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Background

To enable exploration missions of Mars, humans will rely on a supply of fresh tomatoes, potatoes, and other crops grown in pressurized chambers on Mars to supplement stable-stored-food supplies. Within a few months of operation, inedible crop and other food waste will exceed the storage volume of the pressurized habitat. Wastes cannot be discharged from the habitat, lest they “contaminate” the Martian surface in violation of the “Outer Space Treaty” of 1967. To reduce the waste volume and provide power, we proposed an anaerobic-aerobic bioreactor linked operation as a candidate advanced life support technology. The combination of anaerobic-aerobic technologies will treat plant residues, food waste, and greywater. (PAABLO, discussed below) (Note: A separate system will be used to treat human waste, WAABLO) The system produces water, biosolids, and fuel grade methane for conversion to hydrogen with a rectifier system. The hydrogen will then be used to produce electrical power in a fuel-cell. In effect, waste will be converted into power, while reducing the storage volume of waste. Our studies into power generation from biomass are being conducted at Purdue University as part of the Advanced Life Support NASA Center of Research and Training (ALS NSCORT).

Production of methane from plant-based waste materials and greywater on a 600 day mission with six crewmembers on Mars.

Problem:

- Human exploration of Mars requires self-sufficient crews due to the distance and cost of missions.
 - Stable-supplied food lasts 2-3 years with potential for up to 5 years; fresh foods spoil on the order of days to months. To meet nutritional requirements, crew will grow crops to supplement stored food.
 - Crops can grow under hypogravity conditions in controlled environments.
- Within a few months from the start of planetary operations, solid waste will exceed the storage volume without physical or biological processing or waste discharge to the surface of Mars.
 - Solid waste cannot be discharged from the habitat under the “Outer Space Treaty of 1967”, which prevents harmful contamination of Mars.
 - Aerobic processes reduce the volume of solid waste, recover resources, and stabilizes waste. The additional heat load from the aerobic processes pose a problem for the limited capacity for heat removal of 30 kW. Therefore, heat loads from waste processing should be minimized to avoid potential failures that would lead to increased habitat temperatures.

Solution:

- We propose using a linked aerobic-anaerobic bioreactor system to reduce the volume of solid waste while producing biofuels for power generation.
 - Anaerobic processes endothermically transform stored energy in solid waste into biofuels, such as ethanol, methanol, methane, and hydrogen. By using biofuels to generate power, less external power is required, so the

overall energy throughput of the habitat and load on the radiators are decreased.

- Aerobic step enables post-anaerobic processing of recalcitrant material.
- For PAABLO, plant-based aerobic-anaerobic bioreactor linked operation:
 - Detail the systems modeling approach to determine the composition of the plant-based waste materials from crop and menu schedules
 - Explain our experimental methodology to quantify the kinetics of methane production from single and mixed plant-based waste materials in the presence of greywater (shower water with soap)

Experimental Methodology

- Kinetics of methane generation will be determined for individual and blended waste streams under anaerobic and cyclical anaerobic-aerobic conditions
 - Conduct experiments on each crop that generates >1% of the total waste (dry)
 - Conducted blended experiments equal to the mass proportions expected for the nine crops, assuming a six-day feed cycle and 10-day menu
- Proposed Experiment Design for the *Anaerobic Experiments*
 - Select number and order of treatments to vary with *temperature, inoculum mass, and biomass moisture content* with a constant greywater to waste mass ratio. As a control, select treatments will be repeated with potable water.
 - Conduct analyses to establish methane production in sealed vials⁷
- Proposed Experimental Procedure for the Anaerobic Experiments
 - Determine total solids (TS), volatile solids (VS), and chemical oxygen demand
 - Seed and run each treatment for ten days with periodic sampling
 - Measure head-space CH₄ and CO₂ concentrations by gas chromatography
 - Measure liquid-phase concentrations of acetate, sugars, and alcohols by liquid chromatography
- Post-experiment analysis will determine:
 - Maximum rate of methane generation (g CH₄/g VS-crop waste)
 - Rate of methane generation from head-space data over time
 - Carbon balance for each treatment in the gas, liquid, and solid phases

Summary

- Anaerobic systems are a robust technology that allow a rapid and consistent conversion of waste materials into bioenergy.
- PAABLO is a candidate life support technology that
 - Reduces the volume of solid waste;
 - Stores heat as chemical energy, which reduces radiator loads;
 - Provides methane, and possibly hydrogen directly, for electrical power generation on Mars.

September 2007

- Started a new anaerobic reactor using wheat residue as a feed source. Constructed a third anaerobic reactor using tomato paste and glycerol as a feed source.
- Continued methanotroph isolation and enrichment for production of methanol.

December 2007

- Started a new 2 liter anaerobic reactor using basil residue as a feed source.
- Continued methanotroph isolation and enrichment for production of methanol.