2-2-9. Photobiological Fuel Production

Overview

Photosynthetic organisms include anoxygenic phototrophic bacteria using hydrogen sulfides and organic acids as electron donors, in other than oxygenic phototrophs, prokaryotic cyanobacteria, algae and higher plants using water molecules as electron donors. Technologies producing biodiesel, bioethanol and biohydrogen from the biomass produced by the photosynthesis driven by sunlight are essential for realization of environment-friendly and low-carbon future.

Current Status and Frontiers

In this section purple photosynthetic bacteria are addressed on behalf of anoxygenic photosynthetic prokaryotes. And the mechanism of hydrogen production linked to their characteristic photosynthesis machinery and its application toward use as an energy source are discussed. Purple bacteria are the photosynthetic species using bacteriochlorophylls and phylogenetically belonged to the phylum Proteobacteria. The name of "purple" bacteria is derived from the reddish color observed for the growing cultures, that is derived from various carotenoids synthesized as auxiliary pigments. Various energy metabolisms including oxygen respiration, inorganic respirations and fermentations are also observed in purple bacteria, as in non-photosynthetic species of Proteobacteria like Escherichia coli and rhizobium strains. Purple bacteria are photo-heterotrophs with a rather simple photosynthetic system using organic compounds as the electron donors, in contrast to chloroplasts and cyanobacteria using water as the electron donor and generating oxygen. The organic compounds they can use vary, i. e., organic acids like acetate and succinate, sugars including glucose, ethanol and methanol. Purple bacteria have been employed for cleanup of the high-level organic effluents like those from food factories, based on their wide range of nutrient availability.[1] However, the method employing purple bacteria had been gradually replaced by the activated sludge method employing chemotrophic bacteria,[2] because it was a formidable operation to maintain the reaction bath under anaerobic and light (sunlight) illuminated conditions that is preferrable to make the purple bacteria dominant. Although the purple bacteria were known to generate hydrogen gas at that time, the method employing purple bacteria has again become important challenge since the early 21st century when the exhaustion of fossil fuels and the risks of atomic power plants have become practical problems.

Many bacteria including purple bacteria have capabilities to reduce nitrogen in the air and generate ammonia. This reaction is catalyzed by nitrogenases and involves a generation of hydrogen gas as an inevitable by-product as follows.

$$N_2 + 8H^+ + 8e^- + 16ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16Pi$$

For this reaction much of reducing power ($NADH \rightarrow NAD^+ + H^+ + 2e^-$) and ATPs are required but photosynthetic bacteria can supply these energies by photosynthesis if the enough light irradiation is available. Here, the end electron donor should be various organic compounds but it should be water in the case of cyanobacteria. Genetic engineering has also been applied to these bacteria to improve the rate of hydrogen production. A deletion of the gene for the uptake hydrogenase that works to reuse the generated hydrogen gas for the cell growth and site-directed mutations on the nitrogenase to reduce the sensibility against oxygen or to increase the rate of the hydrogen production against that of the ammonia production have been reported.[3,4] Focusing on the difference in the wavelengths used by cyanobacteria (600 to 750 nm) and purple bacteria (750 to 900 nm), co-cultivation or stacking the layers of cultures of these bacteria has been tested to double the hydrogen production. Anyway, laboratory-scale trials have estimated enough levels of hydrogen production. Recently, such a clean and sustainable method for fuel production has been combined with city wastewater treatment systems. One of the problems that need to be overcome is that (1) the organic content in the city wastewater is too low to use as the growth medium for purple bacteria. This would be overcome by applying a technique concentrating the wastewater by a difference in osmotic pressure between seawater and the wastewater placed across a forward osmosis membrane (FO-membrane). Such concentrated wastewater is poor in nitrogenous compounds that work as feedback inhibitors against nitrogenase expression and is favorable to the hydrogen production. (2) How purple bacteria should be grown under anaerobic and light-illuminated conditions and (3) how the generated hydrogen gas should be trapped and collected are other problems. Applying a transparent plastic bag as the reaction bath will overcome these problems. When cyanobacteria are employed, (4) generation of oxygen gas along with the hydrogen gas is also a problem. Developments of chemical catalysts to eliminate oxygen are expected.

References

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