DIRECT SOLAR ENERGY IN MICROBIAL SOLAR CELLS AS A FUTURE SOURCE OF ELECTRICAL ENERGY

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ABSTRACT

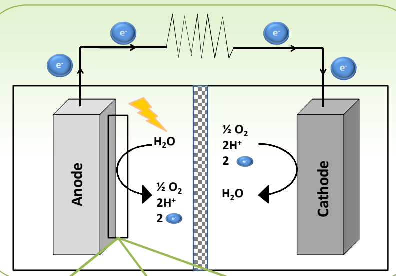
Solar energy is one of the most investigated sources of renewable energy to supply the increasing demand of power. Nowadays, Microbial Solar Cells (MSCs) are photo-bioelectrochemical device of great interest since their only source of energy to generate electricity is light. This review collects information of different microbial photo-biocatalysts such as whole cells, sub-cellular membranes and protein complexes that could be used in MSCs devices. There is also an analysis and comparison of studies that aim to improve the efficiency and power output of MSCs (using whole cells) focusing on variables like anodic treatment with semiconductor materials, use of pure and mixed cultures as biocatalysts, and the addition of exogenous anodic mediators. Finally, a comparative analysis of efficiencies between MSCs and heterotroph Microbial Fuel Cells (MFCs) is presented.

1. INTRODUCTION

As global energy consumption continues to rise, the need for renewable energy source becomes more important. New devices that can acquire electricity from solar energy are of great interest as it is a way to obtain clean energy. To convert solar into electric energy there are two main options: photo-voltaic panels or photosynthesis. The potential use of photosynthetic living microorganism, sub-cellular membranes or protein complexes have recently become popular among researchers on to the energy obtainment with photosynthetic processes which are used by photo-bioelectrochemical cells (PBECs). MSCs are a type of PBEC device that use sunlight as a solely energy source (not fuel is required).

2. MICROBIAL SOLAR CELLS

MSCs are formed by an anodic and a cathodic chamber, both with an electrode. In oxygenic MSCs a photo-biocatalyst on the anode performs a water photolysis releasing electrons, oxygen and hydrogens. These electrons are transferred to the anodic electrode and flow through an external circuit until they reach the cathodic chamber, where they are combined with hydrogen and oxygen to produce water. When the electrons move along the external circuit a potential difference is generated, enabling the production of electrical energy.

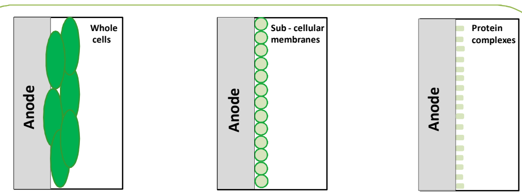


2.1. Photo-biocatalysts

Several types of photosynthetic biocatalysts can lead to different methods using solar direct energy as the main and only requirement for the energetic conversion:

	Advantages	Disadvantages
Whole cells	All photosynthetic enzymes and cofactors Mechanisms to replace damaged or destroyed components	Outer membrane
Sub-cellular membranes	All photosynthetic enzymes and cofactors Lack of outer membrane Small size	No mechanisms to replace damaged or destroyed components Stability Immobilization
Protein complexes	Small size Lack of membrane	

Photo-biocatalysts in MSCs



- **Cyanobacteria:**
  - *Nostoc* sp.
  - Synechocystis sp.
  - Synechococcus sp.
- **Photosynthetic biofilms**
- **Algae:**
  - *Chlorella vulgaris*
  - *Dunaliella tertiolecta*

- **Chlorosomes:**
  - *Chloroflexus aurantiacus*
- **Chromatophores:**
  - *Rhodospirillum rubrum*
  - *Rhodobacter sphaeroides*

- **Cyanobacteria:**
  - PSI
  - PSII
- **Bacterial reaction center**

3. COMPARATIVE ANALYSIS IN EFFICIENCIES

This analysis of previous researches[1-13] is based on two important parameters which enable the efficiency study in order to compare the systems: Peak Power Density (Wmax) and the electric Current Intensity at its Peak Power Density (Iwmax). This review is focused in two comparisons.

3.1. Comparative analysis between different MSCs

In this comparison, Wmax and Iwmax have been normalized to 1mW of irradiated light. There are three different optimizations analyzed:

- **anodes coated with semiconductor materials (Fig.1)**
- **the use of mediators in the anode (Fig.2)**
- **the use of pure or mixed cultures as photo-biocatalysts (Fig.3)**

3.2. Comparative analysis between efficiencies of MSCs and MFCs

When comparing autotrophs and heterotrophs systems **(Fig.4)**, it was taken into consideration that MFCs generate energy working at an organic/inorganic matter saturated concentration. MSCs data have been normalized at a saturated irradiation light power of 100 mW/cm².

Comparative analysis between efficiencies of MSCs and MFCs

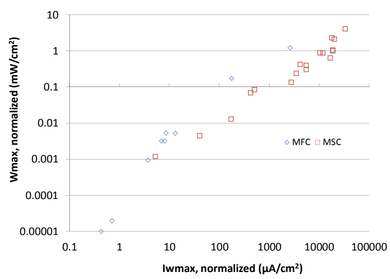


Figure 4|Comparison of Peak Power Density (Wmax) according to Current Intensity (Iwmax) between MFCs (Microbial Fuel Cell - ◇) **and MSCs** (Microbial Solar Cells - □) **.** Wmax and Iwmax of MSCs have been normalized at 100 mW sunlight/cm².

Anodes coated with semiconductor materials

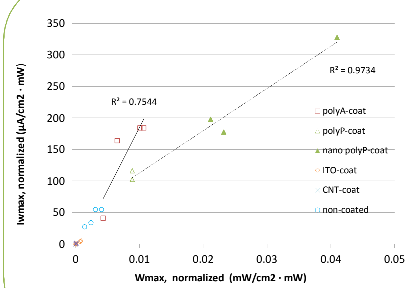


Figure 1|Peak Power Density (Wmax) according to Current Intensity (Iwmax) of MSCs devices with treated anodes: polyA (polyaniline - □), **polyP** (polypirrole - △), **nano polyP** (nanostructured polypirrole - ▲) **ITO** (indium tin oxide - ◇) and **CNT** (carbon nanotube - X); **and non-treated** (○). Both, Wmax and Iwmax have been normalized at 1mW of projected light.

Anodic mediators

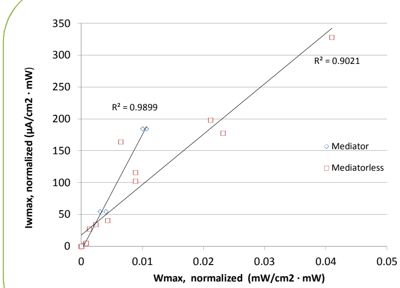


Figure 2|Peak Power Density (Wmax) according to Current Intensity (Iwmax) of MSCs devices with mediator (◇) and non-mediator (□) at the anode. Both, Wmax and Iwmax have been normalized at 1mW of projected light.

Pure or mixed cultures as photo-biocatalysts

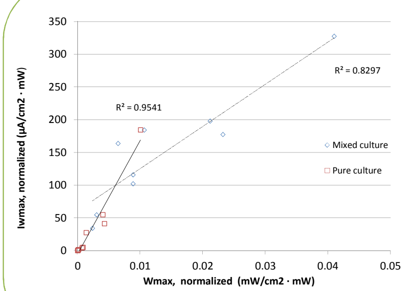


Figure 3|Peak Power Density (Wmax) according to Current Intensity (Iwmax) of MSCs devices with mixed culture (◇) and pure cultures (□)as photo-biocatalysts. Both, Wmax and Iwmax have been normalized at 1mW of projected light.

4. CONCLUSIONS

Photo-biocatalysts:

- Whole cells are the most commonly used biocatalyst in MSCs.
- Investigations in sub-cellular membrane and protein complexes are focused in their application as additional pigments in photovoltaic cells.

Theoretical studies of MSCs with whole cells:

-The peak power density (Wmax) is increased by anodes coated with semiconductor materials, when an anodic mediator is used and when a mixed culture is implemented as a photo-biocatalyst.

Comparative analysis between different MSCs:

- Coating the anode with semiconductor materials shows greater efficiency, being it the determining factor in the optimization.
- Neither the use of an anodic mediator nor pure or mixed culture are a crucial factor in the optimization.

Comparative analysis between efficiencies of MSCs and MFCs

- MFCs have a better efficiency in terms of energy production.

5. OUTLOOK

Until now, no successful commercial applications of the MSCs have been traded.

Multifactorial MSCs studies would have to be performed for reliable comparative analysis. Their requirements should include the standardization of experimental methods, the data to publish and their units.

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