Synthetic Biology and Microbial Fuel Cells: Towards Self-Sustaining Life Support Systems

Project Abstract

NASA ARC and the J. Craig Venter Institute (JCVI) collaborated to investigate the development of advanced microbial fuels cells (MFCs) for biological wastewater treatment and electricity production (electrogenesis). Synthetic biology techniques and integrated hardware advances were investigated to increase system efficiency/robustness, with the intent of increasing power self-sufficiency and potential product formation from carbon dioxide. MFCs possess numerous advantages for space missions, including rapid processing, reduced biomass and effective removal of organics, nitrogen and phosphorus. Project efforts include developing space-based MFC concepts, integration analyses, increasing energy efficiency, and investigating novel bioelectrochemical system applications.

Project Full Description

Innovative strategies are needed to overcome current limitations of wastewater treatment systems in space, while maximizing resource recovery (e.g., energy, water, CO2) and providing substantial cost savings. JCVI is developing MFC technologies that rapidly and efficiently treat high-organic wastewaters with simultaneous electricity generation. This approach employs fixed-film microbial communities as biocatalysts to efficiently oxidize organic compounds into electrons, protons and carbon dioxide. The electrons are biologically transferred to a conductive anode electrode and flow across the MFC circuit, generating a modest electric current. The reduction reactions occur at the MFC cathode electrode using a biotic or abiotic catalyst to reduce electrons, protons, and air to actually produce new (pure) water. This strategy accelerates treatment, decreases secondary sludge biomass, reduces waste gases from anaerobic digestion of solid material, controls unwanted fixed films by accelerated energy removal from biological components and does not necessitate solid and liquid waste separation. MFCs may also treat select “problem” compounds not captured by membrane-based technologies, thereby enabling a new class of water processing systems that significantly increase reliability and savings over current technologies.

Description of this technology

Microbial fuel cells consist of two compartments: an anode and a cathode compartment. The system is designed to treat organic wastes in the anode compartment using specialized microorganisms that are termed "exoelectrogenic". These organisms are able to shuttle electrons directly from their cell to the anode during the degradation of the organics, thereby producing an electrical current. This approach allows an energy offset during wastewater treatment to increase sustainability and reduce costs. Researchers at JCVI have built 75 L MFC reactors that anaerobically remove over 99% of the biological and chemical oxygen demand

(BOD and COD) contained in primary sludge in a 1-5 day period. In comparison, conventional anaerobic systems remove roughly 50% of the BOD in 15-40 days. Researchers are now improving on the scale and energy production capacity from these systems. This project capitalized on the continuing advances made at JCVI on MFC development, and also leveraged their pioneering research on genomics and synthetic biology.

Capabilities provided by this technology

This technology involves adapting cutting edge MFC designs for novel waste stream and product generation strategies, increasing electrical energy recovery, compatibility with reduced gravity, minimizing two or three phase flow issues and separations, and identifying MFC materials of construction and fabrication challenges. In addition to treating wastewater in the anode compartment, the system can also be designed to convert the carbon dioxide that is produced to reduced carbon products. While current models are designed to produce methane from carbon dioxide, other products are of interest for manufacture in space, including nutritional supplements, polymers, and other fuels.

Potential applications for this technology*

This technology has the potential to be utilized in long duration space exploration missions where wastewater is being treated to recover water. Because it can be designed to capture carbon dioxide and recover water/oxygen, it does not impose the substantial oxygen penalties of traditional biological wastewater treatment systems. While the amount of electrical energy produced on the anode is modest, it does serve to offset some of the electrical power required for carbon dioxide conversion on the cathode. This technology could find widespread application for the treatment of municipal wastewater, as well as point-source treatment in both developing and industrialized countries.

Benefits to NASA unfunded and planned missions

This project is a preliminary collaborative examination of the use of novel microbial fuel cell systems for space applications, and is an initial effort supporting the NASA ARC Synthetic Biology Initiative. Potential benefits to space exploration include providing wastewater treatment capabilities without incurring an oxygen utilization penalty, reduced power utilization and the potential to produce other mission-relevant products from the carbon dioxide generated in the anode compartment. It is anticipated that this technology would be best suited to long-duration missions, including lunar and planetary base operations.

This Project benefits one or more other government agencies

Because of it's ability to both treat wastes and generate products from that waste, this work includes foundational aspects that would yield widespread terrestrial commercial and military utilization. US government agencies that could potentially apply this system include the Department of Energy's ARPA-E Program as well as the Department of Defense.

This project benefits the nation

There is an important national need to improve wastewater treatment for municipal wastewater treatment and industry, recycle as many resources as possible, and to generate energy in the process. Analyses indicate that MFC technology can substantially offset the energy required to treat wastewater while providing thorough wastewater treatment. The potential also exists to capture the carbon dioxide produced in this process and convert it into new products, such as fuel. Such capabilities are essential to creating sustainable ecosystems and human manufacturing strategies.