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Study on the environment-resource-economy comprehensive efficiency evaluation of the biohydrogen production technology

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ABSTRACT

Focusing on the incompatible measurement of the environment property, resources property and economy property, the article aims to make a generalized environment-resource-economy analysis of the processes and to present an overview of different biohydrogen production technologies from the standpoint of the mass production and the whole commercialization chain. One part of the model is the emergy comprehensive efficiency index calculation model, the other is the ternary diagram of structure coefficient for emergy input. The model is used to the organic wastewater of the biohydrogen industrialization demonstration project, and then compared with other biohydrogen and typical renewable energy production technologies. The outputs indicate that the industrialization efficiency of biohydrogen production is available. After the application case of demonstration project, the exploratory work enlightens the similar literature from several aspects. Firstly, the efficiency evaluation model supplies a scientific judgment foundation stone for future laboratory research. Secondly, it provides an alternative theoretical logic to optimize the operation and decision-making of the industrialization and commercialization of the new technologies. Thirdly, it provides a new perspective and quantitative calculation method to effectively integrate that the components comprehensive efficiency of biohydrogen technology change with the different technology processes.

1. Introduction

It is necessary to implement the alternative energy sources of fossil energy while considering their linked economics, environmental and societal impacts become a more pressing matter [1]. The key factors for a large utilization of biohydrogen include not only the transportation sector but also the superiority of the cost and efficiency to other energy production technologies. A number of studies analyze the techno-economics of biomass and biohydrogen, in which the

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biomass cost, plant capacity, reactor technology and other variables vary widely among different studies [2]. Currently, the efficiency evaluation of the environment property, resources property, and economy property are unable to be converted each other [3]. It is difficult to comprehensively analyze the commercial efficiency of the economy inputs, resource inputs and environmental impacts. It has been unable to have an analytic comparison of the whole industrial chain efficiency of various biohydrogen technologies, which affects the investment of biohydrogen production technology and its market applications [4,5].

An environment-resource-economy (ERE) comprehensive efficiency model was developed. The emergy theory is used in converting various ecological flows into the same emergy flows by means of the ternary diagram method. The model was applied in the organic waste of the biohydrogen industrialization demonstration project. The outputs imply that it could be generally considered to be a basic framework to evaluate optimization operation of the ERE comprehensive efficiency of the biohydrogen technologies industrialization. And it is also helpful to meet the demands of the government's public-policy, labs technology developing and private investments.

2. Methodology

2.1. Background: concepts of emergy

HT Odum defines "Emergy" as: the available energy used up directly and indirectly to make a service or product [6]. Furthermore, during the formation process of products or services, the total input amount of directly and indirectly available energy, is its emergy, the same as the embodied energy [7]. "Solar Emergy" is the quantity of solar energy contained in the flow and stored energy. Any energy begins in the solar energy, thus it could be measured by solar value standards. Emergy is measured in solar embodied joules, which is abbreviated sej. Different types and levels of energy systems could be measured and compared by the emergy conversion [8]. Emergy Transformity, an important concept in emergy analysis, is defined as "the Solar Emergy required making 1 J of a service or product" [9]. The emergy transformity of a kind of energy (or material)/[sej/J(g)] equals the total required amount sej of a kind of energy (or material) of 1 J. Solar emergy transformity is the required number of solar energy joules (sej) which is converted to a substances and energy unit [10].

By emergy transformity, all kinds of energy (or material) could be transformed into the same criteria. It overcomes the deficiencies of traditional methods of energy analysis, and analyzes the different energy flow, material flow, money flow and other ecological flows of the ecological and economic systems quantitatively [11].

$$\text{Emergy(sej)} = \text{emergy transformity(sej/J)} \times \text{energy(J)} \quad (1)$$

2.2. Emergy flows system of the biohydrogen technology industrialization

2.2.1. Hypothesis of the emergy flows system

Biomass technology emergy flows system includes three input resources: *N*, nonrenewable resources input of the biohydrogen system, is defined as the power energy. *R*, renewable resources input of the biohydrogen system, includes a variety of raw materials. *F*, economic investment and services inputs, are defined as the cost of equipments, devices, labor and information resources. Y_H, refers to the emergy output of the system. It consists of three parts: the Biomass (Y_{HB}), related intellectual and cultural outputs (Y_{HI}), and government subsidies (Y_{HS}).

2.2.2. Process hypothesis of the biohydrogen industrialization system

According to the basic principles of biological system, the products and services of the biomass emergy systems generally need three modules: biological cultivation, biomass reactor and raw materials input [12]. The model is constructed based on the emergy theory in order to convert various ecological flows to the emergy flow. It includes two parts of emergy comprehensive efficiency index calculation model and ternary diagram of structure coefficient for emergy input.

Emergy of ecosystems analysis includes the social-economic-nature complex ecosystem, ecological and economic systems, process of ecological systems, a variety of ecological engineering system and energy analysis [13]. Taking account the fermentation technology and the biohydrogen production into the ERE evaluation, we design the basic indicators which are listed in Fig. 1(a).

There are five indicators in the level of experimental process as shown in Table 1:

The higher RER means the higher regeneration of the biohydrogen production system. RER is inversely proportional to EIR and ELR and proportional to ESR and EYR. Although Odum's indexes system is different in different applications, several main indexes are the same in general: EYR, EIR, ELR, ESI etc. There are correlations in parts of indexes. We take an example of the indexes in Fig. 1(a) as follow:

Definition from Odum,

$$\text{EIR} = \frac{F}{R+N} \quad (2)$$

$$\text{EYR} = \frac{F+N+R}{F} \quad (3)$$

Consolidating the two equations of EIR and EYR, and EYR is transformed to the equation (4):

$$\text{EYR} = 1 + \frac{1}{\text{EIR}} \quad (4)$$

ESR could be rewritten as the equation (5):

$$\text{ESR} = \frac{N+R}{N+R+F} = 1 - \frac{F+R}{N+R+F} \quad (5)$$

Substituting equation EYR into equation (5), we can get the equation (6):

$$\text{ESR} = 1 - 1/\text{EYR} \quad (6)$$

Substituting equation EIR into equation (5), we can get the equation (7):

$$1/\text{ESR} = 1 + \text{EIR} \quad (7)$$

Analyzing the equations, ESR is proportional to EYR, and EYR is inversely proportional to EIR and EIR is inversely