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A Review on Photoelectrode, Photovoltaic and Photosynthetic Microbial Fuel Cells

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ABSTRACT: This review explores the combination of photocells (PECs) and microbial fuel cells (MFCs), including Photosynthetic MFC. It has been found in a series of studies that may be photoanodes and photocathodes well combined with electrogenic and photoelectric microbes. Progress in this area comes from the idea that MFCs that use electrodes turning light into energy produce more energy than the dark reaction in a MFC alone or from solar energy in a PEC. There are a variety of possible designs for creating MFC photos. It should be noted that in addition to electricity, hydrogen, methane and other bio-electric solar fuels are used prepared using MFC-PEC hybrid reactors composed of artificial and native photosensitive materials Electrodes and microbes.

KEYWORDS: Microbial fuel cell, Photo electrochemical cell, Photoelectrode, Photosynthetic bacteria, Microalgae

I. INTRODUCTION

Power goes beyond what is possible with the only dark reaction. Different types of assisted light MFCs are described in the literature, but the total work on this topic is about 2% less than what is commonly known about MFCs. A light MFC can only be based on biological systems, but often consists of an anode or a non-biotic cathode and a biotic electrode. Even if an MFC is improved by light, it remains an MFC because at least one of the two electrodes is in contact with the microbes (Figure 1).

The combination with light is of particular interest when hydrogen must be generated with microbial help. The standard MFC is not able to generate the force necessary to overcome the overvoltage of 0.135 V necessary to produce hydrogen in microbial electrolysis cells [1]. The extra tension comes from solar energy, which is just enough to cause hydrogen evolution when using a photo-bio anode and a platinum cathode [2].

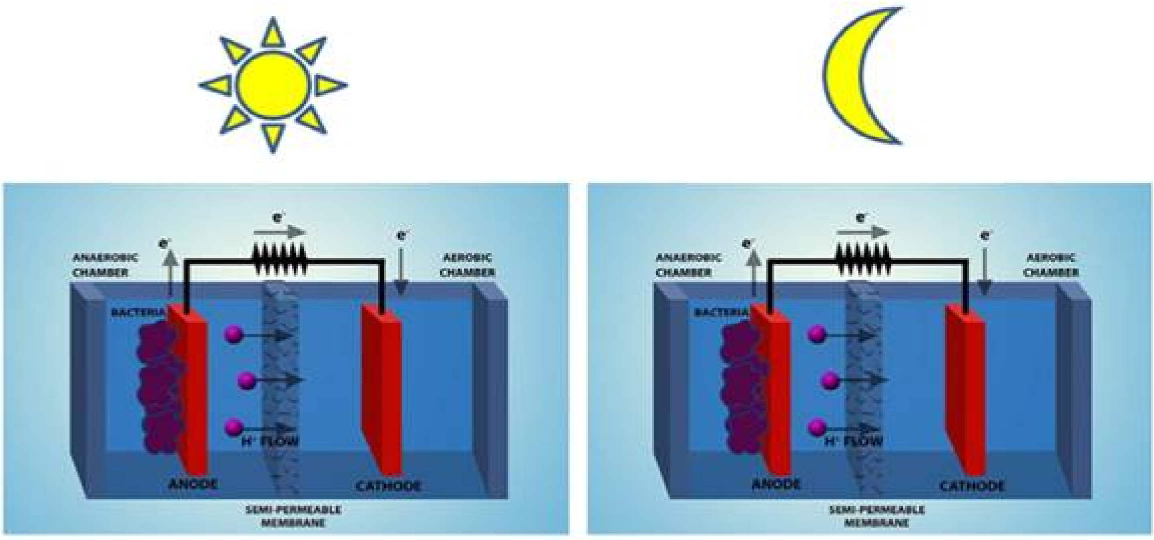

Figure 1: Dual Chambered Microbial Fuel Cell

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The MFC municipality is a bioanode that derives its energy from the microbes that adhere to the surfaces of the anodes and digest the nutrients from the aqueous solutions. From the experimental data in [3] has found 8.98 W/m^2. Under real laboratory conditions, however, MFCs do not produce such high values and are significantly lower, typically 1 to 3 W/m^2. One of the best performances recorded with a microbial bioanode was 6.9 W/m^2 [4]. Little progress has been made in improving the performance of MFCs in recent years.

All the factors to be explored to improve these MFC reactors. One approach to overcome this low-performance obstacle is to improve MFC with light. In an MFC optimized for light, it is believed that light and potency of microbes are combined by increasing tension and energy, but a detailed investigation is required. As a result, more electricity can be produced in such a combined structure and new applications become possible. These include more efficient wastewater treatment plants [5], kitchen waste [6], biofuels production [7] and even chemical synthesis [8]. Microbial fuel cells enhanced with photosynthetic microorganisms have been studied by several authors [9]. While cyanobacteria are generally considered to be anodic microbes, microalgae are described as functional in the cathodes. Conversely, the combination of photocells and microbial fuel cell technologies discussed here is a recent topic that has barely been described. It should be noted that there are many more possible variants of MFC, such as the microbial fuel cell [10], which show that future research is possible and will deal with potentially unexpected special combinations.

II. PHOTOELECTRODE MICROBIAL FUEL CELL

A microbial fuel cell (MFC) is a bio-battery with an anode (negative pole) and a cathode (positive pole). It is similar to the galvanic cell that students use in general chemistry labs to examine the potential of elements and battery operation. The difference between MFCs and galvanic cells is that MFCs use microbes instead of chemicals in the anode. These microbes provide electrons instead of ready-to-use chemicals. The released electrons then migrate through the external circuit towards the cathode as in a galvanic cell (figure 1, left side). At the same time, an equal amount of protons is generated, which also passes through a semipermeable membrane to the cathode. In the cathode, electrons and protons react with oxygen to form water, the final waste. A fascinating aspect of MFC is that there are almost infinite possibilities for variation due to their very simple battery configuration.

A. Microbial Fuel Cell with Photobioanode

A photobioanode combines microbial output and light in the same electrode. The photobioanode is usually a two-sided bifunctional electrode. One side, usually flat and covered with glass, is exposed to light, and on the back or the dark side, the surface is in contact with the microbes. In general, this electrode is a semiconductor used in solar panels. When this semiconductor anode is irradiated, electronic holes are generated and the microbes in the biofilm deliver electrons to the newly created electronic holes. The idea is that the microbes allow a higher excitation rate for the electrons of the valence band (VB) in the conduction band of the semiconductor (CB) (Fig 2). Solar radiation also increases the work potential of the MFC. The ability of the biofilm to supply electrons is a potential limitation. Other researchers have shown that the photobioanode can be divided into two separate anodes to combine their performance, which improves overall performance. The initially used photobiolodes were based on hematite nanowires attached to a FTO glass substrate. The protected side of the glass was illuminated and on the back (dark reaction) the hematite layer was in contact with the bacterial biofilm Shewanella oneidensis MR-1 [11] (Fig 2). The overexpression of a D-lactate transporter in this microbe was recently performed to increase electron donation. This type of photobioanode has been tested for long periods of treatment. To do this, the hematite surface exposed to the germs was covered by a layer of carbon, providing an inert seal against water infiltration, but acting as a biological interaction surface. Carbon is generally the preferred electrode material for microbial adhesion in MFCs. This advanced photobiodate significantly reduced the likelihood of leaching of cultured iron. In a similar approach, a combination of stainless steel hematite anodes was produced and used. It has improved electron replacement for holes in the hematite layer. Using this type of anode, another feature of photobioanodes has become visible. Photobioanodes has improved the thickness of the biofilm by increasing the respiration caused by the lighting, which has accelerated the transfer of electrons from the microbes to the electrodes, which is a desired side effect. This is similar to electrostimulation with a potentiostat.

Biofilms are thicker than a welcome property, because the internal resistance of the anode decreases when the MFC has more source performance and higher currents are possible [12]. The most interesting aspect of these microbial electrolysis cells is that the voltages are high enough to allow microbial electrolysis and hydrogen. The hydrogen-

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releasing reaction (HER) was further investigated by Photobioanode-MFC in an MFC and a separate photocell (PEC) was divided into a separate ECM, however, as Li and his colleagues [13] worked together . Here, the photoanode has not been in contact with microbes or other multimedia components. This reduces the risk of contamination of the cathode that produces hydrogen. Therefore, the dual use of separate MFCs and PECs is a concept that has recently received more attention [13]. Another photo studied as an anodic material is titanium dioxide (TiO_2). The particles of this stable semiconductor, for example, were doped on a macroporous carbon foam on one side of a square surface. The back of the sponge-like carbon remained intact and provided a large area for microbial adhesion [14].

There was no clearly defined separation in an exposed light and the dark microbial side as in most other works. The microbes were then allowed to enter the irradiated area through the pores. To what extent the microbes have survived in full sun, it has not been studied in detail, but the bacteria are usually destroyed in the irradiated TiO_2 surfaces.

The purpose of the above construction was to reduce the 4-chlorophenol to detoxify the contaminated water, in which the Photobioanode principle is used, which works more efficiently with the microbial power of the electrons. This light enriched MFC process improves the degradation of 4-chlorophenols from 28% to 41% [14]. The concept of photobioanode has also attracted the interest of researchers who develop solar biosupercupressors. These biosuppressants are not directly comparable with microbial fuel cells and will not be discussed further in this article. However, it might be interesting to follow this type of study when working with photobioanodes.

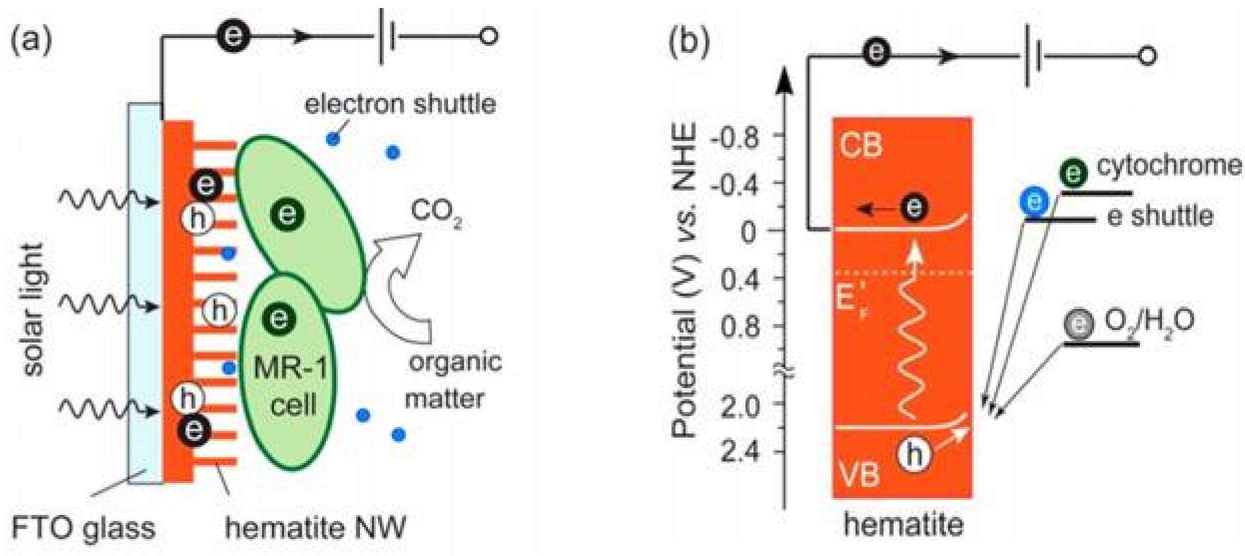

Figure 2: Bifunctional Photobioanode in Microbial Fuel Cell. B) Energy diagram, Promotion and Delivery of Electrons (e) from Microbes into the Semiconductor Hematite

B. Photocathode in Microbial Fuel Cell to Generate more Electricity

Intuitively, the idea could be that more power is generated with an MFC with solar radiation than without. This seems obvious until it becomes clear that most semiconductors are not very good drivers. Therefore, the question to ask is what to do, the combination of photocathodes and MFCs. Titanium dioxide (TiO_2) was one of the first photosensitive materials used in MFC photocathodes. In particular, it absorbs UV light and is often used for this property in sunscreen products. TiO_2 is an economic mineral called rutile, which is extracted at various points. It is a n-type semiconductor that becomes a driver above a certain light intensity. Graphitized and used in an MFC, its performance has improved by 1.57 times and produced 12.03 W/m^3. TiO2, which was used in an MFC, showed that the band capsule can be reduced with TiO_2 [39]. Photocatalytic active lithium tantalus, also known for its water separation properties, is another material that offers better performance with sunlight and MFCs. It was used as a photocathode and supplied when irradiated with UV / Vis 500 W lamb compared to the dark reaction three times more powerful (63 mW/m^3) [15]. The copper-indium photocatalytic sulfide (CuInS2) is also known to be photocatalytically active and capable of generating

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hydrogen. This $CuInS_2$ semiconductor was tested in flower nanostructures. When used as a photocathode in two MFC compartments with a Nafion membrane, the electrical power is 0.108 mW / cm² relatively close to that generated by a Pt/C cm² electrode with 0.123 mW / produced in the dark. The use of microbial fuel cells for the treatment of wastewater with a combination of TiO_2-anode yielded m-2 1284 ± 20 mW [16] is also possible. Previous research suggests that light has an effect on the generation of MFC, but the available data show that semiconductors often do not allow more electricity because they are bad conductors. In the situations described here, however, the forces in Photo-MFC have increased between 1.5 and 3 times. Compared to high density provide experiments conducted MFC without light, the results displayed less frequently cited reference values, for example, 500 W / m 3, the Ringeisen [17] and his colleagues in 2006 and are found to become a widely recognized landmark. Another limitation is the obtainable surface of an electrode from the light rays. This is in contrast to the microbial catalysis, which works in the dark, where an entire volume of anodes is involved in the production of electricity.

III. PHOTOVOLTAIC MICROBIAL FUEL CELL

A. Dye Sensitized Solar Cell Supported Microbial Fuel Cell

There are transparent and non-transparent solar panels and both can be combined with MFC and MEC. So far, MFC researchers have focused primarily on transparent glass-based solar panels. This is probably due to their low open circuit voltages (0.1 and 0.8 V), which are adjustable to the required voltages in MFCs and MECs to increase their performance. For more information on the DSSC research, see the review by Grätzel, which also includes a section on the history of this topic [18]. Hagfeldt al. also provide a detailed examination [19]. The open circuit potential of an MFC cell is just over 0.9 V and is often much lower. MFC and DSSC are therefore an interesting tandem system that allows a stable production of electricity or hydrogen (Figure 3). This combination of an MFC with a ruthenium DSSC dye was exposed by Ajayi to a 40 mW / cm^2 lamp. As a result, hydrogen evolved to 78% efficiency [20]. This is a very good performance, but it should be noted that acetate has been used as a source of electrons and protons. The DSSC voltages also allow HER to replace the expensive platinum currently used in many CEMs in a bioelectrical system with cheaper cathodes. Chae et al. [21] showed the potential of this combination in an MEC DSSC with a carbon felt cathode. As expected, this cathode malfunctioned in the dark reaction when less than 0.7 V was applied, but was as productive as a platinum-loaded carbon felt cathode when the voltage above this threshold was applied. The efficiency reaches 77% with the carbon felt electrode and is slightly less efficient at 82% compared to the Pt cathode. The solar cell area (DSSC) required for potential applications is relatively small compared to the size of an MFC. The use of solar cells (DSSC) not only allows HER under conditions of microbial electrolysis, but also generates hydrogen from microbial solutions that are poor donors of protons and electrons and to some extent, it looks like pure water. Further research is needed to show what happens when the microbial activity is insufficient compared to excessive sunlight. Little is known about the ability of microbial biofilms to sustain and survive the excessive demand for metabolites that supply electrons and protons, such as acetate. Under these conditions, the microbial electrolysis cell is no longer a typical microbial electrolysis cell. However, microbes are expected to help reduce overexpression of HER in DSSC-MEC.

B. Microbes within Dye Sensitized Solar Cell used as Microbial Fuel Cells

The use of live microbes in a dye solar cell (DSSC) has been largely untreated. However, research to date has faced an applied problem. These researchers used wastewater control and DSSC to accelerate wastewater treatment. Their idea was to use the waste water as electrolyte to replace I/I_3, which is normally used in DSSC as a mediator. A nanostructured plasmonic Ag/AgCl on chiral TiO_2 nanofibres was used as photoanode agent. The cathode changed properties during the experiment and was covered with copper [22]. Although there are few reports on the use of waste water and contained microbes, we know more about the use of biological sensitizers. Most of them are plants, although some treat microbial components.

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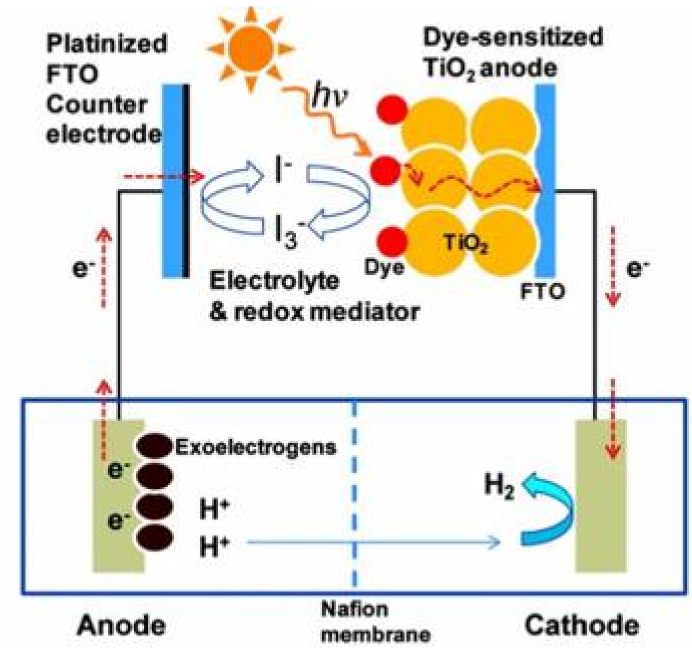

Figure 3: Dye Sensitized Solar Cell (DSSC) Powered Microbial Electrolysis Cell (MEC) For Hydrogen Generation

IV. PHOTOSYNTHETIC MICROBIAL FUEL CELL

Microalgae are also microbes, but the use of algae in an MFC seems exceptionally good, so these MFCs are mentioned here as elsewhere as Microalgae MFC. There are two main uses of algae, which are studied by a number of researchers. The first is the mass of microalgae as a valuable substrate for generating bioelectricity in the dark reaction in an MFC with microbes. The most interesting way to use microalgae is to be a biocatalyst in the MFC cathode. There he produces oxygen, biomass and chemicals. The even more exciting use of microalgae in MFC is to combine the two types of MFC with microalgae that allow a MFC to cyclical microalgae (Figure 4). The main reason for using microalgae in an MFC is to generate metabolic oxygen and release it into the aqueous media of the cathode to produce electricity. Microalgae in MFC cathodes are particularly interesting because they replace the formation of oxygen bubbles. The aqueous oxygen cathode without biotic oxygen in MFC is often cited as a limiting component in an MFC and better solutions have been sought which, for example, do not require agitation. In this context, the use of membrane-free and membrane-free MLC microalgae was also investigated [23]. The most popular solution so far is the air-oxygen cathode (not based on algae). However, it remains to be seen whether this will be the economic solution in the future, since accurate oxygen dosing is important to avoid the destruction of anode generators like Geobacter, which are very sensitive to oxygen. Finally, from an integrative point of view, the MFC micro-algae allows a profitable aeration in the production of biomass and, with the corresponding algae, also chemical substances. If possible, this would reduce the operating costs of electricity production. One of the most convincing arguments for MFC in micro alga is that all nutrients can be reused in the same MFC.

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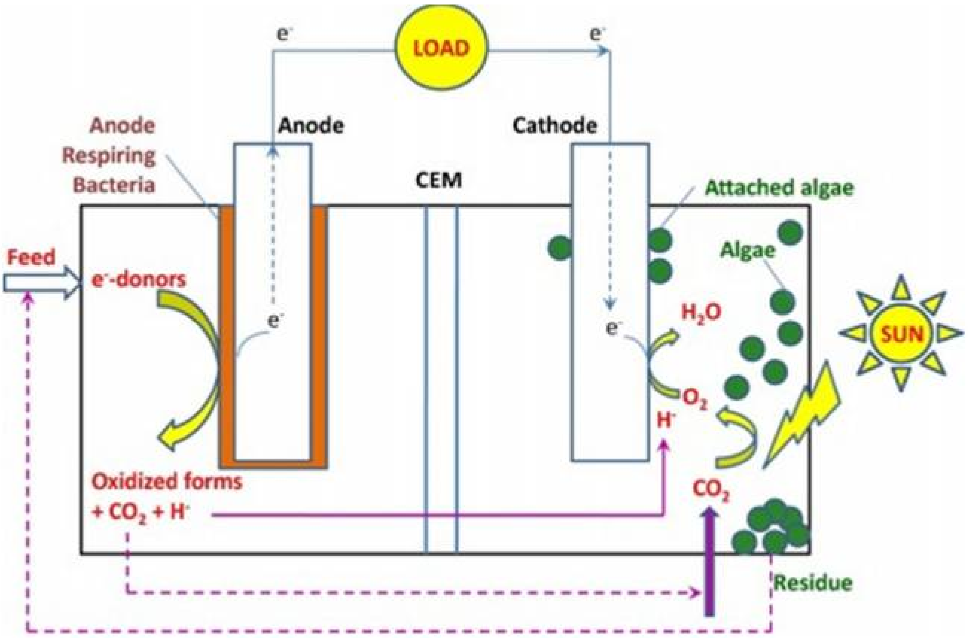

Figure 3: Microalgae–Microbial Fuel Cell

This means that an MFC with micro algae can convert CO_2 into fuel and other alkanes, while MFC works independently and indefinitely. It is not necessary to buy fertilizers (nitrogen, phosphorus, potassium and other nutrients) because the remaining salts are reused as fertilizers, see also Lee et al. [24]. Another key problem for MFCs based on microalgae is the availability of low-cost CO_2. Although CO_2 accumulates in the atmosphere, its concentration is very low and the recovery of air is an energy-intensive task. However, the MFC anode is a source of CO_2, a possible source of this gas, since most MFCs are not very efficient. There are numerous biotechnological processes that can be implemented in the MFC anode and the discharge of non-toxic concentrated CO_2 gas can be directed towards the cathode. The production of bioethanol from corn, sugar cane and vinification is an example of a process that releases a good amount of CO_2. Powell and his colleagues studied CO_2 capture from such bioethanol plants with microalgae. In their study, CO_2 was guided by the anode into a cathode containing microalgae.

The resulting oxygen was reduced in situ with anodic electrons and protons. The success of this process is partially guaranteed because the CO_2 input is greater than necessary because this MFC of yeast produces relatively low levels of electrons. This is because electricity production is not at the expense of ethanol production, which is harvested as an energy carrier. In fact, electrons are most likely derived from side reactions. This is the case when working with Saccharomyces cerevisiae, where the newly produced ethanol is preserved from the crabtree effect. Here the oxidation and the reduction are in equilibrium and the presence of oxygen does not change that. This carbide effect was also observed in an MFC, as shown with a 10-fold triple MFC stack. The inertia for the subsequent oxidation of the ethanol persists as long as the glucose concentrations are sufficiently high. Another potentially important source of biogenic CO_2 is municipal wastewater treatment plants. In particular, large-scale and non-paired MFC anaerobic is a potential source of CO_2-enriched gaseous effluents useful for generating electricity through a microalgae cathode. However, the mass of microalgae could be used as a seasonal energy storage tank that is digestible in the MFC to produce electricity. Based on the reusability of algae mass, the reactor is conceptually developed to generate energy in wastewater treatment plants. Overall, the current challenge is the ability of MFC to microalgae to function as an autonomous unit. The oxygenation of algae is very effective, as shown by Scenedesmus obliquus. Here, the microalgae cathode has passed mechanical ventilation with an efficiency of 32% [35]. Also the cations that accumulate in the catheter over time are problematic and must be removed to keep the cathode functioning. Furthermore, these cations should be recycled. In summary, it should be noted that the cathode of the microalgae has not yet been found to be the same cathode, good or better, of the air-oxygen cathode, much better known.

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V. CONCLUSION

The combination of photocells and microbial fuel cells facilitates the hydrogen evolution reaction. In theory, light-amplified microbial fuel cells generate more electricity than is possible with conventional MFCs. However, to date, electricity generation does not go beyond the obscure process and remains an unresolved challenge when further research is needed. Many photoelectrode designs have been effectively combined with microbes and synergistic effects are possible. The algal cathode is the best studied so far and is of considerable interest because it corresponds to the idea of a source of regenerative energy. In addition to electricity, it also generates biomass, which is then burned in the same structure for the production of electricity. It does not need fertilizer, but CO_2, water and light. These systems have also been used for the decomposition of dyes and the treatment of waste water during the production of electricity. It was also possible to combine photovoltaic solar cells with standard microbial fuel cells, especially when solar cells sensitized with dye attracted interest. Finally, the photo-MFC should be a completely new field of research in bioelectric fuel production.

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