# Should Zero Emission Cars Be Made Compulsory – Is It Feasible?

## Notes for the Teacher

The intended concepts can be taught on different levels. But it seems to be necessary that the students are able to understand elementary concepts of electricity as well as of chemical reactions. It seems useful that students have the ability to use (or is developed through this script) the concept of oxidation and reduction as an electron transfer process.

In the part acquiring the scientific background, activities need to be chosen which are suitable for the learning group (e. g. age range, school level). Here further aspects such as generating hydrogen from methanol, or the function of modern polymer-electrolyte-membrane (PEM)-cells can be added for higher grades.

The structure of the unit is given in the figure below and elaborated further with special impact on possible methods for student-oriented and student-activating activities.

## Questions created by Students

It is expected that students will develop questions on:

- making hydrogen and its properties
- functioning of hydrogen cars
- emission from hydrogen as a fuel

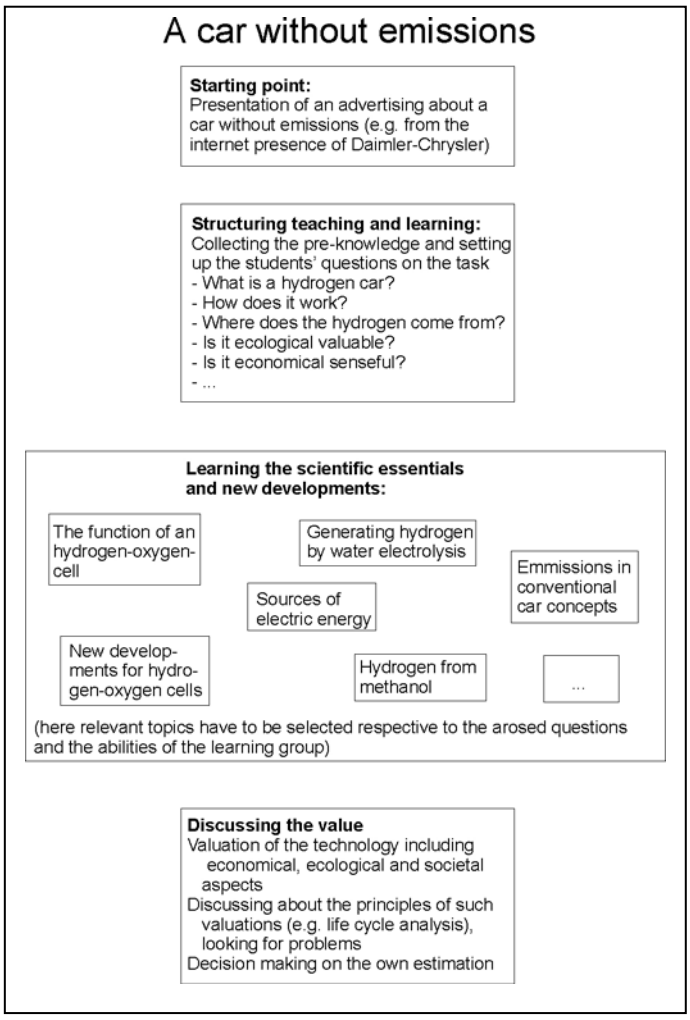
The teacher may need to guide student groups where the students do not have the necessary vision themselves.

## Rationale for the discussions

Such developments are intensely discussed in society and the discussion is driven by different interests, companies and pressure groups. The public opinion is very much influenced also by advertising materials. To compete in such a discussion, as an active member of a democratic society, it is necessary to become competent in understanding the scientific and technological essentials. But it is also necessary to become critical on the societal discussion and the arguments used.

**Developer: Ingo Eilks, Spyros Evlogimenos, Charitos Olympios and Nicos Valanides**
**Edited by: Jack Holbrook**
Institution: ICASE
Country: UK

The main argument for a «Hydrogen-Car» is that there are no emissions. On a closer look it is been seen that this is right only when the hydrogen had been produced on the basis of a no emission technology as well e.g. solar or wind energy sources, or when the burning of hydrogen is not associated with the subsidiary reaction of nitrogen plus oxygen giving oxides of nitrogen as happens at hot temperatures (ca. 3000 celsius). Also the use of methanol is discussed to produce hydrogen, but also this seems to be a solution only if it is not produced from natural gas.




Beside this a lot of discussion is important as to whether the hydrogen technology is a good alternative to reduce emissions, e.g. whether it is helpful just to put the emissions outside the cities. So following a socio-critical and problem-oriented approach, it is intended to follow this discussion and to give an insight to the way it goes. It is intended to make the students aware how difficult such a decision is, how necessary a basic scientific knowledge is and how easy the individual can be misled if there is only less, or intentional information available.

**Developer: Ingo Eilks, Spyros Evlogimenos, Charitos Olympios and Nicos Valanides**
**Edited by: Jack Holbrook**
Institution: ICASE
Country: UK

## Assessment of Personal and social objectives

For the assessment of the personal and social objectives it is helpful to use different kinds of assessment approaches which follow a more qualitative perspective. A written (and maybe anonymous) report done by the students about their individual decision and point of view can be requested by the teacher. It can be judged whether the students are arguing by using facts and opinions correctly and doing it in an understandable and logical way. This can be evaluated also whether there is a critical view in it by looking whether there are arguments from both sides discussed.

A second way of assessing the personal development can be by letting the students reflect on their learning. This can be done by asking what, in their estimation, had been the main things they have had learned, or what the main objectives of this teaching might have been. It can be seen whether student only mentioning tasks from the scientific content point of view, or whether they give answers containing personal development, social awareness, communicative and process skills. Mentioning these aspects means to become aware of them. Becoming aware in this field is the first, and maybe the most important thing, in reaching further.

## Supplementary information

Information about the fuel cell technology and actual developments are available at e.g. *www.daimlerchrysler.com* (→'Corporate Information'→ ,Research and Technology ' (02/09/02))
Respective information on different aspects and viewpoints of pressure groups are available the internet and can be easily searched by sites like www.google.com, e.g. :

| | |
|---|---|
| Producer of hydrogen technology cars | *www.daimlerchrysler.com* (→'Corporate Information'→ ,Research and Technology ') |
| Overview on producers of fuel cell technology | *www.ttcorp.com/fccg/fc_othr.htm* |
| Crude oil Industry | *www.shell.com* (→'Issues and dilemmas' → 'Alternative energy'→ 'Hydrogen fuel cells' ) |
| Environment protection groups | *www.greenpeace.org.au/climate/archive/nonewoil/phasing_out.html* |
| Governmental organisations | *www.umweltbundesamt.de* (choose english version and search for 'fuel cells') |
| Overview on reports in media (Reuters) | *www.planetark.org/index.cfm* (→ 'fuel cells') |
| About hydrogen and fuel cells | *www.miniHYDROGEN.com* |

**Developer: Ingo Eilks, Spyros Evlogimenos, Charitos Olympios and Nicos Valanides**
**Edited by: Jack Holbrook**
Institution: ICASE
Country: UK

## Experimental work

Electric energy from hydrogen and oxygen: Easy cells for the use of hydrogen can be investigated just by using two electrodes 'washed' by the two gases. (if the electrodes are first used to generate hydrogen and oxygen by electrolysis from dilute acid, they will have occluded gases within them – this is the 'washed' effect and will last until the gas is removed). If the electrodes are connected in the external circuit through a milliammeter, a current will be detected.

Modern fuel cells using a more advanced technology on the base of a polymer electrolyte membrane (PEM). Experimental kits and respective descriptions also to investigate such technologies are now available in different countries (e.g. www.heliocentris.com/eng/prods/pr_kits.html or www.carolina.com).

Generating hydrogen: An easy way to generate hydrogen is a simple electrolysis of water (using test tubes inverted in a beaker with plastic coated wire leads -wire exposed for electrodes and an electrolyte such as dilute sulphuric acid). For more advanced studies in higher grades a discussion on alternatives may be of interest. In the student material, the use of methanol is mentioned. Hydrogen can be easily generated by catalytic cracking of methanol on a copper/magnetite catalyst. Respective experiments had been described e.g. by Huntemann, H. et al. (2001) Die Wasserstoff-/Luft-Brennstoffzelle mit Methanolspaltung zur Gewinnung des Wasserstoffs, *Chemie Konkret* 8, p. 15-21. See also Parchmann, I. et al. (1999) Durch die Zelle in die Zukunft? *www.ni.schule.de/~lmgvar/faecher/ch/zelle/*.

# Hydrogen storage and distribution

## Handling hydrogen

Hydrogen being the lightest element has more energy compared to its weight, but the least when compared to its volume. The challenge is thus to find ways of storing hydrogen so that reaches an energy its density is comparable to that of petrol or diesel. Hydrogen can be stored in 3 ways : gas, liquid or as a material.

### As a gas

Increasing the storage pressure of gaseous hydrogen will decrease the storage volume needed. Hydrogen is typically stored under 200 atmospheres (200 bars), although some manufacturers are using 700-900 bars, giving an even higher energy density. Extensive safety tests of the pressure tanks show that it is safe to store hydrogen even under such high pressures. However putting hydrogen under such pressures takes a lot of energy.

**Developer: Ingo Eilks, Spyros Evlogimenos, Charitos Olympios and Nicos Valanides**
**Edited by: Jack Holbrook**
Institution: ICASE
Country: UK

## Liquid storage

When hydrogen is cooled to -253 degrees Celsius it becomes a liquid, giving it a quite high energy density. However it takes a lot of energy to cool it down. It also takes a lot of technology to store the hydrogen at such a low temperature. Even with this cooling technology the hydrogen will still slowly boil away. Typically after 2 weeks, most hydrogen will disappear for the tank if not used before this.

### Methanol storage

Methanol is a liquid alcohol containing hydrogen. It has half the energy density of petrol, but it is already mass produced today and is easy to distribute. However methanol is toxic for humans, but with the right handling this danger can be controlled. Methanol might be the way hydrogen will be stored in the future. Research is being carried out to create reformers that can convert the methanol to hydrogen before entering the fuel cell. Another option is direct methanol fuel calls, where the reforming process happens internally in the fuel cell, making it possible to operate directly on methanol.

### Metal hydride solid storage

Hydrogen can also be stored in solid form with use of metal hydrides. Hydrogen reacts with different types of metal powder creating a solid storage at low pressure. Metal hydride has potential of energy densities close to that of petrol, and at the same time enabling low pressure storage thus increasing safety.

| | | |
|---|---|---|
| Energy content of 1 litre petrol | 8.67 kWh | |
| Hydrogen storage technology | Hydrogen volume of 8.67 kWh | Petrol volume of 8.67 kWh |
| Pressure (atmospheres) | 3107 litre | |
| Pressure (200 bar) | 13 litres | |
| Pressure (700 bar) | 6.4 litres | |
| Liquid hydrogen (-253 degree Celsius) | 3.6 litre | 1 litre |

## Fuel Cells

Fuel cells convert chemical energy in a fuel, mostly hydrogen, in to electricity and heat without any noise and mechanical movement. The only emission of the reaction in the fuel is pure water. A fuel cell is like a battery with the only difference that it will continue to provide energy as long as a fuel is provided. Fuel cells are very scaleable and flexible in design thus giving a wide range of possibilities of usage. A fuel cell can power a small mobile cell phone, or a car, or even be used for large central power plants.
The basic principle of a fuel cell is a chemical reaction between hydrogen and oxygen that produces power and heat. The picture shows the principle. Hydrogen and oxygen are supplied on each side of a

**Developer: Ingo Eilks, Spyros Evlogimenos, Charitos Olympios and Nicos Valanides**
**Edited by: Jack Holbrook**
Institution: ICASE
Country: UK

cell. The cell consists of an electrolyte membrane (PEM) with a catalyst layer on each side. When hydrogen is lead to the first catalyst layer, the anode, the hydrogen molecules are split in to their basic elements, a proton and an electron. The protons migrate through the electrolyte membrane to the second catalyst layer, the cathode. Here they react with oxygen to form water. At the same time the electrons are forced to travel around the membrane to the cathode side, because they can not pass the membrane. This movement of electrons thus creates an electrical current.

## Fuel Cell types

A wide range of fuel cell types exist, each operating on different fuels and at different temperatures. The most common is the PEM fuel cell operating at 50-100 degrees Celsius. The DMFC is a direct methanol fuel cell running on methanol. The SOFC fuel cell is a high temperature fuel cell operating at 650-1000 degrees Celsius making it possible to run on many types of fuels

| **Fuel cell type** | **PEM** | **AFC** | **PAFC** | **DMFC** | **MCFC** | **SOFC** |
|---|---|---|---|---|---|---|
| **Name** | Proton exchange membrane | Alkaline | Phosphoric Acid | Direct Methanol | Molten Carbonate | Solid Oxide |
| **Applications** | Vehicles, mobile applications and combined heat power productions | Space applications | Large scale heat and power productions | Mobile operations from small scale to micro | Medium to large scale combined heat and power productions, up to MW | All sizes of combined heat and power production up to multi MW |
| **Operating temp degrees Celsius** | 50-100 | 50-200 | About 220 | About 70 | About 650 | 500-1000 |
| **Reactant ion** | $H^+$ | $OH^-$ | $H^+$ | $H^+$ | $CO_3^{2-}$ | $O^{2-}$ |
| **Fuel** | Hydrogen | Hydrogen | Hydrogen | Methanol | $H_2$, CO and/or $CH_4$ | $H_2$, CO and/or $CH_4$ |
| **Cell component** | Carbon-based | Carbon-based | Graphite-based | Carbon-based | Stainless-steel based | Ceramic |
| **Catalyst** | Platinum | Platinum | Platinum | Platinum/ruthenium | Nickel | Perovskites |
| **Electrical efficiency** | 40-50% | 60% | 37-42% | 30-40% | >50% | >50% |
| **Cell life time** | <3000 hours | <5000 hours | >5000 hours | <3000 hours | >10000 hours | >10000 hours |
| **Anode reaction** | $H_2 \rightarrow 2H^+ + 2e^-$ | $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ | $H_2 \rightarrow 2H^+ + 2e^-$ | $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$ | $H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$ | $H_2 + O^{2-} \rightarrow H_2O + 2e^-$ |
| **Cathode reaction** | $½O_2 + 2H^+ + 2e- \rightarrow H_2O$ | $½O_2 + H_2O + 2e^- \rightarrow 2OH-$ | $½O_2 + 2H^+ + 2e- \rightarrow H_2O$ | $^3/_2O_2 + 6H+ 6e^- \rightarrow 3H_2O$ | $½O_2 + CO_2 + 2e- \rightarrow CO_3^{2-}$ | $½O_2 + 2e- \rightarrow O^{2-}$ |

**Developer: Ingo Eilks, Spyros Evlogimenos, Charitos Olympios and Nicos Valanides**
**Edited by: Jack Holbrook**
Institution: ICASE
Country: UK

Fuel Cell Advantages and Disadvantages

| Advantages | Disadvantages |
|---|---|
| High electrical and total efficiency potential (much higher than the combustion engine) | Low efficiency (today) |
| Variable loads | Large research and development challenges |
| Low emissions (Zero emissions) | Short lifetime |
| Low maintenance due to no moving parts | High stack and system price |
| Low noise | Few fuel cell suppliers |
| Scalable technology | Missing fueling infrastructure |
| Combined heat and power production | Low life time and not enough operation experience |

**Developer: Ingo Eilks, Spyros Evlogimenos, Charitos Olympios and Nicos Valanides**
**Edited by: Jack Holbrook**
Institution: ICASE
Country: UK