The Global Home of Chemical Engineers

Chemical Engineering for Good Challenge
2019 Competition Submission

How Chemical Engineering Can Be Applied to Solve World Problems on a Micro Scale

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Lead AIChE Chapter

University Name & Location: ____Miami University Oxford, OH______________

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Partner Organization(s) - *optional* _____Miami University Engineers Without Borders______________

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Title of Submission: _______Pond Power: Microbial Fuel Cell Applications for Rural Communities in [Uganda/Rwanda]_________________

Submission Type: _X_ underutilized technology ___technology toolkit

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Contest entries must address '**How chemical engineering can be applied to solve world problems on a micro scale**". Three prizes of $3000, $1500, and $1000 will be awarded as unrestricted grants to the winning chapters. If judges determine that there are less than three submissions worthy of award than fewer prizes will be awarded. An additional bonus prize of $500 will be awarded for the best submission by a collaboration of a US AIChE chapter and an international AIChE chapter.

Submissions are directed at problems that could be implemented by engineering service organizations in partnership with communities (often small and rural) in the developing world. Micro scale refers to the size, cost, and sophistication of the project (not molecular size). Typically these partners have limited technical sophistication, capital, and funds to cover operating expenses. Utilizing appropriate, sustainable (in the broadest sense) technology is critical. This competition is open to all AIChE student chapters, and entrants are encouraged to partner with other organizations experienced in doing this kind of work. Teams may be of any size, and may include students, faculty and professional engineers. AIChE chapters may collaborate and submit a joint entry.

Submissions should utilize chemical engineering technology and skills (beyond the hydraulics calculations commonly used in designing water systems). Entries will either focus on one chemical engineering-based technology that is currently underutilized by teams working on international service projects (**ISP**) ***or*** provide a useful toolkit for ISP teams to identify, select, and utilize existing chemical engineering-based technologies to solve specific problems.

Attach to this cover page the information requested below for your type of submission. All submissions to be in electronic format. *Only materials in English language will be considered.*

1. Recommendation of the application of a specific technology, available today, which is not currently utilized in ISP projects.

A. Define the specific community problem being addressed
B. Describe the specific technology and how it is based on chemical engineering principles; provide electronic copies of or public links to references (papers, descriptions of commercial applications & offerings, patents, other supporting material)
C. Describe what kind of data would be required to design / customize this technology for ISP projects
D. Describe why this technology would be appropriate for implementation in partner communities. . Include consideration of technical, maintenance, financial, and cultural sustainability. Provide estimated typical costs for initial installation, maintenance, and operation.

2. Provide a toolkit for the application by ISP teams of a set of existing chemical engineering-related technologies addressing a general technical challenge that are underutilized. General technical issues include but not limited to topics such as water purification, alternate energy sources, energy conservation, and preservation / preparation of crops and foods. The set must include at least three different technologies.

The toolkit will include:

A. Technology Basics Document intended for use by another design team, that includes description of the problem addressed, description of each technology, and discussion of when each technology is most applicable
B. checklists / tables to help an ISP project team identify candidate applications and select between technical options

C. important data required to select and design. Inclusion of general design procedures & considerations will be considered by the judges as additional added value to the toolkit.
D. references to useful source materials
E. Also provide a discussion of why these technologies would be appropriate for implementation in partner communities, including aspects of technical, maintenance, financial, and cultural sustainability.

Important Information

- the latest information for this competition is always available at **https://www.aiche.org/ace4g**
- **submission deadline**: **November 22, 2019**
- Submit this completed form by deadline date to **ace4g@aiche.org**
- All submissions, references, and supporting materials must be in English language
- The contents of all contest submissions may be made public, with appropriate credits given to the original submitters
- You may direct questions to Alan Zagoria at **ace4g@aiche.org**

General Judging Criteria

- inclusion of chemical engineering-based technologies
- applicability of the proposed solution(s) to micro-scale engineering projects in the developing world intended to improve quality of life (appropriate technology and sustainability). Large industrial-scale projects requiring more capital than could be raised by the volunteer engineering organization and the local partner community will not be considered. We strongly recommend participants view the short sustainability video at https://youtu.be/RmTx-vJKDu0 to better understand the range of sustainability issues we will be judging for.
- discussion of capital and operating costs / sustainability is a must
- supporting material that demonstrates the feasibility, practicality, or previous experience implementing the proposed technology will be highly valued
- originality
- addressing any safety issues
- Type 1: significance of the identified problem and the potential usefulness to an ISP organizations of the proposed solution (relative to what is typically done today)
- Type 2: usefulness of the toolkit

Option 1: Recommendation of the applications of specific technology, available today, that is not currently utilized in ISP projects.

A. Project Description

The Munini community in Rwanda had many issues with water distribution and waste management in their community. After requesting engineering services from EWB, the Munini community began its partnership with Miami University EWB (EWB-MU) chapter in 2014 in tandem with the Non-Governmental Organization (NGO) Vision for Life ICYUSA (VfLI). Initial implementation trips installed a water line, 2000-liter stone water tank, and rehabilitated a polluted spring to serve approximately 2100 - 2200 community denizens. A research project designed fuel-efficient stoves to eliminate CO_x and soot successfully reduced the hazardous conditions in closed spaces during cooking processes. As the population swelled, the water distribution project expanded to cover sanitation needs of the wider community. Superficial cleanliness has already been addressed with the installation of communal hand-washing stations. Additionally, the establishment of formal education programs to better local cleanliness practices were completed.

Major concerns currently include the holding capacity of the refuse pit used to hold the waste from the latrines. At its maximum capacity—and built on a hill at the border of the school—the walls of the pit threaten to burst into a cholera landslide if filled too much further. The Latrine Project is a new program thrust aiming to fortify and expand the current holding capacity of the waste pit, construct more latrines for the community, and improve the design of latrines near the Munini school.

Current discussions between MU and VfLI for the July-August 2020 implementation trip include a new pit in a different location away from the school, expanding current capacity and acting as a multi-chambered composting facility for later agricultural use. HDPE piping will aggregate latrine collection into the new pit while fortification of the old pit is underway. Therefore, this multifaceted implementation will have continuing benefits to the community's agriculture, cleanliness, and waste management structures. Current designs for the composting facility include adequate venting, access hatches, and liquids-solids separation module. A simple, cost-effective device that could expand on the benefits provided by this new pit is the implementation of a microbial fuel cell (MFC) power system during construction. The following paper will describe the steps and calculations necessary to design a system that harvests power from the decomposition of the human waste generated by the community.

B. Power Generation from Organic Decomposition

MFCs work by separating the reduction of biological metabolites utilized by microbes from the oxidation of hydrogen ions with oxygen.[1-5] The reaction-participating electron can then be passed through a connecting wire to generate power. This general process is presented in Figure 1.

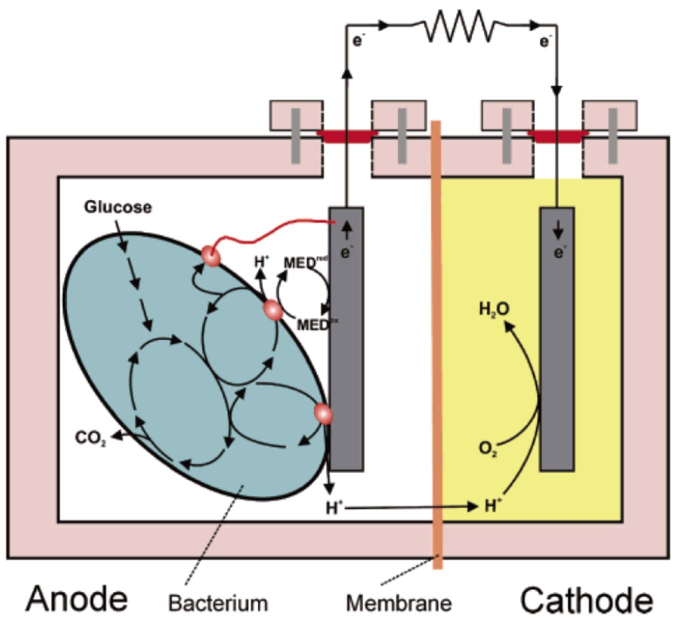

Figure 1. The working principle of microbial fuel cells.[1]

The voltage difference generated by MFCs is small but reliable. Several studies have shown relatively consistent output across many months of use.[6-8] Zhao et. al.[6] and Ewing et. al.[7] performed long-term studies of the type of MFC we will utilize in this implementation, finding a voltage hovering around 0.35 V across 240+ days. Powering basic monitoring systems would increase the sustainability and longevity of the Rwanda project.

Various takes on MFC design have been made. Since these devices utilize the biochemical kinetics of decomposition to generate electricity using available microbes, civil, chemical, environmental, and electrical engineering principles need to be taken into consideration for this entire project.

MFCs can be split into two major categories: reactor (RMFC) sediment (SMFC).[1,5] RMFCs are engineered systems featuring separate chambers, an electrolytic solution, and a semipermeable membrane to separate the oxygen from the aerobic reaction and generate a voltage potential between the cathodic and anodic chambers. This cell is the type seen in Figure 1. However, we will not use this type of cell since it requires active feeding and cleaning to continue generating power. SMFCs utilize different structures and media to replace the electrolytic solution and semipermeable membrane. Figure 2 is similar to the scenario that will be present in the composting facility. Solid waste settling to the bottom of the pit will seal the anode side under a solid layer of organic material, forming both the H^+ conducting medium, separating layer, and fuel source at once. The cathode will sit immediately above the anode to intercept the local acidification.[2,9-11]

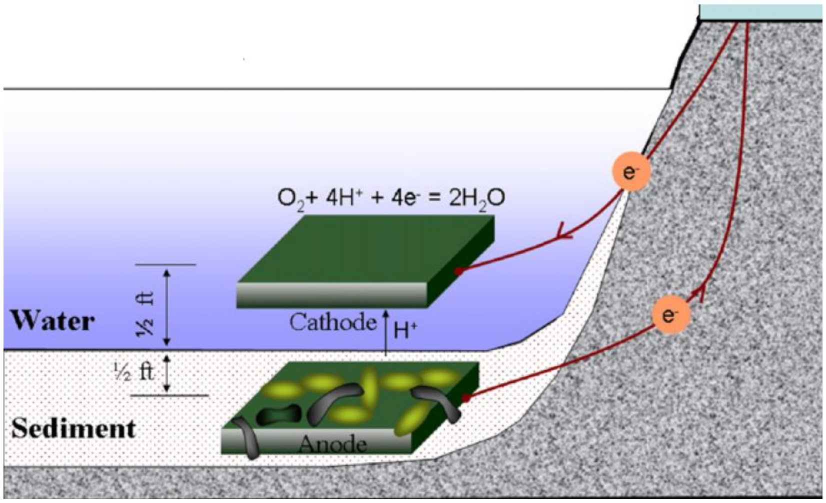

Figure 2. General design of sediment/unmediated microbial fuel cells. The sediment layer provides anaerobic conditions to the anode side, creating the potential difference across the water interface.[1,2,11] Image modified from Donovan et. al.[9]

C. Design of MFC Power System for the Munini Community

The data required to utilize this technology from the Munini system will be highly dependent on the systems we intend to service through these modules. Level sensors monitoring storage tanks, flow meters in pipes, simple weather stations, and even low-frequency radio transmissions could be incorporated into the design without having to introduce solar panels and/or diesel generators to the community. Microbial fuel cells are relatively cheap, requiring only carbon surfaces and some wiring. Small capacitors would also significantly improve the performance of the system. Therefore, simple monitoring and warning systems can be built without imposing financial burden on ourselves or the community. These signals would ideally be electronic such that they can be routed to a centralized notification panel. This panel significantly reduces the amount of attention needed to be given to the distribution system during operation.

System Design: Monitoring Subsystem

The first monitoring points are capacitance devices in the distribution system: water tanks, waste pits, holding drums, etc. Since the entire system is gravity-fed, the levels of intermediate holding drums are important in maintaining the water head downstream. A simple level sensor could be constructed using a floating plastic ball in a guide rail to follow the water level. However, since we do not want people to repeatedly check each tank, electronic level sensors must be used for this panel. A quick Google search yields Honeywell PX2 pressure transducers priced at $92.03 per transducer from Allied Electronics & Automation.[12] This is relatively cheap in terms of grant funding sources, so multiple sensors can be brought along during implementation. These would need to be installed either at the bottom of tanks or at the tank outlet. Power is received from the MFC system and the output is sent to the control panel where it is converted by a simple analog-to-digital circuit like an Arduino to output a true-false value dependent on a set threshold pressure below which an LED would light up on the board to indicate a low pressure zone. A controlling Arduino can be energized with low power already available closer to the center of the community.

This same system could be installed in the composting facility to warn of another overflow situation. However, since this is primarily a slurry of urine and feces flowing into the end of the latrine network, the pressure here is less interesting than the level. A GEMS LS-1900 point sensor functional with highly-viscous fluids is available from TEquipment for $135.00.[13] Two or three of these devices would be sufficient for monitoring of the new composting facility. The old waste pit no longer needs to be monitored after this implementation, as it will be fortified and disconnected from the latrine network. This device is just an on-off switch and is therefore connected straight to an LED from the power supply.

Simple wireless communication systems can even take advantage of the microbial fuel cell. Both Thomas et. al.[14] and Donovan et. al.[10] demonstrated the efficacy of such a system. They showed the use of cheap transmission technology to send signals at low frequency. They further demonstrated this technology by taking remote temperature measurements. However, both papers reference the use of a power management system (PMS) in order to energize the wireless communications. The PMS uses capacitors to build and release charge into the sensor and transmission systems, a system more commonly known as a DC-DC converter. TI Instruments makes the TPS61022 low-voltage boost converter for sale on Mouser.com for $1.68.[15] MFC’s cannot provide high power for extended periods of time, so supercapacitors attached to the primary output electrodes of the MFC will accumulate charge to the required

1.8V needed for the boost converter. Once the voltage difference reaches this threshold, a switch or transistor will switch the capacitor to the converter track. This voltage will be boosted to 5V by the converter and momentarily take a reading from the sensor node and transmit a value to the panel in the community center. Figure 3 is the general idea behind the PMS. The frequency of this transmission is dependent on the size of the intermediate capacitor and the voltage generated by the MFC. Further on-site measurements are necessary to understand the resolution and frequency of these measurements.

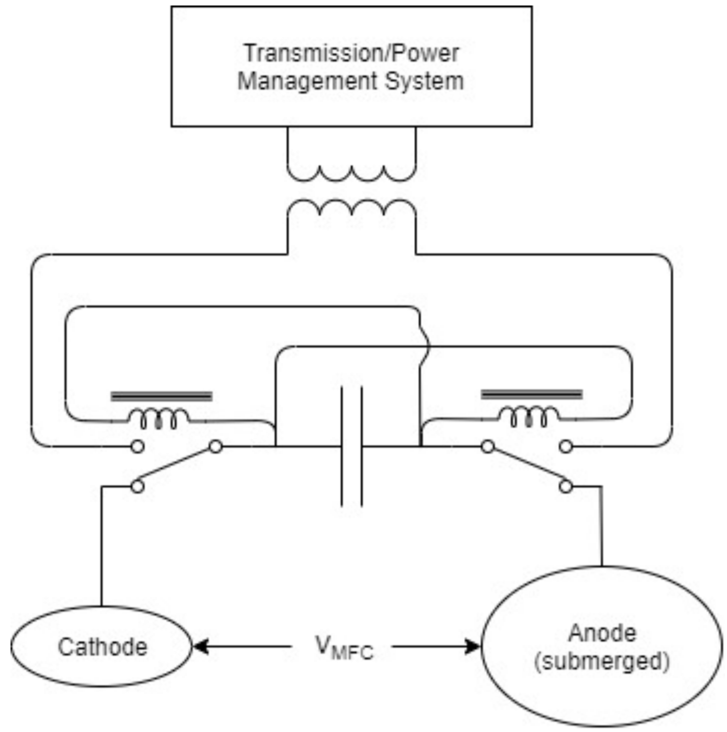

Figure 3. Idea behind the power management system. The voltage difference across the capacitor (—||—) accumulates, while the relays will be set to flip above the 1.8 V threshold necessary to activate the DC-DC converter at the top.

Design of simple weather stations still needs to be discussed but is not outside of the realm of possibilities. Electronic barometers and a small wind vane could be dotted around to create an understanding of local weather. However, more in-depth analysis of the power demands of maintaining such a network would need to be done based on the requirements of the community.

We now have a rough idea of the system we want to design. A receiving Arduino running off the sparing power at the primary community center can receive radio communications from the measurement nodes powered by microbial fuel cells across the system. While this is not a complex control system, it allows for significant minimization of community oversite. The SMFC characteristics will now be described.

System Design: MFC Units

The SMFC has three major components: an anode, a wire, and a cathode. The wiring is very cheap: miles of copper wiring can be sourced locally in Rwanda to construct our electrical network. Enough wiring must be bought to suffice connecting both ends of the fuel cell as well as provide transmission to either a wireless transmitter or directly to the

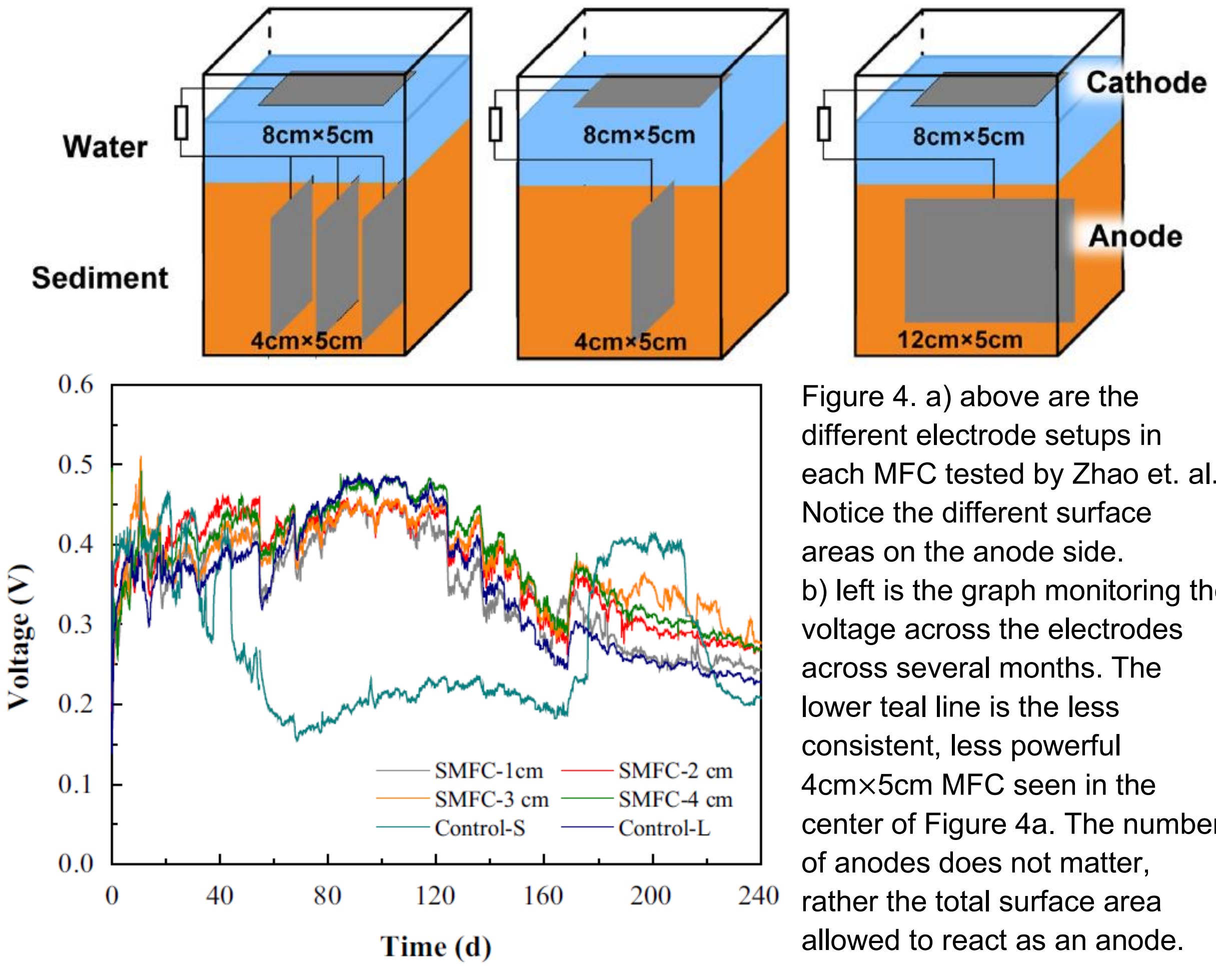

Figure 4. a) above are the different electrode setups in each MFC tested by Zhao et. al.[6] Notice the different surface areas on the anode side.
b) left is the graph monitoring the voltage across the electrodes across several months. The lower teal line is the less consistent, less powerful 4cm×5cm MFC seen in the center of Figure 4a. The number of anodes does not matter, rather the total surface area allowed to react as an anode.

centralized panel. The wires will be insulated with rubber to protect them during their submersion in the waste pit. Joining the wires to the electrodes will be done using conductive adhesive and allowed to set. Wire bundles with two wire can be utilized in long-distance transmission if the wireless system is determined not to be viable.

The electrodes will be made of graphite disks. These can be bought locally, brought from home, or made of granulated charcoal. The surface area of the electrodes plays a major role in the amount of voltage generated.[1,5,6,8,16] The surface areas need to be different in order to take advantage of current density effects. The cathode-to-anode surface area ratio, R, needs to be less than 1. Designs from several mentioned sources utilize this model, citing the increase in current density from one side of the cell to the other as contributing to an increase in the baseline voltage. Some papers utilize an $R > 1$ for finer experimental control, but this is not our objective.

Zhao et al.[6] monitored the setup in Figure 4a over a long period of time. The increased anode surface area produced a greater voltage at a more consistent rate regardless of whether using more electrodes or one larger electrode. Notice the lower voltage for the MFC with lesser anodal area in Figure 4b (Control-S, lower teal line). The paper attributes a hiccup in the voltage due to sustained temperature issues that resolved themselves after rectification. While this SMFC design is used in the Tianjin region of China, similarly reproduceable results should result for the Munini community using similarly dimensioned electrodes due to the general applicability of this technology to any environment. [1-5,17-20]

The anode side of the SMFC will need to be placed secured to the wall of the composting facility in order to have more control over the level of the anode. The waste level can be kept down to a minimum around the anode such that the cathode sits above it, ready to receive H^+ from the decomposition. This setup should not be difficult to maintain, as the large pit will vary in height infrequently.

To ensure the system is working as intended, regular monitoring and tests can be undertaken. Every month the level sensors, pressure sensors, and relay devices should be tested for functionality and connectivity to the central panel. Device tests need to be done according to the manufacturer specifications. Wire testing can be done by monitoring the panel while connecting a small battery to complete the circuit.

D. Suitability of Project for the Munini Community

The goal of this project is to reduce the amount of oversight required to run the water distribution plant and composting facility using very low-power subsystems powered by microbial fuel cells. The addition of these MFC-powered devices would not be a burden to the community and utilize the waste pit already being developed on site. Therefore, these devices increase the longevity and sustainability of the project.

Reference implementations show the technology is available to carry this project forward in the Munini community. Similar implementations, whether used for service projects or not, have seen publishable success. Once the system is buily, the technical aspects of continued maintenance will be addressed. Miami University has a good record with educating the community how to make the most of the various implementations sponsored in Munini, an experience that will carry over well to this implementation as well. The targeted implementation window is sometime during the 2020-2021 academic year.

Cultural and financial considerations will be taken into account by incorporating community voices into the design process. During the planning phase and next implementation trip in July-August, a decision will be made on the best way to incorporate the MFCs into the upcoming waste pit. The community wholly owns the various water and waste distribution systems as agreed by contract between EWB, local governments, and the NGOs. The community and EWB would agree to set a monitoring and evaluation period such that we are sure the system can be tweaked and handled correctly. Adequate planning will ensure the community is able to replace parts as the years continue. The data collected during the implementation would be another example of MFC implementation and could incorporated into a later paper to help improve similar projects elsewhere.

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