Techno-economic insights on biological hydrogen production through an integrated dark- and photo-fermentation process

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Hydrogen is a clean energy carrier that plays a key role in the global energy transition towards sustainability. While its utilization does not contribute to GHG emissions, the same cannot be said for its production. Traditional hydrogen production processes based on fossil fuels, although efficient, are very polluting and produce significant amounts of CO_2. A greener alternative is biological hydrogen production, exploiting microorganisms. Biological processes are promising for their sustainability potential and suitability for decentralized energy production in locations where biomass or wastes are available, but large-scale application is challenged by biological instability, low production yields compared to chemical processes, sensitivity to operating conditions, and costs.

In this work, a two-stage process for biohydrogen production was investigated, comprising Dark Fermentation (DF) and Photo-Fermentation (PF). In DF, organic waste is converted under anaerobic and dark thermophilic conditions, resulting in a gas product containing H_2 and CO_2, which is then upgraded to get the required purity, and a liquid product rich in volatile fatty acids (once separated from the sludge). PF is a biological process in which photosynthetic bacteria, mainly purple non-sulphur bacteria (PNSB), generate hydrogen under oxygen- and nitrogen-free environments in the presence of light and organic carbon sources. To enhance the overall process efficiency, the liquid product of DF can be used as a substrate for PF, allowing for additional H_2 production by metabolizing the unreacted compounds from the first stage.

In this work, a techno-economic analysis is conducted to evaluate the costs and identify the main bottlenecks of the two-stage hydrogen production process. The aim is to assess the feasibility of bio-H_2 production at industrial scale (i.e. small-medium sized plant) and to identify the key challenges related to their implementation, examining cost distribution, overall feasibility, and key areas for optimization. The major cost drivers are identified, offering valuable insights for future process improvements. This work expands on previous studies by considering membranes for H_2 purification, LED light for energetic efficiency, and microbial immobilization in PF, providing a more comprehensive evaluation of the feasibility and economic viability of biohydrogen production.

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