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Economic assessment and prospect of hydrogen generated by OTEC as future fuel

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ABSTRACT

Hydrogen used for production of electricity through electrolysis using renewable energy systems is a costlier proposition. To date 96% of hydrogen production occurs from steam reformation of fossil fuels. Water splitting method from high temperature cracking, photo electrolysis, or biological decomposition processes, are in the research stage.

Life cycle cost analysis on hydrogen economy as transport fuel with fuel cell combine, including resolving its storage and transportation problems with cost of hydrogen production from power generated using different types of Ocean Thermal Energy Conversion (OTEC) plants, are evaluated. Scope of availability of hydrogen refuelling station from 100 MW (net power) OTEC plant could be determined.

Advancement in OTEC technology could help in developing 2nd/3rd generation plants (using solar hybrid OTEC; Uehara cycle). The scope of by-product availability can make its electricity production cost much cheaper and would make a viable proposition in producing OTEC powered hydrogen. This is suggested to resolve the challenges in hydrogen production economy.

Introduction

Economic advancement of countries have been identified from their quantum of energy use. Such energy sources to date are mostly from fossil fuels, mainly for their commercial viability. But this invokes not only the risk of global warming from huge carbon equivalent emission, but threatens sustainable development from depletion of the very fossil fuel itself, in not far off future. Present per capita emission of carbon equivalent has been estimated to be 1.1 metric ton as the global annual average [15]. With growing world population reaching 9 billion by 2050 [5], this carbon equivalent emission value is likely to reach 9.9 billion metric ton, with proportionate depletion of fossil fuel resources from their growing use to meet the economic growth. It has thus become necessary to find the best way to rein in emission and also to find viable alternate energy source that can provide economic growth with assured sustainable development, as well.

Abbreviations: BEV, battery electric vehicle; ECPB, electron coupled proton buffer; FC, fuel cell; FCEV, fuel cell electric vehicle; GHG, greenhouse gas; HER, hydrogen evolving reaction; IEA, International Energy Agency; ICE, internal combustion engine; LCCA, life cycle cost analysis; NG, natural gas; NREL, National Renewable Energy Laboratory; OER, oxygen evolving reaction; OTEC, Ocean Thermal Energy Conversion; PEM, polymer electrolyte membrane; PEC, photoelectrochemical conversion; PHEV, plug-in hybrid electric vehicle; RE, renewable energy; R&D, research and development; RO, reverse osmosis; OC-OTEC, open cycle ocean thermal energy conversion; SOTEC, solar hybridization with ocean thermal energy conversion; SR, steam reforming; TWh, terawatt hour.

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In this context, use of hydrogen as the fuel source, that can be availed by splitting of water and also leaves behind nothing but water on its liberation of the energy, has been identified to be the future energy source in the new millennium. It ensures not only the energy supply and security, but also climate stewardship with ensured sustainability, with particular inclusion of transport sector providing mobile fuel [12].

It may be relevant to add in this context that hydrogen though an environmentally clean fuel, which leaves behind only water on its combustion with liberation of energy, is available only in the combined form with water or hydrocarbons. Hence, though its resource is almost inexhaustible it would always require energy input, either conventional fossil fuels or renewable energy for its production. Since it can be produced passing electric current in water, and can also be used to generate electricity through fuel cells hence it is considered to be instrumental in the storage of electricity, which unlike battery does not require periodic charging to derive power from it.

In view of the fact that hydrogen is a clean fuel with many advantages for sustainable growth, the International Energy Agency (IEA), started to promote hydrogen from 1977, with measures to meet the different challenges faced on its production from carbon free sources, as also sort out its storage problems and explore its scope of use as a clean fuel source [12]. But it has not yet achieved commercial success except for small scale trials as transport fuel, which still remains in the experimental stage.

It is thus needed to assess the present status of development on the prospect of hydrogen emerging as the future clean fuel, particularly the economic evaluation on its productions from the different types of renewable energy sources including Ocean Thermal Energy Conversion (OTEC) systems, and examine prospect of its use in different fields.

Based on the above discussions, it has been proposed to take up the following studies.

1. Present status on generation of hydrogen from different sources both in commercial scale as well as on indigenous R&D efforts on the same.
2. Its production from Renewable Energy (RE) sources including OTEC, as also from indigenous non-carbon sources, with their economic assessment.
3. Present day consumption of hydrogen generated from the above routes.
4. Economic evaluation of hydrogen for use as transport fuel.
5. Economic evaluation of hydrogen generated by OTEC power.
6. Scope of cost reduction of power generated from OTEC.
7. Aspects on hydrogen storage problems and their economy.
8. Identification of green areas of research for achieving economic gains.

A brief resume on above studies are appended below.

Present methods of production of hydrogen

Present production of hydrogen is mainly from the following six sources.

1. Steam reforming (SR) with coal.
2. Steam reforming of natural gas.
3. Steam reforming of naphtha.
4. Biomass decomposition.
5. Electrolysis of water.
6. Water splitting by various indigenous methods, like high temperature cracking, photo-electrolysis, or biological processes – though all these methods having promise are still in the R&D stage or, in pilot plant scale study only.

A brief resume of the above methods are stated below, including their merits and demerits.

Steam reforming with coal/gasification

Steam passed over heated coal under pressure with controlled amount of oxygen, breaks down yielding hydrogen along with other gases, like CO_2, CO. On scrubbing the other gases with appropriate reagents, hydrogen can be obtained by this gasification of coal in large scale, due to the scope of handling large amount of coal [15]. This process of hydrogen production leads to produce water gas, producer gas and synthesis gas.

Though economically viable, coal gasification process of hydrogen production gives rise to large amount of carbon equivalent gases, along with loss of huge coal reserve and is thus not a sustainable technology. Around 5 metric tons of carbon is emitted in the atmosphere per metric ton of hydrogen produced [1].

Steam reforming of natural gas (NG)

Hydrogen production through the route of steam reforming of NG is the cheapest method and is widely used. Though it does produce carbon equivalent gas emission, but is the minimum amongst all fossil fuel routes of hydrogen production [5]. In this process four parts of hydrogen is produced from one part of methane and two parts of water (steam injected) at high operating temperature and pressure, in presence of a catalyst and hence is a rather cheaper and efficient process of hydrogen production [15].

The reaction in the production of hydrogen is [18]:

$$CH_4 + 2H_2O = CO_2 + 4H_2;$$

in case of liquefied petroleum gas (LPG) it would be:

$$C_3H_8 + 6H_2O = 3CO_2 + 10H_2.$$

Its limitation however is not only carbon emission associated with it but its hydrogen conversion efficiency, as determined from the heating value of hydrogen produced. The energy input required to produce hydrogen is only 65–75 percent, against 80–85 percent achievable for hydrogen production by splitting water through electrolysis [15].

Naphtha/oil source

Oil route of hydrogen production is based on the use of steam reforming (SR) of Naphtha with low aromatic content. By this method steam at high temperature (>700 °C) is allowed to pass through naphtha in presence of a suitable catalyst, breaking the C–H bond producing hydrogen, as shown [18]: