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Microalgal biorefinery from CO_2 and the effects under the Blue Economy

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ABSTRACT

In the current global context, industrial processes follow a classical model wherein pollution is accepted as a negative environmental externality that is compensated by a positive economic externality. Positive effects range from the exploitation of mineral resources and their local and regional advantages to the use of energy in industry. The Blue Economy incorporates the concept of rethinking industrial processes and seeking a viable biological solution that reduces pollution. Microalgae have been extensively studied due to the potential of using industrial effluents as a source of nutrients, such as the CO_2 emitted from thermoelectric plants. The biomass produced by these microorganisms can be fully utilized in a microalgae-based photobiorefinery, which operates under the principle of producing biofuels and high-value co-products while aiming to improve economic viability. This review aims to present the concepts of a microalgae biorefinery from the use of greenhouse gases by applying the fundamentals of the Blue Economy to collaborate to reduce CO_2 emissions from thermoelectric plants.

1. Introduction

Modern society faces a number of environmental challenges, such as water and air pollution, global warming, climate change, and the energy crisis, among others, which can be primarily attributed to the massive use of fossil fuels. The continuous use of these fuels emits large amounts of greenhouse gases (GHGs), mainly carbon dioxide (CO_2), which is considered the most significant greenhouse gas. The development of capture, sequestration and biological fixation technologies of this gas has been recognized as the most effective method of reducing global CO_2 emissions [1–3]. Considering that one of the concepts of the Blue Economy is the reuse and recovery of waste [4], CO_2 biofixation is a key part of this proposal since CO_2 is an abundant source of carbon, which must be neutralized to reduce greenhouse-gas-related problems.

The biological fixation of CO_2 by microalgae has attracted attention because microalgae are able to fix this gas using solar energy with an efficiency 10–50 times greater than that of terrestrial plants [5,6]. Among the numerous species of microalgae that have the potential to biofix CO_2, different sequestration capacities and different degrees of tolerance are reported at high concentrations of this gas. Some marine microalgae can easily grow in concentrations of 40% CO_2, and strains isolated from locations close to thermoelectric plants can also withstand high concentrations of industrial combustion gases [6–8].

Microalgal biorefineries are designed to reduce the production costs of microalgae-based fuels through the implementation of highly integrated production processes, wherein not only is waste reduction achieved but also the efficient processing of biomass into energy, chemicals, polymers or food additives, among others. For these reasons, biorefineries have been identified as the most promising and economically viable way to maintain a biomass-based industry [9–12].

In parallel with the goal of sustainable production, the Blue Economy also aims at the use of biodiversity. In Gunter Pauli's book "The Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs," using microalgae was mentioned in 2 of the 100 global success stories discussed in the book. These projects are "Cultivation of *Spirulina* in Alkaline Lagoon in the South of Brazil" and "Biofixation of CO_2 in a Thermoelectric Coal Plant" [13], which remain under development. This review aims to present the concepts of a microalgae biorefinery from the use of greenhouse gases by applying the fundamentals of the Blue Economy to collaborate to reduce CO_2 emissions from thermoelectric plants.

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2. Biofixation of CO_2 and the Blue Economy

Carbon dioxide, which is associated with global warming, has been judged to be the main cause of planetary climate change by intensifying the greenhouse effect. Many scientific and technical studies have investigated approaches to capture and trap this gas as if these were solutions to the problem [14]. However, it is also necessary to consider that the greenhouse effect is natural and positive because if it did not occur, our planet would have much lower temperatures. In addition, when it diffuses into the air, water and soil, this gas enables several biochemical processes, especially those based on photosynthesis.

The increase in CO_2 concentrations comes from the combustion of fossil fuels, on which modern technologies depend [14]. Thus, excess CO_2 production is inherent in our model of development and production based on fossil fuels, burning forests to expand arable land, as well as cars and industry in general.

The main objective of thermoelectric power plants is to transform the chemical energy stored in a fossil fuel (coal, oil or natural gas) into electrical energy in an intensive process conducted in the shortest possible time, and the environment is fundamentally used as an emissions depository [15]. Consolidated technical solutions are routinely applied in electric power plants for reducing emissions of sulfur and nitrogen oxides as well as particulate matter [16]. However, the problem of excess CO_2 emissions persists. Combustion is the reverse of photosynthesis, using oxygen and producing CO_2 and water. Therefore, reducing this gas will require photosynthesis, which applies a cyclic process, as shown in Fig. 1.

The Blue Economy is based on the perception that nature, in its processes of synthesis and separation at ambient pressure and temperature, uses locally available raw materials and reuses waste through connections and systemic relationships between living beings. The system is therefore stable, but it also evolves, thereby developing the environment [13].

Notably, industrial and natural processes have become clearly differentiated in recent times since human processes occur based on the loss control model, while natural processes involve the construction of connections. Understanding the science behind natural processes and applying this knowledge to the critical and creative intelligence of man structures and enables the development of cyclical, systemic processes of synthesis, exchange and separations [17].

By observing and understanding the systemic intelligence existing in natural processes, the Blue Economy seeks to build a platform that groups knowledge and effective action on reality through the transfer and adaptation of existing technologies. An inherent aspect of the conceptual basis of the Blue Economy is the consideration that despite the problems of the traditional economy, seeking opportunities to insert it into the context of biological process is necessary [4,13].

With the application of the Blue Economy, the unsustainable economy, which is based on intensive use of natural resources, may be replaced by high-performance economic biosystems with productivity and results superior to those currently obtained. Advances in the application of concepts and practices of the Blue Economy related to the excess CO_2 released by thermoelectric plants aim to aggregate the possibilities of the results and reduce the environmental impact using a biological variable to intervene the system, e.g., the use of photosynthetic microorganisms. To apply the concepts of the Blue Economy in a thermoelectric power plant, light, microorganisms and CO_2 are required, which form a process of cultivation and production similar to nature in the presence of water and salts. In the implementation of this idea, understanding that CO_2 originates from the burning of coal and is an abundant source of carbon for microalgae is necessary [13].

In addition, the use of fossil fuels can be reduced by burning part of the produced biomass in the boiler. This idea incorporates the perspective of the interrelationships of decomposition and synthesis, circularities and emergent properties of systems. Only in this way can thermal energy production from fossil fuels become environmentally viable.

3. Microalgae biorefinery from the CO_2 capture and sequestration concept

Microalgae are photosynthetic microorganisms that require water, light, CO_2 and inorganic nutrients for growth [18,19]. Carbon dioxide mitigation using photosynthetic microorganisms, particularly microalgae, is believed to be one of the most promising approaches [20] to reduce both atmospheric concentrations of this gas and global warming. In addition, microalgae are able to use CO_2 as a carbon source for biomass production, which reduces nutrient costs [21].

These microorganisms are basically categorized into a variety of classes defined by their pigmentation, life cycle and cellular structure. Eukaryotic microalgae include Chlorophyta (green algae), Rhodophyta (red algae) and Bacillariophyta (diatoms). Cyanobacteria are prokaryotes with structural characteristics similar to those of bacteria, such as the presence of peptidoglycan in the cell wall. These microorganisms are called microalgae due to the presence of photosynthetic compounds (chlorophylls) in their cells [22].

Microalgae cultivation offers advantages such as the rate of reproduction, ease of use in areas not suitable for agriculture and the possibility of directing the cultivation toward the production of several compounds of commercial interest [23]. The microalgae life cycle is

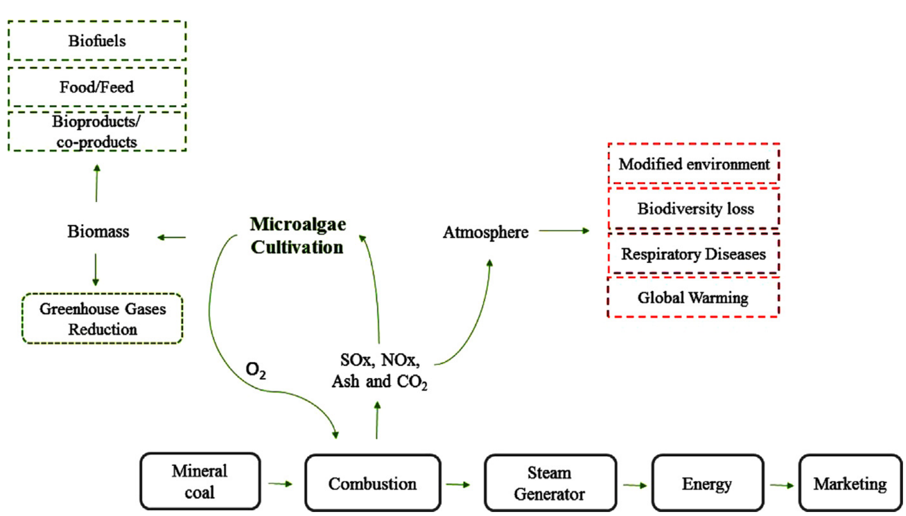

Fig. 1. Microalgae in the application of the Blue Economy concept in thermoelectric plants.