FUTURE'S FUEL BE SOLAR HYDROGEN[1]

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Abstract

Earth runs out of fossil fuels within the foreseeable future. The production of nuclear energy is risky. Hydrogen produced by solar energy through mainly electrolysis is an attractive – maybe the best – alternative to fossil fuels. Solar hydrogen is abundant and everlasting energy carrier. As a fuel it is clean and has the highest caloricity. In spite of high price of solar hydrogen nowadays it is considered to become economically competitive fuel in the next century.

Keywords: economy, electrolysis, energy, fuel, hydrogen, solar cell.

Introduction

According to the most optimistic estimation Earth's fossil fuels provide energy for the next 500 years, pessimistic forecast, however, says humanity runs out of fossil fuels within two centuries and the oil fields will empty in 40...50 years. Production of the fission nuclear energy is risky. The controlled and industrialized fusion nuclear energy production might be realized in the distant future. While the dramatically increasing pollution due to huge consumption of fossil fuels arises social and sanitary problems. All these probably cause rise in prices and problems in supply of energy moreover social and economical trouble all over the world.

There is no doubt that instead of fossil fuel a far better fuel which eliminates the pollution, saves the environment and has the highest caloricity should decrease the expecting trouble not only in supply of energy, but in the societies and the economy as well.

[1]Based on 'Jövőnk energiahordozója a szoláris hidrogén' by dr. László Fábri (*Magyar Energetika,* 1993/3).

The Solar Hydrogen as Fuel is an Attractive Alternative

Solar hydrogen technology (hydrogen production by solar energy from water or other material containing hydrogen) seems to eliminate the problems mentioned above. Since on the one hand solar energy is clean, friendly with environment, abundant (about $2 \times 106\text{km}^2$, 5 % of unused desert area would suffice to supply the yearly total energy demand of the world in the early nineties) and practically everlasting, recirculating energy carrier for humanity, further it can not be possessed or disposed by certain state/s or person/s and on the other hand solar hydrogen is storable, transportable – opposite to thermal or electrical energy produced by solar energy – and can be consumed in accordance with demand at the right place and time, further the firing of hydrogen is pollution-free if small quantity of so called therrnic nitrogen oxides (NO_x) springing when hydrogen burns at high temperature (above 850...1000 °C) isn't considered. By means of catalytic hydrogen firing at low temperature or its firing with pure oxygen, however, the springing of the nitrogen oxides can be eliminated [23].

Hydrogen is the best fuel or energy carrier in respect of the combustion technique. Control of its feeding is easy and when burning the temperature can reach 2000...2700 °C that is suitable for flame cutting. It has the highest caloricity that is 2.4...8.4-fold larger than the traditional fuels have (*Table 1*). The byproduct of burning hydrogen is water that doesn't need fume scrubber and waste container or storage. Moreover hydrogen can be used without major modifications in nowadays existing application which ones consume fossil fuel.

The disadvantages of hydrogen are its low density and explosiveness. Hydrogen gas is 14-fold lighter than air. Because of this hydrogen of large quantity needs huge storage capacity. Calculating on the base of heat value one litre of heating oil holds energy that equals the energy of one cubic metre of hydrogen at 3.92 bar pressure or the energy of one litre hydrogen at 3920.1 bar pressure. The above mentioned oil and hydrogen volumes are equivalent ones because mass in them holds equal energy (*Table 2*).

From point of explosiveness the hydrogen is dangerous when its mixture with oxygen exists at high temperature (above 500 °C). At moderate temperature (below 100 °C) hydrogen can be handled safely. Due to its low density the hydrogen produces combustible fuel clouds much slower than methane or propane [4].

Table 1
Material properties of different fuels [1]

Fuel	Combustion heat	Heat value	Density
	MJ/kg	MJ/kg	$kg/Nm^3(m^3)$
Hydrogen	141.974	119.617	0.09
Methane	55.601	49.949	0.717
Ethane	51.598	47.436	1.356
Propane	50.409	46.348	2.019
n-Butane	49.572	45.720	2.703
Acetylene	50.367	48.651	1.101
Benzine	45.217	42.035	760
Gas oil	44.715	41.843	870
Heating oil	44.380	41.930	925
Black coal	34.750	31.275	1270
Brown coal	28.470	20.725	965
Lignite	27.633	19.687	
Peat	22.609	14.528	120
Wood charcoal	30.564	28.596	200;1200(compact)
Wood	18.841	14.277	400...900

Table 2
Related state variables, heat value and equivalent heating oil volume (Ehov) of hydrogen

Pressure	Temperature	Density	Heat value	Ehov
bar	°C	kg/m^3	MJ/m^3	l_{oil}/m^3_{hyd}
1.013	0	0.09	10.765	0.28
3.92	20	0.324	38.785	1.00
10	20	0.827	98.923	2.55
100	20	8.27	989.233	25.53
150	20	12.41	1484.447	38.31
200	20	16.54	1978.465	51.05
3920.1	20	324.25	38785.250	1000.00

State of the R & D of the Solar Hydrogen Technology

Solar hydrogen is produced by solar energy through photolysis, artificial photosynthesis, thermal split and mainly electrolysis.

The beginning of the intensive research and development of the water electrolysis solar hydrogen technology can be dated from the eighties. Early in the last decade a joint agreement under the name SOLARES was initiated by Saudi Arabia and USA to develop photovoltaic technology. In 1986 Saudi-German plan, by name HYSOLAR was launched for the research and development of the complete water electrolysis solar hydrogen technology [2]. Hydrogen storage of large capacity and suitable for commercialization is investigated at Syracuse University in New York State, USA [3]. For safety's sake hydrogen detectors and elimination devices have been developed, although explosive hydrogen–air mixture comes into existence less rarely than explosive natural gas and air mixture by the researcher's opinion at University of Miami [4]. The optimization of the entire technology, and the analysis of the life duration of the components of the photovoltaic-electrolysis system are performed [5,6]. Among Siemens/Germany, Sanyo, Kyocera/Japan, SOLAREX/USA firms manufacturing solar cells of large quantity the latter one, which has experience of 20 years making photovoltaic modules, has finished the plan of mass production of the solar cells with efficiency 9...10 % and works to create its production line [20].

Photochemical processes for producing solar hydrogen or methane are photolysis discovered in 1973 and the artificial photosynthesis invented in 1979. Photolysis is a method for hydrogen production through crack of water or other material containing hydrogen by means of sunlight and catalyzer or photocathode or semiconductor septum. Their efficiency is about 10 % [7..9]. Methane can be produced by artificial photosynthesis from water and carbon dioxide. The efficiency of 12 % of the process has been attained in laboratory, and as far as known at present the efficiency is limited to 30 % [10].

The experiments of the thermal splitting of water began in 1977 and they were in the same stage in 1991 [11]. The technology of above 1700 K temperature has no expectation for industrial application.

The Economy of the Solar Hydrogen through Electrolysis and Outlook of Hungary in this Field

The present day production cost of solar hydrogen is manifold larger than the price of fossil fuels because the efficiency of the hydrogen production process is very low.

To produce one Nm^3 hydrogen it needs 4...4.5 kWh electrical energy [12] which solar cells are capable of producing from solar energy at conversion efficiency of 8–12 % recently [4, 13., 17, 20]. The newly developed single crystal silicon solar cells were tested at the acceptable efficiency 24...28 % [14, 18, 20]. The conversion efficiency of concentration and multijunction GaAs/Si cells is about 31 % and nearly 35 % in case of GaAs/GaSb cells [20].

The water electrolysis is an already reliable and efficient technology nowadays. Relating the combustion heat of hydrogen to electrical energy needed for hydrogen production through electrolysis the efficiency is between 78 and 89 %. The energy transformation of loss 11 ... 22 % can be said very low, though the efficiency and the life time of the apparatus of water electrolysis can be increased by little development. A water electrolysis process for hydrogen producing at conversion efficiency of 92.4 % (3.84 kWh/Nm^3) has been reported by the Germans [4]. The factors, however, have second rate importance in economical competition considering the modest energy conversion capacity of the solar cells and, in consequence of this, the low efficiency (8 ... 10 %) of the water electrolysis solar hydrogen technology.

In case of Hungary the outlook of the solar hydrogen production isn't the worst one. There are large, uncultivated sandy areas in Kiskunság and Nyirség. Those are suitable for building large-scale solar hydrogen plants and can provide raw material for manufacture of solar cells.

The regions mentioned above have smaller areas and insolation than the large subtropical (Sahara/North Africa, Arabic/Saudi Arabia, Namib, Kalahari/Namibia, Thar/India, Atacama/Chile, Mexican, Australian) and temperate zone (Kara-, Kizil-kum/Turanian Plain, Gobi, Takla-Makan/China Nevada, Arizona/USA) deserts have. Those ones are, however, home resources, which may not be neglected. *Table 3* shows the mass, the energy and the equivalent heating oil volume calculated on the base of heat value of the available solar hydrogen produced by one sq. metre solar cell a year at its current and expected energy conversion efficiency.

Table 3
Production of the solar hydrogen (H_2) and its equivalent heating oil volume (ehov)

Region		Kiskunság, Nyírség		Subtropical deserts		Temp. zone deserts	
Insolation,	kWh/m^{2}an	1200-1300		2000-2500		1700-2000	
H_2 mass,	kg/m^{2}an	2.6$^+$	7.3*	4.8$^+$	13.1*	3.9$^+$	10.8*
H_2 energy,	kWh/m^{2}an	86$^+$	243*	160$^+$	435*	130$^+$	359*
H_2 ehov,	l/m^{2}an	8.2$^+$	22.6*	14.7$^+$	40.6*	12.1$^+$	33.4*

(The amounts are calculated by the current (+) and the expected (*) energy conversion efficiency factors of the solar cells, respectively.)

On the base of the data of *Table 3* and the prices of the first quarter of the year 1993 (commodities price of solar cells is \$ 360/m^2, of heating oil is \$ 0.25 ... 0.32/l [20], quotation of heating oil is \$ 0.16 ... 0.17/l [21]) it can be laid down the production of solar hydrogen through water electrolysis that is not profitable nowadays. The energy of solar hydrogen produced by one sq. metre solar cell a year equals the energy held by heating oil of value \$ 2 ... 4.7. By means of this amount and *the cost of solar cells only* out of the cost of the whole system the payback time can be calculated between 76 and 180 years depending on the location of the system.

The technology will not be profitable even in the near future because the efficiency of the industrially utilizable solar cell manufactured by a large scale won't be increased by leaps and bounds and/or its price won't certainly slump. Probably the solar hydrogen produced by more effective photovoltaic modules will be economically competitive within 50 ... 60 years. Since the prices of fuels or energy carriers might rise 10 ... 20-fold higher than present ones and the cost of solar cells might shrink one tenth of the today's ones till the middle of next century. The estimation is not extreme if the rise in price of crude oil of the last two decades at the rate nine and the drop in cost of solar cells at rate one seventh between 1978 and 1993 (see *Table 4*) further the commercial pre-price \$ 100/m^2 (\$ 1/Wp) calculated by SOLAREX [20], the firm which sets up mass production lines of solar cells, are considered in the extrapolation. The increase in price of the fuels is claimed by the energy tax launched by European Community to combat warming up of the atmosphere. If approved the energy tax would start \$ 3 a barrel (\$ 0.019/l) of oil equivalent rising to \$ 10 a barrel (\$ 0.063/l) by 2000. The initiation of the tax is pondered by USA and Japan, too [22]. Last value of the tax is half the current price of crude oil.

Table 4
The change in price of the crude oil and the solar cells between 1973 and 1993 [13, 15, 19..21]

Oil,	\$/barrel	2.23(1972-3),	29.0(1983),	20.5(1993)
	\$/l	0.014(1972-3),	0.18(1983),	0.13(1993)
Solar cell,	\$/m^2	2400-2500(1978),	450-550(1988),	360(1993)

In the far future, prospectively in the second half of the next century, when the price of the fossil fuels can not be afforded because of flat oil fields and the pollution of the environment the solar hydrogen as energy carrier, however, may attain a monopoly position.

Conclusion

In spite of its disadvantages and present expensive production through solar energy the hydrogen is a first class energy carrier because hydrogen is abundant and practically everlasting, recirculating fuel that can be produced by means of clean solar energy safely in large quantity year after year on Earth. Further it is storable, transportable and can be consumed in accordance with demand at the right place and time moreover its firing is pollution-free and environmentally friendly process and it has the highest caloricity among the non-nuclear energy carriers. Thus the solar hydrogen as a fuel seems to eliminate the energy supply and sanitary problems of humanity.

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