Enhancing Carbon Utilization by Algal Systems via Integrated Biogas Purification, Nitrogen Reuse, and Innovative Carbon Delivery

Cultivation of microalgae on waste CO_2 from biogas will not only provide cost-effective production of algal biomass, but also achieve simultaneous biogas upgrading to renewable natural gas (RNG). This project aims to address the key challenges of biogas-supported algal growth including inefficient gas-liquid mass transfer of CO_2, the presence of algae-produced O_2 in RNG, CO_2 storage when algal growth is not active, and nutrient supply. An innovative system for enhancing algal growth is proposed and consists of three major units, anaerobic digesters (AD), electrochemical reactor(s), and algal photobioreactors (PBRs), with a synergistic cooperation between them. A unique feature of the proposed system lies in the use of an electrochemical reactor to connect AD and algal PBRs. This electrochemical reactor has two important functions, recovering ammonium nitrogen and generating an alkaline solution that is then used to capture CO_2 in biogas. Both ammonium and pH of this alkaline solution can be controlled by manipulating electrical current. The concept of circular economy is incorporated into the research approach by converting wastes into useful products. The specific objectives of this project are to: (1) demonstrate technical feasibility of the proposed system via a synergistic coordination of the major units; (2) adaptively evolve and cultivate algal species that can efficiently use the supplied CO_2 (as bicarbonate) under a high salinity condition; (3) model algal growth under complex growth conditions so that algal process can be precisely controlled and optimized; and (4) conduct life cycle analysis and techno-economic assessment.

This project will be led by Dr. Zhen He who coordinates a multidisciplinary team with complementary expertise from Washington University in St. Louis (algal strain development, culture optimization in photobioreactors, electrochemical nitrogen recovery, biogas upgrading), Lincoln University of Missouri (algal growth), Argonne National Laboratory (life cycle assessment), and Virginia Tech (techno-economic assessment). CLEARAS Solutions, which is operating full-scale algal systems for wastewater treatment and also a potential stakeholder and user of this technology, will be involved in the early stage of the research as an industrial partner.

This project will deliver a scalable and innovative algae growing system evolving from TRL 3 to TRL 4. At the end of the project, a demonstration-scale system (50-L algal systems) will be able to convert more than 70% of the supplied CO_2 (as bicarbonate) into algal biomass with a productivity > 20 g m^{-2} d^{-1} (annual average productivity); such results will be obtained from the outdoor operation for a period of at least 30 days. The system will also produce RNG that contains a target CO_2 concentration <1% and a reduced H_2S content.

Advancements in research and development as well as a holistic understanding of the potential impacts of system deployment across economic and environmental indicators are critical to the successful transformation from bench-scale to transitional-scale systems (i.e. not yet pilot scale). EERE funding can fill this gap for which there exists limited financial support from the National Science Foundation (for fundamental research) or industry (for pilot-scale development). EERE funding will build a bridge to transform basic research towards further development. This project will involve Lincoln University of Missouri (HBCU) as a key partner and offer opportunities for the students from historically underrepresented groups at Lincoln University of Missouri to conduct research at Washington University in St. Louis. This will expose minority students to cutting-edge research subjects, stimulate their interests in scientific and engineering research, and encourage them to pursue a career in STEM. EERE funding will support such activities and help improve diversity in STEM research.