Integrating Chemical Catalysis and Biological Conversion of Carbon Intermediates for Deriving Value Added Products from Carbon Dioxide

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Nearly 80% of the world's primary energy consumption is supported by non-renewable fossil fuels. While the amount of affordable and easily extractable fossil fuel sources is decreasing, the demand for energy is growing continuously. Combustion of fossil fuels and utilization of waste materials leads to significant CO_2 emissions estimated at more than 5 gigatons in 2016. However, this CO_2 represents a potential feedstock for production of renewable biofuels and bioproducts. While biological systems are highly effective in metabolic conversion of reduced carbon compounds into complex molecules, these biological systems are usually not efficient in converting low-energy CO_2 into fuel precursors and biochemicals with high energy content. In contrast, electrochemical reduction of CO_2 represents a promising and potentially sustainable solution for artificial recycling of carbon and storing these intermittent energies in a chemical form. These simple reduced carbon compounds can be used as a substrates for biological catalysts converting them into more complex and energy-dense hydrocarbon molecules that represent desirable feedstocks for generation of alternative fuels and chemical products. Specifically, methanotrophic bacteria are capable of utilizing one-carbon (C1) metabolites such as methanol and formate as the principal carbon source or co-substrate, and could be engineered to generate propene as a valuable commodity chemical in addition to biomass, which could then be converted to biofuels following hydrothermal liquefaction (HTL) process developed at PNNL. Integrating these three electrochemical, biological and thermochemical technologies represents a potentially transformative approach for the energy-efficient electrochemical reduction of CO_2 to chemical intermediates that can then be subsequently undergo biological conversion into energy-dense for biofuel and biochemicals.

The improvements to the technology that will be achieved through this project are as follows: enhanced electrochemical reduction of CO_2 into reduced carbon intermediates; engineered microbes and optimized bioreactor conditions for use of carbon intermediates to enable its conversion into propene; and a fully integrated CO_2 electrochemical reduction and biological utilization system in a single process whose overall operation is optimized for the maximal conversion of CO_2 to propene. Dr. Chao Wang will focus on optimizing the electrically-driven catalytic conversion of CO_2 to reduced carbon compounds methanol and formate. Dr. Marina Kalyuzhnaya will engineer methanotrophic microbes to convert reduced carbon intermediates to propene. The PNNL's scientists, Alex Beliaev and Pavlo Bohutskyi, will be responsible for characterization of the engineered microbe and optimization of the biological production of propene. Finally, Michael Betenbaugh, integrate these separate chemical and biochemical unit operations and serve as manager of the overall project for achieving a fully optimized bioprocess ready for scale-up.