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Comparison of biogas production from an advanced micro-bio-loop and conventional system

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ABSTRACT

Biogas presents a most promising opportunity to reduce the world's dependence on fossil-fuel. The authors proposed an advanced micro-bio-loop (AMBL) to produce a continuous stream of biogas without requiring any additional external input or producing any internal output to its surroundings. The aim of this study was to compare biogas production from AMBL against that of a conventional biogas production system (CBPS) from the perspective of Life Cycle Sustainability Assessment (LCSA). The results indicated that the AMBL was much more energy-efficient and more technologically, environmentally, and sustainably advanced than an equivalent CBPS. The cumulative energy demands of both systems were at two different levels, 77.24 MJ and 130.45 MJ per functional unit respectively. All environmental impacts and total investment of the AMBL were 61% less than that of CBPS. Furthermore, abiotic depletion, eutrophication and ozone layer depletion of the former were merely 0.03%, 0.5% and 1% as compared to the latter respectively.

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1. Introduction

The aggravation of the energy crisis, increasing fossil fuel prices together with environmental concerns have spurred global interest in the search for alternative sources of energy (Leonzio, 2016). Biomass energy, as a renewable and sustainable form of energy, is becoming more important due to its widely applicable characteristics and its environmentally-sound and energy-saving production methods (Medeiros et al., 2014). According to statistics, biomass alone supplies more than 11.5% of the world's primary energy (Maghanaki et al., 2013) and it will account for 55% of the renewable energy target of 2020 (Van Meerbeek et al., 2015). Biogas obtained from biomass serves as one of the major sources of energy that can be used directly to provide heating and electrical energy and is nearly a greenhouse gas (GHG) neutral replacement for fossil fuels (Zheng et al., 2012). The International Energy Agency (IEA) has estimated that biogas alone could supply sustainably nearly 63 EJ for future global primary energy by 2050 (Nielsen and Oleskowicz-Popiel, 2007). Therefore, biogas utilization might prove to be a promising strategy to mitigate climate change, reduce dependence on fossil fuels and diversify production activities.

Biological conversion of terrestrial energy crops for biogas production is regarded as a conventional biogas production system (CBPS) in present date (Li et al., 2014). Crucially, though, quite a few existing issues have blocked the industrialization of CBPS. Among these issues are the procurement and pre-treatment of feedstock, the post-treatment of digestate, along with the storage and transportation of both feedstock and digestate (Lukehurst et al., 2010). Firstly, the difficulties in collecting and managing of raw materials have introduced a lot of uncertainty for a continuous feedstock supply. In this respect, problems may arise due to the scattered geographical distribution of feedstock, unstable natural conditions such as droughts (Mabee et al., 2006), and the lacking reliability, willingness, and co-ordination of supply chain actors (Van Belle et al., 2003). Some works also suggest that the unreasonable management of typical energetic crops might result in increasing

Abbreviations: AbD, Abiotic Depletion; AMBL, Advanced Micro-bio-loop; AP, Acidification Potential; CBPS, Conventional Biogas Production System; CML, Centre for Environmental Studies; EP, Eutrophication Potential; HRT, Hydraulic Retention Time; HTP, Human Toxic Potential; IEA, International Energy Agency; IRR, Internal Rate of Return; LCA, Life Cycle Assessment; LCIs, Life Cycle Inventories; LCSA, Life Cycle Sustainability Assessment; NPV, Net Present Value; Ozone, Ozone Layer Depletion; PB, Payback Period; Photo, Photochemical Oxidation; Rad, Ionizing Radiations.

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quantities of GHG being emitted to the atmosphere (Fargione et al., 2008). Secondly, efficient and economical pre-treatment is one of the crucial steps in the production of biogas from lignocellulosic biomass in order to improve the enzymatic hydrolysis or biodegradability (Taherzadeh and Karimi, 2008). Existing methods of pretreatment such as mechanical processing, acid pretreatment and alkaline pretreatment are energy intensive and may also generate hazardous by-products (Roda et al., 2015). Thirdly, various anaerobic digestates derived from the CBPS are extremely difficult to be disposed and can directly impact soils, water bodies and the atmosphere. Inappropriate storage or application of anaerobic digestates can also lead to gaseous nitrogen emission (ammonia and nitrous oxide) and/or nutrients (N and P) leaching and runoff from arable land into surface and ground waters, which may cause eutrophication in lakes (Nkoa, 2014). Fourthly, open storage and transportation throughout the biogas production chain can bring about a loss of feedstock/digestate over time, leading to indirect environmental impacts (Börjesson and Berglund, 2006). Furthermore, it is quite a costly process, the transport costs for a biogas plants with electrical power capacity of 999 kW can account for 29.0% of total costs (Sgroi et al., 2015). Finally, intensive exploitation of arable lands for the cultivation of crops dedicated for biogas production may yield a negative impact on the global supply and prices of foods, and thus it will be a huge challenge for CBPS (Lardon et al., 2009).

To overcome the above problems, the authors proposed and patented an advanced closed recirculating micro-bio-loop (CN103290059A) comprising of a four-step process, i.e., microalgae culture, de-oxygenation, anaerobic digestion, and aerobic decomposition (Fig. 1). The major advantages of using microalgae for biogas production are: no competition with food crops for arable land, high photosynthetic efficiency and growth rates, few fractions of lignin which reduces the need for energy-intensive pretreatments before fermentation. The advanced micro-bio-loop (AMBL) could operate under sunlight to produce a continuous stream of biogas without adding any additional external input or producing internal output to its surroundings, and thereby avoiding further treatment of biogas residues. Moreover, the most important feature of the AMBL was the recycling of almost all the nutrients extracted from mineralized digestate suspension in anaerobic process. Hence, the AMBL had achieved an *in situ* quality management of the digestate and circumvented the need of continuous feedstock procurement, storage, and transportation.

The objective of this study was to compare biogas production from AMBL with CBPS along their holistic life cycle encompassing production and pre-treatment of biomass, anaerobic digestion, post-treatment, transportation, purification, combustion and infrastructure. Hence, the sustainability assessment of the two different biogas production systems among environmental, economic and social dimensions was presented using Life Cycle Sustainability Assessment (LCSA). The present paper can help to assess their potential positive and negative impacts, so as to figure out the following questions: “Which biogas production system is more energy-efficient, competitive technologically, environmentally, and economically?”, “Can AMBL completely replace CBPS in future biogas industry?”; and “Which system should be promoted for biogas production?”. The results will provide necessary guidance for technology developers, enterprises and government to make more intelligent decisions regarding future biogas industry.

2. Material and methods

2.1. Overview of AMBL

The AMBL incorporated producers, consumers, and decomposers (microalgae, anaerobic bacteria and aerobic bacteria), which shaped a completely independent and sustainable cycling micro-eco-chain. The closed recirculation helped reduce the preprocessing and post-processing steps, thereby cutting down most of the operating costs. Moreover, it recovered almost all the nutrients through mineralization and recirculation of the digestate suspension and had negligible impacts on eutrophication.

2.1.1. Microalgae culture

Single-celled microalgae biomass, promoted as an ideal third generation biofuel feedstock (Shimako et al., 2016), was employed in the AMBL. The production of microalgae culture can take place almost everywhere, obviating the pressure on arable land, so it would greatly reduce concerns about the controversy of food versus fuel (Williams and Laurens, 2010). The chemical oxygen demand (COD) value of microalgae suspension (which generally contains dry microalgae biomass of 0.5 g/L) can be easily up to 3

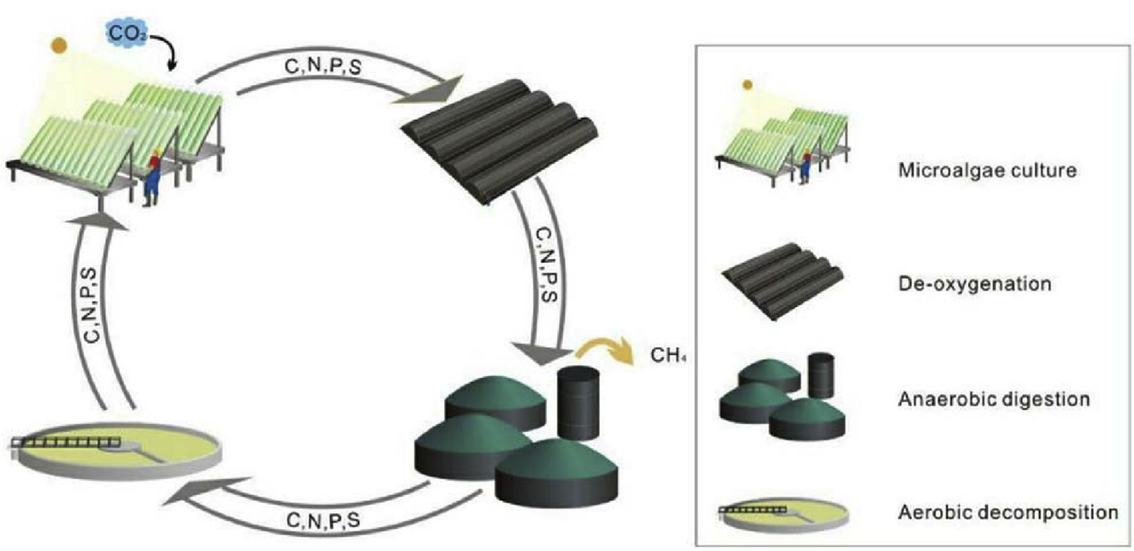

Fig. 1. Schematic diagram of the AMBL.

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