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# What do we mean by the ”hydrogen society”?

*By Erik Hennesø, Danish Power Systems (DPS)* *Second edition, 2017*

As part of the vision about cleaner technology and a significant reduction in the greenhouse effect, initiatives to use hydrogen as fuel for a significant part of the energy sector is under development. Hydrogen is not a primary energy source but has to be produced from other sources. Even if the hydrogen technology has obvious environmental advantages, it also has to be financially viable to gain currency, and both production, storage, transport and usage require more research and development, before this goal is achieved.

## How is hydrogen produced?

**Electrolysis.** In geothermal power plants in Iceland and in areas with hydropower reserves in Greenland, where it’s possible to produce plenty of electricity, it’s reasonable to use surplus power to produce hydrogen. This is also the case in electricity networks when the electricity production exceeds the consumption, for example, in the use of windmills. At present, electrolysis is only responsible for 4 % of the total hydrogen production.

**Biological methods.** Some types of algae have an unusual photosynthesis, so that hydrogen is produced with an efficiency up to 22 %. Also, certain bacteria can produce hydrogen through fermentation processes. However, these methods are still at the experimental stage.

A better-known method is gasification of biomass, where a mixture of gasses, e.g. 30 % hydrogen, 20 % carbon monoxide and 10 % methane can be achieved. The process may not be categorized as hydrogen technology, but it’s neutral regarding the greenhouse effect.

**Natural gas and other fossil fuels.** Methane and other hydrocarbons can with water vapour be reformed to hydrogen and carbon dioxide ($CO_2$). If they originate from fossil fuels they may not be considered a part of the “hydrogen society” but they can still be useful during a transitional period until renewable sources are available to take over their function.

However, it also appears to be possible to recycle collected $CO_2$ with an electrolytic process whereby, together with water, it forms methane and oxygen. In that case, the methane can be reformed (or burnt off) in an environmentally friendly way.

## How can hydrogen be stored and transported?

**Pipelines.** Many pipelines with natural gas can be converted to hydrogen. However, the capacity is lower than for methane as hydrogen has a lower calorific value. Mixtures of natural gas and hydrogen in existing pipelines might also be considered as an option, but in many cases, it is not possible to adjust to a different caloric value.

**Pressurised containers.** The pressure bottles that are currently used (200-300 bar) are clumsy and does not have a particularly high energy content per. unit weight. However, with the use of modern composite materials it is possible to reduce the weight so they, for example, are applicable in fuel cell powered motor vehicles.

**Cooling down gasses.** Liquid hydrogen has a temperature of -253 °C at normal atmospheric pressure. The tanks must be well insulated and provided with a pressure outlet valve as continuous evaporation takes place. The discharge must take place in open air or with the use of efficient ventilation. These tanks have been tested for sizes applicable in cars, but will be more economical in larger installations, such as sea carriage between countries. In ships it is also possible to install cooling systems in order to re-use the evaporated hydrogen.

**Metal hydride compounds.** Certain metals and alloys can (as metal powders) bind hydrogen chemically. During the bonding, heat is generated and for the discharge a corresponding amount of heat is used. By choosing an alloy type where pressure and temperature match, you can utilize the waste heat of the engine or fuel cell to release the hydrogen as it is needed. In terms of volume, the storage of hydrogen is extremely compact (it may be more compact than liquid hydrogen), but the weight is poor (a few percent for the most suitable alloys). This is, to some extent, compensated for by the fact that the container have a low weight due to moderate pressure.

**Other methods of storing and transporting hydrogen.** Hydrogen can also, if necessary at a lower temperature, bind to the surface of graphite or other carbon structures. Another option is to bind hydrogen chemically, e.g. using methanol or ammonia, which can be converted to hydrogen again at the place of consumption. Some energy is wasted (lower efficiency) but on the other hand, the transportation is simple.

## What can hydrogen be used for?

Hydrogen can be used to produce electricity for domestic purposes, for transportation and in an industrial context in the following ways:

**Industry.** Many industries use hydrogen as raw material or as a process material and would benefit from a well-developed distribution system for hydrogen.

**Simple combustion.** Hydrogen can be burnt for domestic heating just like natural gas. Naturally, the vision is to use as much of the energy as possible for mechanical or electrical energy and only use the excess production for heating purposes.

**Internal combustion engines.** Many engines, for example. petrol engines, could be switched to hydrogen. The advantage will be higher efficiency as well as cleaner environment. In principle, the exhaust is pure water vapor, however, there will be a little nitrogen oxides (NOx) due to the high combustion temperature.

**Combustion engines.** Many engines, such as petrol fuelled engines, can be transformed to hydrogen. The advantages would be a higher energy efficiency and a cleaner environment. In principle, the exhaustion is pure water vapour, except for a small amount of nitrogenous oxides (NOx ) due to the high combustion temperature.

**Fuel cells.** Fuel cells are electrical batteries that are characterised by a continuously supply of the active materials on the electrodes. Just like in other batteries, the chemical process is divided into the reducing part (the cathode), where air or oxygen is added, and the oxidising part (anode) where the fuel is hydrogen. The electrodes are separated by an ionconducting electrolyte, which is usually a membrane. A single fuel cell usually yields 0.5 - 1 Volt, and therefore a battery usually consists of a stack of fuel cells, where one cell's cathode is connected to the next cell's anode, and so forth. The hydrogen may be produced in a reformer from methanol, natural gas or other simple organic compounds and be connected to the battery on site. In some types of fuel cells (DMFC) the reforming may take place directly on the surface of the electrode.

The most important types of fuel cells are Solid Oxide Fuel Cell (SOFC), which function at 700-1000 °C, and Proton Exchange Membrane Fuel Cell (PEMFC or Polymer Electrolyte Fuel Cell PEFC), which operates at under 200 °C.

**Gas turbines.** Hydrogen can be burnt in gas turbines with an energy efficiency of up to 60 %. So far this has predominantly been demonstrated on large installations (over 100 kW electricity), but smaller ones are currently being tested.

## What about safety issues?

Hydrogen is not more dangerous than natural gasses or petrol, but it reacts differently.
In a report from 2000, Danish Gas Technology Centre concludes that “when comparing the natural gas, propane, hydrogen and petrol in vehicles, hydrogen, in terms of detonation, surprisingly is more secure than petrol, propane and natural gas. Regarding the risk of ignition emissions, hydrogen is considered to be less safe in cases of in the case of greater emissions due to the low ignition energy in a large area. For smaller, slower leaks, hydrogen is considered safer than the other fuels due to its buoyancy and diffusion properties. This is based on the fact that there is always adequate ventilation.
Positive factors in relation to safety under realistic use and safety management conditions are hydrogen's significant buoyancy and diffusion properties, , relatively high ignition limit and detonation limit. The negative factors for safety are: low ignition energy, high ignition range, high flame speed and detonation capability". These factors are considered more or less significant in case of accidents.

## What about the environment?

When hydrogen is produced by electrolysis or biologically, the system is pollution-free, i.e. $CO^2$ natural. If hydrogen is produced from natural gas, an oil based product or coal, there are two kinds of pollution:

1. The raw materials contain carbon and for every carbon atom one molecule of carbon dioxide ($CO^2$) is produced, which contributes to the greenhouse effect regardless of whether the fuel is burnt in a traditional power plant, in a motor vehicle, or via a fuel cell. However, it may be sensible to use fuel cells because of the improved efficiency, so that fewer grams of fuel are used to produce a given amount of electricity.

2. Fuels can contain impurities and through the reforming process carbon monoxide (CO) and possibly nitrogenous oxides ($NO_x$) may be formed. However, the amounts are usually lower than when it’s produced by a combustion engine. If the reforming process takes place separately from the fuel cell, the last-mentioned might be considered pollution-free. For example, the environmental benefits from driving electric cars powered by hydrogen via fuel cells are very clear in urban areas. Even if the fuel is produced elsewhere with some pollution as a consequence.

## What can Danish Power Systems (DPS) offer in the field of hydrogen technology?

Most of the technologies mentioned above are within the fields of expertise in which Danish Power Systems operates and conducts research, especially:

**Electrolysis.** The energy efficiency can be improved when using special catalysts.

**Metal hydride compounds.** DPS has studied a number of metal hydrides and tested flow and thermic conditions from which we have dimensioned tanks for fuel-cell powered electric vehicles.

**Reformers.** DPS has expertise in, and is currently researching in, natural gas-to-hydrogen and methanol-to-hydrogen reformers.

**Fuel cells.** DPS has developed a new type of Polymer Electrolyte Membrane Fuel Cell (PEMFC or PEFC) using a membrane, which can operate at temperatures up to 200 °C. The most common PEMFC (with Nafion® or similar) only tolerates about 120 °C and works best at 80 °C. Thus, the new fuel cell has several advantages, such as:

- There are no problems with humidity as compared to the Nafion® types.
- At 200 °C the fuel cell tolerates carbon monoxide (CO) concentrations up to at least 3 %. In contrast, for reformer generated hydrogen purification down to approximately 10 parts per million (ppm) is required at 100 °C.
- High current densities can be achieved.
- It is easier to divert the heat and use it for e.g., room heating purposes.
- The fuel cell can be combined with a methanol-to-hydrogen reformer, which can operate at the same temperature. In this case the reformer gets the necessary heat directly from the fuel cell's excess heat generation, and over all the total energy efficiency is improved.

### Further information

Danish Power Systems (DPS) is a private development- and production company working in the fields of chemistry and electrochemistry, with administration, test facilities and production in Kvistgaard, south of Elsinore, Denmark. The company has extensive expertise regarding membranes and electrodes for fuel cells. For further information please contact daposy@daposy.dk.

### Biography

*Erik Hennesø has a M.Sc. in chemical engineering from Technical University of Denmark (DTU) and a Ph.D. in electrochemistry from DTU (1976). Furthermore, he has 40 years of industrial and university research experience in batteries and fuel cells. He is one of the founding members of Danish Power Systems.*