New bioreactor designs for the utilization of methane to produce biologically-derived chemicals and fuels using methanotrophs

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Calysta Energy, Inc. is developing Biological Gas-to-Liquids (BioGTL®) and Biological Gas-to-Chemicals (BioGTC®) platforms that will allow methane-utilizing bacteria (methanotrophs) to effectively produce biologically-derived chemicals and fuels. Methanotrophs contain methane mono-oxygenase (MMO), an enzyme that oxidizes methane into methanol, allowing the bacteria to use an abundant and inexpensive gaseous substrate as a carbon and energy source. There are two major challenges to realizing this technological development: (i) Strain engineering to optimize productivity and overall product yield; (ii) Bioreactor design to maximize methane and oxygen dissolution, maintain safe operation with potentially flammable/explosive conditions, and enable economic process scale-up.

Traditional stir-tank reactors (STR's) provide the industry standard for sugar-based fermentation. However, mass transfer within these units is heterogeneous [1,2] and not easily scalable. Multiple advanced bioreactor designs were developed to reduce power consumption and enhance gas-liquid interactions: Air-lift reactors (ALR's) operate pneumatically to circulate the reaction liquid through a downcomer region and into a riser region, where gas is bubbled through to allow for substrate dissolution and reaction [3,4]. ALR's require less power input than STR's, which depend on mechanical agitation to enhance gas-liquid interaction, but tall units are required to improve single-pass mass transfer. The U-loop reactor [5,6] was developed, scaled-up and operated by BioProtein AS to produce biomass through methanotroph fermentation. Here, the liquid is pumped through a long looped tube, and gaseous substrate is concurrently flowed with the liquid through a series of static mixers to increase mass transfer performance. However, due to the length of the U-loop, capital and pumping costs become inhibitory.

The objective of this project is to develop key bioreactor technology to enable efficient methane fermentation processes for the production of bio-based fuels and chemicals. Using Calysta's in-house fermentation data, we derived the kinetic and mass-transfer parameters for a semi-batch fermentation process of Methylococcus capsulatus (Bath). The kinetic parameters were then used to optimize the conversion of methane to biomass in simulations of new bioreactor designs. The process parameters explored include reactor dimensions, fluid velocities, mass transfer coefficient, liquid recycle fraction, gas hold-up, initial biomass concentration, and pressure. In collaboration with Celanese Corp., we performed computational fluid dynamics (CFD) simulations to predict heat and mass transfer coefficients for different reactor designs. Overall productivity and yields were calculated to compare different bioreactor designs to industry standards and understand how different process parameters affect performance.

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