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MICROALGAE BIO-TECHNOLOGICAL FOR ENERGY RESOURCES IN INDUSTRIAL FACILITIES - A REVIEW

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Abstract. *The increase in urbanization and its consequent industrial demand have caused several negative impacts to the environment and human health. Therefore, a balance is essential on sustainable development. In an attempt to unite environmental conservation with economic development, it is required to search for applicable innovative alternatives to the development process of new products, as well as effective techniques to minimize any environmental issues. The progressive consumption of fuels used in vehicles, as well as in the energy generation industries, has been generating excessive emissions of harmful pollutants, resulting in global warming and climate change. Therefore, microalgae can be used as a promising alternative in an attempt to reduce environmental damages. These microorganisms are present in different aquatic environments and have the ability to adapt to divergent conditions. Among the biochemical composition of microalgae, it is possible to mention carbohydrates, lipids, proteins, fatty acids and pigments, which can be used as raw material in manufacture of products for diverse industrial sectors. The application of microalgae in emissions treatment processes deserves emphasis, because these microorganisms are able to use the pollutant gases in their metabolism as a nutrient source. The proposed work aims to present microalgae energy potential to the industry, especially for biofuels. Many vegetable sources have been used to produce biofuels and obtain energy efficiency, but they are not enough to meet the current demand. For this reason new technologies are able to drive energy efficiency.*

Keywords: *alternative energy; biodiversity; biofuels; climate change; sustainability.*

1. INTRODUCTION

The growing industrial demand has been causing environmental impacts. Therefore, it is necessary to develop new technologies for sustainable and effective remediation processes to achieve a balance between economic development and environmental conservation. In this context, a growing demand for fossil fuels to meet the industrial demand for power generation and vehicles has generated excess harmful releases into the atmosphere, contributing to global warming (Jacob-Furlan *et al.*, 2020). Among the pollutants that stand out the most is carbon dioxide (CO₂), which is pointed out as one of the main causes of climate events. Therefore, there is great motivation for research with the objective of minimizing the consumption of fossil fuels and, consequently, the harmful effects caused by greenhouse gases (GHG), mainly CO₂ (Chen *et al.*, 2017).

In addition to the atmospheric, urban and industrial effluents also cause environmental damage, often irreversible, such as the contamination of seas, groundwater, rivers, among others. Given this scenario, a strategy to reduce the consumption of freshwater and make better use of wastewater would be to seek alternatives to encourage the treatment and reuse of water. The investment in technologies for the treatment of solid waste effluents is a differential in terms of industrial competition, and this can generate added value to the tailings. However, many agrobusiness ventures have not evolved in this direction due to lack of knowledge, financial resources and incentives. This sector generates millions of tons of waste and pollutants that are treated by organic, chemical and biological processes (Ezugbe and Rathilal, 2020). These methods are expensive and technologically difficult to control.

As an alternative to conventional wastewater treatments, biotechnological processes from microalgae are considered promising (Furlan *et al.*, 2020). In this sense, the use of microalgae has stood out in carbon capture processes from the present CO₂ in transfer, in industrial and urban effluents, where there is wide availability of essential compounds for its growth, such as CO₂, and other nutrients (potassium, nitrogen and phosphorus). As microalgae have a high cell growth rate, are able to carry out photosynthesis, using light energy, carbon dioxide (CO₂) and water, and release oxygen (O₂), they have been studied in effluent treatment and purification processes to make methane produced in biodigesters. In addition, biomass and after bioremediation can be used for the synthesis of various products with commercial potential, such as biofuels, fatty acids, bioethanol and pigments.

Therefore, several research and development strategies are being developed in this area in order to promote actions that reduce the environmental existence, which generate renewable energy and purification of toxic gases, which enable the obtaining of drinking water from wastewater, from agro-industrial effluents and brackish water. However, large-scale production is still a challenge due to economic viability in some processes, but it must be overcome as well as technological challenges, such as an example of genetic improvement of strains, developing efficient cultivation methods, contamination control and optimization of biomass extraction processes. In this sense, this work has as global objective to bring a literature review on the treatment processes of agro-industrial and urban supplies and effluents from the optimization of microalgae cultivation in laboratory and pilot scale, with the use of a photo bioreactor airlift developed by researchers of the Sustainable Energy Research and Development Center (NPDEAS) at UFPR.

2. PRODUCTION OF ALGAL BIOMASS

There are some determining factors to obtain the adequate volume of biomass to guarantee the product of commercial value, such as an adequate choice of the microalgae, the culture medium, the type of used system and the production regime, according to the metabolism of each species. The metabolism of these microorganisms may vary according to their species, being photoautotrophic, heterotrophic, mixotrophic or photoheterotrophic (Morais *et al.*, 2021). The photoautotrophic metabolism occurs when energy is obtained from a luminous source and carbon from an inorganic source, through photosynthesis. Heterotrophic metabolism occurs when energy and carbon are obtained from an external organic source, normally by the oxidation of sugars. When the metabolism is mixotrophic, the photosynthesis and the oxidation of organic compounds occur concomitantly and finally the photoheterotrophic metabolism occurs when the source of energy is light, and the source of carbon are organic compounds (Perez-Garcia *et al.*, 2011).

In pilot and industrial scale processes, usually the photoautotrophic metabolism is applied, in which besides light energy CO₂ or HCO₃ dissolved in water is used as carbon source, but still requires other nutrients, especially macros such as hydrogen, oxygen, nitrogen, phosphorus, sulphur, magnesium, silicon and iron and micronutrients (metals) such as manganese, copper, zinc, molybdenum, vanadium, boron, cobalt, calcium, sodium, selenium and nickel (Kroumov *et al.*, 2016), in addition to vitamins, in certain cases (Richmond *et al.*, 1989), however optimisation of the pH and temperature conditions must take place for each species (González-López *et al.*, 2012). This type of cultivation can be applied for remediation of contaminated waters, such as sewage and atmospheric contaminants and emissions from the burning of fossil derived fuels (Napan *et al.*, 2015; Costa *et al.*, 2020).

The cultivation regime is another parameter that reflects directly on the costs and yield of biomass production, so in pilot and industrial scale photobioreactors are used open system (natural ponds, artificial ponds and raceway), closed

(tubular, vertical column, flat plate) or hybrid in batch, semi-continuous or continuous regime. Although all systems have advantages and disadvantages, the open systems are the most widely used, due to the low cost of construction and maintenance. Three main models have been frequently used in large-scale production, the raceways, circular lagoons and sloping tanks (Borowitzka, 1999, 2016).

Photobioreactors are extremely important equipment for the cultivation of microalgae because, despite being more expensive, they provide controlled conditions for high cell productivity. With regard to cultivation on a pilot scale, the FBR used is the airlift type that has the purpose of increasing the passage of light (Suali and Sarbatly, 2012; Kirnev *et al.*, 2020). In relation to open cultivation, photobioreactors have some advantages, among which it is possible to highlight the greater control of cultivation conditions and lower contamination rates, since there is no contact with the external environment. Furthermore, photobioreactors occupy such a smaller area when compared to open systems, and can be installed in urban areas or in soils unsuitable for agriculture. These systems are operated in different regimes, such as continuous, semi-continuous and batch.

In pilot and industrial scale processes, the photobioreactor system is the most suitable for providing the best conditions for algae growth, due to a series of details that favour productivity (Acién *et al.*, 2017). By being designed with geometry, hydrodynamics and adequate environmental and operational parameters they provide an adequate light energy input to the cells. The photobioreactors in synergy with other operational parameters such as temperature, pH, gas transfer, nutrient availability and agitation ensure the success of the microalgae cultivation. Furthermore, other parameters also influence the surface to volume ratio (S/V), quality of the construction material, hydraulic retention time, surface speed of the liquid and gas, flow regime, among others (Merchuk *et al.*, 2019).

Microalgae photosynthesis depends on the light supply through the photobioreactor where the wavelength range at certain levels determines the photosynthetic efficiency (Sivakaminathan *et al.*, 2018). However, when this range is lower than the required parameters some phenomena may be related, such as photo-limitation and photo-inhibition, causing losses of kinetic performance in the photobioreactors. The pipes of the photobioreactor are transparent and allow a S/V ratio of light distribution of the total pipe area. The higher this ratio, the greater the light penetration and the better the biomass productivity (Ooms *et al.*, 2016).

The quality and intensity of light supplied to the system has a direct influence on the productivity of the microalgae. Natural (outdoor cultures) or artificial (indoor cultures) lighting can be used. But the solar position, seasonal variations and the length of the light/dark cycles (photoperiods) are the main issues in solar based systems, as they are more economical than artificially lit systems. In addition, temperature is one of the main parameters that influence cultivation performance. The best temperature range on an industrial scale is between 20-30°C, which may vary according to the species of algae. To maintain this range, it is possible to use heat exchanger devices, which can be installed for thermal control (Nwoba *et al.*, 2019).

Another essential parameter is the pH, being the most suitable range between neutral to alkaline (7-9). To maintain this pH range, practical control mechanisms are integrated into the photobioreactors for maintaining the optimum conditions of this parameter in the process (Vasumahi *et al.*, 2012). Gases are inserted directly into the culture medium by bubbling through diffusers inserted in the photobioreactors. Agitation also prevents cell sedimentation and friction between them and the walls of the tubing, preventing the formation of biofilms. Nevertheless, these gases provide greater homogenization of the medium, pH balance and greater heat and mass transfer. When there is excess of O₂ in the reactor piping, degassers are used to separate the excess (Acién *et al.*, 2017).

However, this parameter is related to cell shear, which can inhibit microalgae growth. Photobioreactors are normally equipped with pneumatic aeration and/or mechanical agitation. The composition of microalgal biomass is predominantly composed of C, N and P, in proportions of approximately 50%, 8% and 1%, respectively. Thus, the availability of these nutrients is essential for robust performance in large-scale photobioreactors. CO₂ is the main carbon source used in crops. This approach, however, has faced some difficulty in implementation, because the nature of these gases is characterized by high levels of impurities (CO, CH₄, NO_x, SO_x, H₂ e particulate matter), in addition to the temperature of the gases (>1000°C), two characteristics that can make bio-based processes unviable. In this sense, the gases from emissions or effluents have various compositions of impurities (CO, CH₄, NO_x, SO_x, H₂ and particulate material), besides the temperature of the gases (>1000°C), two characteristics that can make biological based processes unfeasible (Van end Vervaeren, 2012).

Agitation or mixing is an operation that ensures not only the homogenization of the culture, but also prevents sedimentation or agglomeration of cells among themselves and on the walls of tubular photobioreactors (biofilms). This parameter also contributes to the uniform distribution of nutrients, gas-liquid mass transfer and pH reduction. Although fundamental to the development of the process, this parameter is related to cell shear, which may inhibit microalgae growth. Photobioreactors are normally equipped with pneumatic aeration and/or mechanical agitation equipment (Verma and Srivstava, 2018).

2.1 Microalgae cultivation: factors that may influence the process

The pilot scale allows the prevention and prediction of possible interferences in the cultivation of microalgae on a large scale, some factors such as construction and operation of the photobioreactors should be sufficient. Furthermore, the costs, the availability of area to implement the photobioreactor, the labour during the whole process, energy and water consumption are parameters that influence the viability and quality of the desired final product. Based on these factors, the trends of design and development in industrial production with commercial intent of microalgae should focus on some aspects, such as:

1. Strategy for the improvement of bioremediation techniques of agro-industrial residues aiming at the productivity of microalgae;
2. Strategies that reduce steps in the production process, aiming the increase of productivity of cultures in photobioreactors;
3. Improvement of biomass extraction and storage techniques in order to obtain a high quality of raw material with competitive commercial value;
4. Improvement of techniques to obtain products with added value and marketing potential, derived from biomass, complying with possible standards that ensure quality to the final product.

2.2 Life cycle analysis - (LCA)

Every manufacturing process causes impact on the environment, from raw material procurement, production, use, recycling and reuse possibilities to the disposal of materials. Therefore, life cycle analysis (LCA) is considered a 'cradle to grave' methodology. This methodology is used in directing and managing the definition of environmental strategies (Währlich *et al.*, 2020).

In this context, LCA enables the assessment of the environmental impacts of a given activity throughout its life cycle and is able to identify the main sources of pollution. In this way, LCA offers a comprehensive interpretation that relates actions with environmental impacts (Kyriak *et al.*, 2018). To implement an LCA process there are four fundamental steps which consist of Table 1 shown below:

Table 1: Fundamental steps for LCA analysis:

Parameter	Definition
Setting goals and scope	Limiting the activity that will be carried out;
Inventory analysis	Quantification of inputs and outputs, such as energy, raw materials, water, atmospheric emissions, solid waste) that can be quantified by databases, surveys and software calculations;
Impact assessment	Evaluation of the environmental impact as a result of the "inventory analysis" step. Input and output data are translated into environmental impacts;
Interpretation	Involves improvement discussions proposing recommendations and strategies linked to the defined scope. Interacting with all the previous steps.

All of the aforementioned steps need to be very well aligned, so the interpretation of the results is accurate, since it will guide decision-making aimed at reducing damage to the environment (Scherer *et al.*, 2016).

3. BIOTECHNOLOGICAL POTENTIAL OF MICROALGAE

Microalgae are microorganisms naturally present in different aquatic or humid environments, including rivers, lakes, oceans and soils. In large part, they are photosynthetic organisms that contribute to the planet's primary production, are autotrophic, prokaryotic or eukaryotic, and form cells that have a well-diversified biochemical composition of carbohydrates, lipids, proteins, fatty acids and pigments, and can be raw material in production of various substances for

human and animal consumption, of pharmaceutical products, in the production of food coloring, of environmental and cosmetic indicators (Lourenço, 2006). An example of this application in the development of anti-aging cream due to the high amount of fatty acids in its composition, which help in the regenerative capacity of the epidermis, as an example such as *Arthrospira* and *Chlorella* algae (Satyanarayana *et al.*, 2011; Spolaore *et al.*, 2006). In the food sector what stands out is the biomass with the highest concentration of proteins, within this context, the maximum spirulina species can reach a concentration of up to 71% of protein in its chemical composition on a dry basis, which is much higher than the milk (26%) for example (Satyanarayana *et al.*, 2011).

However, the use and application of microalgae in bioremediation processes has stood out, such as the treatment of emissions from the mitigation of exhaust gases from stationary sources, such as waste incinerators, stationary power generators, industrial exhaust gases and others that contain high concentrations of carbon dioxide that are used by the metabolism of microalgae, favoring their growth (Chawla *et al.*, 2020). For this purpose, the choice of algae should be made according to some criteria such as high growth rate and CO₂ tolerance, high tolerance to toxic pollutants, low sensitivity to high temperatures and pH changes (Huang *et al.*, 2016).

Microalgae can be used as bioremediation agents, after all when compared to traditional combustion emission capture methods that employ recovery, capture and storage, in addition to the direct sequestration steps that occur through chemical, physical, electrochemical and biological processes, generally very expensive. and energy and intensive chemistry. As an alternative to these methods, another capture technique, but more accessible, is the direct fixation of gases, through photosynthetic processes, in this sense, microalgae can be used, as they directly consume the nutrients present in these gases, increasing their biomass (Judd *et al.*, 2015).

Among the nitrogenous compounds, nitrogen dioxide is more soluble in water. In cultivation, this compound is transformed into nitrate, which is consumed by the microalgae, favouring an increase in biomass (Huang *et al.*, 2016). After carbon, nitrogen is the second most important nutrient used for biomass production (Van and Vervaeren, 2012). In several studies (Samorí *et al.*, 2013; Peccia *et al.*, 2013) experiments were conducted on the effect of nitrogen consumption (with nitrogen sources from wastewater and flue gas) by the microalgae, with a positive effect on growth. Sulphur dioxide, another important nutrient, when dissolved in culture water, forms sulphite, which is consumed by the microalgae for the formation of the amino acid, cysteine and methionine, besides being present in lipids of the thylakoids (Van *et al.*, 2012.).

On this basis, microalgae have potential as a promising alternative for the treatment of effluents that are usually concentrated in organic compounds and chemicals. This type of treatment besides being of low cost can generate added value to the waste, since the biomass can be used later in other processes. The effluents most used in this type of treatment are from domestic sewage (Griffiths, 2009), from biodigesters, digested sludge, purified industrial waste, sugar cane vinasse, waste water from olive oil production and waste from pig farming (Bertoldi *et al.*, 2008), dairy industry (Woertz *et al.*, 2009) or brewing industry (Raposo *et al.*, 2010).

The current system of water and sewage treatment occurs in two phases. Firstly, the removal of particulate material and secondly, the degradation of organic material by bacteria, however, microalgae can act together with bacteria or even replace them in this process, because they absorb CO₂ present in various types of waste (Lourenço, 2006). However, these effluents have variable characteristics depending on climate change and the habits of the population, components of chemical origin that vary over time. These two parameters are commonly used to estimate the organic material content. The portion of the sewage collected in Brazil is submitted to biological treatment associated with physical and chemical stages. The physical steps consist of applying precipitation, filtration, sedimentation or flotation methodologies. These treatments, besides using energy, are expensive (Piveli *et al.*, 2013).

The treatment in a digester system by anaerobic digestion has been highlighted, since the biogas generated in this stage can be used in the renewable energy production. However, this treatment does not completely reduce the organic load of the material and an additional stage is necessary to remove the excess load in treatment sludge. However, this alternative is not widely used, due to cost issues (Oliveira *et al.*, 2005).

The biomass produced after the bioremediation treatments can be intended: as raw material in the production of renewable biofuels in the energy sector, such as alcohol, biogas, biodiesel and biohydrogen in addition to other applications (Milano *et al.*, 2016).

3.1 Applicability of the process: Sustainable Energy Research and Development Center (NPDEAS)

The applicability of the process is a fundamental criterion for the development of innovative technological routes focused on large-scale production. For this, it is important to consider the history of research, results and innovative ideas of future projects based on concepts and previous experiences (laboratory, pre-pilot, pilot and industrial scale). As an example, NPDEAS which is a self-sustainable building in energy from microalgae biodiesel, located at UFPR and founded in 2008. It is a reference in terms of research, technological and innovative development related to biotechnology and sustainability from microalgae. The focus of research in NPDEAS is the maximization of

productivity in photobioreactors to obtain biofuel on a large scale. Currently, other processes are being explored, including the capture and direct use of atmospheric CO₂ (Satyanarayana, 2011).

In terms of cultivation systems, the core has equipped laboratories, compact tubular photobioreactors on a pilot scale (volume of 12 L) and industrial scale, with an operational volume of 12 m³, 3.5 km of transparent tubes and occupying an area of only 10 m² each. Their dimensions consist of 8 m high, 2 m wide and 5 m long, such as Figure 1 shown below:

Figure 1: FBR at NPDEAS, Brazil.



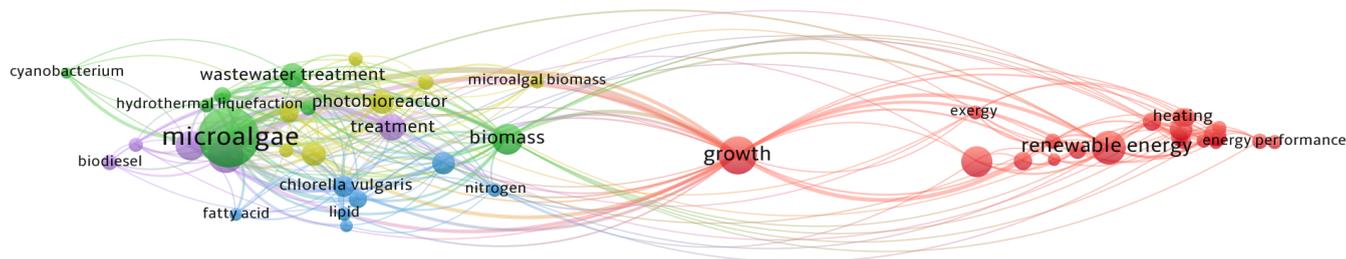
NPDEAS has all the biomass processing stages available, from stump maintenance, harvesting, drying, to extraction and conversion into the desired end product. The first phase consists of cultivation on a laboratory scale to obtain the pre-inoculum. Subsequently, production is scaled up to establish cultivation in pilot scale photobioreactors with an industrial scale. A team of qualified professionals in the areas of Electrical, Mechanical, Chemical and Biochemical Engineering. The research conducted by the group has been developed to meet the demands of the productive sector, emphasizing the technical and scientific limitations, for approximately 12 years.

Numerous research and development (R&D) projects were consolidated with public and private funding, resulting in several invention patents filed (one application granted and one product licensed by the market), in industrial property institutes in Brazil and abroad, besides multiple articles published in high impact journals on renewable energy and related areas, besides several projects and partnerships of UFPR with the industrial sector.

4. SOFTWARE VOSVIEWER

VOSviewer is a software tool for constructing and visualizing bibliometric networks, in order to evaluate this review. The research was made on Scopus, a tool from Elsevier. To have a simple database we searched three key words e.g. as microalgae, alternative energy and microalgae and energy efficiency, see Figure 2. And from the results it was selected 2000 results from each research, to have a vast knowledge of the data. As it turns out, that amounts to papers published in 2021.

Figure 2: VOSViewer about microalgae



The parameters were set to focus on texts, being the subjects that the papers were written on. It can be seen five major clusters, based on the colors, set according to correlated topics. The red one shows alternative energy methods, the green shows microalgae, wastewater and some algae species. In yellow algae cultivation, other species and how to cultivate them. In magenta it shows treatment and products obtained from microalgal biomass, and lastly blue shows what can be processed from microalgae.

As the circles approach one another, it means a close relation between the subjects. And clearly it can be seen in two sets of data, microalgae on the left and alternative energy on the right. And both topics are related, although they are apart from the lines between them, meaning that they were linked together in the papers.

5. FINAL CONSIDERATIONS

Many different vegetable oils have been used for biofuels production, on the other hand, a very large land surface has been required to obtain energetic efficiency. However, biofuels from vegetable sources are not able to satisfy the current demand. For this reason, the scientific community is putting all its effort in the search for a high potential source of biomass. In this context, microalgae are considered the most promising source due to their high oil content and capability of quick growing in photobioreactors. Thus, it is essential to seek and apply strategies with the purpose to minimize any negative impacts to the environment.

Energy efficiency has a huge potential to boost economic growth and avoid greenhouse gas emissions, therefore in order to contribute to climate change reduction, NPDEAS puts its effort on microalgae production on an industrial scale. More research must be done to improve an industrial scale of the process for biofuels production from microalgae. In addition, to obtain concrete results on the efficiency of the process, it is necessary to carry out a LCA analysis to check the environmental and economic viability of the process. Finally, technology replacement programmes can support the manufacturing and rollout of newer technologies and also drive economic motivation and energy efficiency.

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