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Environmental Impact of the Widespread Use of Hydrogen as an Energy Carrier

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Abstract – *The use of hydrogen as an alternative energy source is very promising mainly because it is considered a fully environmentally-friendly alternative fuel. Although no CO_2 is produced by its usage, hydrogen production does emit greenhouse gases and use substantial amounts of energy. On the other hand, there are significant losses during production, distribution and utilization of hydrogen, that result in the release of considerable amounts of hydrogen in the environment. This study focuses on the environmental aspects of the entire hydrogen chain to investigate the overall effects of a global hydrogen economy on the environment. Since hydrogen should be preferably produced from a non-carbon source (no greenhouse gas emissions), the use of renewable energy sources instead of conventional fuels is proposed.*

Keywords*: Hydrogen, Emissions, Environment, Greenhouse Effect*

I. Introduction

The use of hydrogen as an alternative fuel could significantly reduce harmful emissions arising from carbon containing fossil fuels (carbon dioxide and monoxide, NOx, etc). Hydrogen can be burned as a conventional fuel in engines or boilers to provide heat and power. In these cases, small amounts of pollutants are emitted, such as NOx due to high-temperature reactions involving the air’s nitrogen, however these emissions are far lower than those of traditional fossil fuels.

Hydrogen can also be used in a fuel cell to produce electricity directly. Here, the only emission is harmless water vapour. Obviously, the major benefit of hydrogen use is that it does not produce pollutants and therefore all emissions depend only on its combustion method.

Hydrogen should be considered an energy carrier, much like electricity rather than a fuel, because it must be produced from other widely-available compounds [1].

The two most abundant hydrogen-containing compounds are water and hydrocarbons. Producing hydrogen from either of these requires energy usually derived from conventional energy sources that emit the greenhouse gas carbon dioxide as a by-product [2].

As concern increases about possible climate change and reductions in greenhouse gas emissions are implemented in response to the Kyoto protocol, novel methods are required for producing hydrogen without emitting CO_2. It is therefore important to consider the complete chain of processes for hydrogen production and usage, to detect whether greenhouse gas emissions would rise or fall if hydrogen was substituted for other energy carriers. By assuming a 10% loss of hydrogen throughout the whole production, distribution and utilisation chain, it is estimated that hydrogen emissions would be about four times higher than those produced by the use of fossil energy resources in a hydrogen energy economy [3].

II. Emissions During Hydrogen Production

As mentioned above, hydrogen as an energy carrier must be produced using some form of primary fossil fuel, mainly oil and coal [4]. Since these two sources are not environmentally-friendly, several alternatives have been also considered for zero or nearly zero emissions. In the early 1970s, nuclear energy was seen as the most promising potential source for hydrogen production, however the status of the nuclear industry has changed considerably since then and is no longer viewed with the same enthusiasm in many quarters.

The other popular sources for producing hydrogen are renewables such as hydropower, solar or wind power.

These sources generate electric power that can be used to split water into hydrogen and oxygen. Although the requirements of solar-electrolysis systems can be satisfied in terms of area and sunlight, the water for electrolysis would need to be transported to the site and the resulting hydrogen transported long distances to its point of use, leading to a non-effective cost system [5]. Other renewable energy sources, such as wind and biomass, are still at experimental scale in terms of cost effective hydrogen production.

Finally, although the technology to produce hydrogen from renewable energy sources is well understood, it is not yet mature enough to produce hydrogen in large amounts because this technology is currently too expensive for anything other than isolated markets [6].

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The above methods all use conventional (oil, coal), nuclear and/or renewable (hydropower, solar, wind) energy to electrolyze water and subsequently produce hydrogen. Another hydrogen production method is the steam-reforming of hydrocarbons and alcohols (methane, methanol, ethanol, etc). According to the available data on the thermodynamics of steam-reforming, the equilibrium gas mixture may contain only three components of noticeable concentration in the reformer: hydrogen, steam and methane. Thus, the generalized reaction for hydrocarbons and alcohols can be written as [7]:

$$\begin{aligned} & C_n H_{2n+2} O_p + m\, H_2O \rightarrow \\ & \quad n CO_2 + (3n+1-p)\, H_2 + (m-2n+p)\, H_2O \end{aligned} \tag{1}$$

where p=1 corresponds to alcohols and p=0 to hydrocarbons. However, the process is endothermic and the heat required is typically supplied by burning some of the feeding fuel or the hydrogen-rich product. The hydrogen is then purified to 99.9% using a pressure-swing-adsorption plant. The released CO_2 is first captured using a solvent such as activated methyl diethanolamine. Substantial amounts of energy are needed to regenerate the solvent but most of this can be obtained from the waste heat of the plant itself. The CO_2 is then compressed and liquefied before being injected into a pipeline and transported to a suitable sequestration site.

The use of this technology enables the plant to operate with minimum greenhouse gas emissions [8]. Considering the amounts of carbon dioxide produced by such a process are much lower than those produced when using conventional fuels, and that the cost of transporting CO_2 is less than moving quantities of either hydrogen or electricity, the use of this hydrogen production technique would aid enable a soft transition to a hydrogen-based economy.

Finally, producers and users should also be familiarized with the characteristics of hydrogen, while enabling suppliers to phase in the introduction of this novel technology in smoothly and economically.

III. Hydrogen Losses During the Production/Distribution/Utilization Chain

Hydrogen production must be environmentally benign without effecting natural cycles and balances. The hydrogen content of the atmosphere is 180 – 200 × 10^{12} g H_2 with a tropospheric lifetime of 4 - 9 years depending on the actual OH-concentration. A typical increase of 0.5 % per year, corresponding to 0.6 - 1.6 × 10^{12} g H_2 per year, has been reported, regarding the composition of the atmosphere in planetary basis and its hydrogen content [9].

Hydrogen emitters are natural, anthropogenic and photochemical.

The natural sources are emissions from volcanoes, geothermal steam, oceans, and soils with aerobic bacteria. The contribution of these sources to overall H_2-emissions is estimated to be 2 - 5 × 10^{12} g H_2 per year [9]. The most significant anthropogenic source is uncompleted combustion, which is estimated to emit 20 – 80 × 10^{12} g H_2 per year, mainly due to fossil fuel usage [9]. Lastly, photochemical emitters are both natural and anthropogenic and the main sources include methane oxidation (contributing 11 - 16 × 10^{12} g H_2 per year), and the destruction of natural isoprene and terpene emissions, mainly from vegetation (contributing 10 - 35 × 10^{12} g H_2 per year).

Most emitted hydrogen is destroyed in the troposphere. Chemical destruction is estimated to be 10 – 24 × 10^{12} g H_2 per year, where the resulting products are involved in chemical processes [3]. The hydrogen content of the stratosphere and mesosphere amounts to about 30 × 10^{12} g H_2, with a strongly varying lifetime of between 1 and 100 years (depending on chemical composition and temperature). Measurements of isotopic composition indicate that the hydrogen and water vapour found in the upper stratosphere result mostly from hydrocarbon decomposition, and not from tropospheric diffusion of H_2 or H_2O.

At heights of 40 - 80 km, decomposition of H_2 is the dominant destruction mechanism. Above 140 km, atomic hydrogen remains the most abundant chemical compound with a loss flux of 16 - 31 × 10^7 particles/cm^2, corresponding to a total loss of 50 - 100 × 10^9 g hydrogen per year [10]. Current losses of gaseous hydrogen are far below 1 %, while those of liquid hydrogen depend on the handling method and are reported to be between 1 - 10 %. In the worst case, an annual amount of 130 × 10^{12} g H_2 per year is predicted, almost double current hydrogen emissions. On the other hand, a more realistic forecast of 2 - 3 % hydrogen loss would result in 26 – 40 × 10^{12} g H_2 per year, which is comparable to current hydrogen emissions from fossil fuel combustion.

IV. Concluding Remarks

Although its usage has zero emissions, it is clear that hydrogen cannot be considered a completely environmentally-friendly energy source. It is necessary to consider the entire production/distribution/utilization chain to realistically estimate the expected environmental impact of a global hydrogen economy. From an environmental point of view, the production of hydrogen using non-fossil fuel electricity is the favourable option; however it does add substantial extra costs and inefficiencies between energy source and end use.

Additionally, a future renewable energy economy with today's total energy consumption but supplied completely by renewables with a 50 % share of hydrogen, results in water vapour and molecular hydrogen emissions which are comparable to present emissions of these trace gases from fossil fuel combustion.

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