Non-renewable energy

In this chapter, we're going to look at non-renewable energy sources. Where do they come from? And what are the consequences of using them?

1 Fossil fuels

Currently, fossil fuels provide 85% of the world's energy. The most important types of fossil fuels are coal, natural gas and crude oil (petroleum). Where do those fuels come from? And what are their differences?

1.1 Fossil fuels

To investigate fossil fuels, we first look at how they're 'made.' Millions of years ago, plant remains were pressed, by the forces of nature, into so-called **geological reservoirs**. Due to the high pressure, these plant remains slowly turned into fossil fuels. This happened over the course of millions of years.

Now these fuels are mined and burned. This burning causes CO_2 to come into the atmosphere. This CO_2 is then used by plants again, to grow. So in a way, there is a cycle. Plants turn to oil, which is burned to CO_2, which is then again absorbed by plants. It may thus seem like using fossile fuels is sustainable. However, it is not. This is because fossile fuels were formed over millions of years. But, we use up all the fossile fuels of our planet in only a few centuries.

1.2 Coal

Coal is fossilized, condensed, carbon-rich fuel. It is quite abundantly present on our planet. It provides about 24% of the world's energy. And, at the present rate of consumption, we won't run out of coal for 200 more years.

However, using coal isn't very efficient. When creating energy, 65% of it is lost in powerplants, and 10% more is lost in energy transport. And there is an even worse downside to coal. Coal is very carbon-rich. So when burning it, a lot of CO_2 appears. This causes the greenhouse effect problems to grow significantly.

1.3 Natural gas

Natural gas mainly consists of **methane** (CH_4). It has a few downsides to coal. It is generally difficult to transport. And at our current rate of consumption, we will run out of gas in 60 years.

However, natural gas is a lot cleaner than coal. This is mainly because it's more efficient. Only 10% of the energy is lost during the conversion of gas to electricity. Natural gas also contributes less to the greenhouse effect. This is because the gas contains hydrogen atoms. When natural gas is being burned, not only CO_2 is formed, but also H_2O. When this H_2O is formed, energy is produced. However, H_2O doesn't really effect the greenhouse effect.

1.4 Crude oil (petroleum)

Crude oil can be described as buried organic matter. It is rich in **hydrocarbons**, being molecules with carbon chains of various lengths. Attached to these carbon chains are hydrogen molecules. The ratio of hydrogen atoms to carbon atoms is about $8 : 5$. This is lower than the ratio of natural gas $(4 : 1)$, but higher than the ratio of coal. For this reason, crude oil is less clean than natural gas, but more clean than coal.

Oil is usually **distilled**: It is broken up in fractions, based on the molecule length. Examples of parts are **gasoline** (with chains of 5 to 12 carbon atoms), **diesel** (10 to 15 carbon atoms) and **kerosene** (12 to 15 carbon atoms).

2 Handling energy

2.1 Energy sources

Our planet uses up a lot of energy. It gets this energy out of so-called **energy sources**. We can distinguish two types of energy sources.

First, there are the **non-renewable energy sources**. These sources include fossile fuels and nuclear energy. Non-renewable sources contain energy. But once that energy has been released, the energy source is lost. For this reason, they are finite.

On the other hand, there are the **renewable energy sources**. Examples are wind, water and solar energy. Renewable energy sources are either regenerative or (virtually) inexhaustible.

2.2 Dangers of linear predictions

Previously, we have often used the words 'based on the current rate of consumption.' When we use this line, we assume that the rate of consumption remains constant. However, the rate of consumption generally does not remain constant. It usually grows by a (more or less) constant percentage every year. Linear predictions therefore do not work. Instead, the rate of consumption increases exponentially.

Let's consider a country X. We suppose that the oil consumption of this country increases by a constant percentage of 5% every year. Using this, we can calculate the **doubling time**. This is the time it takes for the consumption (or any other magnitude) to double. You can find the doubling time (approximately), by dividing 70 by the rate of growth. For country X, the oil consumption thus has a doubling time of $70/5 = 14$ years.

The doubling time has an important property. During every doubling time, more oil (or other quantity) is used than in all the previous years. (This follows from the exponential relation.) In other words, country X used more oil in the last 14 years alone, than in all the previous centuries together.

2.3 Transforming energy

From↓ To→	**Chemical**	**Electrical**	**Heat**	**Light**	**Mechanical**
Chemical	chemical reactions	battery/fuel cell	fire	fire	engine/rocket
Electrical	battery	transformer	radiator	light bulb	electric engine
Heat	gasification	thermocouple	heat exchanger	fire	steam engine
Light	photosynthesis	solarcells	radiation	prisma	solar sail
Mechanical	heat cell	dynamo/generator	friction	flint spark	gearbox

Table 1: Methods to transform on type of energy into another.

It's nice to have energy sources. But an energy source itself is not really useful yet. This energy needs to be transformed to another kind of energy. Important forms of energy are **chemical energy**, **electrical energy**, **heat**, **light** and **mechanical energy**. Methods to convert from one of these states to another can be seen in table 1.

The principle of **conservation of energy** states that energy is conserved. When transforming energy, no energy is lost. It can not appear or disappear. It can only be converted from one state to another.

3 Methods of heat transfer

Heat is an important type of energy. There are three ways to transfer heat: conduction, convection and radiation. Let's examine them.

3.1 Conduction

Conduction is the transfer of energy from more energetic particles to less energetic particles. The most important law for conduction is **Fourier's law of heat conduction**. Let's examine a plate with area A, thickness dT and temperature difference dT. The **temperature gradient** is then given by dT/dt. Fourier's law now states that

$$\dot{Q} = -kA\frac{dT}{dt}, \tag{3.1}$$

where $\dot{Q}$ is the **heat flow** through the plate. The minus sign in the above equation is a matter of notation. It states that the heat flow is directed opposite to the temperature gradient. (Heat only flows from warm to cold.)

By the way, k is the **thermal conductivity**. It varies (approximately) linearly with the temperature. For gases we have $dk/dT > 0$. (Gases conduct more heat at higher temperatures.) However, for solids and liquids we have $dk/dT < 0$. (Solids and liquids conduct less heat at higher temperatures.)

There are also several other important parameters. First, there is the **thermal diffusivity** α of a material. This is an indication of how fast heat diffuses through the material. It is defined as

$$\alpha = \frac{\text{heat conducted}}{\text{heat stored}} = \frac{k}{\rho c_p}, \tag{3.2}$$

where ρ is the **density** and c_p is the **specific heat** of the material. Another important parameter is the **thermal (conduction) resistance** R of a plate with thickness t. It is given by $R = t/k$.

3.2 Convection

Convection is the transfer of heat from one part of a fluid/gas to another part, by mixing particles. Convection does not occur in solids.

We can distinguish two kinds of convection. In **free/natural convection**, the particles move because of the heat. (For example, the heat may cause density changes, causing some particles to float upward. This is called **buoyancy**.) In **forced convection**, there are other (external) forces causing the movement of the molecules.

The convection heat flow is given by

$$\dot{Q} = hA\Delta T, \tag{3.3}$$

where ΔT is the temperature difference over the plate. Also, h is the **local heat transfor coefficient**. The thermal (convective) resistance is now given by $R = 1/h$.

3.3 Radiation

Radiation is the transfer of heat by (usually infra-red) electromagnetic waves. Let's suppose some radiation hits an object. The radiation can then be either **absorbed**, **reflected** or **transmitted**. The

absorptivity α' denotes the part of the radiation that is absorbed. The **reflectivity** ρ' denotes the part that is reflected. And finally, the **transmittivity** τ denotes the part that is transmitted. It is now directly obvious that $\alpha' + \rho' + \tau = 1$.

We define a **black body** to be some hypothetical body with $\rho' = \tau = 0$ and $\alpha' = 1$. In other words, it absorbs all incoming radiation. Similarly, a **white body** has $\alpha' = \tau = 0$ and $\rho' = 1$. It reflects all incoming radiation. Finally, there is the **opaque body**. It has $\tau = 0$ and $\rho' + \alpha' = 1$. All radiation is either absorbed or reflected. Nothing is transmitted.

3.4 Applying insulation

Let's suppose we want to isolate a wall. We can put a layer of material, a layer of air and another layer of material. The question is, how much heat does this wall transfer? This question is very easy to solve, if we use the thermal resistances. If we place multiple layers of insulation in series, then we may add up the individual resistances. So,

$$R_{total} = R_1 + R_2 + \ldots + R_n. \tag{3.4}$$

The heat flow through the wall is then given by

$$\dot{Q} = -A \frac{\Delta T}{R_{total}}. \tag{3.5}$$

4 Aviation fuels

One of the industries where sustainability is an issue, is avionics. So let's look at what kind of fuel jet aircraft use.

4.1 Fuel properties

When making fuel for jet aircraft, we have the ability to influence certain properties. Important fuel properties include the **maximum freeze point**, the **minimum flash point** (the point at which the fuel mixture is still ignitable), the **clean combustion** possibilities, the **energy density** and the **thermal stability** (how easily the fuel ignites on its own).

Aviation fuel usually consists of hydrocarbons. The chains of carbon atoms have various lengths. The range of these lengths depends on the properties we want to give to our fuel. By using this length, we can already make an important distinction in jet fuel. The so-called **wide-cut** fuels have molecule chains of 5 to 15 carbon atoms in length. The **kerosene** fuels have molecule chains of 8 to 16 carbon atoms in length.

Today, the most often used jet fuels are **Jet A** and **Jet B**. Jet a is a kerosene type fuel. Its maximum freeze point is $-40°C$, while its minimum flash point is $43°C$. On the other hand, Jet B is a wide-cut type fuel. Its maximum freeze point is $-51°$.

4.2 Specific energy and energy density

Two very important fuel parameters for the aircraft industry are the specific energy and the energy density. The **specific energy** denotes the amount of energy that can be produced from one kilo of fuel. The **energy density** denotes the amount of energy that can be produced from one liter of fuel.

Both the specific energy and the energy density should be as high as possible. You don't want your fuel to weigh a lot. Nor do you want it to take up a lot of space. (The more space your fuel takes, the bigger and heavier the storage tanks will be.)

One way to compare fuels, is to make a plot out of them. For this, we put 1/energy density on the x axis and 1/specific energy on the y axis. We then mark several fuel types as points in this plot. The closer a fuel type is to the origin, the better it is.

4.3 Combustion

Let's look at the way fuel is burned. The chemical reaction is given by

$$C_xH_y + (x + y/4)O_2 \rightarrow x\,CO_2 + y/2\,H_2O + \text{heat}. \tag{4.1}$$

So we use fuel and oxygen, to generate CO_2, H_2O and heat. Usually, about $1.25kg$ of H_2O and $3.15kg$ of CO_2 are produced for every kilogram of fuel burned. Next to H_2O and CO_2, the reaction also has byproducts. These byproducts include NO_x, SO_x, **Volatile Organic Compounds** (VOCs) and **Particle Matter** (PM).

An important parameter during combustion, is the **fuel/air (F/A) ratio**. The amount of energy released during the reaction depends on this ratio. There is a certain optimal F/A ratio, giving maximal energy. If the F/A ratio is quite a bit higher than this optimum, then we will have a **fuel rich combustion**. This combustion often results in smoke production. If, however, the F/A ratio is far below the optimum, then there will be a **fuel lean combustion**. This time, the engine has a risk of becoming idle. There will also be a lot of CO and UHC production.

4.4 Thermal stability

Another important parameter is the thermal stability of a fuel. When engines can run at high temperatures, they are more efficient. However, we do not want the temperature be too high. In this case, the fuel may ignite spontaneously. And that's not a good thing.

To increase the thermal stability, we need to increase the **breakpoint** of the fuel. (This is the point at which the fuel might start to ignite on its own.) Increasing the breakpoint is mainly done by processing the fuel, and by adding additives.

4.5 The Fischer-Tropsch process

The **Fischer-Tropsch process** is a process in which synthetic gas (called **syngas**) is transformed to a liquid fuel. The syngas mainly consists of CO and H_2. The liquid fuel consists of hydrocarbons.

To use the Fischer Tropsch process, we first need syngas. This can be made from many types of fuels. We can make it, for example, from coal. This process consists of three steps. First, there is **pyrolysis**, also known as devolatilization. We remove the volatile components. We remain with a carbon-rich substance called **char**. The second step is **combustion**. The volatile components are burned, to generate heat. This heat is necessary for the the third step, being **gasification**. In this step, we use the char, together with H_2O and O_2, to form CO and H_2. The syngas has been created.

Now that we have syngas, we can perform the Fischer-Tropsch process. The reaction of this process is given by

$$(2n + 1)H_2 + n\,CO \rightarrow C_nH_{2n+2} + n\,H_2O. \tag{4.2}$$

For this process, a **catalyst**, like cobalt or iron, is necessary. The resulting liquid (called **parrafin**) is usually distilled, before it is used.

One of the products of this distillation then is **synthetic kerosene**. Synthetic kerosene has several advantages above normal kerosene. Its thermal stability is bigger, and it is cleaner. However, producing synthetic kerosene is, for the moment, still more expensive than simply using normal kerosene.