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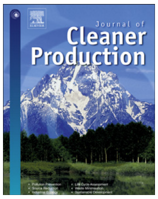

Emergy analysis for transportation fuels produced from corn stover in China

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ABSTRACT

In order to provide more useful information for the decision makers in China to implement sustainable energy policies and to identify which region in China is most suitable to build the biofuel production plants for fast pyrolysis and hydroprocessing of corn stover, the present study has evaluated the production efficiency and sustainability of large-scale transportation fuel production via fast pyrolysis and hydroprocessing of corn stover in China using emergy analysis approach. Both the hydrogen production scenario (i.e. oil hydroprocessing using the hydrogen derived from bio-oil reforming) and the hydrogen purchase scenario (i.e. oil hydroprocessing using the hydrogen purchased from market) in three regions of China (Northeast China Plain (NECP), North China Plain (NCP) and Shaanxi Province (SXP)) have been investigated. The results have shown that maize production, and fast pyrolysis and hydroprocessing are the two biggest emergy input stages of the biofuel production system. The comparison of the emergy indices of all of the six cases investigated indicates that the hydrogen purchase scenario in NCP is the best biofuel production case due to its second best sustainability and the second highest production efficiency. In comparison to bioethanol from cassava chips and wheat and biodiesel from jatropha curcas L, the hydrogen purchase scenario in NCP is also the most sustainable plan for a biofuel production plant in China. As water, fertilizer and hydrogen are the three biggest emergy inputs in this case, improvements on the water management, fertilizer management and hydrogen production technology have been discussed. In order to further increase the efficiency and sustainability of the hydrogen purchase scenario in NCP, some of the necessary efforts required from the relevant sectors have also been put forward based on the results of the emergy analysis.

1. Introduction

With the rapid fossil fuel depletion, energy shortage and growing concerns on environmental pollution all over the world, biofuels are playing an increasingly important role as a renewable substitute for fossil-based fuels for transportation (Li et al., 2015; Pereira and Ortega, 2010). There are many feasible pathways including various thermochemical (e.g. gasification) and biochemical processes (e.g. fermentation) to derive transportation fuels from biomass. Compared with gasification and biochemical processes, biomass-to-liquid transportation fuel production via fast pyrolysis followed by hydroprocessing has some advantages including its commercial feasibility in the near future, the high level of technology development and the low capital and operating cost (Anex et al., 2010). Biomass fast pyrolysis and bio-oil upgrading have been intensively researched and developed over the past decade, and were recently reviewed by Bridgewater (2012) and Elliott (2013).

The first generation liquid biofuels, which are derived from food crops such as cereals, sugar crops and oil seeds, have already become mature commercial market products. However, they have many issues such as compromising food security, high production and processing cost and large life cycle CO_2 emissions when considering land-use change (Sims et al., 2010; Liang et al., 2013).

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The second generation liquid biofuels from non-food biomass feedstocks such as cereal straw, sugarcane bagasse, and forest residues are considered much more sustainable and are being produced at a continuously growing rate as a result of the supports from governments around the world. Corn stover is a valuable biomass with considerable potential for producing the second generation biofuels in most countries with maize production. A number of investigations have already focused on the techno-economic and environmental assessment of biofuel production from corn stover (Anex et al., 2010; Saini et al., 2015; Han et al., 2013; Zhang et al., 2013; Kauffman et al., 2011). China is one of the largest maize production countries and produces about 154 Mt/year corn stover (Wang et al., 2013) which represents an enormous potential for the production of transportation biofuels. Therefore, corn stover is considered as one of the best biomass feedstocks for the second generation biofuel production in China.

When planning a biofuel supply network, the decision-makers should consider not only the economic efficiency and environmental performance of the industrial process but also its long term sustainability. The evaluation of sustainability can be used to provide insight for the development of an industrial-scale production system that will not severely or irreversibly damage the nature environment. Multi-criteria decision-making methodology investigating economic performances, environmental issues and social concerns was often used for evaluating sustainability of industrial systems in previous literature (Ren et al., 2015b, 2016a, 2016b; Yang and Chen, 2014). However, over the recent years, the emergy methodology has been proved to be the most direct and apparent method to represent the essence of sustainability of an industrial system, and be able to estimate all flows of energy, materials, information, services, and currencies on the common basis of "solar energy" (Yang et al., 2010a, 2010b; Baral et al., 2016; Chen et al., 2016). In addition, emergy analysis can identify the balance between the socio-economic development and natural environment and can make comparisons and comprehensive analysis of all flows from ecosystems and industrial systems (Ju and Chen, 2011; Zhang and Chen, 2017). A number of previous studies had described in detail the emergy analysis of the first generation liquid biofuels and the results had indicated that the biofuels generated from soybean (Ren et al., 2013, 2015a; Cavalett and Ortega, 2010), rapeseed (Ren et al., 2013, 2015a), sunflower (Ren et al., 2013, 2015a; Spinelli et al., 2012; Spinelli et al., 2013) and rice (Lu et al., 2012) did not have good sustainability in long term. So far, few have used emergy analysis to evaluate the second generation liquid biofuels produced by fast pyrolysis and hydroprocessing and hence the sustainability of these biofuels has not been fully explored.

The aim of this study is to investigate the feasibility and sustainability of the transportation fuel production system via fast pyrolysis followed by hydroprocessing from the maize field residue (corn stover) in three main maize production regions (Northeast China Plain (NECP), North China Plain (NCP) and Shaanxi Province (SXP)) of China. The region which is most suitable for the biofuel production from corn stover among the three studied regions in China has been identified using the emergy indices. Some efficacious strategic measures have been put forward to promote the sustainable development of transportation fuel production via fast pyrolysis followed by hydroprocessing. The results and suggestions of the present study can provide some useful information for government to formulate energy policies that can promote large-scale transportation biofuel production using corn stover in China.

2. Material and method

In this section, how to apply emergy methodology to the system of biofuel production via fast pyrolysis followed by hydroprocessing is first introduced and then the six cases to be analyzed are identified and selected and finally the three main stages of the biofuel production (maize production, corn stover collection and transportation, fast pyrolysis and hydroprocessing) in the six cases are described.

2.1. Emergy analysis

Emergy methodology was introduced to provide a method of assessing different systems by Odum H. T. (Odum, 1996). and is usually used to evaluate the sustainability of industrial systems (Yang et al., 2010a; Baral et al., 2016; Chen et al., 2016; Park et al., 2016). The biofuel production system in this study has three main stages: maize production, corn stover collection and transportation, fast pyrolysis and hydroprocessing. According to the procedure of emergy analysis, the first step is to define the boundaries of the system, describe and create an emergy flows' diagram as shown in Fig. 1, then, to classify and account for all energy inputs and outputs to create the table of emergy analysis. All inputs and outputs are in the units of J, kg or $. Emergy flows are classified according to their sources as renewable environmental resources (R), non-renewable

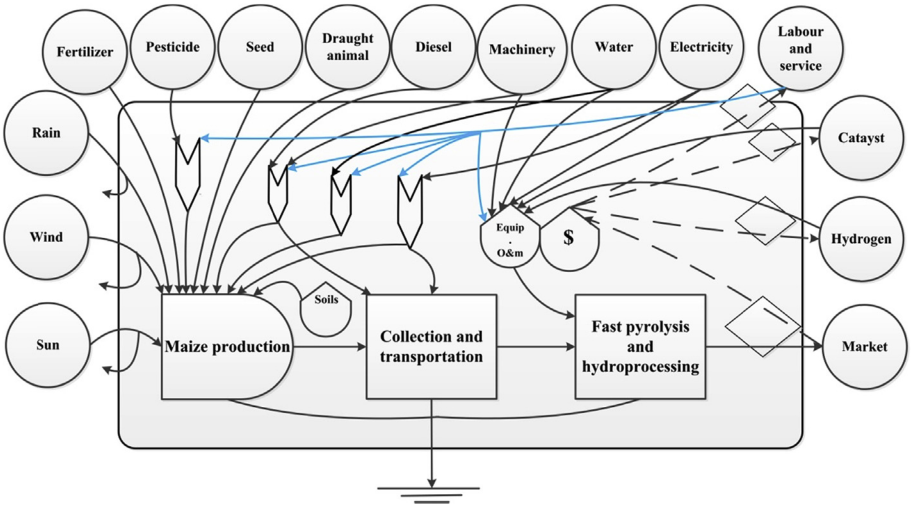

Fig. 1. Emergy flow diagram of biofuels form corn stover.