Chemistry and Industry for
Teachers in European Schools

CHEMISTRY CHANGES EVERYTHING

Pollution-free electricity?

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CITIES (*Chemistry and Industry for Teachers in European Schools*) is a COMENIUS project that produces educational materials to help teachers to make their chemistry lessons more appealing by seeing the subject in the context of the chemical industry and their daily lives.

The CITIES project is partnered by the following institutions:

- Goethe-Universität Frankfurt, Germany, http://www.chemiedidaktik.uni-frankfurt.de
- Czech Chemical Society, Prague, Czech Republic , http://www.csch.cz/
- Jagiellonian University, Kraków, Poland, http://www.chemia.uj.edu.pl/index_en.html
- Hochschule Fresenius, Idstein, Germany, http://www.fh-fresenius.de
- European Chemical Employers Group (ECEG), Brussels, Belgium, http://www.eceg.org
- Royal Society of Chemistry, London, United Kingdom , http://www.rsc.org/
- European Mine, Chemical and Energy Workers' Federation (EMCEF), Brussels, Belgium, http://www.emcef.org
- Nottingham Trent University, Nottingham, United Kingdom, http://www.ntu.ac.uk
- Gesellschaft Deutscher Chemiker GDCh, Frankfurt/Main, Germany, http://www.gdch.de
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Other institutions associated to the CITIES project are:

- Newcastle-under-Lyme School, Staffordshire, United Kingdom
- Masaryk Secondary School of Chemistry, Prague, Czech Republic
- Astyle linguistic competence, Vienna, Austria

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POLLUTION-FREE ELECTRICITY FROM OIL?: FUEL CELLS

Introduction

Oil (and its derivatives) has been used for over a hundred years as the fuel from which to generate electricity. Other chemicals have also been used, from even earlier, to produce electricity in the form of batteries. The problem has always been one or more of the by-products, i.e. the waste materials formed.

The combustion of hydrocarbon fuels is widely used, not only to generate electricity, but also to provide the energy to produce movement in vehicles such as cars, buses, trucks, aircraft and so on. Inevitably, the burners or engines used in these devices run at well below 100% efficiency, and as a consequence, not all of the fuel is put to good use. There is invariably unburned fuel in the waste gases as well as one other problem – namely, the product of incomplete combustion, carbon monoxide, which is a toxic gas. The construction of modern burners and engines also results in oxides of nitrogen being produced. This is surprising to the non-scientist, prompting the question, "how can oxides of nitrogen be formed if the fuel does not contain nitrogen?"

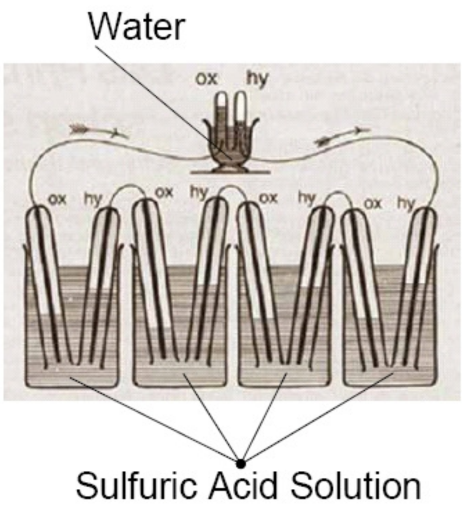
The answer to this question lies in the fact that it is not the fuel, but the air in which it burns, which contains the nitrogen; air consists of **78% nitrogen**, as well as 21% oxygen, along with other gases. At the high temperatures encountered inside a burner (or internal combustion engine) there is sufficient heat energy available to break the strong bonds holding the nitrogen atoms together, allowing them to combine chemically with the oxygen also present in the air. Any means of allowing the energy locked up in the fuel to be extracted at lower temperatures will prevent the formation of these gases, which are responsible for much of the acid rain falling to earth. The damage to the trees (left) is acid rain-related.

One answer to this problem is the **FUEL CELL**.

So, what is a fuel cell?

Well, in simple terms, it's a device which produces electrical energy from chemical a reaction. So in this respect it is like a conventional dry cell or battery, but a fuel cell does this much more effectively. Whilst a battery will eventually run down, a fuel cell will work indefinitely, as long as fuel and oxidant are supplied.

When did this all begin?



The first fuel cell was produced in England by William Grove in 1839, although this was not his original intention. He had been electrolyzing water using platinum electrodes. When the current from his batteries had been turned off, he noticed that a current continued to flow in the external circuit, in the opposite direction to that produced by the batteries. He attributed this to a chemical reaction between the electrolysis products, hydrogen and oxygen, the reaction being catalyzed by the platinum.

The plate shown on the left illustrates several of these 'Groves' cells connected in series, in the same way as conventional cells are connected to make a battery.

The term "fuel cell" was not actually coined until about 50 years later by Mond and Langer, who made an improved version of the device. There has been much work done on fuel cell development since then, but most of the work has been done in the last fifty years.

There are many different types of fuel cell in existence today but we can narrow this down to five main types:

1. Alkaline Fuel Cells
2. Phosphoric Acid Fuel Cells
3. Polymer Electrolyte Membrane Fuel Cells
4. Molten Carbonate Fuel Cells
5. Solid Oxide Fuel Cells

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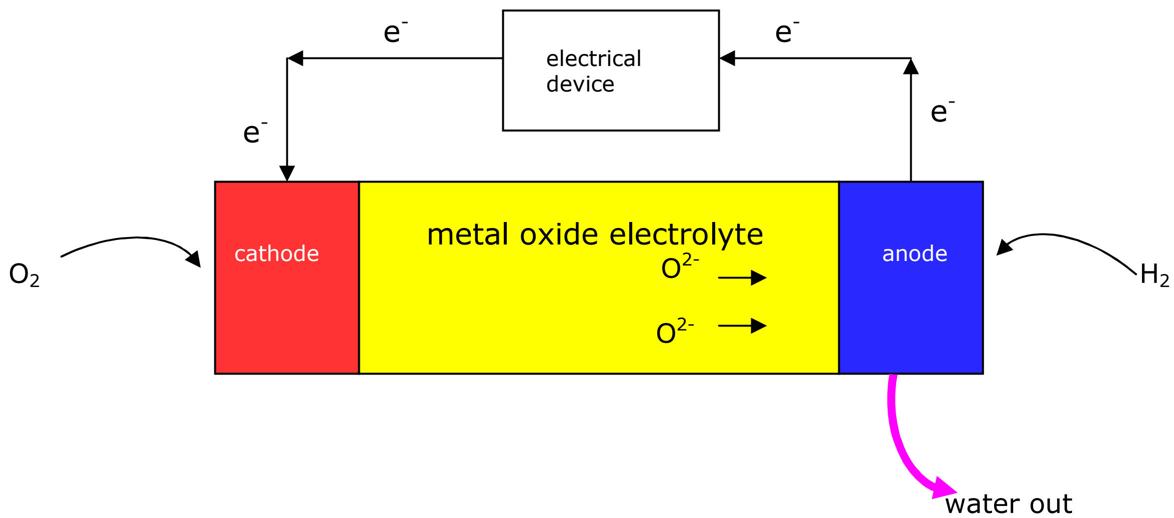
Is this really chemistry?

Each of the five types of fuel cell listed above has its own set of characteristics but they all work on what is loosely the same basic principle. This relies on there being two electrodes with a common electrolyte between them. Ions travel through the electrolyte from one electrode to the other, with chemical reactions taking place on the surface of each electrode. At the same time, electrons (e^-) are liberated by these reactions and it is these which travel around the external circuit to produce the electric current.

In a simple furnace, the combustion of the fuel produces energy in the form of heat and light. In a conventional dry cell (or battery), the electrical energy comes from the chemical reactions taking place inside. The chemicals are consumed and eventually run out. At this point the cell is disposed of. The electrical energy produced in a fuel cell comes from the energy liberated when the fuel is oxidized, but this time, there is a much more efficient production of energy.

The simplest type of cell uses hydrogen as the fuel and oxygen as the oxidant; in reality, this could be a supply of air, which contains oxygen. The use of air would greatly cut costs.
In a solid oxide fuel cell, the solid oxide acts as the electrolyte. Its construction is rather complex, but in essence, it is a ceramic material impregnated with inorganic metal oxides such as zirconium oxide, ZrO_2. This provides the oxo anions, O^{2-}, which are essential to the cell's operation:



<u>At the Cathode</u> $O_2 + 4\,e^- \longrightarrow 2\,O^{2-}$
oxygen molecule → oxo anions

So, each oxygen molecule gains two electrons to become two oxo anions. These oxo ions travel through the electrolyte towards the anode.

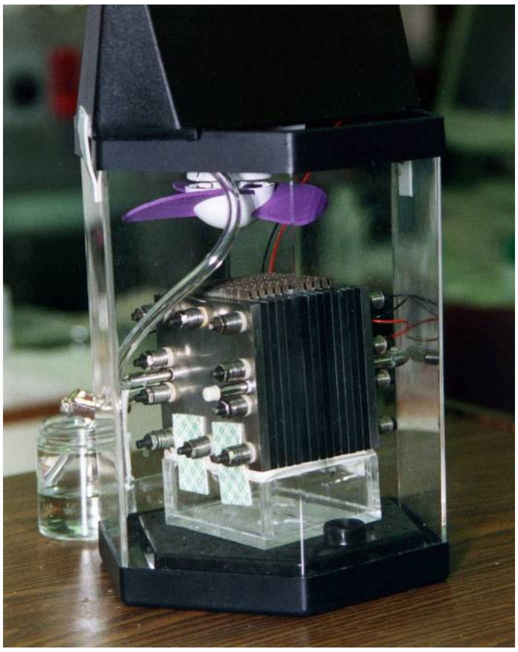
<u>At the Anode:</u> $2\,H_2 + 2\,O^{2-} \longrightarrow 2\,H_2O + 4\,e^-$
hydrogen molecules → water

Two hydrogen molecules combine with the two oxide ions to produce two molecules of water and 4 electrons. These electrons travel around the external circuit and back to the cathode, where the whole process begins again.
The water molecules formed now escape from the anode compartment.

Overall, $2\ H_2 + O_2 \longrightarrow 2\ H_2O$ + electrical energy

The oxo anions act as a catalyst, as they are consumed in the anode compartment but are regenerated in the cathode compartment.

Other fuel cells use hydrocarbon fuels, such as natural gas, liquefied petroleum gas (LPG) and biogas. Gasoline and Diesel can also be used, as can methanol.



A methanol fuel cell (NASA)

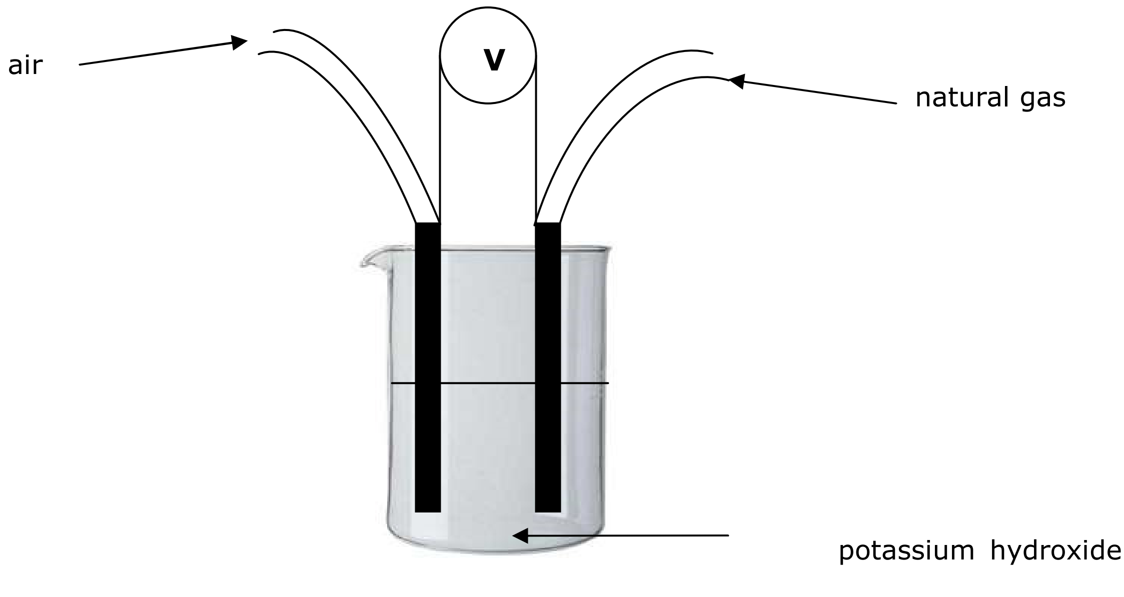
So, you want to try something out?

You can make a very simple fuel cell using two carbon rods (from exhausted 'D' type dry cell is ideal), potassium hydroxide solution, natural gas and air.

Procedure

- Clean the rods
- Wearing eye protection, heat the rods strongly in a Bunsen burner flame for 5 minutes. This activates the carbon and helps the rods to become slightly more porous. Allow the rods to cool before moving on to the next stage.
- When cool, carefully drill a 3mm diameter hole along the central axis of each rod. The hole should be about 20-30mm long (but do not drill the entire length of the rod)

- Attach a rubber tube to the end of each of the rods, covering the drilled hole
- Connect one of the tubes to a natural gas supply and the other tube to hand bellows
- Dip both rods into the solution of alkali (caution: this solution is very caustic, so eye protection and plastic/rubber gloves must be worn)
- Connect a voltmeter to the two rods



- Turn on the gas supply to one rod and operate the hand bellows to blow air into the other rod.
- A small voltage will be produced

Somewhat more complicated procedures can be adopted, with more expensive materials

(see http://uk.youtube.com/watch?v=mibnOhczXEk
or http://blog.makezine.com/archive/2006/06/how_to_build_your_own_band_aid.html
or http://scitoys.com/scitoys/scitoys/echem/fuel_cell/fuel_cell.html)

Applications

- Electrical power generation in Spacecraft
- Commercial electricity generation for towns/remote outposts e.g. weather stations
- Laptops/MP3 players/mobile telephones/hearing aids
- Motor vehicles: Most of the leading automobile manufacturers are developing fuel cell cars (Mitsubishi, Ford, General Motors, Honda, Toyota, etc)


bus

car


bike

aircraft


military


How are fuel cells produced?

Fuel cells are constantly being developed and improved. As stated earlier, there are generally five main types of fuel cell in common use. The method of construction depends very much upon the type of cell, which fuel it will use and the application to which it will be put. Some of the cells listed operate at temperatures of up to 1000 ˚C, others at a slightly lower temperature of about 600 ˚C. The alkaline cells operate at about 60-70 ˚C. Clearly, different materials will be used in each situation.

So what are the benefits?

- Operate from a wide range of fuels
- If hydrogen is the fuel, it is en endless resource; the air is always free!
- Virtually pollution free
- High reliability
- Low maintenance
- Quiet in operation
- Very high energy efficiency – over 80% in some cases, which is well above that of simple electrical cells of conventional combustion engines
- Much greater power density than batteries (more electrical output per unit weight of cell)
- Very long life span

Are there any known risks?

The main problems with fuel cells are that some operate at high temperatures and others use dangerous chemicals. As long as these factors are borne in mind and appropriate safety precautions are taken, fuel cells can be used very safely.

In an ideal world, hydrogen will be the fuel of choice. There is one obvious safety issue with the use of hydrogen as a fuel. This is its very high flammability; extreme measures must be taken to avoid its escape. We only have to look at the disasters of 1937 (Hindenburg airship) and the Challenger space shuttle (1986) for stark reminders of the destructive potential of hydrogen. Safe methods of production and storage of hydrogen must be perfected before hydrogen will be trusted by the general public.

The main reason for this is that it will always be available. 70% of the earth's surface is covered by water. We know that water can be decomposed into hydrogen (and oxygen) very easily by electrolysis. Other procedures exist for the production of hydrogen from other sources (e.g. reforming of petroleum fractions)

Future developments

- Increased efficiency
- Modification to include solid fuels?
- Improved hydrogen-production costs
- Reduction in fuel-cell size – increased portability
- Use of less hazardous materials/operating conditions

Intrigued by what you've read?

There is no shortage of reference material. Have a look at:

www. wikipedia.org/wiki/Fuel_cell
www.fuelcells.org/
http://uk.search.yahoo.com/search;_ylt=A1f4cfNG6WhJSBQAMzxLBQx.?p=+fuel+cell&y=Search&fr=fp-tab-sayt1&ei=UTF-8&rd=r1

http://www.princeton.edu/~chm333/2002/spring/FuelCells/what_is_fuel_cell.shtml

websites of major automobile manufacturers
http://science.nasa.gov/headlines/y2003/18mar_fuelcell.htm

The list is almost endless……

Unless listed elsewhere, all pictures from Google Images.