DLR_School_Lab Köln

Fuel cells

How long before our energy resources are depleted?

"German energy consumption rose considerably in 2020. The price of energy is also likely to rise continuously." These are the words of a large newspaper. That this is true can be seen by any visitor to a petrol station or recipient of a gas and electricity bill. And physicists' insistence that energy cannot be consumed does not really help us here …

Of course, it is true that energy can only be converted into a different form of energy. This will be a central part of our experiment. Energy "consumption" in everyday language usage means the consumption of primary energy sources. In Germany, this generally means the consumption of oil gas, soft and hard coal (fig.1), which are all carbon-based energy sources. They are also referred to as fossilized fuels, as they were produced millions of years ago, thus conserving the solar energy converted by living organisms. The significance of nuclear power has been under discussion for years, even before the Fukushima catastrophe. Since then, the proportion of renewable (regenerative) energy in Germany has increased from year to year.

We have used up a large proportion of the energy that was conserved over billions of years in the last two centuries. If we continue at this rate, we will need the resources of three Earths by 2050!

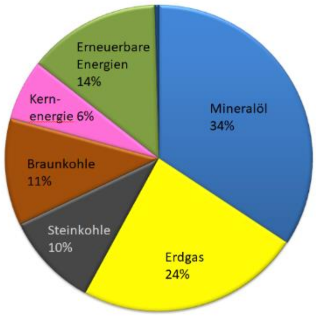

Fig. 1: Primary energy consumption in Germany in 2018. Total 14,981 PJ (Peta Joule = 1015 J)

Tapping into the Sun

Enough energy is available: The amount of radiation that the Sun emits over the world's deserts in six hours contains enough energy to supply the Earth's entire population for a year. The problem is collecting, transporting and storing the energy won through renewable sources such as sunlight, hydrodynamic power, wind and biomass.

Hydrogen as energy carrier

Hydrogen could be the energy source of the future. It is a light, invisible gas that – together with oxygen - burns up into water. Cars powered by hydrogen would produce only water vapour as an exhaust fume.

Shortcuts

Converting energy from one form into another is not without its costs. Each conversion is accompanied by waste heat which is not usually usable and is sometimes even disadvantageous. Figure 2 shows a common method for producing electric energy: a chemical energy source (e.g. coal) is burned. The resultant thermal energy is transferred to a medium (such as water). This drives a machine (e.g. steam turbine) which produces electricity with the help of a generator. The amount of energy that is lost as waste heat during each conversion is specified by a machine's degree of efficiency:

$$\text{Efficiency } (\eta) = \frac{\text{output } (P_2)}{\text{input } (P_1)}$$

A fuel cell is a short cut. It is able to convert chemical substances into electricity directly or, vice versa, use electricity to split chemical compounds.

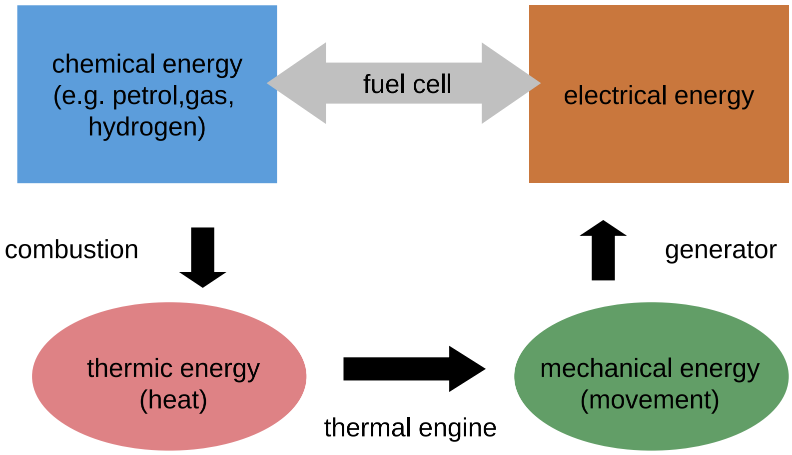

Fig. 2: Conversion of energy

Energy storage

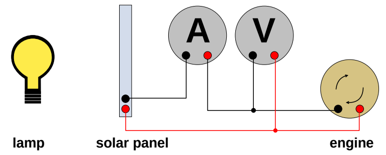

Fig. 3: Circuit diagram for experiment 1

Try it out yourselves: connect a solar panel to an engine and illuminate the solar panel. Measure current and voltage. How long does the engine continue to turn after you have turned off the light?

Repeat the experiment after you have connected a fuel cell in parallel to the engine. Do you notice a difference? What does this tell you?

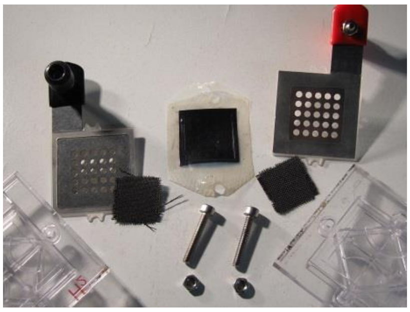

Fig. 4: Components of a simple fuel cell

How does a fuel cell work?

The experiment has shown you that a fuel cell basically works in both directions. In practice, different materials are used for the electrolyser and the fuel cell.

An essential part of our fuel cell is a membrane made of Nafion (a tetrafluoroethylene based fluoropolymer-copolymer (PTFE), a modification of Teflon) (in the centre of figure 4; shown in yellow in figure 5) which separates the two liquid compartments. There is a catalyser layer to either side (the black mesh in figure 4, shown in grey in figure 5). Either platinum or vanadium is used as a catalyst. Electrodes (see the drill holes in fig. 4) are used as electric contacts.

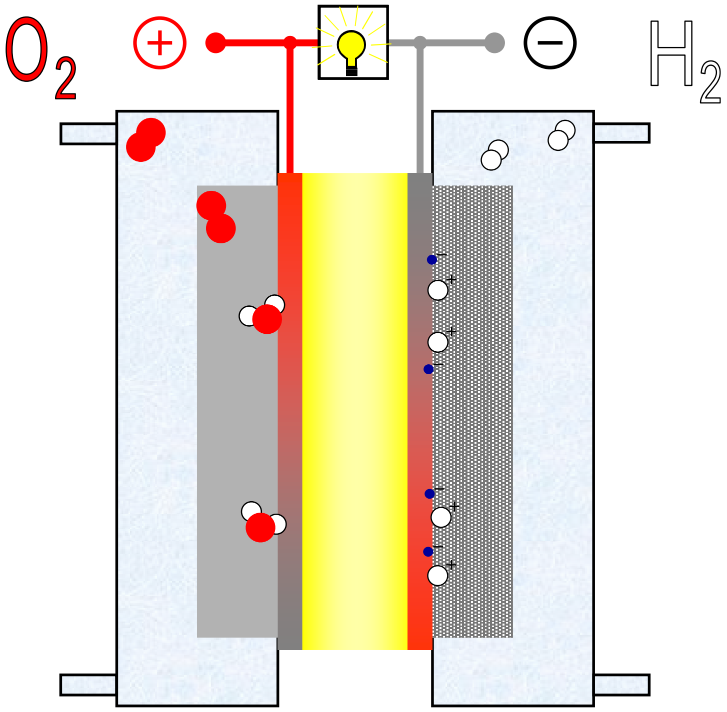

Fig. 5: Schematic depiction of a fuel cell

Reactions in a fuel cell

In fuel cells, the reactions run conversely. Hydrogen is split with the help of a catalyst at the anode:

$2H_2 \longrightarrow 4H^+ + 4e^-$

The protons diffuse across the membrane while the electrons are drawn towards the cathode due to the difference in voltage. The system provides electricity. At the cathode, the protons and electrons combine with the catalytically decomposed oxygen to water:

$4H^+ + 4e^- + O_2 \longrightarrow 2H_2O$

Comparing efficiency

In the second experiment, you will measure and compare the efficiency of different appliances:

We will produce light with the help of a halogen lamp, which will be converted into electricity with the help of a solar panel.

Measure the voltage and the current of the solar panel that is feeding the electrolyser.

Decomposing water with an electrolyser

The use of a catalyst means that water is decomposed into oxygen and hydrogen gas at room temperature. 4 protons, 4 electrons and molecular oxygen are generated at the anode:

$2H_2O \longrightarrow 4H^+ + 4e^- + O_2$

Oxygen escapes into the air or can be collected for further use. The protons pass through the Nafion[1] membrane and are drawn to the cathode. The electrons must travel along an external circuit to the cathode, which requires an electric current. This means that electrolysers consume electricity.

Molecular oxygen is produced when 4 electrons have reached the cathode. The hydrogen is collected for further use:

$4H^+ + 4e^- \longrightarrow 2H_2$

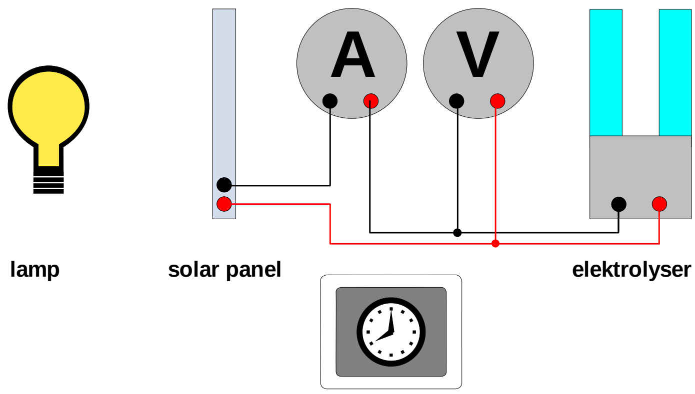

Fig. 6: Circuit diagram of the experiment for measuring efficiency levels

[1]Tetrafluorethylene-Polymer (PTFE), a modification of Teflon

Determine the amount of hydrogen and oxygen that the electrolyser produces in a given amount of time.

Use the exercise sheet provided to calculate the efficiency levels of the different appliances and the apparatus as a whole.

Is our method of producing hydrogen economically viable? Why? What should be changed?

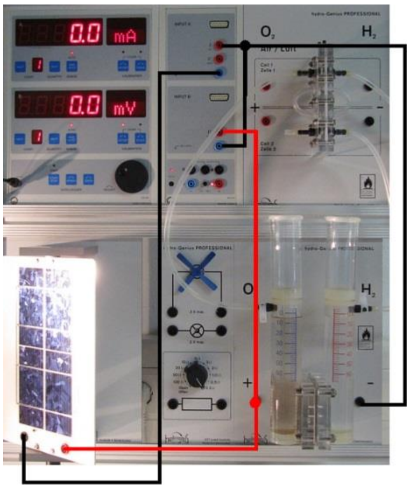

Fig. 7: Demonstration apparatus; connected according to figure 6

Uses

Fuel cells were first used for space flight. They have provided astronauts with electricity, heat and water for over 40 years.

On Earth, it is going to take quite a while until fuel cells can be used commercially. In particular, the problem of storing hydrogen (in pressurised bottles or as metal hydride) has not been solved.

However, there are cars that run on electricity provided by fuel cells. In Hamburg, three public buses have been using fuel cells since 2004.

Fig. 8: HH2 project in Hamburg: buses that run on fuel cells

Aeroplanes now use fuel cells to provide on-board electricity – much as it is done in space. The water vapour that is produced can be collected and used in the kitchen or sanitary areas of the plane.

In 2008, the DLR introduced ANTARES, the first aeroplane powered by fuel cells (see front page and fig. 9).

Fig. 9: ANTARES filling up on hydrogen

It will be quite a while before notebooks can be powered by hydrogen; however the Institute of Engineering Thermodynamics has developed a small mobile energy supplier called “MobilE-Pack” as an alternative to diesel generators.

Fig. 10: Mobile fuel cell system “MobilE-Pack”

Definitions

Voltage (U), [V]
Current (I), [A]
Wattage (P)
$P = U \bullet I$, [W] = [VA]
Energy (E)
$E = P \bullet t$, [J] = [Ws]
Fuel/Calorific value of hydrogen gas:
11,92J/ml

Websites

http://www.dlr.de/tt/

http://www.dlr.de/tt/desktopdefault.aspx/tabid-2882/4338_read-6451/

http://www.dlr.de/desktopdefault.aspx/tabid-77/7419_read-12190/

http://www.lange-aviation.com/

http://www.ag-energiebilanzen.de/

About DLR

DLR is the Federal Republic of Germany's research centre for aeronautics and space. We conduct research and development activities in the fields of aeronautics, space, energy, transport, security and digitalisation. The German Space Agency at plans and implements the national space programme on behalf of the federal government. Two DLR project management agencies oversee funding programmes and support knowledge transfer.

Climate, mobility and technology are changing globally. DLR uses the expertise of its 55 research institutes and facilities to develop solutions to these challenges. Our 10000 employees share a mission – to explore Earth and space and develop technologies for a sustainable future. In doing so, DLR contributes to strengthening Germany's position as a prime location for research and industry.

DLR Cologne

Aviation, space travel, transportation, energy and safety are the research areas pursued in the nine research facilities at DLR Cologne. The basis of the research and development carried out on site are the large testing facilities such as wind tunnels, turbine and materials test benches and a high-flux density solar furnace. The 55 hectare/ 136 acre site is home not only to the research and administrative facilities of the DLR, but also to the European Space Agency's (ESA) European Astronaut Centre (EAC). The DLR has around 1400 employees in Cologne.

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About the experiment:

Recommended for grade(s): 9 to 12
Group size: 5 to 6
Duration: 50 minutes
Subject matter:
- Physics
- Chemistry