Process Optimization and Real-Time Control for Synergistic Microalgae Cultivation and Wastewater Treatment

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The overarching goal of this work is to accelerate the commercialization of high productivity, mixed community microalgal treatment technologies for the synergistic treatment of wastewater and the production of biofuel feedstocks. This project will address a critical barrier to the financial viability and energy efficiency of algal wastewater treatment: an inability to design and operate high rate processes that reliably achieve target effluent qualities, areal productivities, and biochemical compositions (lipid, protein, carbohydrate content) despite fluctuations in wastewater composition, climate, and microbial communities. This barrier stems from a lack of understanding of how process design and operation coupled with environmental factors influence the net rates of nutrient uptake, inorganic carbon uptake and partitioning (into growth, storage lipids and carbohydrates) that directly impact the consistency of biomass yields and biofuel potential from mixed algal communities.

This project will overcome these knowledge gaps by focusing on the Advanced Biological Nutrient Recovery (ABNR™) process – a technology which has the potential to achieve reliable and efficient recovery of phosphorus and nitrogen (including organic phosphorus and nitrogen) from wastewaters to concentrations below the current limit of technology (generally regarded as 0.1 mg-P·L^{-1} and 3 mg-N·L^{-1}). The ABNR process fills a critical need for wastewater treatment facilities with pending nutrient permits by reducing effluent total phosphorus to below 0.04 mg-P·L^{-1} year-round, even at high latitudes (e.g., Wisconsin; Montana). This project will expedite the market penetration of this technology by improving effluent quality, consistent biomass yield and quality, and energy efficiency, all while reducing the physical footprint, capital and operating costs.

The specific objectives of this work are ***(i) to develop a mechanistic process simulator to predict effluent nutrient concentration and process sustainability*** (including costs, energy, biomass yield, etc.), ***(ii) to adapt and train a low-cost monitoring system for real-time characterization of microbial community structure***, and ***(iii) to leverage the validated simulator and monitoring capabilities to advance the financial viability and environmental sustainability of algal nutrient recovery from wastewaters***. These objectives will be accomplished by integrating long-term characterization of a 0.15 million gallon per day (MGD) ABNR treatment system at the Village of Roberts (Wisconsin), comprehensive meta-genomic/-transcriptomic characterization, novel real-time microbial monitoring, process modeling, and sustainable design (including techno-economic analysis, TEA, and life cycle assessment, LCA) to develop optimized process designs and process controls to improve the financial viability and environmental sustainability of wastewater integration with the microalgae-to-biofuel value chain.

Key outcomes from this work will include an optimized and controlled ABNR design as well as a suite of open-source tools that include a calibrated and validated algae process simulator in BioSTEAM (with TEA, LCA) and a novel low-cost, real-time microbial monitoring tool. These tools can be leveraged by other algal cultivation and wastewater treatment technology developers in future work.