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Evaluating the economic impacts of using enzymatic membranes to optimize bicarbonate production and delivery to open raceway ponds

Jonah M. Greene[1], Bruno Klein[2], Cody Hawthorne[3], Kenneth Reardon[3], David Dandy[3], Jason C. Quinn[1]

[1]Department of Mechanical Engineering, Colorado State University, Fort Collins, CO

[2]National Renewable Energy Laboratory (NREL), Golden, CO

[2]Department of Chemical and Biological Engineering, Colorado State University, Fort Collins, CO

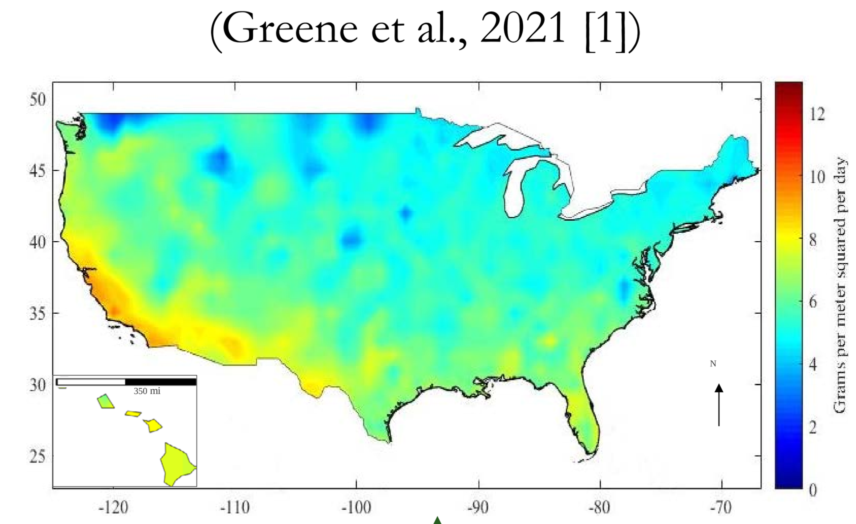
Email: jonahgreene01@gmail.com | Phone: 970-556-8618

Conclusions

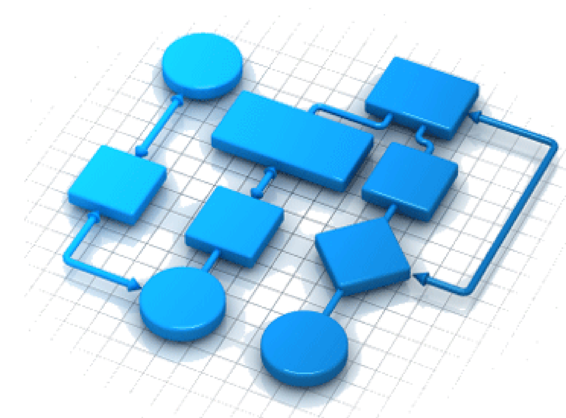
- Gas sparging of CO_2 into algal cultures results in significant losses through outgassing to the surrounding atmosphere. These losses significantly increase system capital and operational expenses.
- Carbon delivery with enzymatic membranes may offer a more efficient and cost effective alternative, however facility wide energy demands may increase by up to 45% due to added pumps and infrastructure
- Eliminating the operational expense of canned CO_2 and increasing the carbon utilization efficiency from 30% to 69% can reduce the minimum biomass selling price by 35.8% or $260 per US Ton (AFDW)

Materials and Methods

High-resolution algae growth modeling (thermal + biological) captures temporal and regional differences in algal productivity (Greene et al., 2021 [1])



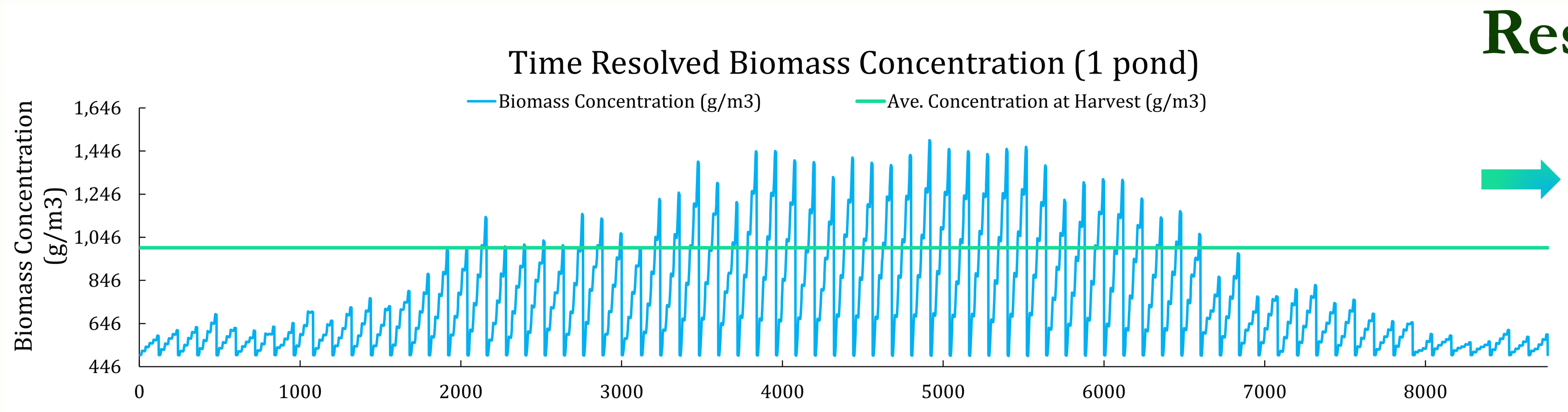
Systems level mass and energy accounting determines energy requirements and quantifies material inputs (consumables)



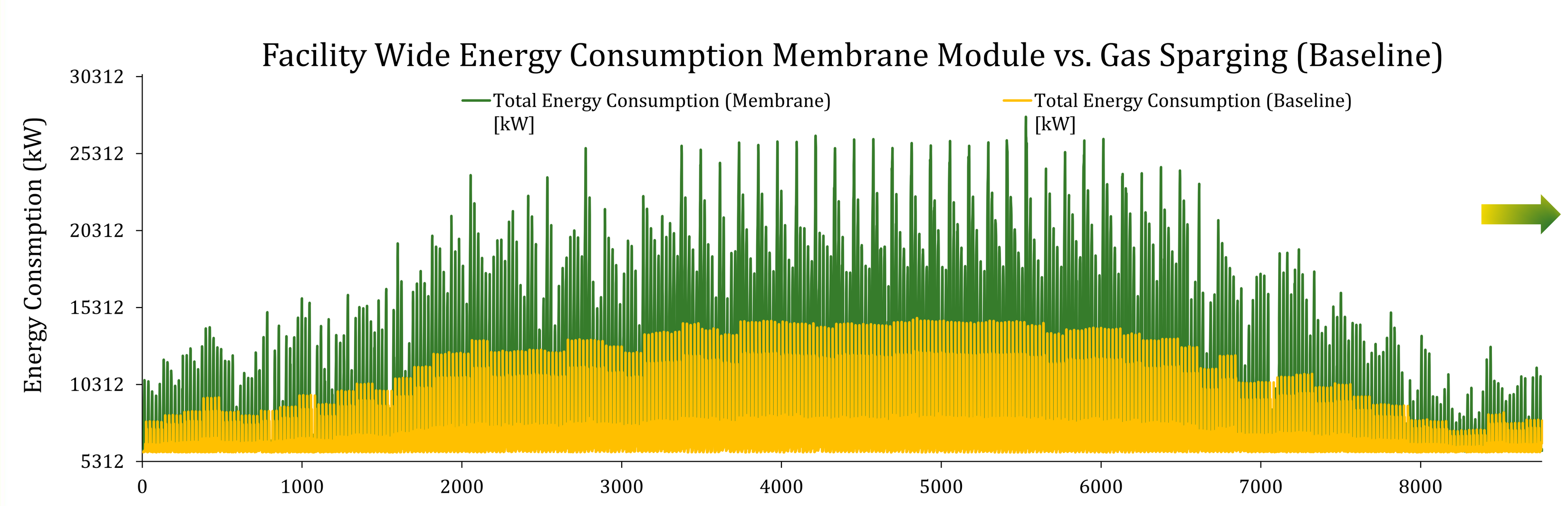
System engineering model informs Techno-Economic Analysis (TEA) to determine capital and operational expenses

Large-scale economic feasibility determined and high-sensitivity variables identified

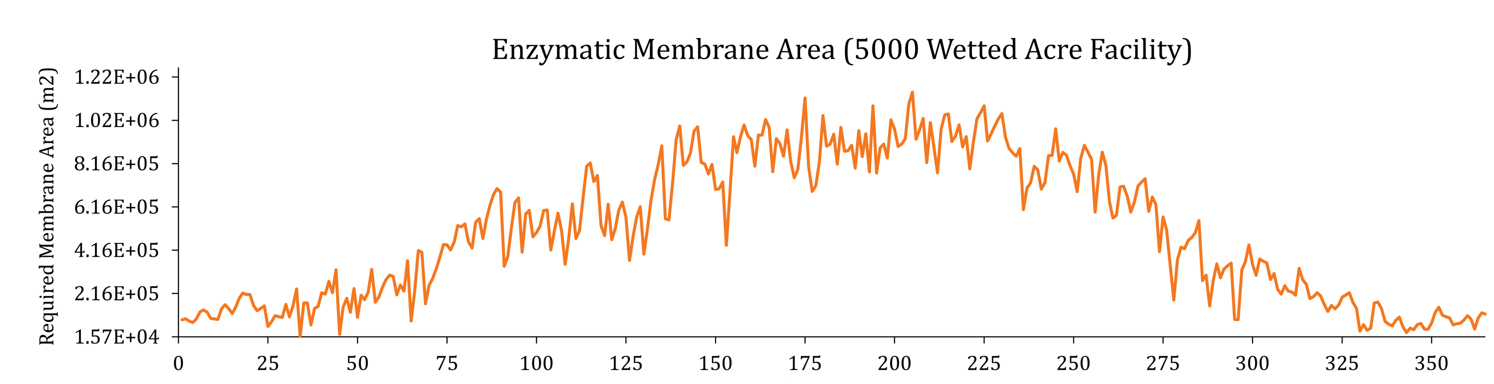
Results and Analysis

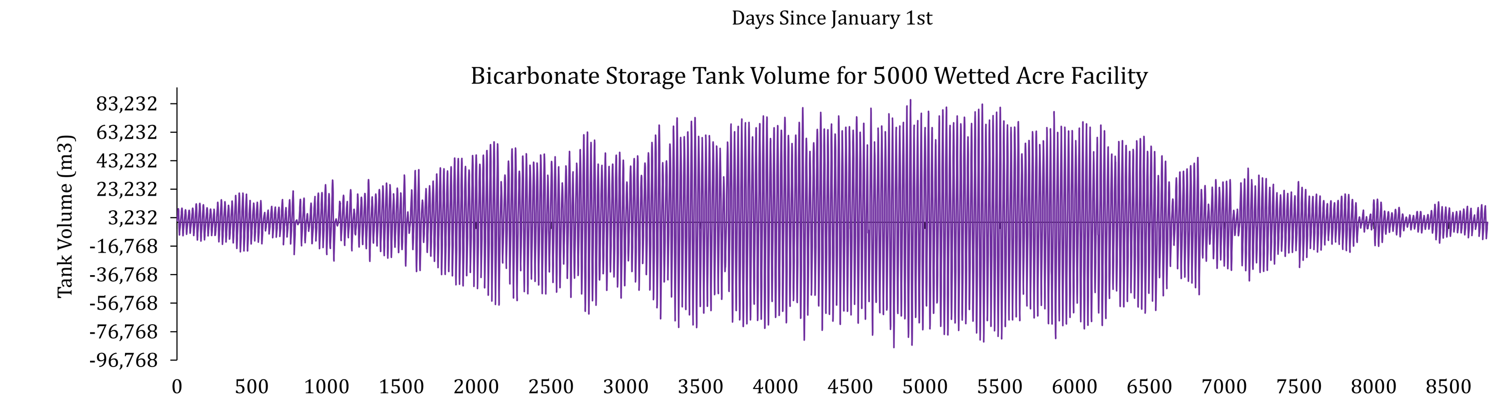


High resolution growth modeling suggests a maximum seasonal variability in algal productivity of 5:1; this variability leads to larger summer flow rates of CO_2 and larger water volumes through harvesting equipment requiring larger infrastructure and increasing capital expenditure. Example results show productivities for Imperial, CA throughout the year.

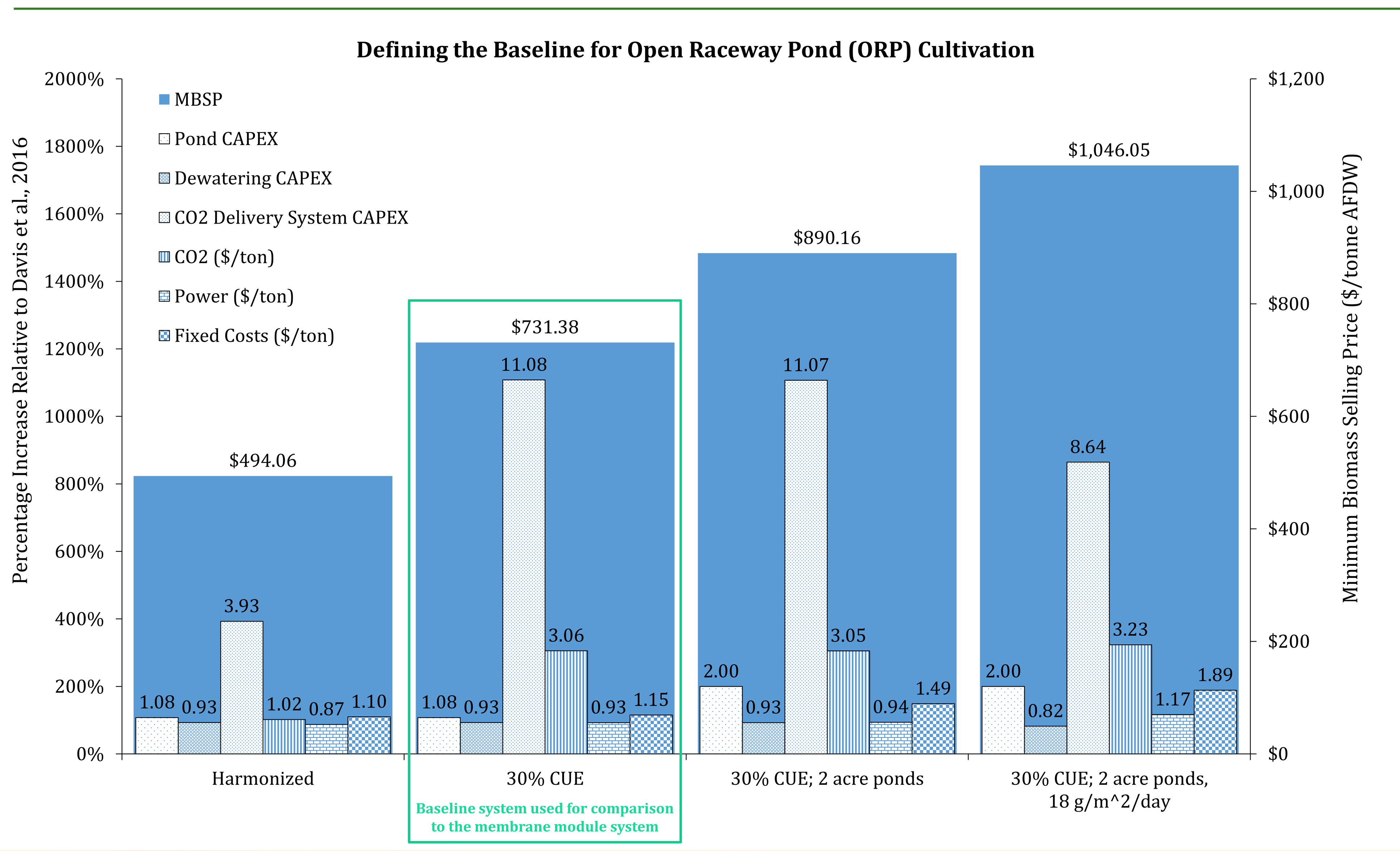


Carbon delivery via the enzymatic membrane will require additional pond cycling (hourly harvesting cycle). The membrane module and bicarbonate storage tank require additional pumps resulting in an increased energy demand of ~45% compared to the gas sparging baseline scenario.



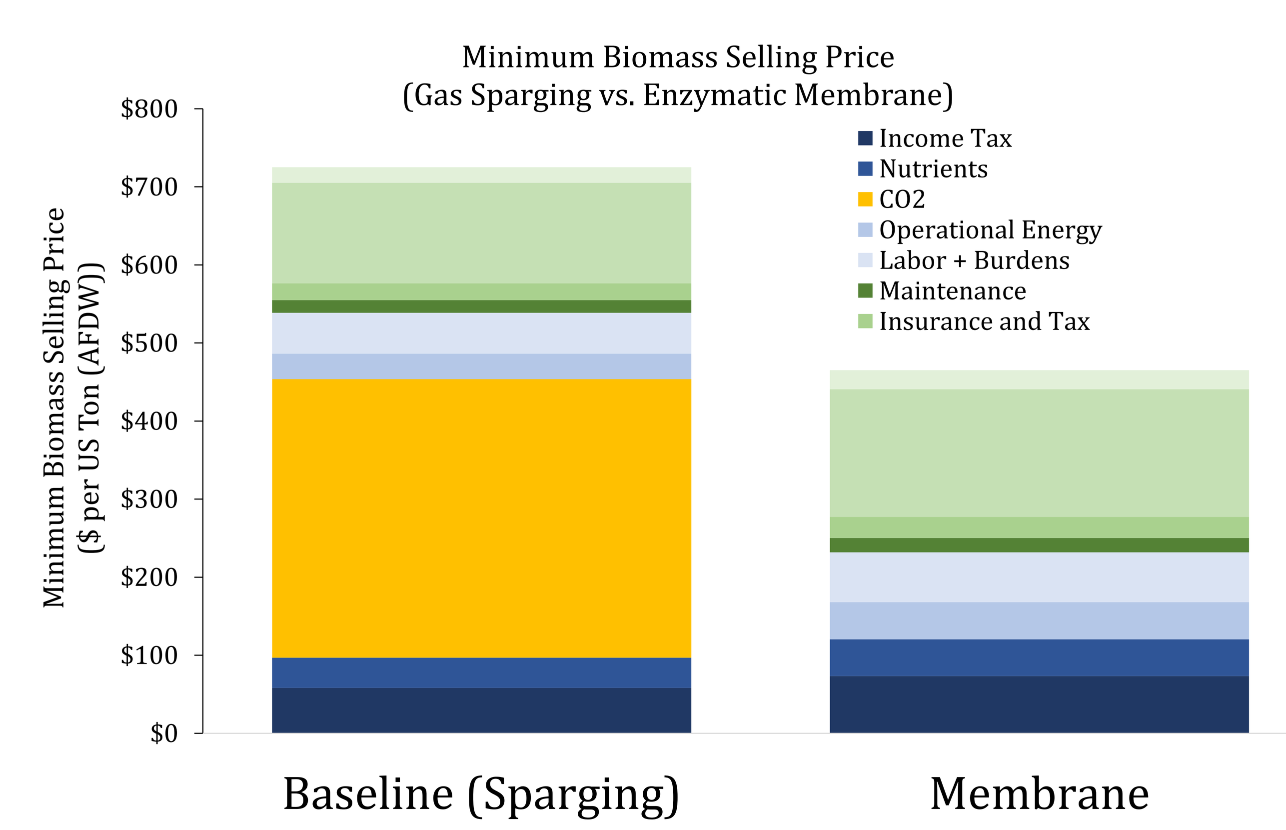


Detailed mass transfer modeling was used in conjunction with hourly growth projections to determine time-resolved inorganic carbon (iC) demands across the facility. Experimentally determined membrane carbon fluxes (moles iC m^{-2} s^{-1}) and facility-wide flowrates were used to determine the required membrane area as well as the required bicarbonate storage tank volume.



Baseline MBSP

In order to establish the baseline cost for algae production in Open Raceway Ponds (ORPs), the model was harmonized with the work of Davis et al., 2016 [2]. Davis et al. report a minimum biomass selling price (MBSP) of $491 US Ton^{-1} (AFDW). A number of high impact parameters including the CO_2 utilization efficiency (CUE) of gas sparging, the biomass productivity, and the pond size were adjust to establish realistic bounds on the baseline scenario. In reality, sparging efficiencies of 30% or less are common, annual average productivities are often below 25 g m^{-2} day^{-1}, and ponds greater than 2 acres experience losses in productivity due to culture mixing difficulties.



Carbon Delivery via Enzymatic Membrane

The baseline system used for comparison in this analysis is highlighted in the green box in the figure to the left. The chosen baseline system was defined by harmonizing the engineering process model with the work of Davis et al., 2016, and adjusting the carbon utilization efficiency from 90% to a more realistic 30%. Despite the increased energy demand and capital expenditure, the use of the membrane module reduces the MBSP by $260 per US Ton or 35.8%.

Summary

Gas sparging is the most commonly used method for delivering CO_2 to algal cultures in Open Raceway Ponds (ORPs). While this method is well-tested and effective, these systems experience large amounts of outgassing to the surrounding atmosphere and often achieve carbon utilization efficiencies (CUE) lower than 30%. With such large losses, system are overdesigned to provide CO_2 gas in extreme excess, resulting in increased capital and operational expenses. This research is focused on the development, testing, and implementation of a hydrogel membrane seeded with the enzyme carbonic anhydrase and designed to convert gaseous CO_2 into aqueous bicarbonate and deliver this inorganic carbon (iC) directly to the algae pond. Despite increased capital expenses for the module, bicarbonate storage tank, and added pumps and infrastructure, preliminary results suggest that the membrane module has the potential to reduce the minimum biomass selling price by 35% by significantly reducing the operational expenditure for CO_2.

References:

[1] J. M. Greene, D. Quiroz, S. Compton, P. J. Lammers, and J. C. Quinn, "A validated thermal and biological model for predicting algal productivity in large scale outdoor cultivation systems," *Algal Res.*, vol. In Press, Feb. 2021.
[2] R. Davis, J. Markham, C. Kinchin, N. Grundl, E. C. D. Tan, and D. Humbird, "Process Design and Economics for the Production of Algal Biomass: Algal Biomass Production in Open Pond Systems and Processing Through Dewatering for Downstream Conversion," NREL/TP--5100-64772, 1239893, Feb. 2016. doi: 10.2172/1239893.

Future Work

- Sensitivity analysis and stochastic manipulation (Monte Carlo) of high impact parameters
- Integrate downstream processing models (hydrothermal liquefaction and fuel upgrading) to determine the impact of reduced biomass production costs on the minimum fuel selling price
- Life Cycle Assessment of the system at scale