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Emergy analysis of cassava chips-suitable feedstock for fuel ethanol in China

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ABSTRACT

The theory and indices of Odum's concept of emergy are explained. The environmental and economic inputs and sustainability of cassava chips production system are evaluated by emergy methodology. The emergy indices of cassava chips production system were calculated as follows: Tr (transformity) was 6.85*E* + 11 sej/kg, EYR (emergy yield ratio) was 1.11, ELR (environmental loading ratio) was 1.75, EIR (emergy investment ratio) was 9.33, and ESI (emergy sustainability indice) was 0.63. The emergy indices of four kinds of feedstock for fuel ethanol—corn, wheat, sugarcane, and cassava chips—were compared. Least solar energy was consumed when taking cassava chips as feedstock for fuel ethanol. According to the emergy indices, using cassava chips as the feedstock of fuel ethanol is helpful for sustainable development in China.

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1. Introduction

At present, the energy crisis and environmental pollution are two major problems the world is facing. Therefore, developing renewable and clean energy has become the great concern of every country. Biofuels can positively impact socio-economic development, e.g., by alleviating poverty, creating jobs, reducing reliance on imported oil and on increasing access to modern energy services (United Nations and Foundation, 2006).

Fuel ethanol as the substitute for gasoline is helpful to ensure energy security and improve environment quality. Fuel ethanol has a long history as an alternative transportation fuel. It was used in Germany and France as early as 1894 by the then incipient industry of internal combustion (IC) engines (Demirbas and Karslioglu, 2007). Fuel ethanol has a higher octane number, 108, broader flammability limits, higher flame speeds and higher heats of vaporization. These properties allow for a higher compression ratio and shorter burn time, which leads to theoretical efficiency advantages over gasoline in an IC engine (Balat, 2007).

Therefore, how to evaluate sustainability of the production system of fuel ethanol becomes the great concern of every country. There are many methods to evaluate fuel ethanol, such as energy analysis (Suiran and Jing, 2009a; Thu Lan et al., 2007, 2008; Cardona Alzate and Sánchez Toro, 2006; Rubo et al., 2008), economic analysis (Suiran and Jing, 2008; Cheng et al., 2003; Krishnan et al., 2000), environmental evaluation (Thu Lan et al., 2007; Tom and Tim, 2007) and exergetic evaluation (Yang et al., 2009).

However, feedstocks are the major inputs in the fuel ethanol production process. The productivity, environmental impact, and sustainability of the agriculture system of feedstock have a great influence on the development of fuel ethanol. It is necessary to evaluate the planting system of feedstock for fuel ethanol.

Because most types of agriculture depend on a combination of natural and economic inputs, it is necessary to account for both in equivalent terms when comparing the resource use of agricultural methods (Campbell, 1998). While the value of economic contributions is routinely quantified by economic analyses, such approaches often underestimate environmental contributions to production systems. If environmental inputs are not properly accounted for relative to economic inputs, optimum use of resources may not be achieved, and management decisions will be based on incomplete analyses (Ulgiati et al., 1994).

In energy analysis, different kinds of energy are calculated on the common unit of joule. There are no differences between 1 J of electricity and coal in energy analysis. In fact, 4 J of coal can produce only 1 J of electricity. Therefore, energy analysis cannot reflect the quality of energy. And free environmental inputs are usually not accounted for.

The emergy methodology was proposed by Odum in 1983. This method is able to evaluate environmental and economic contributions and services on a common basis of "solar energy". As a measure of energy used in the past, emergy (with unit emjoule) analysis is totally different from conventional energy (with unit joule) analysis, which merely accounts for the remaining available energy at present, considers both energy quality and energy used in the past, and therefore proves a more feasible approach to evaluate the status and position of different energy carriers in universal energy hierarchy (Chen et al., 2006).

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Generally speaking, ethanol can be generated from a number of feedstocks, which are usually categorized into starch, molasses and cellulose-based feedstock (Suiran and Jing, 2009b). In China, food grain was taken as the main feedstock of fuel ethanol in the beginning, such as corn and wheat. However, from a long-term consideration, taking food grain as feedstock will increase the total cost of fuel ethanol, and at the same time China has such a big population to feed that the food supply may not be enough for both people and fuel ethanol. Hence, a number of other kinds of feedstock have been proposed, among which cassava is one of the most promising choices (Zhiyuan et al., 2004). Cassava is not a staple food for the Chinese people. Using cassava as the feedstock of ethanol would not a the foodstuff crisis. And cassava is easy to be comminuted, cooking time is short, and gelatinization temperature is low. Nearly 2.8 t cassava chips can produce 1 t of fuel ethanol.

This paper evaluates the production system of cassava chips in China by emergy analysis. Emergy analysis has many indices, and these indices indicate various performance characteristics of the system in terms of efficiency and sustainability.

2. Emergy analysis of cassava chips

2.1. Emergy theory and emergy indices

Emergy is defined as the sum of all inputs of available energy directly or indirectly required by a process to provide a given product or service, when the inputs are expressed in units of the same form (or type) of energy, usually solar emjoules (sej) (Odum, 1996; Brown and Ulgiati, 1997). Solar energy is the primary source which could feed all processes and cycles on Earth. In other words, emergy is the "energy memory" that has been used throughout a sequence of different processes going into a product. Emergy is therefore not a state function, because it considers the specific path from the initial to the present state (Pulselli et al., 2008). To derive the solar emergy of a resource or commodity, it is necessary to trace back all the resource and energy flows which are used to produce a resource or commodity, and express these input flows in the amount of solar energy that went into their production (Brown and Ulgiati, 2002).

The ratio of the total emergy inputs to the mass or energy of the product gives a unit, namely specific emergy or transformity (Tr), in unit of sej/g or sej/J, respectively. Moreover, specific emergy can be conceived as an indicator that represents the position that a given transformation process (and its product) occupies in the hierarchical network of the earth's biosphere (Odum, 1996). Through multiplying the inputs and outputs by certain transformities, the emergy amount of each resource, service and corresponding product can be calculated.

With the same accounting unit, the environment cost and benefit can be clearly analyzed through a series of emergy-based ratios and indices. Emergy analysis has many indices, and these indices indicate various performance characteristics of the system in terms of efficiency and sustainability. In order to make the emergy indices clear, an emergy consumption figure of a system is given in Fig. 1. There are three categories of inputs emergy flows: *R* as renewable environmental resources, *N* as non-renewable environmental resources and *F* as the purchased resources. The *R* and *N* flows provided by the environment are economically free. The economic inputs, *F*, are provided by the market and related to fluxes that are accounted by the economy. *F* can also be divided into two categories, renewable purchased (F_R) and non-renewable purchased (F_N). The outputs, *Y*, may include products, services and also emissions that are released to the environment (Giannetti et al., 2006). There are many emergy indices for better evaluation of the concerned system and indication of various performances of the system in terms of ecological efficiency and sustainability (Zhou et al., 2009).

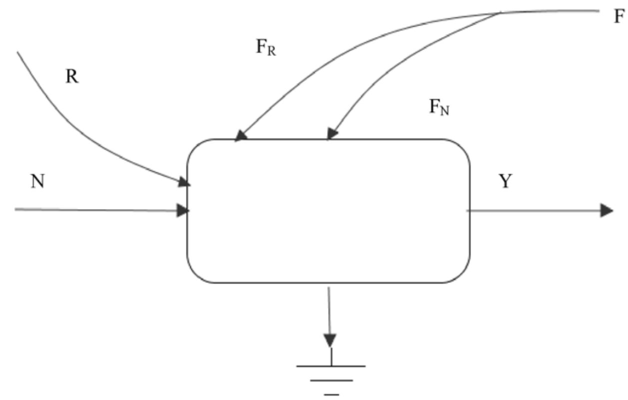

Fig. 1. Inputs and outputs emergy flows of the system.

EYR. The emergy yield ratio (EYR) is the ratio of the output (*Y*) emergy to the purchased (*F*) emergy. This ratio is a measure of the ability of the system to exploit and make local resources available by investing in outside resources.

ELR. The environmental loading ratio (ELR) is the ratio of non-renewable purchased (F_N) emergy plus non-renewable environmental (*N*) emergy to renewable purchased (F_R) emergy plus renewable environmental (*R*) emergy. This index is used to evaluate how much "pressure" is placed on the environment by the system. ELR values less than 2 indicate a relatively low impact on the environment (or processes that could use a large area of a local environment to 'dilute the impact'); values between 2 and 10 mean that the system caused a moderate impact; up to 10 are indicative of relatively concentrated environmental impact (Brown and Ulgiati, 2004).

EIR. The emergy investment ratio (EIR) is the ratio of the emergy fed back by the economy to "natural" (renewable and non-renewable) environmental emergy inputs.

ESI. Emergy sustainability index (ESI) is the ratio of the emergy yield ratio EYR to the environmental loading ratio ELR. ESI's of less than 1 appear to be indicative of products or processes that are not sustainable in the long run and those with ratios greater than 1 indicative of products and processes that are sustainable contributions to the economy. Medium level of sustainability seems to be characterized by ESI's between 1.0 and 5.0, while processes and products with higher ESI's have accordingly greater sustainability (Brown and Ulgiati, 2002).

The emergy/dollar ratio is the ratio of total emergy use of a state or country to gross national product (GNP) for the national economy. It can be used to convert money payments into emergy units.

2.2. Cassava-suitable feedstock for fuel ethanol

Cassava grew only in South American originally, but it was introduced to China 200 years ago. The planting areas of cassava were 600,000 ha, and the yields of cassava were 11 million t in China in 2005. It is estimated that the planting areas will increase to 1 million ha in 2015 (http://www.topo100.com/e/DoPrint/?classid=731&id=5174). Cassava grows mainly in Guangxi, Guangdong, Hainan, Yunnan, Fujian provinces in China. The growth period of cassava is usually 8–12 months in the south of China.

Cassava is usually used to produce amylum, feedingstuff, and ethanol. As feedstock for fuel ethanol, cassava has two advantages

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