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Algae: From Resource Depletion to Resource Recovery

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Generally, when we think of algae in water quality context, we think of how nutrients in agricultural runoff, municipal wastewater effluent, and urban stormwater provide the conditions for algae blooms in water bodies. These algal blooms lead to eutrophication and dead zones, causing water quality and negative economic effects.

The same biological processes that lead to water quality problems from nutrient pollution can be harnessed to treat, and recover, nitrogen and phosphorus through production of algae biomass for wastewater bioremediation. Algae can be cultivated and harvested to create biomass that can be transformed into biofuels and bioproducts.

As the wastewater sector seeks to manage high energy costs while recovering resources to meet tighter nutrient limits, the algae bioproducts and biofuels industry is searching for productive feedstock. The potential is being recognized, as demonstrated by awarding of the 2016 Paul L. Busch Award to Jeremy S. Guest, assistant professor in the Department of Civil & Environmental Engineering at the University of Illinois at Urbana–Champaign. This $100,000 award recognizes Guest's work with algae treatment and resource recovery.

In October 2016, the Water Environment Federation (WEF; Alexandria, Va.) and the Algae Biomass Organization (ABO; Preston, Minn.) hosted the forum Algae in Wastewater Treatment at the Algae Biomass Summit. The forum brought together algae technology developers, leading design and engineering firms, municipalities, regulators, and other stakeholders to review the state of algae-based tertiary wastewater treatment systems. Forum participants also discussed opportunities and challenges in deploying such systems in the context of an evolving economic, environmental and regulatory landscape.

Types of Algae

The wastewater treatment plant at Suncor is typical of refineries. Wastewater flows through an oil separator, followed by dissolved-air flotation. The pretreated effluent is then collected in an equalization tank prior to being pumped to the MBBR. The MBBR effluent is discharged into a lagoon prior to discharge to the Saint Lawrence River.

Photosynthetic algae use nutrients from nitrogen and phosphorus in wastewater, capture carbon as carbon dioxide, use energy from sunlight, and produce oxygen as a waste product. Heterotrophic algae use organic chemicals for carbon and energy.

Blue-green algae are photosynthetic, but actually are bacteria (cyanobacteria) that contain phyocyanin, which give the blue-green color. Blue-green algae also produce microcystins, which are toxins that cause many of the negative effects of algae blooms in lakes. Other algae are eukaryotes, as opposed to bacteria, and are generally green, brown, and red. Common green algae strains are shown in Figure 1 (see p. 1).

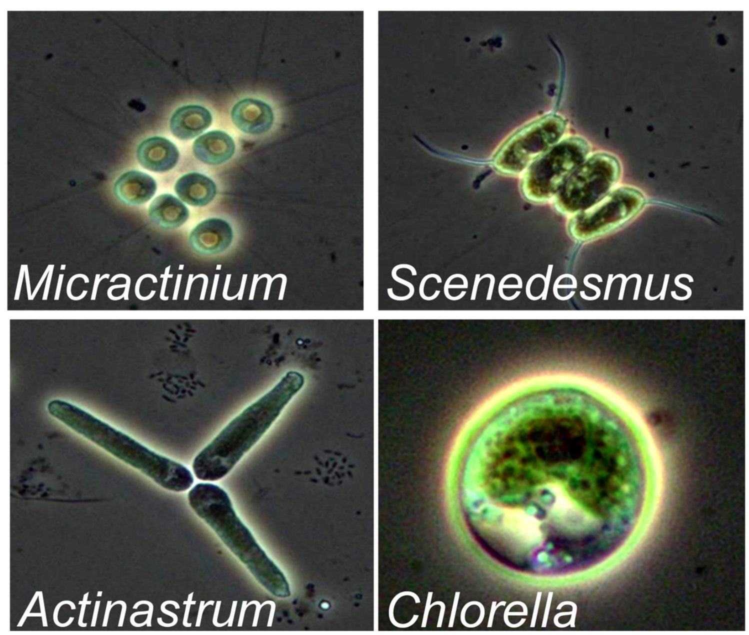

Figure 1. Common green algae strains

Algae Treatment

The use of algae as wastewater treatment is common, as the biological processes take place in ponds and lagoons naturally. About half of the 16,000 regulated water resource recovery facilities (WRRFs) have ponds/lagoons. These features are prevalent especially at smaller WRRFs (Bastian 2016). The efforts now are focusing on how to use microalgae for wastewater treatment within conventional WRRFs.

Similar to other biological wastewater treatment techniques, algae treatment can utilize suspended- or attached-grown methods. Suspended-growth ponds use paddles keep microalgae suspended for sunlight, coupled with a shallow depth for light penetration. The layout of these ponds gives rise to the name raceways, as shown in Figure 2 (p. 2).

Attached growth techniques utilize a substratum that rotates alternatively through wastewater (to provide nutrients) and atmosphere (to provide sunlight and carbon dioxide). Two common types of attached growth algae treatment technologies are biofilm rotating algae biofilm reactor (RABR) and revolving algal biofilm (RAB).

In pilot tests in Chicago, an RAB system has demonstrated the potential for recovering nutrients from wastewater. The RAB system is capable of producing concentrated algae biomass (10% to 25% solids), which has value and can be used to produce a variety of products (Kumar 2016).

Several types of wastewater are applicable for algae treatment including municipal wastewater, produced water from oil and gas extraction, dairy farms and swine wastewater. During treatment, nitrates and phosphates are combined with water and carbon dioxide to grow the algae. Microalgae often is represented by the chemical formula $C_{106}H_{263}O_{110}N_{16}P_1$. It is important to note the phosphorus to nitrogen ratio of 1 to 16 when evaluating the design, as well as looking to add carbon dioxide to balance the carbon:nitrogen:phosphorus ratio and achieve completed nutrient assimilation, according to Ron Sims, who gave the presentation Microalgae-based approaches to Algae-based tertiary wastewater treatment at the forum.

Most of our existing laws and regulations that deal with wastewater were designed with conventional treatment systems in mind. How does algae fit in the regulatory environment? 40 CFR Part 503 includes definitions for Class A and Class B biosolids. Algae from municipal wastewater (as part of the treatment system) are subject to Part 503. Algae solids from municipal treatment could meet class A or Class A/EQ in a number of ways. Metals are unlikely to be problematic and consistent low metals and pathogens may provide basis for reduced monitoring, said Robert Bastian in his presentation, Algae Biotechnology for Wastewater Treatment: Regulatory Issues, at the forum.

Figure 2. Suspended-growth ponds or raceways

Bioproducts and Bioenergy

A number of bioproducts can be produced from algae biomass. Fertilizers from algae solids generally have about 8% to 10% nitrogen content and 1% to 2% phosphorus content, Bastian said. The biomass also can be used as feed for aquaculture and agriculture. Products from phycocyanin include pigments and antioxidants, Sims also reported.

The first techno-economic analysis (TEA) for algae biofuels integrated with wastewater treatment was performed in 1960, according to Algae Biotechnology for Wastewater Treatment: An Introduction presented by John Benneman. Using anaerobic digestion, the biomass can produce biogas, especially when mixed with food wastes and municipal wastewater biosolids to generate more methane for combined heat and power (CHP). Additional processing, such as hydrothermal liquefaction ("pressure cooking") can convert algae to biocrude oil. Other processes can produce biodiesel, bioplastics, acetone, butanol, and ethanol, Sims said.

When evaluating any energy resource recovery opportunity, it is important to calculate the energy return on investment (EROI): Does the system provide more usable energy than it consumes?

According to recent work in Europe, algae biofuels have an EROI of 1.9, substantially higher than corn ethanol's and biodiesel's value of 1.3. In addition, biomethane from algae enables greenhouse gas savings of more than 50% compared to diesel. Furthermore, algae biofuel production per hectare is 10,000 kg CH4/ha/yr, enough to fuel 10 vehicles, double sugar bioethanol and palm oil diesel, reported Frank Rogalla in his presentation, Wastewater Treatment and Energy Recovery with Cultivation of Microalgae.

Conclusions

State regulators, municipalities, and other industrialized jurisdictions increasingly are moving toward tertiary wastewater treatment as a means to mitigate the environmental effects of nitrogen, phosphorus, heavy metals, and other components of traditional wastewater treatment systems. But traditional systems can be an expensive and energy intensive proposition.

Algae-based systems, which make up just a small fraction of tertiary systems in use today, offer a potential solution, providing a low input-energy platform for nutrient recovery with a variety of opportunities for production of value-added coproducts.

Occasional high-effluent NH_4-N concentrations have been observed at the facility; the data were reviewed to determine the cause of the decreased nitrification. However, no clear correlation with the temperature could be found. In most instances, the higher NH_4-N concentration in the effluent could be attributed to a high influent NH_4-N load.

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