Bio-hydrogen from dark fermentation: a sustainable path for energy transition

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The transition to a sustainable energy system necessitates innovative solutions for producing renewable and low-emission fuels. Clean hydrogen is increasingly recognized as a key energy carrier for the decarbonization of energy-intensive sectors. In this context, dark anaerobic fermentation emerges as a promising biological process for producing bio-hydrogen from organic waste under mild operating conditions and without the need for light. This process, carried out by heterotrophic anaerobic bacteria, enables the valorization of various organic substrates, converting them into bio-hydrogen and short-chain fatty acids. In recent years, the massive proliferation of *Sargassum polycystum*, a brown macroalgae belonging to the class Phaeophyceae, has become a serious environmental concern in tropical and subtropical coastal regions. Initially a key ecological component of the Sargasso Sea, this species now forms large floating masses that compromise marine ecosystems, reduce biodiversity and cause significant damage to the local tourism economy. The management of such algal masses is particularly complex and costly, necessitating the development of sustainable strategies that integrate environmental mitigation and biomass energy valorization. This study explores the feasibility of hydrogen production via dark fermentation using *Sargassum polycystum* biomass as a substrate. This approach offers a double value: on the one hand, it enables the reduction of the environmental impact of invasive algal masses; on the other hand, it generates a clean energy source, contributing to the objectives of a circular economy and the decarbonization of the energy sector. The chemical-physical characterization of the biomass, including thermal and spectroscopic analyses, supports the optimization of the fermentation process. At the same time, the implementation of advanced experimental systems, including also membrane gas separation systems, allows real-time monitoring of bio-hydrogen production and waste gas separation. Preliminary results suggest that dark fermentation offers a sustainable and potentially scalable approach for converting problematic marine waste into renewable energy.

Keywords: *dark fermentation, biohydrogen production, Sargassum polycystum, sustainable energy*

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