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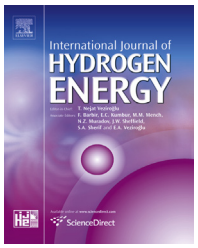

Comparative impact assessment study of various hydrogen production methods in terms of emissions

Fahad Suleman[*], *Ibrahim Dincer*, *Martin Agelin-Chaab*

Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, L1H 7K4, Canada

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ABSTRACT

A comparative environmental impact assessment is performed for different hydrogen production methods. The methods are characterised on the basis of different energy sources such as renewables and fossil fuel. Steam methane reforming (SMR) of natural gas is studied and is categorized under the fossil fuel based hydrogen production. Renewable based hydrogen production includes electrolysis using sodium chlorine cycle. Electrolytic hydrogen production is also compared using membrane cell, diaphragm cell and mercury cell. Wind and solar energy is utilized for electricity generation which is in turn used in electrolytic hydrogen production. The present study uses life cycle assessment (LCA), which is an analytical tool to identify and quantify environmentally critical phases during the life cycle of a system or a product and/or to evaluate and decrease the overall environmental impact of the system or product. The LCA 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, greenhouse gases 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. The second highest abiotic depletion value is electrolysis using mercury cell which is 0.00786 kg Sb eq. However, thermodynamic results suggest-that SMR is the most efficient method of hydrogen production because the amount of hydrogen energy produced as output in the system is larger than any other method.

Introduction

Energy has become a critical component of all activities and plays a major role in the economic development of any country. Energy demand in every sector keeps increasing due to the large amount of consumption, increasing population, change in life style and technological advancement. Almost every sector is dependent on energy which comes mainly from fossil sources. A report by the US Energy Information Administration [6] predicted that the world energy consumption will rise by 56% between the years

* Corresponding author.
E-mail address: Fahad.Suleman@uoit.ca (F. Suleman).
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2010–2040. In this prediction, conventional fossil fuel will share about 78% and rest of the number will be fulfilled by renewable 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 people getting health issues such as lung and respiratory disorder, eye irritation and blood related disease [8]. The 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 transportation sector increases 1.1 percent [6] and majority of the energy demand is being provided by fossil fuels. These negative results motivate researchers to look for an alternate of fossil fuels and a lot of work has been done in this search.

Energy strategies will play an important role for future world stability. In case of energy consumption in transportation several renewable technologies are available in terms of renewable biofuels, solar car, electric vehicle etc. Each of them has some limitations for example in electric car, a battery need to charge by external electricity which also comes from conventional method. A solar vehicle is dependent on the solar radiation and might not work in areas where sun light is not consistent. Among various alternatives, hydrogen as a potential fuel for vehicles offers the highest potential gain which can replace petroleum products and thus decrease the Greenhouse gas (GHG) emissions and air pollution. Due to their environmental compatible property, hydrogen possibly will become one of the most feasible energy carriers in the future for various applications [12].

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]. Some studies focus on the contribution of hydrogen regarding the solution of environmental problems [5]. Researchers, scientists and engineers have encouraged the use of hydrogen in various economic sectors and applications. Hydrogen is extensively available on earth along with different chemical composition such as water and natural gas. It is colourless, odourless and nontoxic. It does not produce acid rain, harmful emissions and providing 2–3 times more energy than other common fuels [13]. In fact, hydrogen can be produced from available abundant sources by different method. 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]. Scientists are still looking for renewable sources of hydrogen production on a large scale.

Renewable-based hydrogen can lead to the notably lower environmental impacts. It depends upon many factors involved over their lifetime such as natural resource extraction, plant construction, final product distribution and utilization. Sufficient evaluation of environmental impact and use of energy throughout the production and utilization from cradle to grave is critical for the proper assessment of technologies [8]. In order to study any operation from cradle to grave life cycle assessment (LCA) is the methodology that represents a systematic set of procedures for examining the inputs and outputs of materials and energy. A life cycle is the interlinked stages of a product or service system, from the extraction of natural resources to their final disposal.

Modes of hydrogen production

Production of hydrogen is considered one of the important aspects, including the energy consumed and emissions during the process. Currently, hydrogen that is produced covers only 2% of the world energy demand [9]. Hydrogen can be produced from a diversity of energy resources such as fossil fuels, renewable and nuclear using a variety technology which are discussed below.

- **Fossil Fuel Hydrogen Production:** Hydrogen can be produced from the fossil fuels by steam reforming and coal gasification. About more than 90% of hydrogen is produced from fossil fuels and steam reforming is the most common method [14]. In steam reforming of natural gas, three steps are involved for hydrogen production. Methane is first cleaned from impurities then mixed with steam and passed over an externally heated reactor at high temperature, where carbon monoxide (CO) and hydrogen (H_2) are produced. After this step, additional hydrogen can be generated through a water-gas shift reaction by which carbon monoxide and water is converted to hydrogen and carbon dioxide (CO_2). Finally, the hydrogen gas is then purified for use. Following are the chemical reaction for steam methane reforming and water gas shift reaction, respectively.

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad (1)$$

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (2)$$

- **Renewable Hydrogen Production:** Hydrogen can also be produced from non-conventional renewable sources such as solar, geothermal, biomass and wind. Renewable based hydrogen production has the advantage of being environmentally friendly with zero or minimum greenhouse gas emissions. Hydrogen is not available as a separate element. It is obtain from a number of sources such as hydrocarbon, biomass, water and other chemical elements with hydrogen. Therefore, energy is required to extract hydrogen from above mentioned sources. Dincer et al. [4] categorized four forms of energy: thermal, electrical, photonic and biochemical which drive hydrogen production process. These four forms of energy can be obtained from renewable sources that can be used to fascinate the primary energy demands for environmentally benign hydrogen production.