Commercial Pilot for Closed-loop Wastewater Treatment and Biofuel Production Using Microalgae

Peter Valdez, Eric Sundstrom, Lucie Novoveska, Matthew Atwood*

Algae Systems, LLC, 6321 Jordan Rd, Daphne, AL 36526 USA
*Corresponding Author: matwood@algaesystems.com

ABSTRACT

Algae Systems has recently commissioned a pilot facility for treating wastewater and producing biofuel in a beneficial alignment of economic and sustainability concerns within an integrated process. Through the application of systems thinking, wastewater and CO_2 are converted to clean water and transportation fuel. With widespread adoption of this technology, treatment of wastewater can be transformed from a major energy sink to an energy source, while simultaneously improving the economics of municipal wastewater treatment.

Keywords: wastewater treatment, biofuels, algae cultivation, carbon capture, hydrothermal liquefaction

1 INTRODUCTION

Clean water and fossil fuels are becoming increasingly scarce. There is a significant need for developing sources of sustainable energy that do not interfere with our limited supplies of water. Synergistically, the production of clean water is dependent on available energy resources.

In traditional wastewater treatment, significant energy is used to dilute, discharge, or landfill valuable resources including organic carbon, nitrogen, phosphorus, and freshwater. This situation is untenable due to energy costs and global scarcity of clean water. Development of new technologies requires a systems approach, in which the output from one process becomes the input for the next. Microalgae are a potentially valuable feedstock for biofuels, particularly if cultivated from waste streams [1]. Integration of wastewater treatment, algae cultivation, carbon capture, and energy production intrinsically improves the energetic [2] and economic favorability of each component process.

2 OUR APPROACH

The National Research Council outlined the major challenges that they considered to be of “high importance” for the sustainable development of algal biofuels [3]. They are water usage, nutrient supply, land usage, energy return on investment, and greenhouse gas emissions. Our approach for developing algal-based biofuels attempts to alleviate all of those substantial concerns.

Figure 1 summarizes Algae Systems’ integrated approach for treating wastewater and producing biofuels. By coupling wastewater treatment and algae cultivation, the wastewater provides sufficient amounts of water and nutrients to cultivate algae at a large scale. Carbon is supplied for the algae as CO_2 using a proprietary system for capturing CO_2 from the environment. The algae are

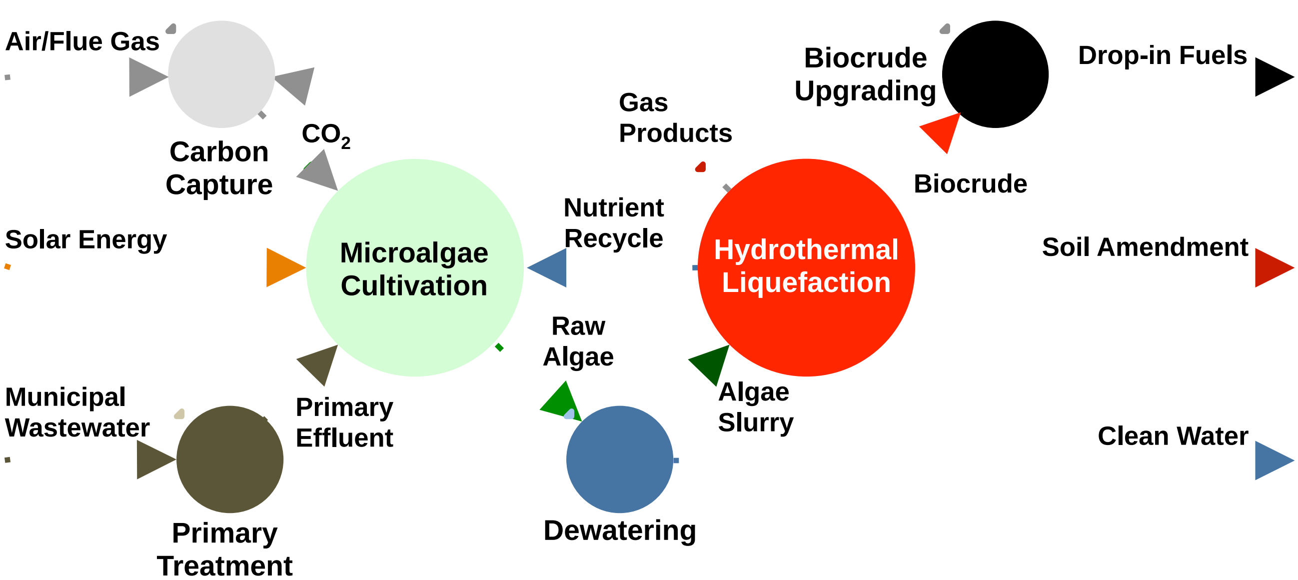

Figure 1. The Algae Systems approach for wastewater treatment, carbon capture, and biofuel production.

cultivated using a patented offshore system of photobioreactors to minimize land use. The algal biomass is harvested and partially dewatered before being fed into a hydrothermal liquefaction (HTL) reactor. The high-temperature and high-pressure process produces an energy-dense biocrude. This biocrude has been shown to have a net energy return on energy invested [4]. Carbon that is not ultimately converted into biofuel can be easily sequestered as a nutrient-rich soil amendment to reduce the greenhouse gas emissions of the overall process. By-products from the unit operations are easily recycled within the plant using different integrated technologies. The integration of the aforementioned technologies creates a synergistic system that can provide clean water and clean energy. The following sections provide details about each major technology we are integrating into our algal biorefinery.

2.1 Wastewater Treatment

Algae cultivation as an independent system requires substantial amounts of water and nutrients. In a typical wastewater treatment facility, large amounts of nitrogen and phosphorus-rich fresh water, are readily available. When cultivating microalgae using municipal wastewater, the algae naturally consume available nitrogen, phosphorus, and other nutrients during growth. Algae growth produces oxygen through photosynthesis; this oxygen is used by the microbial community to oxidize organic carbon, thereby reducing the biochemical oxygen demand (BOD) of the waste stream. The resulting water is then suitable for discharge or beneficial re-use. Algal wastewater treatment does not require aeration, and can therefore be viewed as an energy-efficient alternative to traditional wastewater treatment technologies.

Algae Systems has developed and patented a novel system for treatment of municipal wastewater with algae grown in low-cost floating photobioreactors (PBRs). In partnership with Daphne Utilities in Daphne, AL, Algae Systems has built and operated a pilot facility to demonstrate this new technology. Up to 40,000 gallons of raw municipal wastewater is initially subjected to solids removal and disinfection. The resulting primary effluent is deployed to four quarter-acre arrays of PBRs floating on Mobile Bay, Figure 2 shows some of the PBRs.

Algae Systems' PBRs consist of large, clear bags made of durable, flexible plastic. These inexpensive bags provide a large, flat surface area for growth into which wastewater, algae inoculum, and concentrated CO_2 can be supplied. Offshore algae growth avoids competition for arable land and allows co-location with existing urban wastewater sources. As compared to cultivation on land, growth in enclosed, offshore bags provides a number of other advantages- including wave energy for mixing, temperature control, contaminant control, CO_2 containment, reduced site preparation, and physical support of PBRs.

Harvested algae biomass is dewatered, producing concentrated slurry. The treated effluent has very low nitrogen and phosphorus, >60% reduction in chemical oxygen demand, and no measurable fecal coliform, making the Algae Systems process competitive with traditional secondary and tertiary treatment alternatives.

2.2 Carbon Capture

Algae Systems is partnered with Global Thermostat, a company specializing in the development of technologies capable of concentrating CO_2 from the environment. The Global Thermostat technology will be integrated into the pilot site in Daphne to capture CO_2 from the air and from any processes within the plant. The captured CO_2 will be fed to the photobioreactors as the primary carbon source for the microalgae. Use of atmospheric carbon capture eliminates the need to co-locate with existing CO2 sources, thereby increasing the number of potential project sites.

During each phase of fuel production, a percentage of the total biomass is converted to biochar. This recalcitrant carbon can then be permanently sequestered as a soil amendment. Sequestration of atmospheric carbon during the fuel production process makes possible the production of carbon-negative fuels that effectively remove carbon from the atmosphere with each gallon burned.

Figure 2. Floating photobioreactors on Mobile Bay

2.3 Biofuel Production

Biofuel production is often limited by the abundance of an available feedstock from biomass, but Algae Systems is demonstrating a scalable methodology for producing high-quality biomass from low-value material. The availability of the algal biomass necessitates another scalable technology that uses few additional resources to convert the biomass into a biofuel.

HTL can process biomass such as microalgae in their natural wet state, circumventing the need to excessively dry feedstocks, which is extremely energy intensive. The water in the biomass slurry acts as both solvent and reagent for the reaction, eliminating the need for significant amounts of petroleum derived solvents or reagents for fuel processing. The resulting fuel, termed biocrude, is useful as a near-direct replacement for crude oil.

At the Daphne plant, concentrated algae slurry is processed in an on-site HTL reactor to produce fuel. In addition to demonstrating the successful conversion of algae to biocrude at the pilot scale, the Algae Systems proprietary process can reduce the nitrogen content of the biocrude to <3 wt %, a >50% reduction in nitrogen compared to previously reported values [4]. Lower nitrogen content in the biocrude reduces the need for downstream processing and is therefore a critical improvement for the feasibility of HTL [5].

Biocrude can be used as-is as a low-grade fuel or upgraded to a more refined fuel product. The reduced nitrogen content of the biocrude permits the use of traditional hydroprocessing techniques to reduce the overall heteroatom concentration and create a finished product. The resulting hydrocarbons should be in the gas to diesel range.

3 CONCLUSIONS AND OUTLOOK

Operation of the Daphne, AL pilot plant will continue through 2015. During this period we will carefully study and optimize the operations of our pilot facility. We will measure important factors such as the total material and energy balances and the total capital and operational costs of our process. We anticipate treating wastewater at a cost equal to or even less than traditional methods, while producing a profitable and carbon-negative biofuel. Most importantly, we seek to achieve a new standard for how wastewater can be treated in an economic and sustainable way.

4 ACKNOWLEDGEMENTS

The authors gratefully acknowledge IHI Corporation for engineering support and Rob McElroy and Daphne Utilities for the on-site support. We also thank Ana Zapata for the photo.

REFERENCES

[1] Clarens, A.F., Resurreccion, E.P., White, M.A., Colosi, L.M., Environ. Sci. Technol. 44, 1813-1819, 2010.

[2] Sturm, B.S.M., Lamer, S.L., Appl. Energy 88, 3499-3506, 2011.

[3] National Research Council. Sustainable Development of Algal Biofuels in the United States . Washington, DC: The National Academies Press, 2012.

[4] Valdez, P.J., Nelson, M.C., Wang, H.Y., Lin, X.N., Savage, P.E., Biomass Bioenergy 46, 317-31, 2012.

[5] Frank, E.D., Elgowainy, A., Han, J., Wang, Z., Mitig. Adapt. Strateg. Glob. Change 13, 137-158, 2013.