Material Issues in Photobiological Hydrogen Production

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Issues pertaining to photosynthetic cell modification, photobioreactor materials development, and the state of the art in these fields will be addressed. The research aims to modify and redirect green algal photosynthesis for enhanced hydrogen (H_2) production, coupled with parallel efforts to design and deploy the cheapest possible scale-up facility for the commercial production of H_2 gas. A three-pronged approach seeks to (i) increase the continuity and yield of H_2-production in the model green alga *Chlamydomonas reinhardtii*, (ii) optimize the absorption and utilization of sunlight by the cells so as to achieve the maximum possible solar-to-chemical conversion efficiency, and (iii) to explore affordable bioreactor designs that are best suited for photosynthetic H_2 production, harvesting, and sequestration.

(i) Improvement in the continuity and yield of green algal hydrogen production can be achieved upon attenuation of the photosynthesis/respiration capacity ratio in the cells, such that cellular respiration entirely consumes the photosynthetically generated oxygen. Anaerobiosis, i.e., the absence of oxygen, is a prerequisite for photobiological H_2 production. Under anaerobic conditions, afforded by an attenuated photosynthesis/respiration capacity ratio in the cells, spontaneous and sustained photosynthetic H_2-production is observed. Recent advances are based on the genetic identification of the chloroplast sulfate permease, followed by genetic engineering for the attenuation of sulfate uptake by this photosynthetic organelle. A slow-down in the supply of sulfates to the chloroplast causes limitation in the capacity and rate of photosynthesis, and permits cellular respiration to quantitatively consume photosynthetic oxygen and, therefore, to promote a spontaneous and sustained H_2-production.

(ii) Green algae under bright sunlight have low solar-to-chemical conversion efficiencies. Reason is the large arrays of light absorbing chlorophyll antenna molecules in the photosystems where, under bright sunlight, the rate of photon absorption far exceeds the rate at which photosynthesis can utilize them, resulting in dissipation and loss of the excess energy as fluorescence or heat. Up to 80% of absorbed photons could thus be wasted, lowering solar conversion efficiencies and cellular productivity. The work identified genes that regulate the chlorophyll antenna size of photosynthesis, and described manipulation of their expression to attain a “truncated chlorophyll antenna size”. The latter helps to diminish over-absorption and wasteful dissipation of excitation energy by individual cells, while permitting for greater transmittance of sunlight deeper into a high-density mass culture. Such altered optical properties of the cells result in greater photosynthetic productivity and better overall solar conversion efficiency of the mass culture. The above-described advances, based on genetic modifications of the green algae, compromise cell fitness and survival of the strains in the wild but promote the conditions needed for efficient mass cultivation in photobioreactors, thus promoting enhanced photosynthetic H_2 gas production.

(iii) Properties and costs of tubular modular photobioreactor facilities, which are suitable for the scale-up of green algal mass cultures, and for H_2-production and harvesting will also be presented.

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