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Estimating Algae Production at Commercial Scale and Different Geographic Locations and Operating Conditions using Computational Fluid Dynamics

Sandia National Labs has developed a verified CFD model for calculating the production of algae from different cultivation systems, including PBRs and open raceways, across a wide range of environmental (e.g., temperature, solar insolation, wind speed, and humidity) and operating conditions (CO_2 addition, pH, flow rate, and harvest frequency). The model of algae growth in a fully mixed pond has been validated. The model can be used to optimize algae productivities of existing facilities and provide estimates of algae production (tonne/acre/year) at scale and at different geographic locations, based on lab- or pilot-scale production data that will be generated during the project, coupled with regional meteorological data. The model will inform both the techno-economic models and life cycle analyses through detailed mass and energy balances.

The math models include transient turbulent hydrodynamics, suspension transport subject to settling, free-surface flow, nutrient and dissolved-gas transport, and optical-radiation heat transfer and absorption with depth. Sandia has extensive experience with applying the US Environmental Protection Agency's Environmental Fluid Dynamics Code (EFDC) to environmental fluid dynamic problems similar to the raceway and has licensed its own version called SNL-EFDC. EFDC solves the three-dimensional, primitive-variable, vertically-hydrostatic, free-surface, turbulent-averaged equations of motions for a variable-density fluid. Dynamically coupled transport equations for turbulent kinetic energy, turbulence length scale, salinity, and temperature are also solved. The model is forced by boundary loadings, atmospheric conditions (e.g. temperature, pressure, wind shear, precipitation, etc.) and re-circulating boundary conditions. Thermal gains to the growth media are from wind-driven atmospheric convection and solar radiation absorption while losses are through radiative heat transfer at night and any conductive exchange with the walls and bottom of the raceway. SNL-EFDC is coupled with CE-QUAL to model water quality. This model, which operates fully in all three dimensions, initially had 23 independently-activated scalar variables, all of which are tracked in space and time (i.e., there is no averaging except within a single finite difference cell). The ability to monitor pH, heat content, salinity growth dependence, and dissolved CO_2 concentrations including uptake by algae and exchange with the atmosphere (or added sources) was specifically added by Sandia. Figure 1 shows a typical raceway pond mesh and representative results. This model has also been transferred into ANSYS-Fluent to provide more CFD capabilities and an improved user interface.

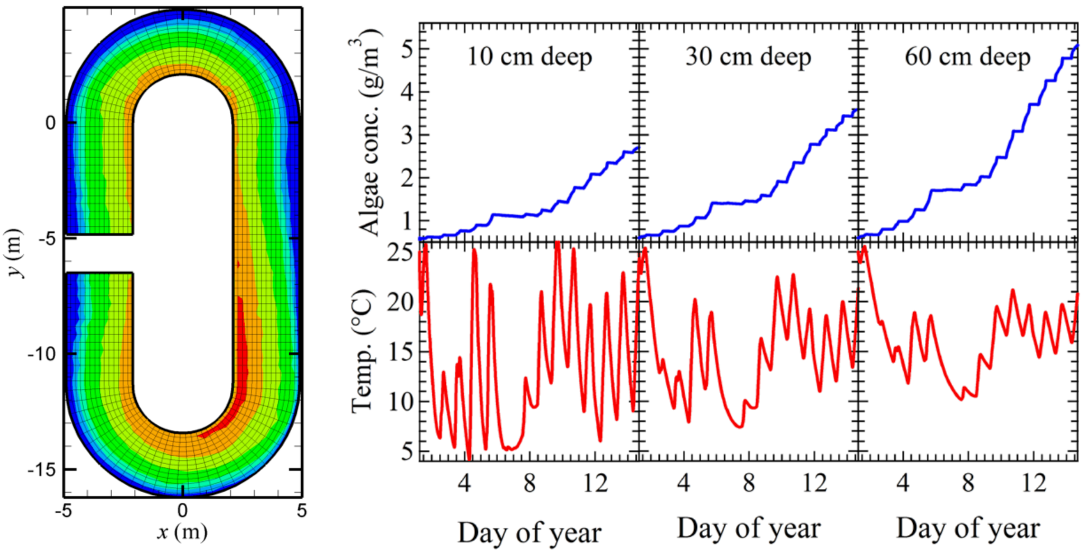

Figure 1. (a) Curvilinear orthogonal grid developed for a 43-m-long and 3-m-wide closed-circuit algal raceway showing variable algae concentrations. The flow is clockwise in this model. (b) Results showing effect of water-column depth on algae growth and water temperature. As the depth increases, the water body serves as a heat "buffer," moderating the water temperature fluctuations. Algae grow more efficiently when maintained closer to their optimal temperature of 20°C.