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Environmental impact assessment and comparison of some hydrogen production options

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ABSTRACT

In this study, environmental impact analyses and comparisons of various hydrogen production methods are presented. The methods considered are categorized on the basis of various energy sources such as renewables and fossil fuels. For the fossil fuels based hydrogen production, steam methane reforming (SMR) of natural gas is studied. Renewable based hydrogen production includes electrolysis using sodium chlorine cycle. Electrolytic hydrogen production is also compared using different types of cells, such as the membrane, diaphragm and mercury. Wind and solar based electricity is also used in electrolytic hydrogen production. The environmental impacts results of the hydrogen production processes indicate that SMR of natural gas has the highest environmental impacts in terms of abiotic depletion, global warming potential, and other impact categories. The abiotic depletion for SMR is found to be 0.131 kg Sb eq. which is the highest among all methods including renewable based hydrogen production. The second highest abiotic depletion value comes from the electrolysis, using the mercury cell, which is 0.00786 kg Sb eq.

Introduction

Energy is considered as a key component of all activities and plays a major role in the economic development of any country. Over time, energy demand in every sector keeps increasing due to several factors, including increasing population, change in life style and technological advancement. Almost every sector of life is dependent strongly on energy which comes mainly from fossil sources. A report by US-EIA [1] predicted that the world energy consumption will rise by 56% between the years 2010–2040. In this prediction, conventional fossil fuels will share about 78%, and the rest of this is expected to be fulfilled by renewables and nuclear sources. The massive utilization of fossil fuels is responsible for climate change, greenhouse gas emissions, and pollutants (e.g. CO, CO_2, SOx, NOx, ashes etc.). All these gases and air pollutants damage the stratospheric ozone layer and create smog. This results in critical human health issues, such as lungs and respiratory disorders, eye irritation and blood related diseases [2]. Transportation sector is the second major consumer of energy where petroleum and other liquid fuels consumption are very high after electricity generation (industrial). Annual energy utilization in the transportation sector increases 1.1 percent [1] and majority of the energy demand is being provided by fossil fuels. In order to replace or

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minimize the negative impacts of these traditional methods of energy production, many researchers focus on renewable energy sources [3].

Energy strategies will play an important role for future world stability. In case of energy consumption in transportation, numerous renewable technologies are available, such as renewable biofuels, solar and electric vehicles, etc. Each of these has some limitations, for example, in an electric car a battery needs to be charged by external electricity which also comes from the conventional methods of generation. Another major disadvantage of electric vehicles is the large amount of time required to charge the battery and during charging, the vehicle cannot be used. A solar vehicle is dependent on the solar radiation and might not work in areas where sun light is not consistent. Moreover, solar vehicles are designed for slower speed as compared to fossil vehicles because of the limited power available in solar vehicles. Among various alternatives, hydrogen as a fuel for vehicles offers the highest potential which can replace petroleum products and thus decrease the Greenhouse gas (GHG) emissions and air pollution. Due to their environmental compatible properties, hydrogen possibly will become one of the most feasible energy carrier in the future [4]. However, there are certain challenges in the use of hydrogen as fuel for vehicles, primarily due to storage requirements, and there are also potential opportunities and solutions developed [5,6].

Many researchers have studied the properties and behaviour of hydrogen as a fuel. Hydrogen can provide ecologically benign transportation systems depending on the energy and material source [7]. Numerous studies have focused on the contribution of hydrogen regarding the solution to environmental problems (e.g., [8]). Researchers, scientists and engineers have encouraged the use of hydrogen in different sectors [9]. Hydrogen is extensively available on earth with different chemical compositions such as in water and natural gas. It is colourless, odourless and nontoxic. It does not produce acid rain, harmful emissions and provides 2–3 times more energy per unit mass than gasoline and other alternative fuels such as biodiesel, methanol, ethanol, natural gas, and liquefied petroleum gas [10]. This reveals that hydrogen has a potential to replace or minimize the use of gasoline. However, hydrogen implementation depends upon several factors such as efficient methods of hydrogen conversion and utilization. Hydrogen can be produced from available abundant sources by different methods. Again majority of hydrogen is produced from fossil fuels using a process called steam reforming of natural gas, which is responsible for massive emissions of greenhouse gases. About 48% hydrogen demand is fulfilled by natural gas, 30% by petroleum industry, 18% from gasification of coal, 3.9% from electrolysis and remaining 0.1% from other processes [11]. Researchers and scientists still look for renewable sources of hydrogen production on large scale.

Today's world is in a serious need of alternatives to conventional fuels. Among various alternatives, hydrogen has the highest potential in terms of availability and low emissions of pollutants and greenhouse gases. At present, hydrogen is mainly used as a chemical substance rather than a fuel despite its market of fifty billion US$ for 40 Mt annual production [12]. Several studies, such as Dincer [12] Dincer et al. [13] Hussain et al. [14] Marban et al. [15] and Naterer et al. [16] introduced and promoted hydrogen as a future energy carrier and their basic remarks about hydrogen can be summarized as follows:

- Hydrogen is a high quality energy carrier, which can be used at high efficiency with zero or near zero emissions.
- During combustion with air or when used in a fuel cell to generate electricity, only water and small quantity of NOx are products.
- It has been technically proven that hydrogen can be used for transportation, heating, and power generation, and could replace current fuels in all their present uses.
- Hydrogen exhibits the highest heating value per mass among all chemical fuels as shown in Fig. 1 and is regenerative and environmentally friendly. Moreover, hydrogen has attractive electrochemical property, which can be utilized in a fuel cell.
- Hydrogen can be stored in different forms such as in gaseous form suitable for large scale storage, in a liquid form which is suitable for air and space transportation or in the form of metal hydrides to be convenient for small scale storage requirements

Renewable-based hydrogen can lead to the notably lower environmental impacts. Renewable sources such as solar energy, wind power, geothermal energy and other sources are available for hydrogen production. Many researchers have utilized such energy for the production of hydrogen. Ganovskii et al. [17] used exergetic life cycle assessment on hydrogen production from renewables such as solar and wind to evaluate exergy and economic efficiencies and environmental impacts. Furthermore, fossil fuel technologies for producing hydrogen from natural gas and gasoline from crude oil are compared with options using renewable energy. Solar energy considered here comprises two main systems: a solar photovoltaic system that produces electricity which in turn drives a water electrolysis division to produce hydrogen. Solar energy is converted into direct current electricity by photovoltaic elements, which is transformed by inverters to alternating current (ac) electricity and transmitted to the power grid. The 1.231-kW photovoltaic system combined with water electrolysis can produce 807.3 J s^{-1} of hydrogen exergy, when the efficiency of electrolysis and transmission losses have considered.

Hajjaji et al. [18] conducted a comparative life cycle assessment to study the environmental impacts of eight hydrogen production scenarios. Their study analysed the sustainability and performance of different options in the production of H_2 and focused on the key factor of every alternatives. The assessment was carried out by using impact assessment method such as the CML baseline 2000 and Eco-indicator 99 through the SimaPro 7.1 package. The results indicated that the biomethane reforming systems have the lowest impact which is 0.41 pt compare to other systems. The natural gas reforming method is not suitable in terms of environmental pollution because it has the highest emissions of global warming gas and has the greatest contribution to the abiotic depletion potential impact. However, bio-ethanol which is considered to be a biofuel (wheat derived), hydrogen production from bio-ethanol systems have a higher