CHAPTER 1

ENERGY CONVERSION

Let's start with the first question. What is energy?

I notice that when I ask this question to students, they usually have trouble giving an exact definition.

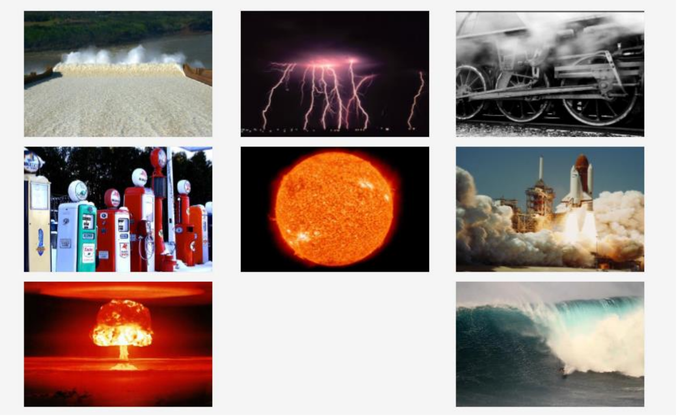
And I must say it is not easy.

The scientific definition for energy would be something like: the capacity of a system to perform work.

- We humans use energy to do some work.
- We use energy for heating air and water.
- We use energy for transportation of people and products by cars, trains, trucks and planes.
- We use energy to produce food and products.
- We use energy to illuminate houses and streets.
- We use energy to watch TV, do our laundry, working on computers and surfing the internet.

At the moment you are consuming energy by reading this lecture.

Energy appears in many forms in our daily life, like gravitational energy, kinetic or mechanical energy, electrical energy, heat radiation, wave energy, chemical energy and nuclear energy.



1.1 Basic concepts:

- ✓ The total amount of energy is always conserved. The form of energy may change in time, but the total amount does not change. This means that if we want energy to work for us, we usually convert it from one form to another form. An example is the electric motor; this is a tool in which we convert electrical energy into mechanical energy.
- ✓ The unit of energy is joule (J).
- ✓ Power is the energy per time and is expressed in watts (W).
- ✓ 1 watt is 1 joule per second.
- ✓ In this project, we will use a more practical unit, which is generally used to express the electrical energy, kilowatt-hours (kWh).

- ✓ 1 kWh equals the energy of a power of 1 kW being used for 1 hour.

- ✓ 1 kWh equals 3.6 million joules.

1.2 Energy problem:

The world as we know today is based on the capability of humans to convert energy from one form to another form. The most prosperous and technologically developed nations are also the ones which have access to and are using the most energy per capita. Therefore, many people believe that the biggest challenge for human kind in this century is tackling the energy problem.

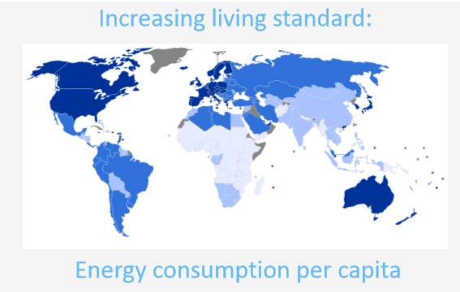
Why do we have a problem?

The first challenge the human kind is facing is a supply-demand problem.

The demand is constantly growing. The world population is still rapidly growing, and some studies predict a world population of 9 billion around 2040 in reference to the 7 billion people living on this planet today. All these people will need energy, which increases the global energy demand. In addition, the energy consumption per capita is linked to the living standard of a country.

In 2010, in the United States (US) around 230 kWh of energy per capita per day was used, whereas countries in Africa, like Nigeria, only used one tenth of this energy, around 23 kWh per day per capita.

In this graph you see the living standard expressed in human development index.



The darker the color, the more developed the regions are. However, the light colors in this figure are getting darker by the year.

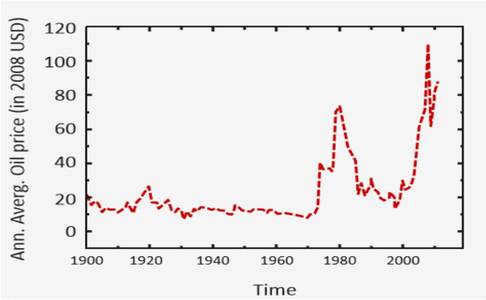
In many countries the living standard is rapidly increasing like China and India, where approximately 2.5 billion people are living. These people represent more than a third of the world's population. Both increasing world population and increasing living standards will increase the energy demand.

The International Energy Outlook 2013 predicts that the energy consumption will increase by 56% by 2040 in reference to 2010.

The increasing demand in energy has economic impact, as well.

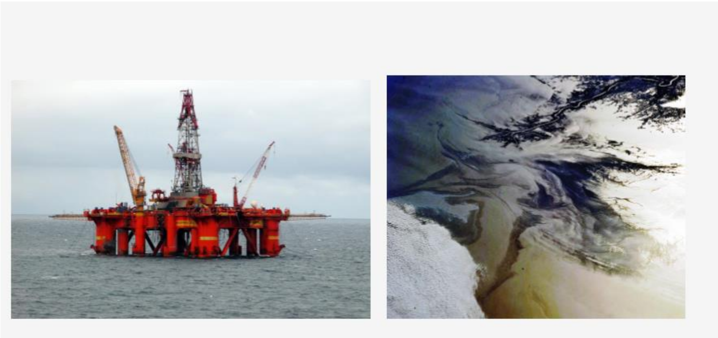
If there is more demand for a product, while supply does not change much, the product will get more expensive.

As an example we show a plot of the annual averaged price for an oil barrel, normalized to the value of the 2008 US dollar. First, you can see that prices went up during the oil crisis in the 70s. In this decade some countries stopped producing and trading oil for a while. The second era of higher oil prices started at the beginning of this millennium. Due to the increasing demand from new growing economies, the oil prices have been significantly increased.



the annual averaged price for an oil barrel, normalized to the value of the 2008 US dollar.

A second challenge that human kind is facing is related to the fact that our energy infrastructure heavily depends on fossil fuels like oil, coal and gas.

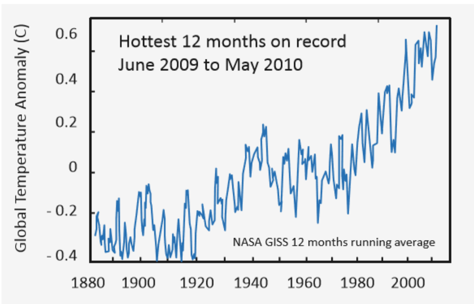


Fossil fuels are nothing but millions and millions of years of solar energy stored in the form of chemical energy. The problem is that humans deplete these fossil fuels faster than they are generated through the photosynthetic process in nature. Therefore, fossil fuels are not a sustainable energy source. In the coming century we will see that we are running out of the oil and gas reserves if we continue our current rates of consumption. Another barrier is that it is technological more challenging to get the fossil fuels out of the reserves currently left. Governments and companies are willing to take higher risks, like we have seen in the Gulf of Mexico spill in 2010.

A third challenge is that by burning fossil fuels we produce the so-called greenhouse gases (GHG) like carbon dioxide. The additional carbon dioxide created by human activities is stored in our oceans and atmosphere.

Most scientists think the increase in carbon dioxide is responsible for the global warming and climate change, which can have drastic consequences of the habitats of many people.

Therefore, human kind is looking for alternative energy sources, like solar and wind.

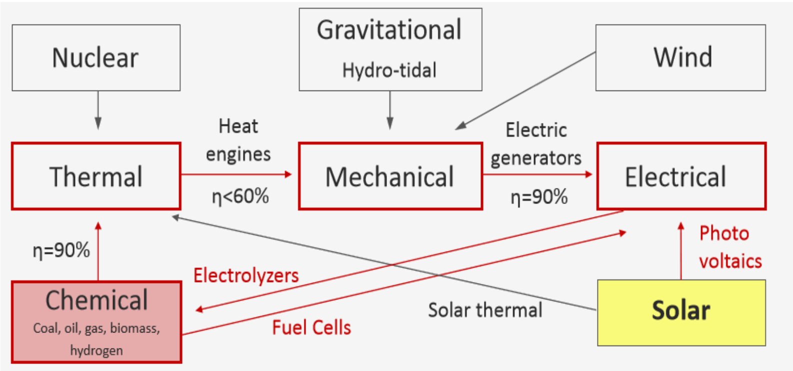


Here you see the increase in carbon dioxide concentration in the Earth's atmosphere up to 2000.

1.3 Energy conversion:

As I mentioned earlier, energy appears in nature in several forms.

We humans make energy work for us by converting it from one form to another form. Let's consider fossil fuels. How are fossil fuels converted into other forms of energy? I will illustrate that in the following simple diagram.



- ✓ By burning fossil fuels roughly 90% of the chemical energy is converted into heat.
- ✓ Using heat engines, thermal energy can be converted into mechanical energy.
- ✓ Heat engines have a conversion efficiency of up to 60%. The far majority of the current cars and trucks are based on this principle. Mechanical energy can be converted into electricity, using electric generators with an efficiency of 90%.
- ✓ This shows that in all process steps of making electricity out of fossil fuels, at least 50% of the initial available chemical energy is lost in the various conversion steps.
- ✓ Chemical energy can be directly converted into electricity using a fuel cell.
- ✓ The most common fuel used in fuel cell technology is hydrogen.
- ✓ Typical conversion efficiencies of fuel cells are 60%.
- ✓ A regenerative fuel cell operates in the reverse mode and converts electrical energy into chemical energy.
- ✓ Such an operation is called electrolysis, and the device operated in such a mode is called electrolyzer.
- ✓ Typical conversion efficiencies of hydrogen electrolyzers of 50-80% have been reported.
- ✓ Another route of making electricity is based on an alternative 'fuel' , nuclear energy.
- ✓ Nuclear energy is the energy generated in nuclear fission reactions and generates heat as well.
- ✓ This can be converted in electricity using the just introduced heat engines and electric generators.

Next, we will look at alternative energy conversions, which are not based on fuels.

Hydroelectricity is one example. This potential energy of rain water falling in mountainous areas or elevated plateaus is converted into mechanical energy using dams. Using so-called tidal pools, the potential energy stored in the tides can also be converted to mechanical energy and subsequently electricity.

The kinetic energy of wind can be converted into mechanical energy using wind mills.

Finally, solar energy can be converted into electricity as well. If solar light is directly converted into electricity using devices based on semiconductor materials, we call it photovoltaics. Photo means light and voltaic means electricity. Typical efficiencies of most commercial modules are in the range of 15 to 20%.

Solar light can also be converted into heat. This is what we call solar thermal energy.

Examples are: heating of water flowing through a black absorber material that is heated in the sunlight. This heat can be converted into electricity again using heat engines. As the conversion efficiency of heat engines strongly depends on temperature, concentrated solar power systems are used to generate electricity through solar heating using so-called high temperature collectors.

Next to generating heat and electricity, solar energy can be converted into chemical energy as well. This is what we refer to as solar fuels. This is possible by using photovoltaics and regenerative fuel cells, but solar light can also be directly converted to fuels using photo-electrochemical devices.

This means we can convert solar energy into electricity, heat and chemical energy.

1.4 Renewable energy sources

Renewable energy sources are energy sources that are replenished by natural processes at a rate comparable or faster than its rate of consumption by humans.

Consequently, hydro-, wind- and solar energy are renewable energy sources.

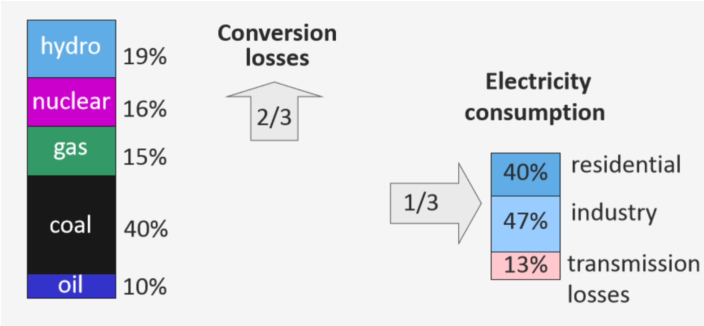
Fossil fuels and nuclear energy are not renewables, as their fuels are consumed faster than they are generated in nature. From all the energy sources based on chemical, thermal, nuclear, hydro, wind, solar, and geothermal, roughly a third is being used to generate electricity.

Electricity is a form of energy that can be easily and cheaply transported with relatively small losses through an electric grid. We might not realize it anymore, but electricity has made today's modern society possible. It is a symbol of modern life and progress. Electricity has been practically used for more than 100 years now.

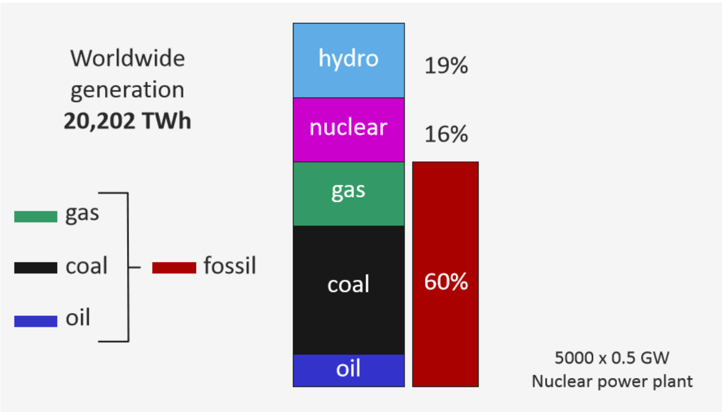
Electricity provides us the energy to cook food, to wash, to do the laundry, illuminate the houses and streets, watch TV, aircondition and heat, work on computer and surf on the internet. The access to electricity determines the living standard of humans.

We must realize that around 1.2 billion out of the 7 billion people worldwide still do not have access to the electricity grid. The electricity worldwide is mainly generated from oil, coal, gas, nuclear and hydropower.

Here, we see the relative contribution of these sources to the global electricity generation in 2007.



65% of the electricity is coming from fossil fuels, where coal is the dominant contributor. Unfortunately, coal produces roughly two times more carbon dioxide per generated unit of energy in reference to gas. Nuclear is responsible for 16% of the world's electricity generation and hydropower is with 19% by far the largest contributor among the renewable energy sources. In the conversion from chemical and nuclear energy to electricity,
two thirds of the energy is lost.
One third ends up in the form of electricity. 40% of the electric energy is used for residential purposes and 47% is used by industry. 13% is lost in transmission.
As you can see, in 2007, transport did not play a significant role in the electricity consumption. However, it is expected that transport related electricity consumption will increase in the coming decades, as well.
In 2007, 20200 TWh of electricity was generated world-wide.



If we consider a 0.5 GW nuclear power plant, it means we need around 5000 nuclear plants around the world if our electricity needs would be fully covered by nuclear power. Realize that sources for electricity generation might differ from country-to-country. For example, In the Netherlands, electricity generation heavily depends on the local gas resources, whereas in Brazil hydro-electricity is the most important resource. In the last hundred years the human kinds energy infrastructure heavily relied on fossil fuels. We are quickly using the solar energy of millions and millions of years, converted into chemical energy by the photosynthetic process and stored in the form of gas, coal and oil.
How did we do that before the industrial revolution? The main source of energy back then was wood and biomass, which is a secondary form of solar energy. The energy

source was replenished in the same characteristic time as the energy being consumed. In the pre-industrial era, human kind was basically living on a secondary form of solar energy.
I am not claiming that this energy consumption was a fully sustainable way of living.
We have to take in mind that deforestation due to increasing population density was already playing a role at the end of the first millennium in Europe.
The sun has been the energy source for all the processes on the surface of our planet. Wind is a result of temperature difference in the atmosphere induced by solar irradiation, waves are generated by the wind, clouds and rain are initially formed by the evaporation of water due to sunlight.

As the sun is the only real energy source we have, we need to move back again to an era in which we start to utilize the sun to satisfy our energy needs.
In the next chapter, I will introduce you to that technology!