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Review

A critical review on microalgae as an alternative source for bioenergy production: A promising low cost substrate for microbial fuel cells

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ABSTRACT

The environmental pollution caused by the excess of human energy consumption and the foreseeable depletion of fossil fuels underline the need for new eco-friendly, sustainable and cost effective energy sources. Recent research works on microalgae have identified this new bio-material as a promising technology for bioenergy production, wastewater treatment, the development of high value added products and CO_2 capture. Microalgae can be used to produce biodiesel, bioethanol, methane or hydrogen. However, one of the newest applications of this bio-material is its use in microbial fuel cells (MFCs). The resulting microalgae-MFC systems can produce electricity using the electrons released to the anode during microalgae degradation. Furthermore, microalgae can be grown in the cathode chamber, capturing the CO_2 therein and using light as power source.
This critical review presents an overview of new applications of microalgae for bioenergy production. It includes as a novelty the use of microalgae for electricity generation in microalgae-MFCs and capturing the CO_2 emissions of these systems, their advantages, limitations and future prospects.

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1. Introduction

The energy sector worldwide has been forced to change rapidly due to global warming. The most widely used energy sources are based on fossil fuels even though it is well know that the reserves of oil, gas, coal or uranium will be exhausted in 55–75 years. The increase in the world population, estimated at around 9.7 billion people in 2050, along with a sharp economic growth of emerging countries as China and India, will increase the energy needs of the world [1,2]. The continued use of fossil fuels has several negative environmental impacts due to greenhouse gas (GHG) emissions to the atmosphere, such as CO_2, which contributes to global warming and the acidification of the oceans [3,4].

The long-term solution to such environmental problems is the development of renewable technologies to produce energy that will reduce CO_2 emissions to almost zero in 2100 [5]. To stimulate and promote research in the bioenergy field new policies have been adopted around the world. Thus, in July 2015, Denmark generated 140% of its electricity needs from wind energy, and shared its excess with other countries. This demonstrates that renewable energies are feasible for satisfying the world's energy needs. A recent report from the International Energy Agency (IEA) reveals that the energy produced from biofuels and waste have the highest potential. The energy obtained from biofuels and waste represented 10.0% of the world's total primary energy supply, compared with 2.4% from water, and 1.1% from other sources such as the wind or the sun. Therefore, it is expected that biofuels will play an important role in the future as sustainable energy source [6].

There are many options available to produce bioenergy and one of the most promising is the use of microorganisms. Microalgae are photosynthetic microorganisms that have the ability to accumulate lipids, hydrocarbons, etc. that are suitable for the production of biodiesel, methane, hydrogen or ethanol, among others.

Many studies demonstrate that the development of this biotechnology could supply 30% of the global fuel demand in an environmentally friendly way, without having a negative impact on food production [6]. Some research works confirm that the production of biodiesel using microalgae is more sustainable than its production from agricultural crops since the process does not affect the supply of agricultural products [7]. In recent years, many advances have been made in the field of MFCs [8]. Microbial fuel cells are an alternative way to produce electricity and microalgae can be grown in the cathodic chamber consuming the small amount of CO_2 produced in this compartment. Then, the algal biomass can be recirculated to the anode to be used as substrate by the anodic microorganisms [9].

This critical review provides an overview of the use of microalgae to produce a wide range of bioenergy, including bioelectricity and biodiesel. It focuses on their use in microbial fuel cells for electricity production, and the advantages of this technology and its limitations.

2. Microalgae used in biotechnology

2.1. Brief history of microalgae

Microalgae were used in China 2000 years to survive famines but the first research works focusing on microalgae valorization were performed during the Second World War. Harder and von Witsch in 1942 proposed that some types of microalgae could be used as source of lipids, as a feasible food supplement or for producing oil [10–12]. At the beginning of 1960s, the biology and physiology of microalgae were well known [12]. However, interest in this bio-material increased rapidly with the oil crisis in the 1970s when microalgae started to be considered as a potential alternative to fossil fuels to produce energy [13]. Later, in 1980, the US Department of Energy started the Aquatic Species Programme (ASP), the main purpose of which was to promote algae as a source of green fuel which could compete with fossil fuels [14].

The great efforts made in recent years have led microalgae to be considered as a green and feasible alternative for bioenergy production based on an effective and low cost technology [15]. Recent studies have demonstrated the positive evolution of microalgae for use as feedstock for producing biodiesel, bio-ethanol, bio-hydrogen, bio-oil and bio-gas [16–21].

2.2. Definition of microalgae

Microalgae, some of the oldest living organisms, are microscopic photosynthetic organisms that can be found in marine and freshwater environments. They are a diverse group of prokaryotic and eukaryotic photosynthetic microorganisms with a unicellular or simple multicellular structure that allows them to grow rapidly and live in extreme conditions [16]. Due to this simple structure, they harness solar energy quickly and efficiently through photosynthesis. They use sunlight to produce oils or sugars in a more efficiently way than crop plants. Moreover, autotrophic production is more efficient than heterotrophic production, and therefore microalgae are commonly used as substrate for biofuel production. They usually grow in aquatic environments, which provide them with many nutrients in dissolved form, such as CO_2 [17].

Microalgae can be grouped into different categories based on the pigmentation of their biological structure: i) green algae (*Chlorophyta*), red algae (*Rhodophyta*) and diatoms (*Bacillariophyta*) [19]. They can also be classified into two groups: i) autotrophic, which only require inorganic compounds to grow, such as CO_2, salts (nitrate ion, phosphate) and light. This subcategory can be divided into photoautotrophs, which use solar light as a source of energy and chemoautotrophs, which require an external source of organic compounds as source of energy. ii) Heterotrophs can also grouped into photoheterotrophs, which use solar light as source of energy and chemoheterotroph, which oxidizes organic compounds to get energy. However, there are some types of microalgae that can use different sources of energy and carbon, which are called iii) mixotrophic [18,19,22].

More than 100,000 different species of microalgae exist around the world, but no more than 30,000 have been investigated and classified, according to their color, size, pigments, cell wall constituencies or metabolism, as suitable for human needs. Microalgae also include the unicellular organisms (phytoplankton) existing in natural water, which are an essential source of carbon for aquatic fauna [15,23,24].

Table 1 shows the most common species of microalgae used in biotechnology, their biomass production, the type of culture medium they require and the operation mode.

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