Renewable Energy 259 (2026) 125048

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Enhancing microalgal biohydrogen production: Unlocking higher yields with hydrothermal pretreatment with niobium phosphate

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ARTICLE INFO

Keywords:
Acidogenic fermentation
Resource recovery
Wastewater treatment
Biomass valorization
Microalgae biomass

ABSTRACT

Microalgae cultivated in wastewater hold promise as a substrate for biohydrogen (bioH_2) production. However, their rigid cell walls pose a challenge to fermentability. In this context, this study evaluated hydrothermal pretreatment with niobium phosphate (NbP) at 100–180 °C for 0–70 min, using up to 75 % NbP (relative to the dry weight of microalgal biomass). The hydrothermal pretreatment at 180 °C for 10 min with 75 % NbP released 7431 mg total carbohydrates (CHt) L^{-1}, increasing the availability of fermentable substrates in subsequent dark fermentation (DF). When this pretreated biomass was subsequently fermented at pH 5.0 (sample PB5), bioH_2 production reached 1.03 mmol H_2 mol^{-1} CHt, with a maximum cumulative output of 0.17 mmol H_2 and a CHt conversion efficiency of 83.6 %. In contrast, pH 5.5 and 6.0 reduced bioH_2 yields and promoted methanogenic activity, while no pH control resulted in negligible bioH_2 evolution. In conclusion, hydrothermal pretreatment with niobium phosphate and pH improvement synergize to enhance hydrogenogenesis, integrating wastewater treatment and renewable biohydrogen production.

1. Introduction

The global energy transition toward sustainable and low-carbon systems is intensifying, with renewable energy sources such as solar, wind, hydropower, and biofuels expected to play a central role in decarbonizing power, heat, and transportation sectors. Renewable electricity generation is projected to reach over 17,000 TWh by 2030, an increase of almost 90 % from 2023 levels, meeting the combined power demand of China and the United States [1]. Despite this progress, achieving net-zero carbon emissions necessitates integrating renewable biofuels into the energy mix, particularly in sectors where electrification remains challenging, such as industrial processes and heavy transport [2]. Among renewable energy sources, hydrogen (H_2) stands out as a versatile energy carrier with high energy density, minimal carbon footprint, and diverse production pathways [3].

Dark fermentation (DF) of organic biomass has emerged as a promising technology for bioH_2 production, leveraging microbial consortia to convert primarily carbohydrates (CHt) into H_2 and volatile fatty acids (VFAs) under anaerobic conditions [3]. This process is particularly advantageous due to its ability to valorize diverse feedstocks, including agricultural residues and wastewater-grown biomass, without requiring complex external inputs like high-voltage electricity or pure oxygen [4]. However, achieving high H_2 yields is still a challenge.

Microalgae have garnered attention as a feedstock for bioH_2 production owing to their rapid growth rates and ability to be cultivated in wastewater, avoiding competition with arable land and food production [5]. Furthermore, wastewater-grown microalgae contribute to resource recovery through nutrient removal, reducing the environmental impact of wastewater discharge [6]. The main species commonly found in wastewater, *Chlorella vulgaris* and *Tetradesmus obliquus*, possess robust

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https://doi.org/10.1016/j.renene.2025.125048
Received 29 July 2025; Received in revised form 2 November 2025; Accepted 15 December 2025
Available online 16 December 2025
0960-1481/