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Hydrogen: A brief overview on its sources, production and environmental impact

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ABSTRACT

A brief overview is presented involving the terms of availability of hydrogen, its properties and possible sources and its production methods, and finally, its relationship with renewable energy utilisation, environment and climate.

Solar hydrogen, preferably obtained from water, is confirmed once more to be the most environment and climate compatible (causing the least damage), energy source; though not necessarily the most economic one. Production cost of hydrogen obtained from terrestrial biomass, is not the lowest either, however carbon-neutral feature of terrestrial biomass renders it highly desirable in view of steep rise in global temperature.

Introduction

Growth in population and economy in the world are directly proportional to fossil fuel utilisation and environment deterioration [1–3]. The present situation in this relationship is shown in Table 1 [4–8]. Presently, 81% of total primary energy supply, and 66% of electricity generation are based on fossil fuels (coal, natural gas and oil), leading to almost 100% of CO_2 emissions in the world [9]. At current consumption rates, world's proven coal, oil and natural gas reserves are expected to last for approximately 200, 40 and 60 years. Peak production rates of liquid fuels, and natural gas seem likely to occur in 2005–2015 and in 2030 [10]. Afterwards, the overall resources will be in decline.

Sustainability of conventional fuels has been a major concern because of their depletable nature. Presently, the concern is rather focused on the rise in global temperature mainly due to GHG (greenhouse gas) emissions resulting from their processing and combustion [11].

Owing to efforts in the direction of transition to low carbon energy technology, experts hope to "bend down" the GHG emission curve by 2020 [12]. Cutting down the rate of global warming to 1.5 °C is another goal on which IPCC and COP are jointly working [13,14]. Using hydrogen as a fuel will definitely contribute to that effect.

A "sustainable energy source" would be one that is not substantially depleted by continued use, does not involve significant pollutant emissions or other environmental problems, health hazards or social injustices [15]. Renewable energy forms, especially hydrogen produced from water using solar energy comes very close to this definition.

Various studies are available involving all aspects of hydrogen technology and the rationale for the hydrogen energy system [16–21] including the present energy system, its depletable fossil fuels and their adverse effects on the

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Table 1 – Worldwide fossil fuel consumption and environmental damage 2015–2016 [4–8].

Fossil fuel used [4]	(in 10^{18} J per year)
Coal	112.5
Petroleum	208.6
Natural gas	126.6
Total	447.8
Damage on Environment [5,6]	(in 10^9 $)
Coal	522.0
Petroleum	442.8
Natural gas	252.0
Total	1216.8
Effect on Economy and Society	
Population (total) [7]	7.4×10^9
Distribution of damage	$ 164.4 per capita
Gross world product (WP) [8]	$ 74,152.5 $\times 10^9$
Distribution of WP	$ 10,020.6 per capita
Total damage/WP	0.0164

Table 2 – Properties of hydrogen [16].

Molecular weight	2.016	Amu
ρ (gas)	0.0838	kg/m^3
HHV	141.90	MJ/kg
	11.89	MJ/m^3
LHV	119.90	MJ/kg
	10.05	MJ/m^3
T (boiling)	20.3	K
ρ (liquid)	70.8	kg/m^3
Critical point		
temperature	32.94	K
pressure	1284	kN/m^2
density	31.40	kg/m^3
T (self-ignition)	858	K
Ignition limits in air	4–75	(vol%)
Stoichiometric mixture in air	29.53	(vol%)
T (flame)	2318	K
D	0.61	cm^2/s
C_P	14.89	kJ (kg.K)

environment and climate change [22], the critical role of hydrogen as an energy currency [23], and issues related to climate change and hydrogen energy [1–3].

In the present study, a brief overview on hydrogen is presented including its sources, main production methods, and positive impact on the environment and global warming, with emphasis on rapidly informing the readers especially who are new to or outside of the field regarding the urgency of acceptance of hydrogen as an alternative. Possibility of wider information on the subjects covered is offered through cited references most of which are review papers.

Hydrogen

Hydrogen is not readily available on Earth in elemental form. However, it can be produced from its compounds found in natural or industrial sources. Hydrogen is the most abundant element in the universe, making up approximately 75% of all matter [24]. In Earth's crust, it is the tenth most abundant element, and it is found in combination with other elements. Hydrogen is not found in Earth's atmosphere since the Earth's gravitational pull is not strong enough (unlike Jupiter and Saturn) to retain the light weight H_2 molecules. Scientist believe that helium and hydrogen, were the first elements formed in the early stages of cosmic evolution.

Three isotopes of hydrogen are available: protium, deuterium and tritium. Consisting of one proton and one electron, protium is the main component of hydrogen, the simplest element. Although it is the lightest element, hydrogen has the highest energy content per unit mass among all fuels. Some of its properties are given in Table 2 [16].

Hydrogen is scarce on Earth's surface (0.14%), and it is found only in trace amounts (0.07%) in the atmosphere. Though quite uncommon, presence of hydrogen has been encountered in larger amounts in some wells containing nitrogen [25]. Small amounts of hydrogen may exist in mixtures with natural gas in crustal reservoirs.

Although a variety of technology at different scales have been developed for hydrogen as an energy carrier, it is widely used as chemical feedstocks in the industry.

Wide-scale use of hydrogen as a fuel would lead to escalation in production capacity by several folds. The energy input for hydrogen production is always greater than the energy output from hydrogen. Consequently, energy, as well as feed stocks, will be required to obtain hydrogen. Considering the levels of energy consumption in the world and the adverse effects of the present fossil based energy sources on the environment, renewable energy sources are ideal for sustainable hydrogen production [26,27].

Hydrogen production methods

Hydrogen gas has an important role in industrial processes, mostly as feedstocks. Presently, fossil fuels constitute the main sources for hydrogen production. Chemical grade hydrogen is possible by water electrolysis. Approximately 95% of the hydrogen produced is used captively [24]. As utilisation of hydrogen as a fuel grows and as global temperature keeps rising, it will be necessary to produce it at larger scale using diminishing amounts of fossil resources. Several detailed reviews on overall evaluation of hydrogen production methods are available [18,28–41].

Methods are available for hydrogen production from fossil fuels [16,42–63], especially from methane, the main constituent of natural gas [16,47–53,55–59] and coal [16,42,58,61–63], from biomass [16,60,63–80], water [16,81–137]; compounds like metal hydrides [16,138–142] and H_2S [143–152] and biological sources [16,153–165].

Various studies on hydrogen production costs are also available [11,21,28,34–37,40,41,71], allowing comparison of methods [18,28,107]. The results for solar hydrogen from water are presented in Table 3 [107] as an example.

Fossil based hydrogen production methods have commercialized mature technologies established at higher efficiency and lower product cost ranges. Natural gas is mostly methane, and the SMR (steam reforming of methane) process is widely used for hydrogen production from natural gas, at an efficiency range of 65–75%. Another process is partial oxidation of natural gas which has lower efficiency 50% [16]. For

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