we can obtain. The factor $\frac{T_C}{T_H}$ is called the *thermodynamic loss*.

**Example**

Suppose we have a large iceberg with volume 1 km x 1 km x 100 m and temperature 0 $^oC$ ($T_1$). Put the density to 1 kg/dm$^3$). It is moving from the North southwards in the Atlantic, where the temperature is 20 $^oC$ ($T_2$). Regard the Atlantic as a hot source and the iceberg as a cold sink. Estimate how much work the melting of the iceberg would generate. Compare how long time a power plant of 1000 MW has to work to generate the same energy.

**Solution**

From tables we know that when one melts a kilogram of ice the heat is around 335 kJ. The melting iceberg thus absorbs ($10^3$ x $10^3$ x 100) m$^3$ x $10^3$ kg/m$^3$ x 335 kJ = 3.35 x $10^{16}$ J. With the heat engine rule, the maximum work we can get is

$$W = Q_2 \frac{T_1 - T_2}{T_2} = 3.35 \times 10^{16} \frac{293 - 273}{293} = 3.35 \times 10^{16} \times 0.068J \approx 2.3 \times 10^{15} \text{ J}$$

$$t = \frac{W}{P} = \frac{2.3 \times 10^{15}}{1000 \times 10^6 \times 3600x24} days = 27 \; days \approx 30 \; days$$

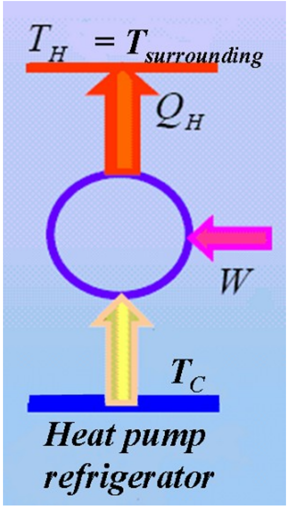
So it is around a month's work for such a large power plant.

**Coefficient of Performance, *COP***

In the expression $\frac{W}{Q_H} \leq \left(1 - \frac{T_C}{T_H}\right)$ we define the coefficient of performance; *COP*, as

$COP = \frac{W}{Q_H}$ for instance when we discuss refrigerators.

**Refrigerator. Heat pump**




The above picture describes both the heat pump and the refrigerator. The 4:th year KTH students, Baltzar von Platen and Carl Munters invented the absorption refrigerator in 1922. It became a worldwide success and was commercialized by Electrolux in Stockholm.

Heat is taken from a low temperature reservoir, work is put in and heat is added to the high temperature reservoir. The performance of a refrigerator is given by:

$$COP \le 1/\left(\frac{T_H}{T_C} - 1\right)$$

**Example**
Let us look at a normal refrigerator in the household, where $T_H$ = 273+25 K and $T_C$ = 273-4 K. What is the *COP* number?
**Solution**

$$COP \le 1/\left(\frac{T_H}{T_C} - 1\right) = 1/\left(\frac{298}{269} - 1\right) = 9.3$$

So, we have $COP \le 10$

**Example**
We have a refrigerator operation between the reservoirs at 0 °C and 100 °C. Let 1.0 kJ of heat be absorbed from the cold reservoir. How many joules will be rejected from the hot reservoir?
**Solution**
We use the expression $\frac{W}{Q_H} \le \left(1 - \frac{T_C}{T_H}\right)$ and solve the equation for $W$:

$$W = 1.0 \times 10^3 \left(1 - \frac{273}{373}\right) \text{J} = 268 \text{ J} \approx 270 \text{ J}$$

**Example**
Determine the coefficient of performance, *COP*, for the refrigerator above.
**Solution**

The definition for the coefficient of performance is $COP = \frac{W}{Q_H} = \frac{1.0 \times 10^3}{268} \approx 3.7$

**Heat pump**

The picture above can be used for both a refrigerator and a heat pump. The idea is to get heat inside a house and to put the cold reservoir outside the house. Some heat pumps work with the reservoir as the air around us, while others use ground source heat, which has about the same temperature the whole year. The *COP* can be found around 3.5-4.0 in such apparatus. The *COP* definition for at heat pump in steady-state operation is given by:

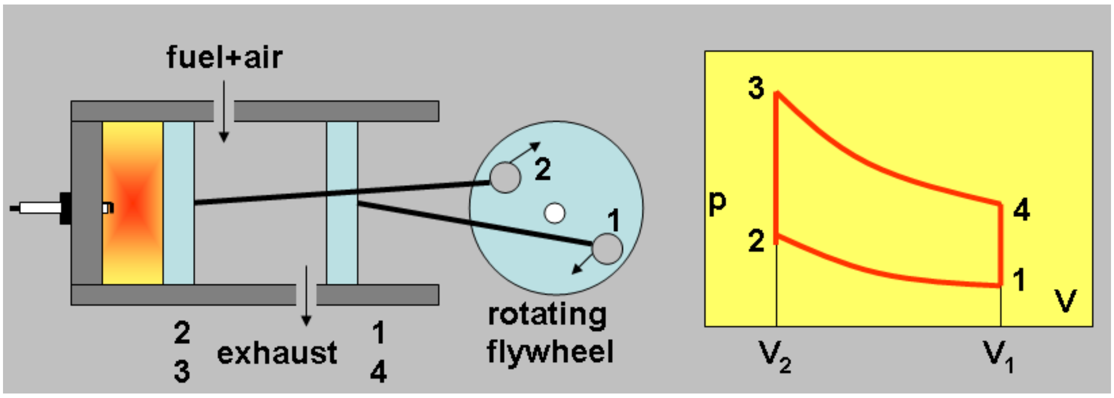
$$COP = \frac{Q_C}{W} \leq \frac{T_H}{T_H - T_C} = \frac{1}{\eta}$$

Here $W$ stands for the compressor's dissipated work, and $\eta$ for the efficiency of the so-called Carnot cycle.

**6.2.7 Combustion.**

**The Otto motor (ordinary car engine)**

A combustion engine such as the Otto motor needs fuel (petrol, gasoline, diesel, ethanol) to be mixed with air inside the engine. If we compare with heat engines there is no external heat reservoir included. Below is show how the Otto engine works schematically.




The piston moves inward from position 1 and the fuel/air mixture enters the chamber. When the piston passes the entrance of the fuel/air input, the gas mixture is compressed. One sees on the left figure how the pressure increases. At the end position 2/3 the ignition takes place via the spark plug, the temperature rises and the gas expands from volume $V_2$ to $V_1$. The gas delivers power to the piston that moves to the other end position, and the cycle starts all over again. The efficiency of the Otto motor is rather low and can be expressed by the following equation:

$$\eta = \frac{W}{Q_H} = 1 - \frac{1}{r^{\gamma - 1}}$$

The constant $r$ is just the ratio of the two volumes $V_1$ and $V_2$:

$$r = \frac{V_1}{V_2}$$

It is also denoted *compression ratio* and in many engines it is around 8:1. In the formula one also sees the constant $\gamma$, which just is

$\gamma = \frac{c_P}{c_V}$ =1.4 for air that can be found in Chemical tables. Thus we have the following formula for the Otto motor:

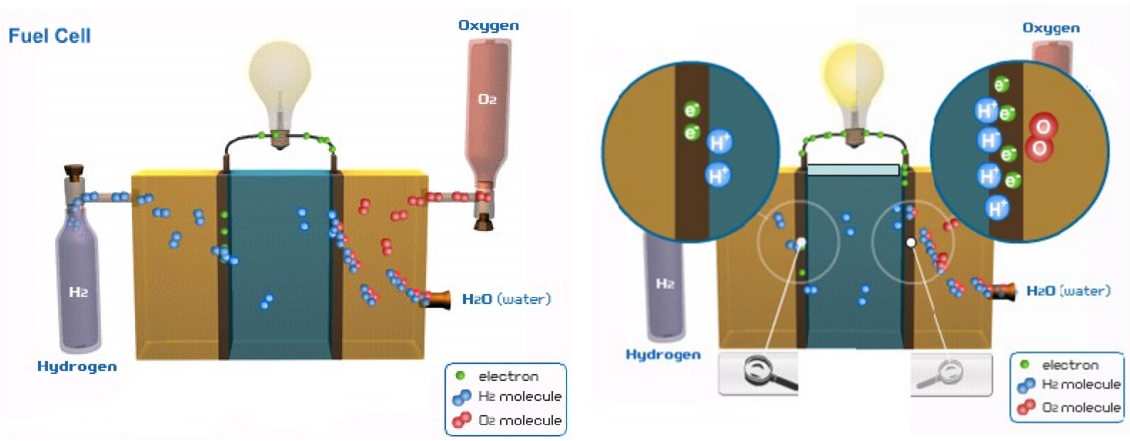
$$\eta = \frac{W}{Q_H} = 1 - \frac{1}{r^{0.4}}$$

Maximum ratios in the Otto motor is around 10, while in the diesel engine one can reach values up to 25, due to so called self ignition, making the diesel engine much more efficient than the Otto motor.
For an Otto motor the real efficiency is around 30% due to friction losses and that the equations above just holds for ideal gases.

**Example**
Calculate the maximum efficiency for an Otto motor with compression ratio 8:1.
**Solution**

$$\eta = \frac{W}{Q_H} = 1 - \frac{1}{r^{0.4}} = 1 - \left(\frac{1}{8}\right)^{0.4} \approx 56\%$$

**6.2.8 Fuel cells**




The fuel cell is an electrochemical apparatus that produces electricity. It can be constructed in several ways with different kinds of fuel where an external fuel goes into the anode side and is consumed, whereas the oxidant is found on the cathode side. The reactants flow into the system and the reaction products flow out. However, the electrolyte still remains within the cell. The cells can function as long as the flows are maintained.
The electrodes of the fuel cell are stable since they are catalytic. There are many combinations of fuel and oxidant possible. In the figure above, a hydrogen cell uses gaseous hydrogen as fuel and gaseous oxygen as the oxidant. There are still other types of fuels including hydrocarbons and alcohols. There are still other that use oxidants including air, $ClO_2$ and chlorine.

Toyota fuel cell car

### 6.2.9 Energy transport

Energy transport, or artificial energy transport varies quite a lot different depending on what kind of form the energy is found in. If we look at fossil fuel, such as oil, one can use pipelines, ocean liners, cars, while ship and trains mainly transport coal. Pipelines most often transport gas. In the case of nuclear fuel, ship and trains are used, since we have small volumes and high security is needed. Conductors of course transport electric energy. Distant heating is transported via pipelines.
All kinds of energy transports face losses. Let us look at the losses of electric transmission and distant heating.

**Energy storage**

It is not just the efficiency of a system that matters, but only how effective the different forms can be transferred, such as how to covert chemical energy to electric energy etc. Below is shown a table where the energy density [kJ/kg] is given for different fuels and storage media.

| | |
|---|---|
| Deuterium (D-D fusion) | $3.3 \times 10^{11}$ |
| Uranium-235 (fission) | $7.0 \times 10^{10}$ |
| Hydrogen LHV | $1.2 \times 10^{5}$ |
| Methane | $6.0 \times 10^{4}$ |
| Gasoline | $4.4 \times 10^{4}$ |
| Waterfall fall 100m | $9.8 \times 10^{2}$ |
| Silver oxide-zinc battery | 435 |
| Lead acid battery | 120 |

**Electric energy transmission**

Large powers of electric energy, around 70 TWh annually, are transmitted long distances in Sweden, from the Northern waterfalls down to the South of Sweden. However, this leads to great losses that can be reduced in various ways. Generally one can describe the losses of a conductor with resistance *R* by the equation:

$$P_{losses} = RI^2$$

Here *P* stands for the power (W), *I* for the current (A) and *R* for the resistance (Ω). The transmitted power $P_{trans}$ can be calculated when the incoming voltage is *U* (V) with:

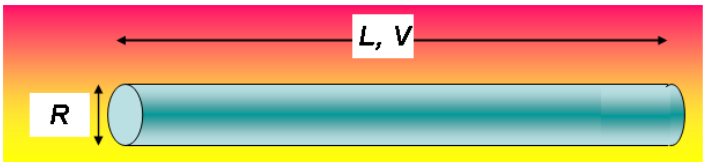
$$P_{trans} = UI - P_{losses} = UI - RI^2 = (U - RI)I$$

We can calculate the coefficient of losses $\frac{P_{losses}}{P_{trans}}$

$$\frac{P_{losses}}{P_{trans}} = \frac{RI^2}{(U - RI)I} \approx P_{trans}\frac{R}{U^2}$$

From this equation we observe that in order to reduce the losses we can either reduce the resistance *R* or increase the voltage *U*, or both. However, at higher voltages the risk of electric discharges increase why the cost will go up in order to avoid this. A lowered resistance *R* will also increase the costs since the cables have to be thicker. One can use high voltage direct current to obtain lower losses.

**Distant heating**




Suppose we have a tube with length *L* and volume *V* and that the flow through the tube is $\Phi = \frac{dV}{dt}$, i.e. $m^3$ per second.

Let us introduce a pressure gradient *G* in the direction of the tube. The gas or liquid in the tube has some kind of viscosity (or friction) that we denote $\mu$ and depends on the medium. We study the Newton's equations regarding forces and end up with an expression for the velocity of the gas in the tube that is shown to vary with the tube radius:

$$u(r) = \frac{G}{4\mu}\left(R^2 - r^2\right)$$

This is the so-called Poiseuilles law.

If we now try to derive the flow $\Phi = \frac{dV}{dt}$ through the tube we have different velocities depending on the radius *r* and get:

$$\Phi = \frac{dV}{dt} = \int_0^R u(r)2\pi r dr$$

Here *u(r)* is the velocity of the gas in the tube depending on the radius *r* and the circumference is $2\pi r$. If we use the Poiseuille's law we get the flow through the tube:

$$\Phi = \frac{dV}{dt} = \frac{G\pi R^4}{8\mu}$$

We observe that the flow depends on the radius of the tube as $R^4$ and is inverse proportional to the friction (viscosity) $\mu$.

**Example**

If we have a gas passing through a tube with radius *R*. How much will the flow through the tube increase if we increase the tube radius by 20 %?

**Solution**

Since the flow is given by $\Phi = \frac{dV}{dt} = \frac{G\pi R^4}{8\mu}$ we see that it depends on $R^4$, and if we have a new radius with radius *1.2R* we will have a flow that is $1.2^4$ times larger $\approx$ 2.01 times larger.

One can also show that *the transport power per meter* tube is $\frac{dP}{dx} = G\frac{dV}{dt} = \Phi\, G$.
The total transport power *P(L)* of a tube with length *L* will become:

$$P(L) = \frac{8\mu L\left(\frac{dV}{dt}\right)^2}{\pi R^4} = \frac{8\mu L\Phi^2}{\pi R^4}$$

We see that if we increase the flow Φ the power losses will decrease by $\Phi^2$, but still more important is to increase the tube radius since the losses are inversed proportional to $R^4$. There is still a possibility to decrease the losses, and that is to lower the viscosity by for instance heating the medium, since the losses are directly proportional to μ. This is what one does with crude oil.