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TECHNOLOGY VS NATURE: BIODIVERSITY TO CHALLENGE

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ABSTRACT

When discussing biodiversity and algae in the context of "trees," it generally refers to two distinct but fascinating subjects: sub aerial (living) algae on the bark of actual trees or high-tech urban "Algae Trees" designed for climate action.

1. Natural Algae on Tree Bark (Sub aerial Algae) Tree bark serves as a living, nutrient-rich micro-ecosystem for thousands of microscopic algae, fungi, and bacteria.
2. Species Diversity: Bark habitats are largely dominated by green algae (like Trebouxiophyceae and Trentepohliales) and Cyanobacteria.
3. The "Algae Tree" Study: Research in tropical forests reveals that algal communities vary greatly depending on the tree species (e.g., *Terminalia alata*) and environmental factors like sunlight and humidity. Open canopy areas of the forest support significantly higher biodiversity than closed, dark canopies.
4. Ecological Role: These microscopic communities function as biological indicators of air quality and play a vital role in local nutrient and carbon cycling.
5. The "Algae Tree" (Climate-Tech Innovation) in urban development, an "Algae Tree" is an engineered biotech structure used to actively combat air pollution in crowded, congested cities.
6. The Pioneer Installation: India's first Algae Tree was unveiled in Bhopal. Developed by the Mushroom World Group, it operates as a vertical photo bioreactor that houses living microalgae to naturally purify the air. Biodiversity Function: While it does not boast the sprawling ecosystem of a natural forest, it leverages the massive natural biodiversity and photosynthetic efficiency of microalgae. Performance Metrics: A single engineered algae tree can reportedly absorb 1.5 tons of CO_2 annually—the equivalent of up to 25 mature trees—and reduces nearby PM 2.5 particulate matter by up to 55%.

KEYWORDS: Carbon dioxide, oxygen, performance matrix, algae tree, lichens, seaweed, green algae, red algae, brown algae, blue green algae, phycology.

INTRODUCTION

Algae (the plural of alga) traces its roots to the Latin word *alga*, which directly translates to **seaweed**. The term was first incorporated into English in the late 16th century. While the Latin word itself is of somewhat obscure origin, etymologists point to a few possible linguistic connections:

Surface Connections: It may be linked to the Latin word ulva, which refers to grass-like or rush-like aquatic plants.

Slime & Filth: Some historical Indo-European roots associate the word with being slimy, dirty, or putrefying.

The Greek Alternative: Historically, the Ancient Greeks used a completely different word, phŷkos (φῦκος), to describe seaweed. This Greek root lives on in the modern scientific study of algae, which is known as **phycology**.

An algae tree (often called a "liquid tree") is a specialized artificial carbon-capture system that uses microscopic algae to absorb carbon dioxide and release fresh oxygen. Because cities face shrinking green cover and **high pollution**, these systems offer an innovative way to help clean the air in dense, crowded environments.

Figure 1: Algae Tree.

Design: Instead of wood and leaves, it consists of a vertical water tank or bioreactor filled with microalgae.

The Process: Small pumps pull polluted air into the tank. The microalgae consume carbon dioxide through photosynthesis and push clean oxygen back out.

Self-Sustaining: They are usually powered entirely by solar panels, which run the pumps, sensors, and LED light.

Efficiency: Developers claim a single unit can absorb up to **1.5 tons** of CO_2 a year, which is roughly equivalent to the filtering impact of **20 to 25 mature trees**.

In May 2026, India installed its first "Algae Tree" at Swami Vivekananda Park in Bhopal, Madhya Pradesh. Developed by the Mushroom World Group under the Smart City initiative, the Bhopal unit is capable of reducing PM 2.5 pollution by about 45–55% within a 15-meter radius.
City Impact: It provides a space-saving alternative for combating smog in congested urban center.

While algae systems are highly efficient at trapping carbon, environmental experts note they are meant to complement natural forests rather than replace them. Natural trees provide vital ecosystem benefits like shade, cooling, soil protection, and habitats for biodiversity that artificial structures cannot replicate. An algae tree (often called a "liquid tree") is a biotech-powered, urban carbon-capture device rather than a real tree. It uses water filled with microalgae to naturally absorb carbon dioxide and release oxygen through photosynthesis. These compact, solar-powered systems are designed for densely populated cities where traditional tree planting is difficult.

How It Works
Microalgae Power: Millions of microalgae float inside a transparent, bio-reactor chamber. As polluted air passes through, the algae consume CO_2 up to 50 times faster than terrestrial plants.

Pollution Reduction: The system traps harmful dust and particulate matter (like PM 2.5 and PM10) from the surrounding air.

Self-Sustaining: The units are typically solar-powered, using renewable energy to run the internal pumps, water circulation, and smart sensors.

Capacity: Developers of these systems claim that a single unit can absorb around 1.5 tons of CO_2 per year—the equivalent cleaning power of roughly 20 to 25 mature natural trees. Environmental experts note that while these devices are excellent supplements for reducing pollution in crowded areas like traffic intersections or corporate parks, they cannot replace real trees. Natural forests and trees provide vital ecosystem benefits that algae trees cannot, such as providing shade, cooling the local environment, retaining soil, and supporting wildlife habitats.

India's most prominent "Liquid Tree" (an artificial, microalgae-based bioreactor that purifies the air) is located at Swami Vivekananda Park in Bhopal, Madhya Pradesh. Developed by Mushroom World Group, this solar-powered structure absorbs carbon dioxide and releases oxygen.

Noida, Uttar Pradesh: A 1,600-liter exterior liquid tree (photo bioreactor) is installed at the DS Group Headquarters, in partnership with Liquid Trees.

Kochi, Kerala: A prototype disguised as a waiting shed was unveiled at the Kerala University of Fisheries and Ocean Studies (KUFOS) headquarters.

These high-tech installations act as a natural bodyguard against pollution, purifying as much air as 20 to 25 mature trees in highly compact urban spaces. The fuzzy, crusty, or leafy green and orange patches often seen on tree trunks are usually lichens. A lichen is not a single plant, but a partnership between algae (or cyanobacteria) and fungi. The fungus provides a safe structure, and the algae use photosynthesis to produce food.

Lichens: The most common organism on tree bark. They can look like flat crusty patches, raised leafy lobes, or hanging threads (like the Trentepohlia genus which appears as bright orange or rusty-red). A lichen is a hybrid colony of algae or cyanobacteria living symbiotically among filaments of multiple fungus species, along with bacteria embedded in the cortex, or "skin", in a mutualistic relationship. Lichens are the life form that first brought the term symbiosis (as Symbiotismus) into biological context.

True Algae: Sometimes, the tree bark has a powdery green or orange coating that is just pure algae. This thrives in damp, shaded, and high-humidity areas, often on the north side of the tree.

Will it harm the tree? No. Both algae and lichens are completely harmless. They use the tree bark simply as a physical resting place and do not rob the tree of nutrients. However, if you notice lichens spreading rapidly, it is usually because the tree is growing slowly or is in decline, allowing more sunlight to reach the bark. Removal is rarely necessary because they are harmless. If you dislike how it looks, you can naturally remove it by gently scrubbing the bark with a soft brush and water. To prevent future growth, you can prune nearby branches to improve sunlight and air circulation around the trunk.

Yes, marine algae—specifically microscopic phytoplankton—produce an estimated 50-80% of the world's oxygen. That means at least one out of every two breaths you take comes directly from ocean algae.

Origin

Phytoplankton: These microscopic, single-celled algae float in the upper layers of the ocean. Some single species, like Prochlorococcus, generate up to of the oxygen in our entire biosphere all by themselves.

Macroalgae: Larger seaweeds and kelp also contribute to this massive ocean oxygen factory.

1. Green Algae (Chlorophyta)

- Characteristics: Contain chlorophyll as their primary pigment, making them bright green. They can be unicellular (Chlamydomonas), colonial (Volvox), or multicellular (Spirogyra).
- Habitat: Mostly found in freshwater, though some live in soil or damp tree bark.
- Importance: They are believed to be the evolutionary ancestors to modern land plants.

2. Red Algae (Rhodophyta)

- Characteristics: Contain a red pigment (phycocyanin and phycoerythrin) that masks the green chlorophyll. These pigments allow them to absorb blue and purple light, making them well-suited for living in deeper waters.
- Habitat: Almost exclusively marine, mostly found in tropical oceans.
- Importance: Often used in Asian cuisine (e.g., Nori) and as a source of agar.

3. Brown Algae (Phaeophyta)

- Characteristics: The largest and most complex algae, ranging from simple filaments to massive, towering structures. They contain a brownish pigment (fucoxanthin) along with chlorophyll.
- Habitat: Found almost entirely in marine environments, particularly in cold or temperate coastal waters.
- Importance: They form underwater forests (kelp) which serve as critical habitats for marine life.

4. Blue-Green Algae (Cyanobacteria)

- Characteristics: Technically a group of photosynthetic bacteria (cyanobacteria) rather than true algae. They contain blue and green pigments and thrive in stagnant, nutrient-rich water.
- Habitat: Found in diverse environments ranging from fresh and marine waters to hot springs.
- Importance: They can fix atmospheric nitrogen, but are notorious for producing toxic "algal blooms" that are harmful to wildlife and human.

The cost of a "liquid tree" (an urban photo bioreactor that uses microalgae to capture CO_2 and release oxygen) ranges widely depending on the scale and application:

- **Small/Indoor Units:** Commercial, ready-to-use indoor air-purifying devices like the "OAK" by AlGreen can cost between $14,879 to $19,580 (roughly ₹12.5 lakh to ₹16.5 lakh).
- **Outdoor/Institutional Units:** Larger research and municipal prototypes (such as those installed at universities or smart city bus stops) range from ₹80,000 to ₹1,00,000 for basic setups, up to higher investments for large-scale urban infrastructure.

Maintenance: Maintaining a liquid tree requires periodic algae replacement and water management, which typically costs around ₹2,000 to ₹3,000 every 8-9 month.

The "Algae Tree" in Bhopal is India's first urban carbon-capturing device that mimics the function of real trees using microalgae. Installed at Swami Vivekananda Park, it utilizes a solar-powered photo bioreactor to filter polluted air, absorb carbon dioxide, and release fresh oxygen.

Core Mechanism

Air Intake: Small, solar-powered fans draw polluted urban air into the system.
Filtration: Filters trap dust, PM 2.5, and harmful particulate matter.
Photo bioreactor: The filtered air is bubbled through transparent glass tanks containing water and living microalgae.
Photosynthesis: Algae consume carbon dioxide.

Specification

Capacity: One unit absorbs up to 1.5 tons of CO_2 annually.
Efficiency: The CO_2 absorption equals the impact of 20 to 25 mature terrestrial trees.
Air Quality: Reduces PM 2.5 particles by 45–55% within a 15-meter radius. PM 2.5 refers to microscopic atmospheric particles or droplets that are 2.5 microns or less in diameter. About 30 times thinner than a human hair, these fine pollutants are the primary driver of poor air quality and pose significant health risk. PM 2.5 refers to microscopic particulate matter with a diameter of 2.5 micrometers or less. These particles are about 30 times smaller than a human hair and pose a major threat to air quality and health.

Why PM 2.5 is Dangerous

Deep penetration: They enter the lungs and penetrate straight into the bloodstream.
Systemic health risks: They trigger heart disease, asthma, and respiratory failure.
No safe level: The World Health Organization (WHO) warns that even low concentrations carry health risks.
Sources: Vehicle exhaust: Cars and trucks burn fossil fuels.
Industrial emissions: Power plants and manufacturing facilities.
Burning: Wildfires and open waste burning

Why is it so dangerous? Because of its extremely small size, PM 2.5 can bypass the body's natural defense mechanisms. When inhaled, it travels deep into the lungs, irritates the respiratory tract, and can even enter the bloodstream, potentially leading to:
Respiratory issues: Asthma, coughing, and reduced lung function.
Cardiovascular problems: Increased risk of heart attacks, irregular heartbeats, and cardiovascular disease.

Systemic damage: Long-term exposure is strongly linked to inflammation, reduced birth weights, and increased mortality.

Biomass: Algae growth is periodically harvested to produce biofuel or organic fertilizer.

Power: The entire purification and circulation process is powered by onboard solar panels. PM 2.5 is not a single chemical, but rather a complex mixture of microscopic solids and liquid droplets.

Common origins include

Outdoors: Vehicle exhaust (especially diesel), industrial emissions, power plants, wildfires, and agricultural burning.
Indoors: Cooking (frying or roasting), burning wood or candles, smoking, and poorly ventilated heaters.

- You can monitor localized pollution levels using resources like the World Air Quality Index or the IQAir Air Quality Map. On high-pollution days, you can minimize your exposure by:
- Staying indoors and keeping doors and windows closed.
- Using a HEPA air purifier to clean indoor air.
- Wearing an N95 or equivalent particulate mask when venturing outside.

The "Algae Tree" in Bhopal is India's first artificial, solar-powered air purification system installed at Swami Vivekananda Park. Developed by the Mushroom World Group, it acts as a biological filter. It continuously captures carbon dioxide, filters particulate matter, and releases oxygen by harnessing microalgae and solar energy.

Air Intake: Fans draw polluted street air into the tree's internal chamber.
Filtration: Filters trap dust and harmful pollutants like PM 2.5.
Photo bioreactor: Filtered air bubbles up through a glass tank of water and microalgae.
Photosynthesis: Algae absorb the carbon dioxide.
Self-Sufficiency: Solar panels provide the electrical power required to operate the water pumps and fans.
Continuous Cycle: Internal LED lighting sustains the algae's photosynthetic activity during the night.

The system functions as a highly efficient carbon sink in densely populated urban spaces where space for natural trees is limited.

Importance: Algal biodiversity encompasses the immense variety of photosynthetic organisms, from microscopic phytoplankton to massive microalgae (seaweeds). Representing several distinct evolutionary lineages, these foundational primary producers drive global carbon cycles and produce up to 70% of Earth's atmospheric oxygen.

- **Biogeochemical Engines:** Algae form the base of the food web in nearly all aquatic ecosystems, playing a critical role in sequestering carbon and cycling nitrogen.
- **Ecosystem Architects:** Microalgae such as kelp and Sargassum create complex, three-dimensional habitats that shelter, feed, and support countless marine species.

- **Biochemical Diversity:** Algae possess unique metabolic pathways, yielding high-value compounds like agar, alginate, omega-3 fatty acids, and carotenoids.

Microalgae and Cyanobacteria: Single-celled, often microscopic, organisms that include photosynthetic bacteria and eukaryotic protists. They include the incredibly diverse diatoms and dinoflagellates.

Macroalgae: Multicellular seaweeds, commonly classified into three distinct groups:
Green algae (*Chlorophyta*)
Brown algae (*Phaeophyta*)
Red algae (*Rhodophyta*)
Blue-Green algae *(Cyanobacteria)*

Performance
Capacity: A single unit reportedly absorbs around 1.5 tons.
Efficiency: It is claimed to be equivalent to the CO_2 absorption of 20-25 mature terrestrial trees.
Coverage: It can reduce PM 2.5 pollution up to 55% within a 15 meter radius.
A bioreactor filled with algae—commonly called an algae bioreactor or photo bioreactor (PBR)—is a controlled, enclosed system used to rapidly cultivate microalgae or macro algae. These specialized systems optimize light, carbon dioxide, and nutrients to produce dense algae biomass for biofuels, food supplements, wastewater treatment, or carbon capture.

Key Types of Algae Bioreactors
Tubular Photo bioreactors: Horizontal or vertical glass/plastic tubes that maximize sun exposure. Tubular Photo bioreactors (TPBRs) are closed, scalable cultivation systems consisting of transparent glass or plastic tubes where microalgae, cyanobacteria, or plant cells are grown. They maximize light exposure and maintain strict sterility, making them highly favored for producing premium food supplements, pharmaceuticals, cosmetics, and specialty biochemical.

Mechanism
- **Fluid Dynamics:** A liquid culture circulates through a network of horizontal, vertical, or coiled tubes (typically <0.1 m in diameter to allow light to penetrate dense broth).
- **Circulation:** Flow is driven by mechanical pumps or airlift systems, which gently push the culture while minimizing shear stress on delicate cells.
- **Gas Exchange:** The system routes culture to a central degassing column to release oxygen (which can inhibit growth if it builds up) and inject necessary CO_2 and nutrients.

Figure 2: Verities of Algae.

Key Advantages
- **Contamination Control:** Being a closed system, they prevent airborne contaminants, pest infestations, and unwanted competing microbes.
- **High Productivity:** The high surface-area-to-volume ratio allows for excellent light utilization.
- **Environmental Control:** TPBRs allow for precise regulation of temperature, pH, and light, permitting consistent outdoor operation across varying climates.

Drawbacks and Challenges
- **High Capital Cost:** Setting up extensive piping, pumps, and temperature-control systems demands significant initial investment.

- **Energy Requirements:** Maintaining constant fluid velocity and cooling the transparent tubes during peak sun hours requires substantial electrical energy.
- **Maintenance:** Over time, algae can coat the inside of the tubes (bio fouling), requiring routine chemical or mechanical cleaning.

Flat-Panel Bioreactors: Narrow, rectangular, transparent walls offering high light efficiency. Flat-panel bioreactors, commonly known as flat-plate photo bioreactors (PBRs), are closed cultivation systems used primarily for the mass production of microalgae, cyanobacteria, and plant cell cultures. Their distinguishing feature is a narrow, flat, rectangular geometry that provides an exceptionally high surface-area-to-volume ratio, allowing for optimal light penetration and superior photosynthetic efficiency.

Advantages

- **High Biomass Yields:** Rapid light/dark cycling ensures cells grow efficiently, producing significantly higher biomass per volume than tubular systems.
- **Low Shear Stress:** Many designs use airlift circulation rather than mechanical impellers, which prevents physical damage to delicate cell walls.
- **Contamination Control:** Being closed systems, they protect the culture from environmental contaminants and allow for precise sterilization.
- **Superior Light Distribution:** The thin panel design prevents cells from self-shading, enabling even light absorption.

Application

- **Biofuels:** Cultivating lipid-rich microalgae for sustainable, net-energy-positive biodiesel production.
- **Nutritional Supplements:** Producing proteins, omega-3 fatty acids, and natural pigments (e.g., spirulina, astaxanthin).
- **Pharmaceuticals**: Growing high-value recombinant proteins and therapeutic compounds.
- **Wastewater Treatment:** Using microalgae to bio remediate industrial and municipal runoff.

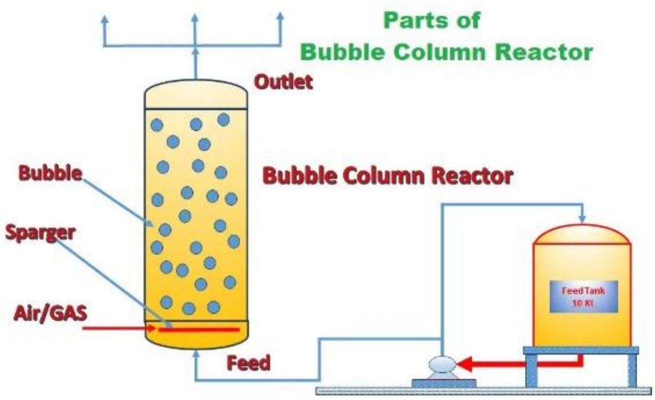
Challenges

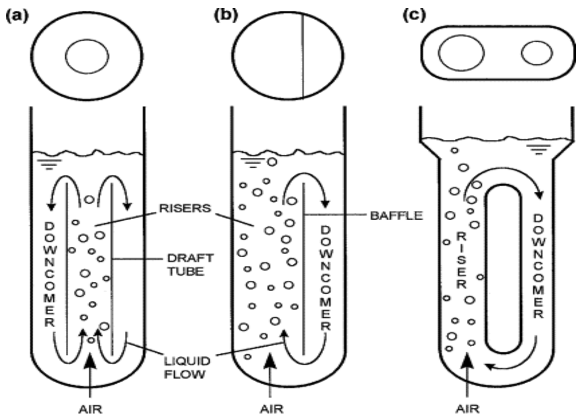
- **Scalability:** Maintaining uniform temperatures, gas exchange, and pH control becomes geometrically complex in large-scale commercial setups.
- **Wall Growth:** Microalgae tend to stick and grow on the transparent panels, which blocks essential light over time.
- **Capital Costs:** High-quality transparent materials and automated monitoring equipment make initial setup expensive compared to open ponds.

Column/Airlift Bioreactors: Vertical cylinders utilizing pumped air to circulate and mix the algae culture. Column and Airlift Bioreactors are pneumatically agitated fermentation systems that utilize injected gas to achieve mixing and mass transfer, eliminating the need for mechanical impellers. They are highly efficient, energy-saving, and particularly well-suited for aerobic cultures and shear-sensitive organisms.

Bubble Column Bioreactors (BCR): A bubble column consists of a tall, cylindrical vessel where compressed gas or air is sparged from the bottom. The rising gas bubbles agitate the liquid, providing both oxygen and mixing without any internal moving parts. A bubble column consists of a tall, cylindrical vessel where compressed gas or air is sparged from the bottom. The rising gas bubbles agitate the liquid, providing both oxygen and mixing without any internal moving parts.

- **Structure:** Simple vertical cylinder with a gas distributor (sparger) at the base.
- **Flow Pattern:** Chaotic, turbulent gas-liquid flow with no defined directional circulation.





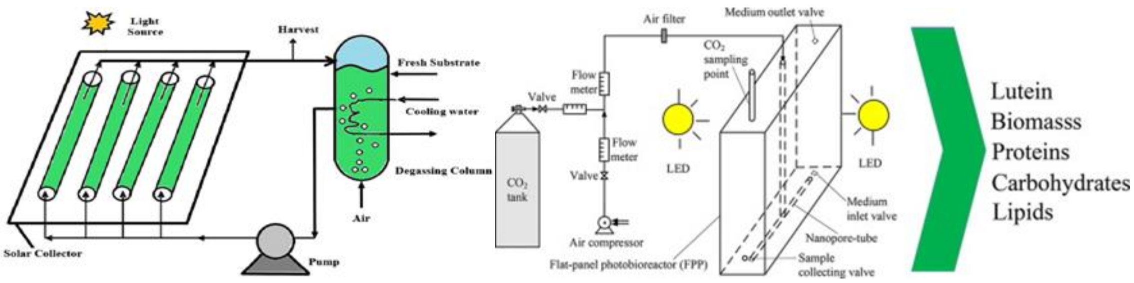


Figure 3: Photo bioreactors.

Advantages: Low capital and maintenance costs, simple design, easy to scale up for large volumes.

Disadvantages: Poor mixing at high viscosities, potential for gas bubbles to coalesce, limiting oxygen mass transfer.

Airlift Bioreactors (ALR): An airlift bioreactor is an advanced variation of a bubble column that uses a partitioned design to induce a highly organized, directed circulation loop.

- **Structure:** Divided into a riser (where gas is injected) and a down comer (where no gas is injected), usually separated by an internal or external draft tube.
- **Flow Pattern:** The gas-liquid mixture in the riser has a lower bulk density, causing it to flow upward. The denser, de-aerated fluid in the down comer flows downward, creating continuous, predictable circulation.
- **Internal Loop:** Contains a draft tube inside the main vessel.
- **External Loop:** Uses separate, external conduits for fluid to travel up and down.

Advantages of Airlift Designs

- **Low Shear Stress:** Gentle mixing protects delicate biological material (e.g., plant cells, mammalian cells, and algae). Lower Energy Consumption: Relies solely on compressed gas rather than high-torque electric motors, avoiding excess heat generation.
- **Superior Mass Transfer:** Controlled circulation maximizes gas-liquid contact time and oxygen uptake.

Common Applications

- **Wastewater Treatment:** Aerobic digestion and biological contaminant removal.
- **Single-Cell Protein:** Large-scale production of yeast and bacteria.
- **Plant and Animal Cell Culture:** Cultivation of shear-sensitive cells for secondary metabolites and vaccines.
- **Microalgae Cultivation:** Photo bioreactors often use airlift principles for efficient light distribution and gas exchange.

Algal Membrane Bioreactors: Systems that combine algal growth with membrane filtration to continuously clean waste water and harvest biomass. Algal Membrane Bioreactors (AMBRs) are a sustainable wastewater treatment technology that integrates algal-bacterial symbiosis with membrane filtration. Microalgae consume dissolved nutrients (nitrogen and phosphorus) from wastewater while releasing oxygen that aerobic bacteria use to break down organic pollutants. The membrane filter traps the biomass and produces high-quality, sanitized effluent.

How the Technology Works

- **Nutrient Uptake:** Microalgae directly assimilate nitrogen and phosphorus from the wastewater stream.
- **Symbiosis:** Algae generate oxygen through photosynthesis, which bacteria utilize to degrade organic matter.
- **Physical Separation:** Membranes (typically microfiltration or ultrafiltration) physically block algae and sludge from escaping into the effluent.
- **Biomass Recovery:** Concentrated algal biomass can be harvested for downstream uses like biofuels, fertilizers, and bioplastics.

Key Benefits

- **High Pollutent Removal:** Effectively captures emerging pollutants, heavy metals, and pharmaceuticals.
- **No Secondary Clarification:** Eliminates the need for bulky secondary settling tanks, saving physical footprint.
- **Carbon Sequestration:** Absorbs and sequesters CO_2 from industrial emissions or the atmosphere.
- **Sustainable Byproducts:** Recovers valuable resources from wastewater rather than just treating it.
- **Membrane Fouling:** Algal cells, extracellular polymeric substances (EPS), and microbial metabolites coat and clog the membrane pores.
- **Energy Costs:** Maintaining constant aeration to scour membranes and provide artificial light (in closed photo bioreactors) can be power-intensive.
- **Scale-up Limitations:** Operating large-scale biological membranes continuously without frequent cleaning remains difficult.

Algae absorb carbon dioxide and expel oxygen through photosynthesis, the exact same biological process used by plants. Powered by sunlight, algal cells pull CO_2 from their aquatic environment and transform it into organic energy (sugars), safely releasing oxygen as a natural byproduct.

Carbon Dioxide Absorption

- **Direct Diffusion:** Because most algae live in water, CO_2 diffuses directly from the surrounding environment across the algal cell membrane.
- **Enzyme Activation:** Algae use a specialized enzyme called carbonic anhydrase.
- **Bicarbonate Conversion:** This enzyme converts dissolved CO_2 into bicarbonate which is easily processed inside the cell.

In the context of environmental science, PM 2.5 stands for particulate matter with a diameter of 2.5 micrometers or less. When discussing PM 2.5 in relation to algae, it generally refers to one of three areas: the toxic impact of air pollution on algae, the use of algae to treat this pollution, or the creation of fine particulate matter from algal biomass.

Toxicity to Algae

Growth Inhibition: PM 2.5 suspended in the air often settles into bodies of water. The toxic, water-soluble components of PM 2.5 (like heavy metals and nitrates) can inhibit the growth of microalgae. PM 2.5 stands for particulate matter with a diameter of 2.5 micrometers or less. It is a microscopic mix of solid particles and liquid droplets found in the air, roughly 30 times smaller than the width of a single human hair. Because they are so small, these fine particles pose a severe threat to public health. Unlike larger dust particles that get trapped in your nose and throat, PM 2.5 can bypass the body's natural defenses, traveling deep into the lungs and even passing directly into the bloodstream.

Key Health Impacts

- Respiratory Issues: Can trigger or worsen asthma, coughing, and bronchitis.
- Cardiovascular Risks: Long-term exposure is linked to heart attacks, strokes, and irregular heartbeats.
- General Symptoms: Can cause eye, nose, and throat irritation, as well as shortness of breath.

PM 2.5 is largely created by chemical reactions and combustion. Common sources include:

- Vehicle exhaust (especially diesel engines)
- Power plants and industrial factories
- Wildfires and agricultural fires
- Wood stoves and residential heating

Cell Damage: High levels of PM 2.5 water pollution can disrupt cellular functions in algae, including inhibiting chlorophyll production and causing cell decay.

Algae-Based Solutions for PM 2.5 Pollution

Bio filtration: Because they are highly efficient at absorbing nutrients and toxic compounds, microalgae are actively researched and utilized in biological filters to capture and reduce particulate matter and greenhouse gases in industrial environments.

Anti-Inflammatory Products: Scientists study algae-derived compounds—particularly metabolites from brown algae—to develop therapeutic treatments that combat respiratory and systemic inflammation caused by inhaling human PM 2.5.

Algal Biomass and Biofuel Emissions: Co-firing Emissions: When algal biomass is burned alongside coal for energy (co-firing), the process generates and releases fine particulate matter.

Ash Morphology: The combustion of algae produces varying amounts of PM 2.5 depending on the species used (e.g., Chlorella or Sargassum), the reaction temperature, and the specific alkali metals present in the algae.

The Photosynthesis Reaction

- **Light Absorption:** Algae use pigments like chlorophyll to capture light energy from the sun.
- **Water Splitting:** This captured solar energy triggers a reaction that splits water molecules H_2O into H_2 and O_2.
- **Sugar Production:** The hydrogen is combined with the absorbed carbon dioxide to create energy-rich sugars (like glucose) to fuel the algae's growth.

Oxygen Expulsion

- **Waste Release:** Since oxygen is not needed for building these sugars, it becomes a cellular waste product.
- **Passive Release:** The oxygen molecules naturally diffuse back out through the cell membrane and are expelled into the water or atmosphere.

The Carbon Fixation Cycle

- **Carbon Sequestration:** The carbon from the absorbed CO_2 is permanently trapped (or "fixed") inside the algae as organic matter.
- **Biomass Growth:** This trapped carbon is used to build biomass, which serves as a foundation for the aquatic food web and is increasingly used to create sustainable bioplastics and biofuels.

CONCLUSION

Algae are a vast, diverse group of photosynthetic organisms that form the foundational pillars of global biodiversity. Accounting for nearly 40% of the planet's photosynthesis, they are the primary producers at the base of aquatic and terrestrial food webs, making them vital for ecosystem stability and health. The diversity and importance of algae span multiple dimensions:

Primary Production & Food Webs: From microscopic phytoplankton to large seaweeds, algae convert sunlight into organic matter. They sustain vast arrays of aquatic life, serving as the essential food source for zooplankton, small fish, and marine mammals.

Habitat Creation: Marine algae build structural habitats like kelp forests, which support high localized biodiversity by providing shelter and nursery grounds for numerous species.

Taxonomic Range: Algae are a polyphyletic group (originating independently) comprising thousands of distinct species across major lineages, including green algae (Chlorophyceae), red algae (Rhodophyceae), and cyanobacteria. Environmental Indicators: Because they are highly sensitive to changes in water chemistry, algal biodiversity is used by environmental scientists to monitor the ecological health of aquatic bodies.

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