INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 10507–10514

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Is the hydrogen production from biomass technology really sustainable? Answer by life cycle emergy analysis

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ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form
3 April 2016
Accepted 13 April 2016
Available online 5 May 2016

Keywords:
Emergy analysis
Hydrogen
Supercritical water gasification
Sustainability

ABSTRACT

The Sustainability performance of biomass-based hydrogen is in debate. This study aims at using Emergy Theory to investigate the sustainability hydrogen production from corn stalks by supercritical water gasification, all the inputs including renewable resources, non-renewable resources, purchased inputs in the whole life cycle of hydrogen have been incorporated and transformed into emergy. The emergy indices with respect to this technology can be summarized as follows: the transformity is 5.5323E + 13 sej/kg, the emergy yield ratio (EYR) which is a measure of the ability of the system to exploit and make local resources available by investing in outside resources is 1.0117, the environmental load ratio (ELR) which indicates the load on the environment by the system is 5.0684, the environmental investment ratio (EIR) which can measure the utilization level of the invested emergy is 85.8303 and the emergy index of sustainability (ESI) which is a measure of the sustainability of a product, a process or a service is 0.1996. Therefore, it is not sustainable in the long term perspective for hydrogen production from corn stalks by supercritical water gasification in the current situation of Huaibei city in China. According to the results of sensitivity analysis, two implications are obtained for enhancing the

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http://dx.doi.org/10.1016/j.ijhydene.2016.04.082

sustainability of hydrogen from corn stalks: one is developing innovative agricultural system to reduce the consumption of nitrogenous fertilizer and phosphate, and another is to improve the yield and utilization efficiency of corn stalks.

Introduction

Energy like the freshwater is a fundamental resource that guarantees the normal life of well-being and the economy development all over the world [17]. Hydrogen has been recognized as a promoting potential energy carrier of the future for its advantage of zero CO_2 emissions during its oxidation [23]. Due to the use of non-renewable sources, the traditional pathways for hydrogen production such as natural gas by steam reforming, coal gasification and water electrolysis cannot fulfill the target of sustainable development. Hydrogen production from biomass has received more and more interests and attentions, for biomass is not only the fourth largest source of energy in the world accounting for 15% of the world's primary energy consumption, but also a kind of renewable energy resource [9].

Hydrogen production from biomass has been recognized as a promising technology, however, it also has major challenges, and there are no completed technology demonstrations [10]. Balat had pointed out that biomass to hydrogen has three main limitations, namely seasonal availability and high costs of handling, non-total solid conversion and tars production and process limitations such as corrosion, pressure resistance and hydrogen aging [2]. Therefore, there is a difficult question: is the biomass to hydrogen really sustainable? There are many studies that focus on the sustainability of hydrogen production pathways. For instance, Manzardo et al. [16] established a model by combining gray-based multi-criteria decision making method and life cycle thinking for sustainability assessment of hydrogen technologies. Hacatoglu et al. [7] developed a novel sustainability assessment methodology for hybrid energy system with hydrogen-based storage using life cycle emission factors and sustainability indicators. Ren et al. [24] established a sustainability decision making framework for the prioritization of hydrogen production pathways based on fuzzy Analytic Network Process and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method with the considerations of both hard and soft criteria. There are also many studies specially focusing on the sustainability of biomass-based hydrogen production. For instance Balat and Kırtay [33], had a comprehensive review of hydrogen from biomass, and they pointed out that biomass gasification offers the earliest and most economical route for the production of renewable hydrogen. Ren et al. [19] developed a sustainability framework which consists of fifteen criteria in economic, environmental, technological, and social-political aspects for sustainability assessment of biomass-based technologies for hydrogen production. In order to investigate whether ‘biomass to hydrogen’ is really sustainable or not, an index which can represent the sustainability is prerequisite. Emergy analysis which has the ability to measure the sustainability of a process, a service or a product has been widely used in various fields [1,20,27]. However, there are few studies focusing on using emergy analysis for investigating the sustainability of biomass-based hydrogen, but it had been demonstrated that emergy analysis has the ability to measure the sustainability of hydrogen production pathways [15]. In the emergy analysis, emergy index of sustainability (ESI) is an index to measure the sustainability of a process or a service. However, the traditional emergy theory does not include the life cycle thinking, a life cycle emergy analysis method has been developed in this study for investigating the sustainability of biomass-based hydrogen.

The objective of this study is to use life cycle emergy analysis to analyze the sustainability of biomass to hydrogen, and an illustrative case, namely vaporization hydrogen production from corn stalks by super-critical water in Huaibei city of China has been studied.

Emergy analysis

In this section, the emergy theory and emergy indices were firstly introduced, and hydrogen production from corn stalks by supercritical water gasification was analyzed by this method.

Emergy theory and emergy indices

Emergy as a new concept is an expression of all the energy, resources and services used in the work process that generate a product or services in units of one type of energy [31]. Solar equivalent joules (sej) is the common basis that has been usually used to account all the directly and indirectly energy contributions to obtain a certain product or a service [12]. The link between the various types of resources and emergy is transformity, and transformity is a concept that represents the “energy quality” and “energy transformation ratio”, the corresponding emergy can be calculated by using the consumption of each item (energy quantities or mass quantities) multiply the corresponding transformity [18,25]. Due to different units of the resources, the units of the transformities will vary as the format of sej/unit of the resource, when the unit of the resource is J, then the unit of the transformity is sej/J, when the unit of the resource is kg, then the unit of the transformity is sej/kg.

The inputs and outputs emergy flows of a system in the traditional emergy analysis method has been shown in Fig. 1 and the emergy indices and corresponding calculated methodology used in this paper has been shown in Table 1.