ACS Sustainable Chemistry & Engineering

pubs.acs.org/journal/ascecg

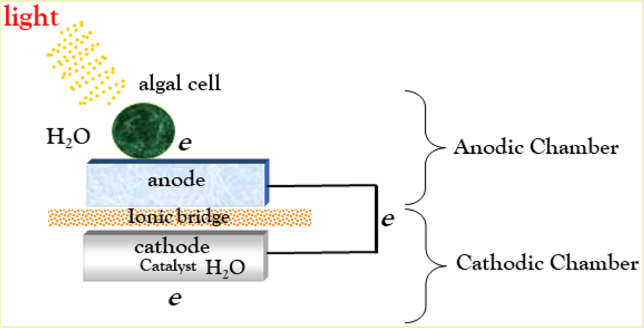
Research Article

Algal Biophotovoltaic Devices: Surface Potential Studies

Fong-Lee Ng, Siew-Moi Phang,* Mitsumasa Iwamoto, Takaaki Manaka, Cheng-Han Thong, Keito Shimosawa, Vengadesh Periasamy, G. Gnana Kumar, Kamran Yunus, and Adrian C. Fisher

Cite This: ACS Sustainable Chem. Eng. 2020, 8, 10511−10520

Read Online



ABSTRACT: The exploitation of renewable energy sources for delivering carbon-neutral or carbon-negative solutions has been accomplished through the strategies involving the removal of CO_2 from the atmosphere. Algae-fuel is deemed to play a major role in this emerging carbon-negative market via the bioelectricity generation using biophotovoltaic (BPV) cells. Accordingly, we investigate the bioelectricity generation of a freshwater green alga strain from Japan, *Chlorella vulgaris* (NIES-642), using carbon paper and indium−tin-oxide (ITO) electrodes. The ITO equipped BPV demonstrates the maximum power output of 0.25 mW m^{-2}, which is remarkably higher than carbon-paper-based BPV (0.21 mW m^{-2}). The surface potential studies were conducted to understand the electron transfer at the interface of algal biofilm and electrodes using the Kelvin probe method. The minimal surface potential difference (0.2 V) observed for ITO compared to those of other processed electrodes demonstrates the maximum BPV power generation, owing to its lower electrical resistivity and higher electron donor/acceptor capacity.

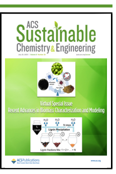
KEYWORDS: *Algal biophotovoltaic device, Bioelectricity, Biotechnology, Surface potential, Algal biofilm*

INTRODUCTION

Chlorella vulgaris is a freshwater, unicellular green microalga that has the fast growth rate and ability to withstand different growth conditions.[1] In freshwater bodies, the formation of microalgal biofilm is a common aquatic phenomenon as blue-green algae (also known as cyanobacteria) and microalgae are the primary photoautotrophic organisms that form biofilms in the presence of light.[2] Adhesion of microalgal cells on ship hulls increases fuel and energy consumption as a result of higher frictional resistance against water.[3,4] In photobioreactors, the surface accumulation of microalgal cells attenuates light and significantly reduces the amount of light impinged on cells behind the biofilm. However, microalgal biofilm is advantageous in algal biophotovoltaic (BPV) devices as attachment of the algal cells on the anode surface promotes faster electron transfer across the cell−electrode interface and improves power output from the devices.[5]

The light-driven water splitting occurring under the photosynthesis process generates a pair of electrons and O_2, and the released electrons can then be harvested and converted into bioelectricity. Microalgae are being used in the development of BPV devices, to harvest solar energy for bioelectricity generation.[6] Bioelectricity generation from photosynthetic microorganisms by Çevik and collaborators demonstrated enhanced power output from their algal BPV devices. This was achieved by growing an algae and cyanobacteria mixture on graphite electrode involving mediators,[7] treating *Choricystis* sp. with boron[8] and modification of gold electrodes with a conducting polymer coating.[9] Hasan and collaborators (2015) immobilized green alga, *Paulschulzia pseudovolvox*, on Os-polymer modified graphite where the photocurrent density was further improved to 11.50 μA cm^{-2} compared to bare-graphite electrodes (0.02 μA cm^{-2}).[10] Despite the increase in power output observed in the improvised algal BPV system,[11−16] the exact mechanism involved in the electron transfer from microalgae (electron donor) to the anode (electron acceptor) remains unclear. Classification of a material as an electron donor or electron acceptor is dependent on its ionization potential and electron affinity.[17] The electron is donated when it attains more energy than the minimum energy required for electron liberation from the highest occupied molecular orbital (HOMO) level to the lowest unoccupied molecular orbital (LUMO).[18] The gap between the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) is known as the energy band gap, specifying the charge transfer interactions within the molecule.[19] Efficient

Received: April 17, 2020
Revised: May 29, 2020
Published: July 8, 2020



https://dx.doi.org/10.1021/acssuschemeng.0c02831
ACS Sustainable Chem. Eng. 2020, 8, 10511−10520