Upgrading Biogas through *in situ* Conversion of Carbon Dioxide to Biomethane in Anaerobic Digesters

There has been an increasing interest in upgrading biogas to have >95% CH_4, named "biomethane" or "renewable natural gas (RNG)". Such a gas can be directly used as a transportation fuel or supplied to natural gas pipelines. In this project, we will develop an innovative system for *in situ* biological conversion of CO_2 to CH_4. This system consists of four major units, anaerobic digestion (AD), microbial electrochemical system (MES), thermoelectric generators (TEG), and gas-cleaning unit, with synergistic cooperation between them in a "loop" connection. A unique design of this system lies in the integration of a membrane supplied H_2 into an upflow anaerobic reactor via the creation of three physical zones within AD, conventional AD zone, CO_2-to-CH_4 conversion zone, and gas/liquid separation zone. Three zones along the direction of liquid flow would allow biological CO_2 conversion to take advantage of a solution from AD zone containing substrate, nutrients, and warmer temperature while minimizing the interference with each other. The project will integrate several existing processes/technologies, such as membrane supplied H_2, thermoelectricity, and microbial electrochemical systems, in innovative and synergistic ways to ensure both novelty and a high chance of success. The specific objectives of this project are to: (1) accomplish *in situ* biological CO_2 conversion to CH_4 with membrane-assisted H_2 delivery; (2) develop an organic thermoelectric generator (TEG) that is low cost, scalable, and biocompatible for waste heat conversion to electricity; (3) synthesize custom sorbents in-house featuring a transition metal-oxide nanomaterial for gas cleaning; and (4) conduct life cycle analysis (LCA) and techno-economic assessment (TEA) of the proposed system.

This project will be led by Dr. Zhen He who coordinates an multidisciplinary team with complementary expertise from Washington University in St. Louis (AD, MES, and gas cleaning), Cornell (thermoelectricity), Argonne National Laboratory (life cycle assessment), and Virginia Tech (techno-economic assessment). Anheuser-Busch company, which is also a potential stakeholder and user of this technology, will be involved in the early stage of the research as an industrial partner. Two types of wastes will be examined for supplying real biogas CO_2 to conversion, a livestock manure (high solids) and a brewery wastewater (soluble organics).

This project will deliver a scalable and innovative biogas upgrading system evolving from TRL 2 to TRL 4. At the end of the project, an integrated bench-scale system will be able to produce pipeline quality renewable natural gas containing >97% CH_4 via two steps, biological CO_2 conversion to CH_4 that generates a biogas of >95% CH_4 and gas cleaning that reduces impurities and further enhances the CH_4 content to >97%. Our target CO_2 concentration in the final RNG is <1%. The H_2S content will be kept below 5.7 mg/Nm^3 (or 0.25 grain/110 scf).

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 allow us to build a multi-disciplinary and multi-institute team to jointly advance the proposed technology. It encourages the potential technology user/stakeholder like Anheuser-Busch to participate in the early-stage research and will attract more users/stakeholders in its further development. This project will act as a bridge to transform basic research towards further technological development.