What is your understanding of the "Hydrogen Society"?

By Erik Hennesø, Danish Power Systems (DPS)

Various projects have been initiated, as part of the vision about cleaner technology and a reduction in the greenhouse effect, in the use of hydrogen as fuel for a significant part of the energy sector. Hydrogen is not a primary energy source (when we are not talking about nuclear power), but has to be produced from other sources. Even if the hydrogen technology has obvious environmental advantages it also has to be financially sound to gain recognition, and both production, storage, transport and usage require more research and development, before this goal is achieved.

How can hydrogen be produced?

Electrolysis

On sites where it is possible to produce plenty of electricity, such as geothermic power stations in Iceland and in areas with water power reserves in Greenland, it is appropriate to use the excess power to produce hydrogen. This is also the case in places on the grid system and at times when the electricity production exceeds demand 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 in that hydrogen is produced with an efficiency usage of up to 22%. Certain bacteria can also 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, such as 30% hydrogen, 20% carbon monoxide and 10% methane can be achieved. Strictly speaking the process may not belong to the hydrogen technology but is neutral with respect to the green house effect.

Natural gas and other fossil fuels

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

It also seems plausible to re-use 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 transformed to carry hydrogen. However, the capacity is lower than for methane as hydrogen has a lower caloric value. Mixtures of natural gas and hydrogen in existing pipelines might also be considered but for many applications modifications are not possible in order to suit different caloric values.

Pressurised containers

Currently used pressurised containers (200-300 bar) are clumsy and not particularly energy dense. However, with the application of modern composite materials it is possible to reduce the weight so that they for example, become useful for fuel cell powered motor vehicles.

Cooling down gasses

Liquid hydrogen has a temperature of -253 °C at normal atmospheric pressure. Containers must be well insulated and provided with a pressure outlet valve as continuous evaporation takes place. The outlet must take place in open air or with the use of efficient ventilation. These containers have been tested for sizes applicable in cars, but will be more economical in larger installations, such as maritime transportation between countries. In ships it is also possible to install cooling systems for re-using 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 release a corresponding amount of heat is used. By selecting a type of alloy where pressure and temperature are optimal, it is possible to use the excess heat from the motor or the fuel cells to release the hydrogen as it is needed. With respect to the volume of hydrogen, it is very compact (it can be even more compact than liquid hydrogen), but weight wise it is disadvantageous (1.2%-1.9% for the most useful alloys). This is to some extent compensated for by the container because of the moderate pressure, which can result in a lower weight.

Other methods of storing and transporting hydrogen

Hydrogen can also at a lower temperature bind to the surface of graphite or other carbon structures. Another possibility is to bind hydrogen chemically, e.g. using methanol or ammonia, which on the site of use can be converted into hydrogen. Some energy is wasted (lower efficiency) but on the other hand transportation is easy.

What can hydrogen be used for?

Hydrogen can be used for the production of 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 an auxiliary material and would benefit from a well developed distribution system for hydrogen.

Simple combustion

Hydrogen can be burnt for the purpose of 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.

Combustion engines

Many engines, such as petrol fuelled engines, can be transformed to use hydrogen instead. 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, which are characterised by the active materials on the electrodes being continuously replenished. Just like in other batteries the chemical process is divided up into the reducing part (cathode), which is supplied with air or pure oxygen, and the oxidising part (anode), where the fuel is hydrogen. The electrodes are separated by an ion conducting electrolyte, which is usually a membrane. A single fuel cell usually yields 0.5 - 1 Volt, and hence 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 operate 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 no more dangerous than natural gasses or petrol, but reacts differently. Danish Gas Center produced a report in 2000, which among other things concluded that when "comparing the fuels natural gas, propane, hydrogen and petrol in motor vehicles surprisingly, with respect to detonation, hydrogen is safer than petrol, propane and natural gas. Concerning the risk of ignition of a leak hydrogen is collectively assessed to be less safe in cases of major leaks due to its lower ignition energy in a large range. For smaller, slower leaks hydrogen is considered to be safer than the other fuels due to its buoyancy and diffusion properties. This, of course, is depending upon proper ventilation! Positive factors in relation to safety under realistic use and safety management conditions are hydrogen's significant buoyancy and diffusion properties, and relatively high ignition and detonation thresholds. The negative factors, which are considered more or less important in constructed accident scenarios, with respect to safety are the lower ignition energy, wider ignition range, high flame speed and detonation capability".

And what about the environment?

When hydrogen is produced through electrolysis or biologically then it is virtually pollution free. If hydrogen is produced from natural gas, an oil based product or coal then two kinds of pollution need to be considered:

1. The raw materials contain carbon and for every carbon atom one molecule of carbon dioxide (CO_2) is produced, which adds to the green house effect irrespective of whether the fuel is burnt in a traditional power station, in a motor vehicle, or via a fuel cell. However, it may be sensible to use fuel cells because of the enhanced energy efficiency and thus a smaller amount of fuel is required to produce a fixed 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 that produced by a combustion engine. If the reforming process takes place separately from the fuel cell then the fuel cell part may be considered almost pollution free. There will be a real environmental advantage in urban areas when driving electric cars powered by hydrogen via fuel cells, even if the fuel is produced elsewhere with some pollution as a result.

What can Danish Power Systems (DPS) offer in the context 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 enhanced using special catalysts.

- **Metal hydride compounds.** DPS has researched a variety of metal hydrides and tested flow- and thermic conditions from which specifications of dimensions for containers have been developed for use in fuel cell powered motor vehicles.

- **Reformers.** DPS has expertise in and is currently researching 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 120 °C and works best at 80 °C. Thus, the new fuel cell has a number of 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 50 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 enhanced.

Further information

Danish Power Systems (DPS) is a private consultancy and production firm based in Copenhagen, Denmark, mainly consisting of chemical and electrochemical engineers, and researchers associated with Danish Technical University. For further information regarding the development of domestic or industrial applications or commercial joint ventures, please contact daposy@daposy.dk.

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