Biohydrogen production from microalgal biomass: Energy requirement, CO₂ emissions and scale-up scenarios

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HIGHLIGHTS

• The H₂ yield was 7.3 gH₂/kg Biomass by C. butyricum from S. obliquus dried biomass.
• The H₂ production consumed 71–100 MJ/MJH₂ of energy and emitted 5–6 kg CO₂/MJH₂.
• In a possible scale-up, the energy consumption may attain 6–8 MJ/MJH₂.
• Scale-up is advantageous in terms of CO₂ emissions, reaching (−716) to (−613) g/MJH₂.
• The best scenario would produce H₂ 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 CO₂ 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 H₂ yield obtained was 7.3 g H₂/kg of S. obliquus dried biomass. The results show that the production of biohydrogen required 71–100 MJ/MJH₂ and emitted about 5–6 kg CO₂/MJH₂. Other studies and production technologies were taken into account to discuss an eventual process scale-up. Increased production rates of microalgal biomass and biophydrogen are necessary for bioH₂ to become competitive with conventional production pathways.

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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. Microalgal 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 microalgal species are extremely rich in lipids and sugars, making them suitable for biodiesel, bioethanol and bioH₂ 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., biophydrogen 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 Mallick, 2009; Silva et al., 2006), bioethanol (Miranda et al., 2012ab) and bioH₂ 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 H₂ from organic substrates, especially carbohydrates (Chong et al., 2009). The yields