INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 4019–4033

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Life cycle assessment of hydrogen production from a high temperature electrolysis process coupled to a high temperature gas nuclear reactor

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ARTICLE INFO

Article history:
Received 20 April 2014
Received in revised form
12 January 2015
Accepted 17 January 2015
Available online 10 February 2015

Keywords:
Hydrogen production
LCA
GHG
Nuclear energy chain
High temperature electrolysis
High temperature gas reactor

ABSTRACT

The life cycle analysis (LCA) is a versatile tool to evaluate process and production systems, and is useful to compare environmental burdens. For the purposes of this LCA, a high temperature electrolysis process was coupled to a high temperature gas nuclear reactor. The system function is the production of hydrogen using electricity and heat from nuclear power, with a functional unit of 1 kg of hydrogen, at the plant gate. The product system consists of the following steps: (i) the extraction and manufacturing of raw materials (upstream flows), (ii) the electrolytic cell fabrication, (iii) the nuclear fuel cycle, and, (iv) the hydrogen production plant. Particular attention was paid to those processes where there was limited information available on inventory data, for example mining and processing of rare earth metals, and electrolytic cell assembly, which are the primary components of a hydrogen generation plant. The environmental impact assessment focuses on the emissions of greenhouse gases (GHGs), as related to global warming. Additionally, other environmental loads, to complete the environmental profile of the product system, were included. The results were low GHGs emissions, with a value of 416 g of CO_2eq $kg^{-1}H_2$. As to the process components, the electrolytic cell showed the highest environmental impact.

Introduction

Hydrogen blended with other elements is very abundant on the Earth; as is the case of oxygen to make up water molecules, of carbon into hydrocarbon molecules; and to a lesser extent as a gas (the lightest of all), mixed with gases in the atmosphere. The water molecule, a natural and massive source of hydrogen, is an abundant resource in sea water; however, great amounts of energy are required to split its molecule. Hydrogen is a secondary carrier of energy that, unlike electricity, once separated from composed molecules, can be stored in large quantities for long periods of time. One of the benefits is its reversible quality, to return its stored chemical energy back into electrical energy by means of a fuel cell. There are several emerging technologies for hydrogen production, mainly based on renewable sources and nuclear energy. Most of them are still being defined to reach

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http://dx.doi.org/10.1016/j.ijhydene.2015.01.093

conclusive results. Currently, there are four different conventional ways of producing hydrogen: (i) from natural gas through steam reforming, (ii) from processing oil (catalytic cracking), (iii) from coal gasification and, (iv) from electrolysis using different energy mixes. The latter, the electrolysis technologies, can be categorized into three main types: alkaline electrolysers, proton exchange membrane (PEM) electrolysers, and high temperature electrolysers (HTE).

Hydrogen used in vehicles, with fuel cell technology, represents a promising future for the hydrogen economy that mitigates climate change. However, there are challenges to be solved before its intensive use, such as: (i) the cost of the fuel cell, (ii) the method of storing hydrogen on board the vehicle to ensure an adequate cruising range, due to weight, (iii) the creation of hydrogen distribution infrastructure and, (iv) hydrogen production that is energetically efficient. This last point focuses on the possibility of large-scale hydrogen production for the transport sectorwhich is a measure of global warming mitigation. The life cycle analysis (LCA) is a useful tool to quantify environmental burdens in the production chain, defined as “cradle to grave”. This tool facilitates the systematic evaluation of the environmental impacts from new products, processes, and activities.

For nuclear power, free of carbon dioxide emissions, hydrogen can potentially be produced on an industrial scale from: (i) high temperature electrolysis (HTE) of water from electricity generated by means of nuclear power; (ii) high-temperature electrolysis of steam (HTES) from a mix of heat and electricity generated by means of nuclear power and, (iii) thermochemical splitting of water from heat produced by means of nuclear power, or by both nuclear heat and electrical power.

Literature, reports different LCA studies in the field of hydrogen production. These take into account the impact of the source of energy supply, whose results concerning the electrolytic process are shown in Section 3.4.3.

In the case of production from nuclear energy, studies have been performed for different hydrogen production methods:

- Utgikar [1] studied a nuclear-high temperature electrolysis plant, whose approach was to supply energy, both heat and electricity, to the hydrogen plant from a nuclear reactor.
- Ozbilen [2] analyzed the Cu–Cl thermochemical cycle, which highlighted four scenarios related to the supply of energy for hydrogen production and primary inputs.
- Solli [3], Lattin [4] and Giraldi [5] separately assessed the S–I thermochemical cycle, where several scenarios based on the production of hydrogen were analyzed. The results showed variations in the magnitude of GHGs emissions depending on the configuration process technology, and the change of the source of external power supply.
- Patyk [6] recently assessed the generation of hydrogen from the HTE process from two energy sources: nuclear and wind; He studied various production scenarios. The following observations are highlighted comparing Patyk's findings with our results: (i) conventional prototype water pressure reactor as a nuclear energy source was selected, (ii) it did not use the Brayton cycle thermal analysis, while on the current study it was included, and (iii) the exchange between electric and thermal energy flows were not considered by Patyk.

This work assessed a steam electrolysis process with a nuclear energy supply. The temperature of the steam is heated to temperatures above 1000 K in this process. High-temperature electrolytic water-splitting using electricity from nuclear to reach the temperature required for hydrogen production was used.; At higher reactor outlet temperatures, the power cycle efficiency increases, thereby increasing hydrogen production efficiency. Gas helium-turbine prototypes with a recuperator and an intermediate cooling have demonstrated thermal efficiency at levels greater than 40%. Although still under development, the use of a direct closed gas–turbine cycle and a modular reactor showed reductions of costs (capital, operation, and maintenance) due to the simplification of the power generation cycle and safety systems [7,8].

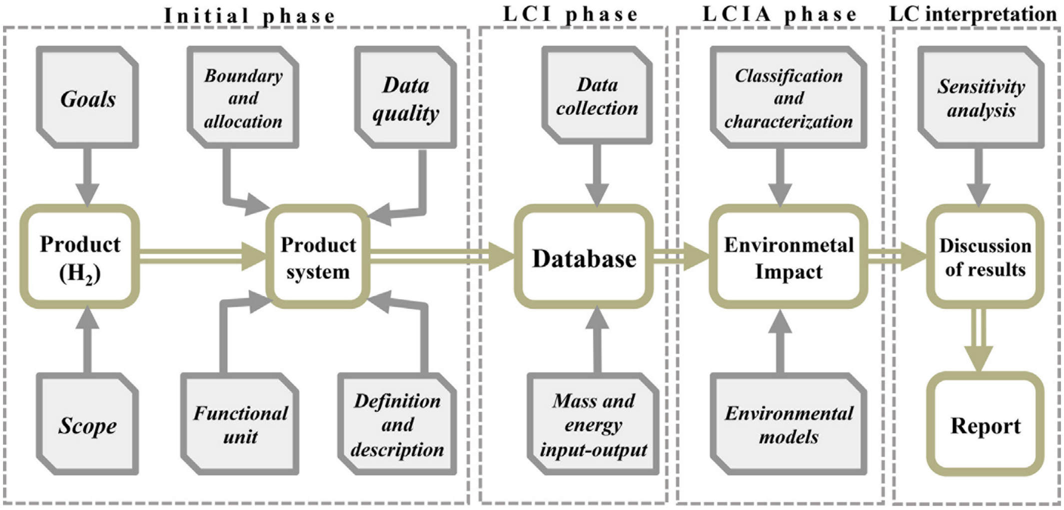

Fig. 1 – Procedure for the development of the LCA.