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Life cycle assessment of biohydrogen production in photosynthetic processes

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ABSTRACT

The outcomes of biohydrogen from photosynthesis processes are still small, however different development methods and laboratory studies are carried out to increase the production yield and meanwhile optimize the process to lessen the negative impact on the environment and climate change. The Life Cycle Assessment (LCA) gives the possibility to compare different biohydrogen production approaches using different photosynthesis methods and, at the same time, identify the environmental "hot spots" of the whole process.

Inventory analysis and the results of different researchers in this field allow to find values of selected ecoindicators in order to evaluate the biohydrogen production efficiency with the selection of the best initial data for life cycle analysis. These ecoindicators weigh the resources needed for biohydrogen production whole system.

This paper presents the first aspects for the implementation of a life cycle assessment.

1. Introduction

The need for a sustainable energy supply is becoming more and more pressing in light of declining fossil energy resources, environmental pollution, climate change and increasing dependency on oil exporting countries. Consequently, alternative fuels are required to fulfill criteria that should include: no release of carbon dioxide (or zero net carbon), sustainable resource, suitability for the transportation sector and being in an affordable price range (comparable to the current oil price) [1].

Hydrogen can consequently play the role of a clean and efficient fuel since it is the only common fuel that is not chemically bound to carbon.

The branch of the biological production of hydrogen (biohydrogen) provides a wide range of approaches to generate hydrogen, and photosynthetic microorganisms (e.g. microalgae) offer an alternative and innovative approach.

Biological hydrogen production has been produced continuously at laboratory scale [2,3] while biohydrogen production on a commercial scale is expected in the very near future. Given the expected market penetration of hydrogen technologies and the fact that the relative environmental impacts of biological hydrogen production systems have not been scientifically established to date, there is a need for a reliable life cycle assessment (LCA) of environmental impacts associated with biological hydrogen production systems or technologies [4].

2. Objectives of the paper

This paper intends to provide a starting point for a quantitative Life Cycle Assessment (LCA) approach to assess the

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environmental impacts of a scale-up photobiological hydrogen production process [5,6].

An LCA is suggested as an appropriate tool to provide information on environmental repercussion of a photobiohydrogen system by means of inventory and simplified impact assessments.

The first part of the paper aims to illustrate and compare the costs of hydrogen production. The central part is mainly focused on the description of the LCA methodology together with the explanation of the reasons off leading an LCA on this novel hydrogen production methods. At the end the preliminary aspects of an environmental impact assessment have been highlighted.

This paper is proposed as a first attempt for a scientifically-based, decision-driven framework approach for the assessment and identification of feasible biohydrogen production pathways based on a broad range of sustainability parameters (availability, accessibility and acceptability).

3. Photobiological biohydrogen production

The three main types of photobiological H_2-producing processes found in nature are: i) oxygenic photosynthesis coupled to H_2 production by hydrogenases (green algae, and in cyanobacteria); ii) oxygenic photosynthesis coupled to H_2 production by nitrogenases (cyanobacteria); iii) nonoxygenic photosynthesis coupled to nitrogenase-catalyzed H_2 production [7].

The ability of green algae to photosynthetically generate molecular hydrogen is well known together with the problem connected with oxygen as a positive suppressor of hydrogenase gene expression, and inhibitor of the [Fe]-hydrogenase [8].

It has been assessed that deprivation of sulfur-nutrients in green algae can represent a starting point for a commercial scale of the photobiohydrogen production [8].

3.1. *Basics of the biohydrogen from algae*

As described in the paper of J. Rupprecht (2009) [1], algae are able to produce hydrogen that is a clean fuel, only producing water when burned, and when used in fuel cells, offers the highest conversion efficiency (~60–70%).

For a penetration of the biohydrogen in the market and to compete with fossil fuels, production efficiencies have to be improved: hydrogen production has to take place at an efficiency of 7% under outdoor conditions to be commercially viable.

The drawbacks of microalgae biofuel production that also affect an LCA for this production process can mainly be identified in:

a) Rather little experience with the development of closed, large-scale photo-bioreactors.
b) High material costs for closed, highly efficient bioreactor systems.
c) No existing infrastructure and production pipeline.
d) High energy requirement for cultivation.
e) Expensive harvesting.

Some aspects of the technology required are not yet established which causes high prototype costs.

3.2. *Two-stage bioreactor: a cycling biohydrogen production process*

In light of a cyclic hydrogen production process *Chlamydomonas reinhardtii* has been developed by researchers at the National Renewable Energy Laboratory and the University of California – Berkeley [5,6]. *C. reinhardtii* cells are grown in a stirred tank reactor with light in a medium containing a low level of sulfur, then transferred into an anaerobic medium in a second stirred tank (see Fig. 1). The effect of sulfur deprivation is suppression of the first step of photosynthesis and consequently leaves two electrons use by hydrogenase enzyme to produce H_2. A pressure swing absorption unit purifies the hydrogen leaving the systems [5]. Eventually, cells left in the sulfur-deprived medium of the second stirred tank will begin suffering other sulfur deprivation effects and hydrogen production will decrease. To prevent this decrease in production, cells are removed and can be regenerated for use in the cycle again by providing sulfur and light. Also, to prevent build-up of material that cannot be used by cells; a fraction of the cells must be completely removed from the cycle and discarded [5].

The ideal algal hydrogen production system previously described would meet several criteria from cell wasting to the features of reactor material [8].

3.3. *Hydrogen costs comparison*

In order to understand the economical scale-up of this innovative plant, a cost comparative analysis, from the main hydrogen production, is carried out.

In the Fig. 2 it can be observed that the price for photobiological hydrogen is not far away from the main methods using fossil fuels (mainly from gas) that currently constitutes more than 96% of the world's hydrogen production [10,11]. The graph can also be considered as the basis for a benchmarking assessment of the hydrogen production based on photosynthetic processes.

3.4. *Progress in the photobiological hydrogen costs*

The costs regarding the state of art for photobiological hydrogen production is shown in Table 1. The projected H_2 production costs for the photobiological processes described above are comparable to the costs projected for H_2 produced in

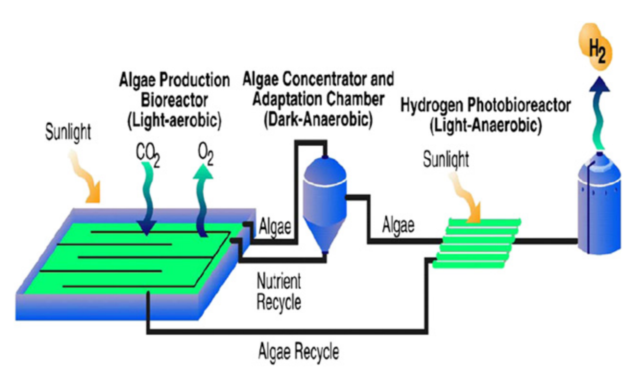

Fig. 1 – Principle of photobiological hydrogen production [6].