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Biohydrogen production from microalgal biomass: Energy requirement, CO_2 emissions and scale-up scenarios

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HIGHLIGHTS

- The H_2 yield was 7.3 $g_{H2}/kg_{biomass}$ by *C. butyricum* from *S. obliquus* dried biomass.
- The H_2 production consumed 71–100 MJ/MJ_{H2} of energy and emitted 5–6 kg CO_2/MJ_{H2}.
- In a possible scale-up, the energy consumption may attain 6–8 MJ/MJ_{H2}.
- Scale-up is advantageous in terms of CO_2 emissions, reaching (−716) to (−613) g/MJ_{H2}.
- The best scenario would produce H_2 to supply 5.5% of a Lisbon urban taxi fleet.

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ABSTRACT

This paper presents a life cycle inventory of biohydrogen production by *Clostridium butyricum* through the fermentation of the whole *Scenedesmus obliquus* biomass. The main purpose of this work was to determine the energy consumption and CO_2 emissions during the production of hydrogen. This was accomplished through the fermentation of the microalgal biomass cultivated in an *outdoor* raceway pond and the preparation of the inoculum and culture media. The scale-up scenarios are discussed aiming for a potential application to a fuel cell hybrid taxi fleet.

The H_2 yield obtained was 7.3 g H_2/kg of *S. obliquus* dried biomass. The results show that the production of biohydrogen required 71–100 MJ/MJ_{H2} and emitted about 5–6 kg CO_2/MJ_{H2}. Other studies and production technologies were taken into account to discuss an eventual process scale-up. Increased production rates of microalgal biomass and biohydrogen are necessary for bioH_2 to become competitive with conventional production pathways.

1. Introduction

The two main drivers of the production of biofuels are the depletion of fossil fuels, and environmental impacts of increasing fossil fuel consumption. Biofuels that can be readily produced without a large increase neither in arable land nor reduction in tropical rainforest areas are very important issues in the future. Microalgae may offer this opportunity. Its use as a feedstock for biofuels has led to much excitement and initiative within the energy industry (Darzins et al., 2010). Some microalgae species are extremely rich in lipids and sugars, making them suitable for biodiesel, bioethanol and bioH_2 production, respectively. Besides the fact that microalgae cultivation may avoid the need of arable land, there is also the possibility of using brackish, saline and wastewater for their growth. Additionally microalgal biomass could be harvested on a daily basis (John et al., 2011).

Microalgae are therefore a good source for liquid (e.g., biodiesel and bioethanol) and gaseous (e.g., biohydrogen and biogas) biofuels production. *Scenedesmus obliquus*, in particular, is a microalga with good biomass productivity rates, around 0.09 $g L^{-1} day^{-1}$ (Gouveia and Oliveira, 2009), which has been proven to be very versatile as a raw material for biofuel production. This microalga contains approximately 12–14% (w/w) of oil and 10–17% (w/w) of sugars (Demirbas, 2009) and is therefore a good source for biodiesel (Gouveia and Oliveira, 2009; Mandal and Malick, 2009; Silva et al., 2009), bioethanol (Miranda et al., 2012ab) and bioH_2 production (Demirbas, 2009; Ferreira et al., 2013a). In a study conducted by Miranda et al. (2012b), *S. obliquus* biomass accumulated starch in a concentration of 30% (w/dw) starch (glucose equivalents).

In all bioconversion processes, the adequacy of the fermenting microorganisms to the substrate feedstock and the values of product yield are of primordial importance (Kotay and Das, 2008). Species of *Clostridium* are frequently found in hydrogen-producing consortia and are also very effective in producing H_2 from organic substrates, especially carbohydrates (Chong et al., 2009). The yields

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