# Algae Used in Achieving Carbon Neutrality by Treating Wastewater

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**Abstract.** Many countries are committed to carbon neutrality, especially in reducing carbon dioxide emissions and mitigating the greenhouse effect. Wastewater treatment is also a growing concern in many countries, especially in recent years when many new pollutants have emerged in sewage, posing certain challenges to sewage treatment projects. Algae have advantages of high photosynthetic efficiency and high carbon sequestration capacity. Algae can also treat different pollutants in wastewater. Algae are also important raw materials for biofuels. The purpose of this review is to discuss the application of algae in wastewater treatment and the impact of algae itself and its processed products on carbon neutrality. This review first outlines different algae cultivation systems, including open pond system and closed photobioreactor system, then discusses the application of algae in treating different types of wastes, for example, nitrogen and phosphorus elements, heavy metal elements, and emerging contaminants. Finally, this review discusses the impact of combining algae with wastewater treatment on carbon neutrality.

**Keywords:** Algae; wastewater treatment; photobioreactors; carbon neutralization.

## 1. Introduction

With the extensive use of fossil fuels and the excessive emission of carbon dioxide, the atmospheric carbon dioxide content continues to rise, leading to the intensification of the greenhouse effect and the frequent occurrence of extreme climate. Therefore, people need to take effective measures to reduce carbon dioxide emissions and absorb carbon dioxide in the atmosphere to achieve carbon neutrality.

The purpose of wastewater treatment is to reduce carbon in wastewater and some nitrogen and phosphorus compounds [1], heavy metals (Chromium, copper, lead, zinc) [2, 3], so as to meet the emission standard.

Traditional water treatment methods consume a lot of electricity, and developed countries use 0.6% to 3% of the total power generation for domestic wastewater treatment [1]. There are new micropollutants in wastewater [4]. Traditional water treatment methods are difficult to treat these pollutants, so it is necessary to find new ways of wastewater treatment.

It is noticeable that algae can use solar energy to efficiently absorb carbon dioxide and produce biomass through photosynthesis, which is more efficient than terrestrial plants [5]. Algae are also effective in carbon fixation, capturing $CO_2$ at rates significantly higher than forests. Their use in wastewater treatment can help achieve carbon neutrality while producing nutrient-rich biomass [6]. Algae is a new source of biofuels, in which green algae contain a large amount of lipids, and can use wastewater resources to produce biofuels. Therefore, green algae-based biofuels have certain advantages, so algae-based biofuels may replace fossil fuels in the future [7]. The combination of wastewater treatment and algae has advantages of feasibility, high efficiency, and low energy consumption. Algae can directly absorb carbon dioxide through photosynthesis, and the biomass produced by photosynthesis can be further processed into biofuels, such as biodiesel. These biofuels can replace traditional fossil fuels, thereby reducing carbon dioxide emissions. Therefore, it is necessary to further discuss the importance and necessity of integrating algae into wastewater treatment, as well as the positive impact on carbon neutralization.

This review will discuss the algae culture system, the application of algae in the treatment of different wastes in sewage and its impact on carbon neutralization.

## 2. Algae cultivation system

The algae culture system is mainly divided into open system and closed system (closed photobioreactor). The difference between the two is whether algae are in direct contact with the outside world.

### 2.1. Closed Photobioreactor System

Photobioreactor (PBR) is a controlled system designed to cultivate photosynthetic organisms (such as microalgae, cyanobacteria, and photosynthetic bacteria) by using light energy. The main feature is to provide an artificial and controllable environment. By optimizing environmental conditions like light, temperature, pH, and nutrient supply, PBRs enhance biomass growth and the production of valuable metabolites. At present, the mainstream PBR is mainly divided into three categories: Tubular PBR, Flat-panel PBR, and Column PBR.

#### 2.1.1 Tubular PBR

It is composed of glass or plastic tubes. The culture solution circulates in the tubes. It is usually used in conjunction with an airlift pump or a mechanical pump to remove gas. The pipes are arranged in many shapes, such as straight, curved, and spiral. Through different arrangements, the degree of contact with sunlight can be increased, but it may also increase the operating cost [8]. Too long tubular PBR will generate dirt, so it needs a cleaning system to clean the dirt, which will increase the cost and reduce the operation efficiency [9].

#### 2.1.2 Flat-panel PBR

A cuboid-shaped photobioreactor is composed of a plurality of transparent plates or panels, with a narrow culture space inside, like a flat transparent panel. Because of its extremely high specific surface area, it is suitable for dense microalgae culture [9]. Flat-panel PBR is still difficult to use on a large scale. There are still some shortcomings in the control of lighting. An advanced optical modulation system is required. Therefore, the cost is increased.

#### 2.1.3 Column PBR

Column PBR is usually a vertical cylindrical container. The airlift effect is generated by introducing gas (usually air or carbon dioxide mixture) into the bottom to achieve carbon dioxide transfer. [8] and drive the culture medium to circulate in the internal or external draft tube.

### 2.2. Open Pond System

Open pond cultivation is a traditional method of large-scale cultivation of microalgae or photosynthetic microorganisms, which includes raceway pond, circular pond, and unstirred pond. It has the advantages of low construction cost and high yield [10]. Because they are exposed to the air, they will also suffer from varying degrees of pollution.

#### 2.2.1 Raceway Pond

A system mainly used for algae culture, which is characterized by its long, narrow, annular or runway structure. The water flow in the pool is driven by mechanical devices (such as paddle wheel or water pump) and circulates continuously along a specific path. A variety of algae have been successfully cultured in raceway pond [8]. It is the most common algae cultivation system at present, and almost 95% of the algae in the world are produced by this system [10]. However, due to the open cultivation environment, it is easy to be polluted and greatly affected by the environment, so it is easy to encounter the problem of unstable light.

#### 2.2.2 Circular Pond

An ancient open-air algae cultivation device, mainly used in Southeast Asia. The whole algae culture pond is round and constructed of concrete. The circular pond is usually 20-30 cm deep and 40-50 cm in diameter, with a pivot mixer in the center for mixing [8,10]. But there are many

disadvantages, such as being easily polluted and high cost. It also faces some problems in temperature control [8].

### 2.2.3 Unstirred Pond

Just as the name says, it is a pond without an artificial mixing or forced circulation device, which mainly relies on natural processes for water mixing. It is an easy-to-build commercial system, which is not suitable for large-scale planting due to lack of mixing [10].

## 3. Wastewater Treatment & Biomass Production

Wastewater is mainly divided into three categories: industrial discharges, agricultural wastewater, and domestic sewage. The main waste contained in wastewater from different sources varies. Industrial wastewater often contains high concentrations of heavy metal ions, while agricultural and domestic wastewater often contains many nitrogen and phosphorus elements. Removing these pollutants is necessary for wastewater treatment. Algae can utilize nutrients in wastewater for their own growth, while industrial biomass can further process algae into biofuels for use in daily life or industrial production. At present, a large number of experiments and applications have indicated the effectiveness of algae in wastewater treatment and the high efficiency of reducing specific pollutants in wastewater. Next, this review will introduce the application of algae in treating different types of waste.

### 3.1. Nitrogen And Phosphorus

Domestic and agricultural sewage is rich in nitrogen and phosphorus. Wastewater containing excessive nitrogen and phosphorus will lead to water eutrophication, water bloom, and other problems, and seriously damage the ecological environment. Therefore, it is necessary to remove nitrogen and phosphorus from wastewater as much as possible. In Mexico, food and beverage industrial processing will produce many industrial wastewaters, and the application of Chlorella in this kind of wastewater treatment can bring significant results. Through using Chlorella, the nitrogen and phosphorus content and soluble chemical oxygen demand (COD) can be significantly reduced [11]. S. Rossi et al. reported that through using outdoor high-speed algae ponds, the bacteria algae symbiosis system for the treatment of piggery wastewater reached 90%, 90% of total ammonia nitrogen (TAN), and $PO_4^{3-}$ removal efficiency, with significant results [12].

### 3.2. Heavy Metal

Industrial wastewater often contains a large number of heavy metal elements, including copper, iron, zinc, and other heavy metals. It is necessary to reduce the content of these substances for water purification. Zohra Djezzar et al. proposed the special role of green algae: Spirogyra, in adsorbing divalent copper ions in industrial wastewater. It can be seen from the experiment that this kind of algae can effectively remove these substances [13]. Katarzyna Kipigroch et al. reported that the mixed algae population is a good biosorbent for copper and cadmium ions. The effectiveness of this process for treating copper is 70-85%, while the effectiveness of cadmium is 40-70%, which can remove these two substances to a large extent, providing a more effective method for removing copper and cadmium ions in wastewater [14]. According to Katarzyna Kipigroch, two different algal cultures have significant effects on the removal of Zinc and lead in water [15]. These methods provide feasible and effective methods for the removal of heavy metal ions in industrial wastewater.

### 3.3. Emerging Contaminants

There are more new pollutants in sewage, such as antibiotics, grease, and so on. In recent years, more antibiotics have been found in water, and traditional sewage treatment plants consume a lot of chemicals to treat these wastes, but they cannot effectively remove such wastes. Traditional treatment methods are not only expensive but also may produce secondary pollution [16]. The experiment of

Shengnan Li et al. shows that the mechanism of algae-based technology is mainly bioadsorption, bioaccumulation, and biodegradation. It is effective for treating antibiotics in wastewater, but it is limited by many factors, like light intensity, pH value, temperature, and there is still room for improvement [16]. Pesticides have become a thorny problem in Agricultural Sewage [17]. P. Mullai et al. reported the use of freshwater algae Ottelia alismoides as a biosorbent to absorb specific pesticides in wastewater, indicating the effective role of this kind of algae in absorbing some pesticides [18].

## 4. Effect On Carbon Neutralization

The application of algae in wastewater treatment provides a collaborative path to water resource recovery, energy production, and carbon neutralization. It is not only to treat wastewater, but also to transform and utilize the resources in Wastewater.

### 4.1. Direct Effect

Algae can directly absorb carbon dioxide and release oxygen through photosynthesis [1]. When treating wastewater, it can not only use nutrients such as nitrogen and phosphorus in wastewater to help its growth, reduce the content of such waste, but also absorb carbon dioxide in the air. Therefore, the combination of algae and wastewater treatment can not only improve the utilization rate of wastewater but also contribute to carbon neutralization.

### 4.2. Indirect Effect

Algae have the characteristics of high lipid content, while biodiesel based on algae has the advantages of high carbon dioxide storage capacity [19], which can effectively absorb carbon dioxide and store it. Adding algae into wastewater treatment and using its products to produce biodiesel can effectively decrease the cost of wastewater treatment and biodiesel production [20]. Compared with traditional fossil fuels, algal biofuels significantly reduce carbon dioxide emissions, with low sulfur content and less sulfide emissions from combustion, which is conducive to protecting the marine environment and preventing ocean acidification [21].

## 5. Conclusion

This review describes the feasibility and necessity of integrating algae into wastewater treatment system. Algae have high carbon fixation, high light, and efficiency. The wastewater treatment system based on algae can effectively absorb carbon dioxide in the air and fix it. Some special algae can effectively remove nitrogen, phosphorus, heavy metal elements, and some new pollutants in wastewater, which greatly improves the efficiency of wastewater treatment. Algae can use nutrients in sewage for their own growth, and can produce high lipid biomass, which can be further processed into alginate biodiesel for use in the transportation industry, which can effectively reduce the use of fossil fuels, thereby reducing greenhouse gases, especially carbon dioxide emissions. Algae can not only directly absorb carbon dioxide in the atmosphere through photosynthesis in the process of wastewater treatment but also process its growth products into biofuels to replace chemical fuels, so as to reduce carbon dioxide emissions and alleviate carbon neutralization. However, there are still some problems in algae culture, such as high scale cost, difficult control of environmental factors such as pH, temperature, and light in the culture process, and easy pollution of algae culture pond. Moreover, the production cost of algae biofuels is high, and it is difficult to replace fossil fuels on a large scale. Therefore, in the future, we can improve the algae culture system, improve the algae species, and optimize the biofuel processing technology, so as to better combine algae and wastewater treatment, and help the global carbon neutralization cause.

## References


[1] Seyedeh Fatemeh Mohsenpour, Sebastian Hennige, Nicholas Willoughby, et al. Integrating Micro-Algae into Wastewater Treatment: A Review. Science of The Total Environment, 2021, 752: 142168.

[2] Katarzyna Kipigroch, Marta Janosz-Rajczyk, Beata Skowron-Grabowska. The Use of Algae in the Removal of Cd and Cu in the Process of Wastewater Recovery. Desalination and Water Treatment, 2016, 57(3): 1508–1514.

[3] Katarzyna Kipigroch. The Use of Algae to Remove Zinc and Lead from Industrial Wastewater. Desalination and Water Treatment, 2020, 199: 323–330.

[4] Jayaprabakar Jayaraman, J. Kumaraswamy, Yarrapragada K.S.S. Rao, M. Karthick, et al. Wastewater Treatment by Algae-Based Membrane Bioreactors: A Review of the Arrangement of a Membrane Reactor, Physico-Chemical Properties, Advantages and Challenges. RSC Advances, 2024, 14(47): 34769–34790.

[5] Shaikh Abdur Razzak, Saad Aldin M. Ali, Mohammad Mozahar Hossain, et al. Biological CO2 Fixation with Production of Microalgae in Wastewater – A Review. Renewable and Sustainable Energy Reviews, 2017, 76: 379–390.

[6] Zhuo Xie, Xiaoyu Zhao, Yuanyuan Jia, et al. Wastewater Treatment Performance of Algal Species Isolated from Algal-Bacterial Granular Sludge. Bioresource Technology Reports, 2025, 30: 102111.

[7] Ashfaq Ahmad, Fawzi Banat, Habiba Alsafar, et al. Algae Biotechnology for Industrial Wastewater Treatment, Bioenergy Production, and High-Value Bioproducts. Science of The Total Environment, 2022, 806: 150585.

[8] Qingshan Huang, Fuhua Jiang, Lianzhou Wang, et al. Design of Photobioreactors for Mass Cultivation of Photosynthetic Organisms. Engineering, 2017, 3(3): 318–329.

[9] Zubair Hashmi, Ibrahim Maina idriss, Juliana Haji Zaini, et al. Advancements in Photobioreactor Systems: Optimizing Operations for Enhanced Microalgal Growth and Bioremediation. Algal Research, 2025: 104282.

[10] Shaikh Abdur Razzak, Khairul Bahar, K. M. Oajedul Islam, et al. Microalgae Cultivation in Photobioreactors: Sustainable Solutions for a Greener Future. Green Chemical Engineering, 2024, 5(4): 418–439.

[11] Cesar E. Najar-Almanzor, Karla D. Velasco-Iglesias, Minerva Solis-Bañuelos, et al. Chlorella Vulgaris-Mediated Bioremediation of Food and Beverage Wastewater from Industries in Mexico: Results and Perspectives towards Sustainability and Circular Economy. Science of The Total Environment, 2024, 940: 173753.

[12] S. Rossi, A. Pizzera, M. Bellucci, et al. Piggery Wastewater Treatment with Algae-Bacteria Consortia: Pilot-Scale Validation and Techno-Economic Evaluation at Farm Level. Bioresource Technology, 2022, 351: 127051.

[13] Zohra Djezzar, Amel Aidi, Hanane Rehali, Sbarina Ziad et al. Characterization of Activated Carbon Produced from the Green Algae Spirogyra Used as a Cost-Effective Adsorbent for Enhanced Removal of Copper(Ii): Application in Industrial Wastewater Treatment. RSC Advances, 2024, 14(8): 5276–5289.

[14] Katarzyna Kipigroch, Marta Janosz-Rajczyk, Beata Skowron-Grabowska. The Use of Algae in the Removal of Cd and Cu in the Process of Wastewater Recovery. Desalination and Water Treatment, 2016, 57(3): 1508–1514.

[15] Katarzyna Kipigroch. The Use of Algae to Remove Zinc and Lead from Industrial Wastewater. Desalination and Water Treatment, 2020, 199: 323–330.

[16] Shengnan Li, Pau Loke Show, Huu Hao Ngo, et al. Algae-Mediated Antibiotic Wastewater Treatment: A Critical Review. Environmental Science and Ecotechnology, 2022, 9: 100145.

[17] Ting Wang, Shali Ai, Yaoyu Zhou, et al. Adsorption of Agricultural Wastewater Contaminated with Antibiotics, Pesticides and Toxic Metals by Functionalized Magnetic Nanoparticles. Journal of Environmental Chemical Engineering, 2018, 6(5): 6468–6478.

[18] P. Mullai, S. Vishali, E. Sobiya Studies on the Application of Algae Biomass as an Adsorbent in the Treatment of Industrial Azadirachtin Insecticide Wastewater. Desalination and Water Treatment, 2022, 251: 7–17.

[19] Manish Kumar, Naushad Ahmad Ansari, Raghvendra Gautam. Algae Biodiesel as a Alternative Green Fuel: A Futuristic Scope. Cleaner Chemical Engineering, 2025, 11: 100178.

[20] Kuber Singh Mehra, Iyman Abrar, Ravi Kant Bhatia, et al. A Comprehensive Review of Algae Consortium for Wastewater Bioremediation anA Comprehensive Review of Algae Consortium for Wastewater Bioremediation and Biodiesel Production. Energy Conversion and Management, 2025, 325: 119428.

[21] D. Christopher Selvam, T. Raja, Beemkumar Nagappan, et al. The Role of Biodiesel in Marine Decarbonization: Technological Innovations and Ocean Engineering Challenges. Results in Engineering, 2025, 25: 103974.