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ALGAE BIOREMEDIATION

TRANSFORMING WASTEWATER INTO VALUABLE PRODUCTS

Algae cultivation in the wastewater as the parallel bioremediation and biomass production presents an innovative ecology model. Nutrients, organic carbon, and minerals that would otherwise be lost by the discharge into environment, are recovered by algae for production of biomass that can be used further. Biomass can be valorised for a variety of products, from the low-added-value biofuels, organic fertilisers, or biomaterials (including biodegradable bioplastics) to the high-added-value compounds for phyto-pharmacy, cosmetics, and agriculture, bringing new financial streams to the companies.

ADVANTAGES OF ALGAE BIOREMEDIATION FOR WASTEWATER TREATMENT

1. **VERSATILITY IN GROWTH CONDITIONS:** Algae have the remarkable ability to grow in various wastewaters, making them suitable for different industrial applications. This adaptability ensures that algae bioremediation can be implemented across multiple sectors, contributing to widespread environmental benefits.

2. **SOURCE OF ECONOMIC GROWTH:** The cultivation of algae in wastewater treatment facilities can create additional jobs and income opportunities. This aspect of algae bioremediation is particularly appealing as it not only addresses environmental issues but also supports economic development.

3. **CONTRIBUTION TO THE CIRCULAR BIOECONOMY:** Algae and wastewater together form essential components of the circular bioeconomy. By transforming wastewater into a resource, this approach promotes sustainability and resource efficiency.

4. **MITIGATION OF EUTROPHICATION:** The use of algae helps in absorbing excess nutrients from wastewater, which, if untreated, could lead to the eutrophication of water bodies. This significantly reduces the negative impacts on aquatic ecosystems and environmental health.

5. **RECOVERY OF VALUABLE RESOURCES:** Algae bioremediation facilitates the recovery of nutrients and energy from wastewater, turning waste into valuable secondary raw materials. This maximizes resource utilization and supports sustainable waste management practices.

6 **WATER RECYCLING AND REUSE:** Treated water can be safely returned to technological processes, used for agricultural irrigation, or released into the natural environment. This promotes water conservation and ensures that water resources are efficiently utilized.

7 **CARBON SEQUESTRATION:** Industrial CO2 emissions can be utilized for algal growth, which captures and fixes carbon into biomass. This process contributes to the reduction of greenhouse gases and can aid in the establishment of carbon credits, aligning with global efforts to combat climate change.

8 **ENERGY SAVINGS IN WASTEWATER TREATMENT:** The symbiotic relationship between algae and bacteria in wastewater treatment systems reduces the need for energy-intensive oxygenation processes. Since oxygenation accounts for a significant portion of a wastewater treatment plant's energy consumption, using algae can lead to substantial energy savings.

9 **ENHANCED BIOMASS PRODUCTION:** Algae utilize the nutrients and organic carbon in wastewater for biomass production. This biomass can be further processed into biofuels, fertilizers, and other value-added products, offering a sustainable alternative to conventional resources.

10 **IMPROVEMENT OF ENVIRONMENTAL SUSTAINABILITY:** By integrating algae bioremediation into wastewater treatment, industries and communities can significantly lower their environmental footprint and reduce unpleasant odor.

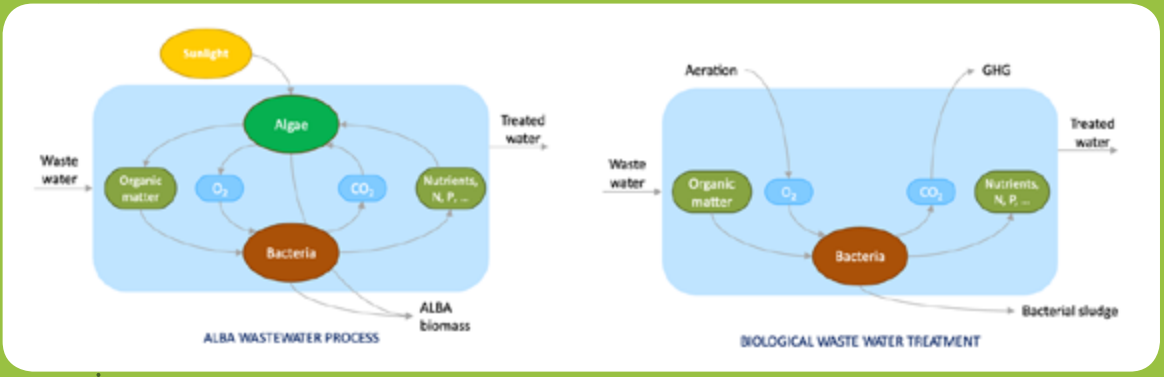

Figure 1. Wastewater treatment with (left) and without algae (right). Source: AlgEn, algal technology center, llc.

ADVANTAGES OF ALGAL TREATMENT FOR BIOGAS PLANT DIGESTATE

1 **NUTRIENT RECOVERY:** The algal treatment process effectively recovers nutrients from the liquid phase of anaerobic digestate, which is rich in agricultural value. This not only addresses waste management challenges but also repurposes valuable resources for sustainable use.

2 **REDUCTION OF POLLUTANTS:** In the case study of the Koto biogas plant in Slovenia, algae demonstrated an impressive ability to reduce COD (Chemical Oxygen Demand) by 90%, nitrogen by 91%, and phosphorus by 64%. Such high reduction rates indicate the potential for significantly mitigating environmental pollution.

3 **BIOMASS PRODUCTION:** The process leads to the production of substantial amounts of biomass, reaching up to 30g/m2 per day in optimal conditions. This biomass can serve various purposes, including as a substrate for fertilizer or biogas production, showcasing the versatility of algal treatment.

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4 **COST AND EMISSION REDUCTIONS:** By stabilizing the liquid digestate into biomass, logistical costs and greenhouse gas emissions associated with storage and transportation are significantly reduced. This makes the algal treatment a cost-effective and environmentally friendly solution.

5 **ENHANCED BIOGAS PLANT EFFICIENCY:** Implementing algal technology in biogas plants offers a pathway to improve the quality of the liquid digestate fraction. It supports the creation of better-quality energetic substrates, enabling a more efficient and sustainable biogas production process.

6 **CO2 AND HEAT UTILIZATION:** The process facilitates the recycling of CO2 emissions and the effective use of excess heat, aligning with circular economy principles and contributing to the overall efficiency of biogas plants.

7 **ODOR REDUCTION:** Algal treatment can help reduce odors associated with biogas digestate, improving the environmental and social acceptability of biogas plants.

8 **ON-SITE RECYCLING:** Nutrients recovered from the digestate can be cycled back on-site, promoting a closed-loop system that minimizes waste and enhances sustainability.

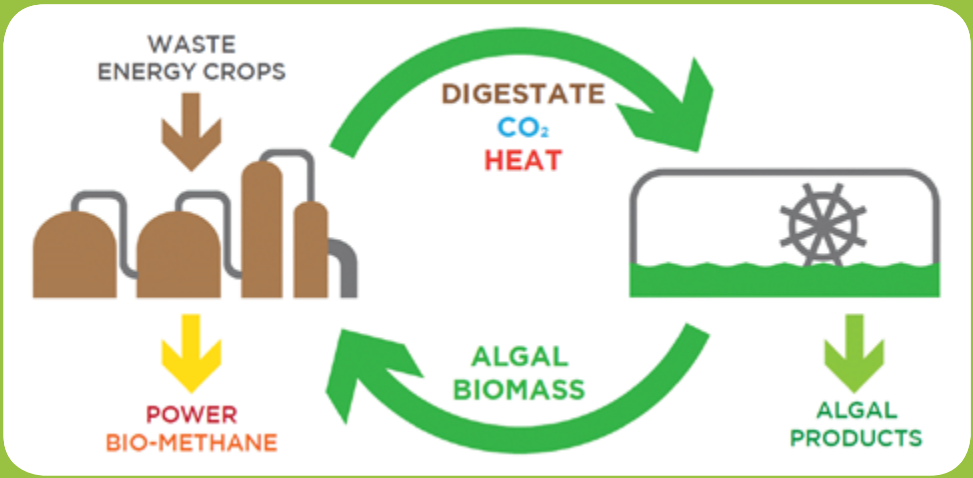

Figure 2. Circularity in biogas plants with algal systems (source: Algen, algal technology center, llc (www.algaebiogas.eu)).[5] ↑

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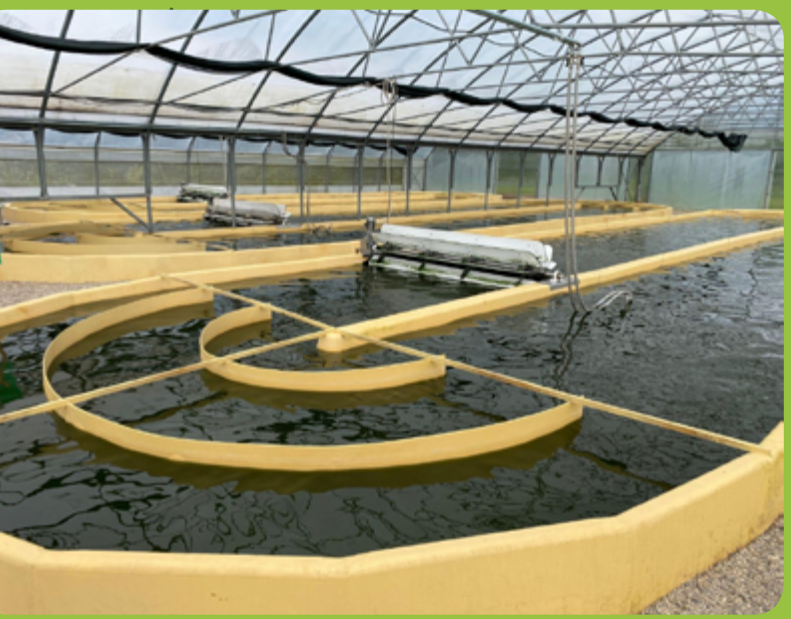
WIDE VARIETY OF NEW PRODUCTS

1 **VERSATILE PRODUCT RANGE:** Algae biomass can be valorized into a wide array of products, spanning from biofuels, organic fertilizers, and biomaterials such as biodegradable bioplastics, to high-value compounds used in phyto-pharmacy, cosmetics, and agriculture. This versatility allows for the development of sunscreens, moisturisers, biopesticides, biostimulants, and animal feed supplements from algal extracts, highlighting the potential of algae as a key resource in sustainable product development.

2 **SUSTAINABLE AGRICULTURE AND SOIL IMPROVEMENT:** Through processes like composting and pyrolysis, macroalgal biomass can be stabilized for agricultural use, enhancing soil fertility, nutrient retention, and plant growth. Biochar produced from macroalgae improves the retention of essential nutrients in soils and acts as a bioenergy source, carbon sequestration agent, and a component for water treatment and soil remediation.

3 **BIOREFINERY AND RESOURCE RECOVERY:** A biorefinery approach to microalgae production maximizes the utility of the biomass by producing both high- and low-value products while recovering nutrients from waste streams. This strategy, exemplified by projects like SABANA, Water2Return, and Saltgae, demonstrates the efficiency of algae in nutrient recycling, offering a sustainable solution for waste management and product diversification.

4 **BIOSORBENTS FOR ENVIRONMENTAL REMEDIATION:** Algal biomass can serve as an effective biosorbent for the removal of pollutants, including heavy metals from contaminated effluents. After their use as biosorbents, algae can be repurposed as fertilizers, contributing to soil enrichment and sustainability. This dual use of algae not only addresses pollution but also supports agricultural practices by improving soil health and nutrient content.



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ALGAE SYSTEMS INTEGRATION INTO EXISTING INSTALLATIONS

1 **DIVERSE PRODUCTION SYSTEMS:** Algae biomass production is versatile, utilizing both closed systems like (photo)bioreactors for sterile and rapid biomass production of specific ingredients such as pigments, and open systems like raceway ponds for cost-effective production with lower initial investments. Photobioreactors can be installed both indoors and outdoors, including vertical setups to maximize yield per land area, while raceway ponds offer flexibility by operating either completely open or within greenhouses for continuous production in various climatic conditions.

2 **INNOVATIVE AND PROMISING APPROACHES:** Research and development efforts are ongoing to explore various algae cultivation systems, including thin-layer systems, biofilms, and algal turf scrubbers. These innovative approaches aim to achieve higher production efficiencies and offer promising solutions for algae biomass production on a global scale.

3 **INTEGRATION WITH EXISTING TECHNOLOGIES:** Algae cultivation systems can be easily integrated as side streams into existing technological setups without necessitating significant changes. This feature is particularly beneficial for wastewater treatment systems and industrial technologies, where algae can contribute to the treatment process by utilizing waste streams for biomass production, thereby enhancing sustainability and efficiency.

4 **BENEFITS FOR BIOGAS PLANTS AND WASTEWATER TREATMENT:** Algal systems can significantly augment biogas plant operations by treating digestate to recycle nutrients, thus reducing storage, transport costs, and the environmental footprint. Moreover, the addition of algal raceway ponds to wastewater treatment processes can potentially replace secondary and tertiary treatment stages, leading to a substantial reduction in the production of unwanted sludge, aligning with agricultural regulations in many countries.

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BUSINESS MODELS WITH ALGAE GROWN IN WASTEWATER OR DIGESTATE

To fully realize the potential of algae grown in wastewater or anaerobic digestate, innovative business models are needed that can capture the value of these products. Here are some possible business models:

1. Algae production and processing for specific industries: Companies can focus on producing algae for specific industries, such as aquaculture or biofuels. By optimizing their production and processing methods for these specific markets, they can create high-value products that meet the needs of those industries.

2. Integrated systems for wastewater treatment and resource recovery: Companies can develop integrated systems that use algae to treat wastewater and recover valuable resources, such as nutrients and biofuels. By offering a complete solution for wastewater treatment and resource recovery, these companies can provide value to municipalities, industrial facilities, and agricultural operations.

3. Carbon credits and offsets: Companies that use algae for carbon sequestration or biofuel production can generate carbon credits or offsets that can be sold on carbon markets. This can provide a new revenue stream for companies and incentivize the development of sustainable practices.

4. Direct-to-consumer products: Companies can develop direct-to-consumer products, such as fertilisers or biostimulants, that use algae grown in wastewater or anaerobic digestate. This can provide a way to capture value from these products without relying on traditional supply chain.

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