CE 598 Water Reuse

# Microalgae for Wastewater Treatment and Reuse

*Leslie R. Kryder*

*November, 2007*

# *Outline*

### *Introduction*

Several researchers in the United States and abroad have sought to develop processes that remove nutrients (primarily nitrogen and phosphorus) from wastewater by growing any of several strains of microalgae in the water. While nutrient removal can be accomplished by a variety of biological and chemical processes, microalgae holds promise of being able to accomplish nutrient removal with a net energy savings to the water treatment system. The nutrients, instead of being waste, become feed for the algae, which in turn become either a feed or a fuel source. The treated wastewater is of a quality suitable for many industrial applications.

According to Asano et al., energy cost is the second highest treatment plant operating cost after labor. Processes that require high energy include biological treatment by activated sludge systems, pumping, and equipment for drying and dewatering sludge. Nitrification adds 20%-30% additional electricity costs to an activated sludge system. (Asano et al. 2007, p363-364) If techniques can be perfected, the water treatment process can become simultaneously a form of reuse. Microalgae harvesting may be a significant advance toward reducing constraints on the water-energy nexus.

In a recent National Geographic article, Joel Bourne discusses the relative energy balance of various biofuels, comparing fossil-fuel energy on the input side to the energy generated by the final product. Corn ethanol is rated at 1.0:1.3; cane ethanol 1.0:8.0; biodiesel from canola or soy 1.0:2.5. He does not give a rating for biodiesel from algae. However, on an acre of land, microalgae can produce an order of magnitude more fuel than corn; and two orders of magnitude more than soy, because of the speed with which algae grows. (Bourne 2007).

This paper reviews several promising directions that researchers are pursuing for treating wastewater using microalgae, and the beneficial byproducts of the process.

### *Sustainability of Microalgal Wastewater Treatment*

Scandinavian researchers evaluated three wastewater treatment methods based on two frameworks for quantifying the degree to which a process tends toward a sustainable system. The frameworks are known as the "socio-ecological principles" and "emergy analysis." Emergy analysis locates every resource in an energy hierarchy of the biosphere: "The position of an item in the energy hierarchy is suggested to correspond to the relative influence of that item, [sic] on the system of which it is a part." (Groenlund, et al. 2004, p157)

The wastewater treatment methods considered were 1) a conventional wastewater treatment system (not further defined), 2) a conventional treatment plant used together with a constructed wetland, and 3) a model microalgae-based wastewater treatment plant. After comparing costs, use of renewable and non-renewable energy sources, and other factors such as environmental load and emergy yield, they conclude that the microalgae-based treatment violated the socio-ecological principles to a lesser degree than the other treatment methods. Unfortunately, the monetary inputs were larger than for the other treatment methods. They observe that if the microalgae biomass could be used other ways, this would narrow the cost gap and could make the process cost-effective. They suggest identifying byproducts, for example, valuable biochemicals and methane collection. They seem to be unaware of the potential for using the biomass for animal feed or biofuel. (Groenlund, et al. 2004)

### *Disposal of Animal Manure*

Animal manure is typically disposed of by recycling it on crop land. The animal waste is high in nitrogen and phosphorus which are valuable nutrients for plant cultivation. As the demand for animal protein continues to grow, the amount of manure being produced has begun to exceed the available land. Dr. Fedler proposed a multi-step process where wastewater is introduced into an anaerobic system such as an integrated facultative pond. The resulting effluent is high in ammonia-nitrogen and also generates methane gas. The methane gas can be used as a fuel source; the ammonia must be further treated as it is toxic to many fish. However, certain algaes consume the ammonia. The algae can become a food source for fish or livestock. Alternatively, the algae-biomass can be converted to electricity using a gasifier. (Fedler 2006)

### *Four Useful Byproducts of Microalgae-based Processing*

Dr. J. H. Reith and colleagues developed a process using microalgae to purify wastewater. They identified four beneficial byproducts: fine chemicals (e.g. colorants and bioactive substances), biofuel, carbon-dioxide fixation, and water purification. This team experimented with a "bubble column" photobioreactor system that sends wastewater through a series of outdoor basins or ponds. They note that the key to making this process profitable is the multiple byproducts that result. The process removed ammonium, nitrate, and phosphate from wastewater to < 10 micrograms per liter. The resulting biomass can be used as feed, especially for aquaculture, agrochemicals and other bioactive substances, and energy sources such as biodiesel, hydrocarbons, methane, and ethanol.

They compared the "bubble column" system to two others: high rate algal ponds and semi-closed bioreactors with positive results. The "bubble column" approach provides a low maintenance, yet robust system, that can be used year-round with small amounts of supplemental heat in winter. Compared to the semi-closed bioreactors, the energy demand is relatively low, and so is the initial investment; compared to the high rate algal ponds, the biomass density is much higher, and bubble column process can restrict what's grown to one strain of algae. In addition, the system is able to use "waste heat" from the algae to partially power the algae drying process. The authors showed that the process produces both industrial grade water and biomass at realistic market prices (0.4 Euro/cubic meter and 2 to 4 Euors per kg, respectively). Chemicals would provide additional revenue. They measured the carbon dioxide uptake of the algae and concluded that the process is a net carbon dioxide fixer. (Reith et al, 2004) Of course, if the algae is later "burned" the carbon-dioxide would be released. (Groenlund et al. 2004)

### *Microalgae as a Bio-hydrogen Source*

A team of researchers from Australia and Germany focused on the potential for generating bio-hydrogen ($H_2$) from algae. [Although the water requirements and outputs are not quantified, the authors point out that water is a byproduct of hydrogen combustion]. Biofuels are especially important because about two-thirds of current energy consumption is from burning fuels; and one-third from electricity. Yet, most of the non-carbon dioxide releasing fuels such as nuclear, photovoltaic, wind, geothermal, wave, and hydroelectric, drive electricity generation. Microalgae can directly generate two types of biofuel, bio-hydrogen and biodiesel.

Some green algae produce hydrogen when exposed to light. Researchers have recently experimented with several mutant strains of microalgae that exhibit the hydrogen production characteristics using a two-phase system (an aerobic step and an anaerobic step). In step one, algae cells are grown to accumulate biomass. Then, the algae is transferred to a sulphur-depleted medium to induce hydrogen production. Efforts are underway to increase the photon to hydrogen conversion rate above 2%. The resulting biomass can be converted to biodiesel. (Hankamer et al. 2007)

### *Microalgae in an Integrated Aquaculture System*

Portuguese researchers investigated the potential to use microalgae to process fish-farm effluents (primarily inorganic nitrogen and phosphorus) in seawater and use the microalgae as food for the *Tapes decussates* bivalve clam. The nutrient removal efficiency for ammonium and nitrite-nitrogen was in the range of 80%-100%, for nitrate 41%-100%, and for phosphorus 21%-99%. After treatment, the water is similar in quality to fresh seawater. Researchers note the importance of this process, since fish farm effluent nutrient levels are generally too low for removal using standard bacterial systems. (Borges et al. 2005)

### *Harvesting Microalgae: Bioflocculation*

A team of Korean researchers, aware that the cost of harvesting microalgae is the major limitation on viability of this technology, investigated the use of microbial flocculants for harvesting microalgae. Since *Chlorella* is a form of green algae widely used in pond-based wastewater treatment, they tested over 100 bacterial strains for their ability to flocculate *Chlorella vulgaris* in a culture suspension. They found that *Paenibacillus* sp. AM49 was the most effective strain on *Clorella vulgaris*; it also exhibited a high rate of effectiveness with several other varieties of green algae, including two, *Botryococcus braunii* and *Scenedesmus quadricauda,* which are known to be good for biofuel production. A microbial flocculant would be significantly cheaper than traditional flocculants and is believed to be less potentially toxic than synthetic polymers which are currently available. (Oh, et al. 2001)

### *Harvesting Microalgae: Immobilized Algae System*

In a 2006 study, researchers in Germany tried a technology that they called the twin-layer system using *Chlorella vulgaris* and *Scenedesmus rubescens* to determine how effectively the system would remove nutrients from wastewater. The twin layer system immobilizes the algae on a substrate; then attaches this layer to a layer of fibrous tissues which provides the growth medium. Using this technique algae does not mix with the wastewater, but is able to draw the nutrients out of it. Within 9 days, the microalgae removed nitrate to 0.10 mg per liter or less; phosphate to less than 0.4 mg per liter; and approximately 95% of ammonium. (Shi et al. 2007)

### *Conclusion*

Researchers are pursuing a variety of strategies to make use of microalgae cultivation in wastewater for water purification and energy production. Microalgae as a fuel source holds a distinct advantage over corn and soy-based products because it can be cultivated on land that is not otherwise used for producing crops, and its per acre level of production is much higher. Microalgae can potentially reduce the high cost of nutrient removal during wastewater treatment and nitrification. This review of the research also brings up several considerations and concerns.

1. Is the energy balance of algae-based biofuel sufficiently great to make the process worthwhile as an alternative to fossil fuels? Wastewater treatment plants must be located close enough to plants that harvest and use the algae biomass in order to make these processes energy- and cost-effective.
2. At what point will removing nutrients from wastewater impact downstream agriculture that may be taking advantage of the nutrients? This may be especially a problem in developing countries where synthetic fertilizers are too expensive. If more fertilizer must be applied to crops to make up for the reduction in nutrients in the water, this decreases the energy ratio advantage.
3. If mutant strains of algae are used for biofuel production as discussed by Hankamer et al., what will the environmental impact be if that algae escapes into the wild? Would this result in another invasive species?
4. Is the process fast enough to fit in with the existing wastewater treatment requirements? What are the costs of retrofitting existing treatment plants to make use of the algae-biofuel production process?
5. What kinds of regulations would be needed for the dual-purpose water treatment and biofuel production plants? What kinds of wastewater treatment and water quality regulations should the processes be subject to?

Much work remains to be done to perfect microalgae cultivation as a means of wastewater treatment and source of feed, biofuel, and other valuable byproducts. However, the time when microalgae are used commercially may not be very far off. At least one company, GreenFuel, working together with Arizona Public Service, is testing algae production for commercial application. (Bourne 2007)

## Bibliography

Asano, T., Burton, F. L., Leverenz, H. L., Tsuchihashi, R., and Tchobanoglous, G. (2007). *Water Reuse, Issues, Technologies, and Applications*, Metcalf & Eddy | AECOM.

Borges, M. T., Silva, P., Moreira, L., and Soares, R. (2005). "Integration of consumer-targeted microalgal production with marine fish effluent biofiltration–a strategy for mariculture sustainability." *Journal of Applied Phycology*, 17(3), 187-197.

Bourne, J. K., Jr. (2007). "Biofuels: Boon or Boondoggle?" *National Geographic* (October 2007), 38-59.

Fedler, C. B. (2006). "Potential Biomass Production from Recycled Wastewater." *Biocycle*, 47(7), 46-50.

Groenlund, E., Klang, A., Falk, S., and HanAeus, J. (2004). "Sustainability of wastewater treatment with microalgae in cold climate, evaluated with emergy and socio-ecological principles." *Ecological Engineering*, 22(3), 155-174.

Hankamer, B., Lehr, F., Rupprecht, J., Mussgnug, J. H., Posten, C., and Kruse, O. (2007). "Photosynthetic biomass and H2 production by green algae: from bioengineering to bioreactor scale-up." *Physiologia Plantarum*, 131(1), 10-21.

Oh, H. M., Lee, S. J., Park, M. H., Kim, H. S., Kim, H. C., Yoon, J. H., Kwon, G. S., and Yoon, B. D. (2001). "Harvesting of Chlorella vulgaris using a bioflocculant from Paenibacillus sp. AM49." *Biotechnology Letters*, 23(15), 1229-1234.

Reith, J. H., Zessen, E., Drift, A., Uil, H., Snelder, E., Balke, J., Matthijs, H. C. P., Mur, L. R., and Kilsdonk, K. "Microalgal mass cultures for co-production of fine chemicals and biofuels & water purification." *Presentation CODON Symposium "Marine Biotechnology; An ocean full of prospects ?" 25th March 2004*, Wageningen.

Shi, J., Podola, B., and Melkonian, M. (2007). "Removal of nitrogen and phosphorus from wastewater using microalgae immobilized on twin layers: an experimental study." *Journal of Applied Phycology*, 19(5), 417-423.