The Hydrogen Economy

Joaquin Sitte PhD
Sitte Lab, Wellington, NZ
joaquin@sittelab.net

***Abstract*—The use of hydrogen as the main source of energy has been suggested over the last fifty years, first as as means to eliminate industrial air pollution and more recently as means to stop global warming. A simple analysis shows that hydrogen despite of qualifying as the *ultimate* clean fuel is not useful enough to take the role of main energy source for our technical civilisation.**

I. Introduction

In a *Hydrogen Economy* the main carrier of energy is hydrogen, instead of fossil fuels. Hydrogen combustion does not release carbon dioxide into the atmosphere. *Burning* hydrogen only leaves behind water. Hydrogen is the ultimate *clean* fuel. Furthermore, hydrogen is abundant. It is the most common element on earth, and in the universe. Hydrogen can be burnt for heating or in internal combustion engines for doing mechanical work. Hydrogen can also be directly converted to electricity in *fuel cells*.

Burning hydrogen means letting it react with oxygen to produce water and energy

$$2H_2 + O_2 \rightarrow 2H_2O + \text{energy} \tag{1}$$

The reaction of 4g (2 mol) of hydrogen with oxygen to form water releases $572kJ$ of energy. Thus we can say that the energy density (energy content per unit mass) of hydrogen is $572kJ/4g = 186kJ/g$

For comparison let us take a fossil fuel such as natural gas. Natural gas consists mostly of methane. Methane, CH_4, is the lightest hydrocarbon molecule and reacts with oxygen to produce carbon dioxide, water and energy.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{energy} \tag{2}$$

The reaction of $16g$ (1 mol) of methane with oxygen, at standard conditions, releases $891kJ$ of energy. The energy density of methane is $891kJ/16g = 55,69kJ/g$, which is less than a third of the energy density of hydrogen. However if we take the energy per volume it is the other way around. At standard conditions both hydrogen and methane are in gaseous state. This means that a mole of hydrogen and a mole of methane have the same volume. Therefore the energy per unit volume of methane is $891/286 = 3.12$ times that of hydrogen; just because methane is much heavier than hydrogen.

The idea of a *Hydrogen Economy* has been around since the early 1970s. Why is it then that we do not yet live in an Hydrogen Economy? There are a few reasons that make hydrogen not as useful as it promises to be at first thought.

The first is that, despite of being abundant as an element, hydrogen it is not found in large quantities in gaseous state ready to burn. Instead, hydrogen is bound in other molecules, such as water. Thus, if we want large quantities of hydrogen we have to *extract* it from the molecules in which it is bound. For example by splitting water into oxygen gas and hydrogen gas by electrolysis. Producing molecular hydrogen takes energy that has to come from somewhere. The energy spent in producing hydrogen gas can later be recovered by letting it *burn* with oxygen to from water again. Therefore hydrogen serves as a store for energy generated otherwise.

The whole point of an Hydrogen Economy is that the energy it uses does not contribute to global warming. Therefore the hydrogen has to be produced without CO_2 emissions. If we use electrolisis of water for producing hydrogen the required electricity has to come from renewable resources (photovoltaic solar panels, wind, geothermal power stations, etc.) But then, why wouldn't we use this electricity directly to drive an *electrified* economy? The only reason would be that hydrogen can store energy that could then be transported to where energy is needed and be available any time. The same thing could be achieved with batteries and pumped hydroelectric generation.

Industrial quantities of hydrogen are used in oil refining and fertiliser production. The methods of generating this hydrogen gas produce carbon dioxide emissions.

Splitting water by electrolysis takes about 260 kJ/mol which is about the same as the energy released by burning H_2.

The amount of hydrogen required to meet the yearly average per capita energy consumption of 76 GJ is 530 kg per person.

There are two main processes for hydrogen gas production: methane or coal steam reformation and electrolysis. In methane or coal steam reformation coal or methane and steam (water) are heated at high pressure in the presence of a catalyst to produce CO_2 and H_2. The reaction is endothermic, of course, and thus needs a supply of energy. If the energy comes from burning fossil fuel, then there is CO_2 release in the fossil fuel combustion and, in case of the methane reformation, there CO_2 release in the process of separating the hydrogen from the water and the methane. The coal or methane steam reformation method of hydrogen production is therefore inappropriate for the reduction of CO_2 emissions, even if renewable energy is used to provide the required heat for the reaction.

Only water electrolysis using renewable electricity can supply hydrogen without CO_2 emission.

If a high efficiency photocatalityc cell for water splitting can be developed, the in conjunction with a fuel cell, which are already very efficient, the photo catalytic cell could replace silicon solar panels!

II. Conclusion

The combustion of hydrogen releases energy and leaves behind only water and no CO_2. This makes hydrogen a *clean* fuel. However, hydrogen gas is not found in nature ready to burn, instead it has to be produced first. The energy required for its production can be recovered later by burning it. Thus, hydrogen is not a source of energy but a medium for intermediate energy storage. Only if there is no CO_2 released in the hydrogen production, as is the case in the electrolysis of water using solar electricity, does hydrogen qualify as a *clean* fuel. Hydrogen can be converted back into electricity with fuel cells. Because there is is loss of energy in hydrogen production as well as in its conversion back to energy it is far more efficient to use the solar electricity directly. Hydrogen may only be useful in case when the direct use of solar electricity impractical, for example in long haul air transport.