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Harnessing Cyanobacteria for Hydrogen Production from Light Through Bio Electrochemical Route

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Electrochemistry has the unique distinction of being considered as interdisciplinary Science where Chemistry, Physics, Mathematics, Biology, Electrical engineering etc., find a common kinship. To emphasise this point, one can cite a recent work reported in *Angewandte Chemie*[1] where the Cyanobacteria which is an ancient, single-celled photosynthetic prokaryotes has been harnessed to produce hydrogen through electrochemistry route. It is worth pointing out that the cyanobacteria have been fundamental to Earth's oxygenation for over 2.4 billion years. It must also be pointed out that beyond their role in the process of evolution these organisms are now at the centre of a significant milestone in sustainable energy research.

This study outlines a novel electrochemical strategy to optimize these "bio-factories" for H_2 production. In this process, electrons extracted from water oxidation at the manganese cluster in Photosystem II (PSII) are transported through a specialized photosynthetic electron transport chain, which can ultimately supply high-energy electrons to a hydrogenase enzyme to produce hydrogen gas . However, a significant technical barrier is that the molecular oxygen generated as a byproduct of photosynthesis inhibits the hydrogenase enzymes required for this reaction. Cyanobacterial hydrogenases become inactive in the presence of oxygen, though they can fortunately be reactivated within seconds once oxygen is removed. The traditional oxygen-removal methods such as adding glucose alongside an oxygen-consuming enzyme mix of glucose oxidase and catalase are problematic because the cyanobacterial cells metabolize the glucose which becomes an electron donor instead of relying exclusively on water splitting, which is the goal of the work.

To bypass this, researchers developed a novel electrochemical solution by incorporating cyanobacterial cells into an electrode modified with a viologen-containing redox polymer deposited on a Glassy carbon electrode. By applying a negative potential of -270mV Vs SHE, the viologen species are reduced and function as electrochemical oxygen scavengers, neutralizing molecular oxygen near the cells. This constant consumption creates a steep diffusional gradient that forces oxygen out of the cellular environment, maintaining the strict anaerobic conditions required for hydrogenase activity. Using Scanning Electrochemical Microscopy (SECM), researchers confirmed the system scavenges oxygen without accumulating harmful hydrogen peroxide, effectively facilitating sustained water-splitting.

In wild-type cells, electrons are often diverted toward metabolic processes like CO_2 fixation. To resolve this, researchers engineered the mutant strain *PsaE-16-HoxUYH*, in which the hydrogenase enzyme is genetically fused directly to Photosystem I (PSI). This fusion ensures an alternative pathway for high-energy electrons to reach the hydrogenase enzyme, resulting in a significant reduction in the diversion of energy toward cellular growth. By integrating this electrochemical oxygen-scavenging protection with the metabolic precision of the PSI-hydrogenase fusion, the researchers have transformed cyanobacteria into more efficient

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bio-factories. This dual-approach is highly significant, providing a sustainable and biotechnologically viable method. This paves the way for the development of large-scale bio-photoconversion devices for clean, efficient energy conversion. However, the scaling this technology to meet large scale commercial demands will require further innovation to enhance conversion efficiency, lower costs, and ensure the robustness of the system in real-world, large-scale applications.

Reference

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