William Busby

1. Provide an overall description. This description should reflect some knowledge of the project so please do some preliminary research into this project before proceeding.

A microbial fuel cell (MFC) is a bio-electrochemical device that harnesses the power of respiring bacteria to convert organic substrates directly into electrical energy. At its core, the MFC is a fuel cell, which transforms chemical energy into electricity using oxidation reduction reactions. Microbial fuel cells rely on living biological catalysts to assist the movement of electrons throughout their systems instead of the traditional chemically catalyzed oxidation of a fuel at the anode and reduction at the cathode.

The MFC is modeled off of cellular respiration in cells: they use metabolic reactions to convert nutrients into energy (ATP). In 1911, M. C. Potter came up with the idea of using microbes to produce electricity. While Potter succeeded in generating electricity from E. coli, his work went unnoticed for two decades when Barnet Cohen created the first microbial half fuel cells in 1931. By connecting his half cells in series, he was able to generate a current of 2 milliamps. By 1999, researchers in South Korea developed the mediator-less MFC which greatly enhanced the MFC's commercial viability, by eliminating costly mediator chemicals required for electron transport.

Microbial fuel cells function by letting bacteria oxidize and reduce organic molecules, as they normally do. Bacterial respiration is essentially one big redox reaction in which electrons are transferred. Whenever electrons move, there is the potential to harness an electromotive force to perform work. Microbial fuel cells consist of an anode and a cathode separated by a membrane that allows positive ions, or cations, to cross. Microbes at the anode oxidize the organic fuel generating protons (H+) that pass through the membrane to the cathode, and electrons which pass through the anode to an external circuit to generate a current. The trick of course is collecting the electrons released by bacteria as they respire. The purpose of this is to create an electrical current and to do that, one needs to collect the electrons released by the respiring bacteria. There are two ways to go about this: through mediator and mediator-less MFCs. Mediator MFC’s use a mediator chemical to transfer the electrons from the bacterial cells to the electrode. Different types of bacteria, called exoelectrogens can be used that transfer electrons extracellularly.

Exoelectrogens are electrochemically active bacteria. While aerobic bacteria use oxygen as their final electron acceptor and anaerobic bacteria use other soluble compounds as their final electron acceptor, exoelectrogens are a special class of bacteria that can use a strong oxidizing agent or solid conductor as a final electron acceptor, and in our case this will be an anode.

When bacteria consume an organic substrate like sugar under aerobic conditions, the products of cellular respiration are carbon dioxide and water. When placed in an environment without oxygen, cellular respiration will instead produce carbon dioxide, protons and electrons instead of carbon dioxide and water. Therefore the anode chamber of the MFC must have no oxygen present.

In mediator based MFC's, a mediator takes the place of oxygen in the bacterial electron transport chain. The mediator crosses through the bacterial outer membrane and accepts electrons that would normally be accepted by oxygen or other electronegative solubles. Once the mediator has been "reduced" it exits the cell full of electrons which it transfers to the anode. In mediator-less MFC's the exoelectrogenic bacteria sticks to the surface of the anode and uses an oxidoreductase pathway to directly transfer electrons through a specialized protein into the surface of the anode.

The positively charged half of the cell, the cathode chamber, consists of an electrode subjected to a catholyte flow consisting of an oxidizing agent in solution. The oxidizing agent is reduced as it receives electrons that funnel into the cathode through a wire originating from the cathode.

In order for any fuel cell to work one needs to have a means of completing a circuit. In the case of the MFC, there are a cathode and an anode separated by a cation selective membrane and linked together with an external wire. When an organic "fuel" enters the anode chamber, the bacteria produces protons, electrons, and carbon dioxide, with the anode serving as the electron acceptor in the bacteria's electron transport chain.

The newly generated electrons pass from the anode to the cathode using the wire as a conductive bridge. At the same time protons pass freely into the cathode chamber through the proton-exchange-membrane separating the two chambers. Finally an oxidizing agent or oxygen present at the cathode recombines with hydrogen and the electrons from the cathode to produce pure water, completing the circuit. By replacing that wire with a light bulb or another electricity requiring device, one has used bacteria to create electrical energy.

The most immediately foreseeable application of an MFC is in waste water treatment. Microbes love sewage, and the conditions of a wastewater treatment plant are ideal for the types of bacteria that can be used in an MFC. Exoelectrogens breakdown and metabolize the carbon rich sewage of a wastewater stream to produce electrons. The electricity generated from the MFC also offsets the energy cost of operating the plant, and in the process purifies the water. The Naval Research Laboratory (NRL) has a very different idea of how remotely operated vehicles could be powered in space, they have begun work on a prototype rover that is powered by the exoelectrogenic bacteria Geobacter. NRL's Dr. Gregory P. Scott plans to use a hybrid MFC/battery system to power a 1 kg hopping rover. The MFC would only be able to power low load devices such as the rover's electronics, sensors and control system. The battery or capacitor would be used for higher power loads, like locomotion or operation of a more power intensive scientific instrument. Since a rover spends a large amount of time stationary analysing samples, the MFC could be used to recharge the batteries or supercapacitors for the next heavy load.

Plant Microbial Fuel Cells work by taking advantage of the up to 70 percent of organic material produced via photosynthesis that can’t be used by the plant. Naturally occurring bacteria around the roots break down this organic residue and release electrons as a waste product. By placing an electrode close to the bacteria to absorb these electrons, one can use the energy stored in the electrons to power an electrical current. Although the Plant-Microbial Fuel Cell currently only generates 0.4 W per square meter of plant growth compared with the 200 W produced by one square meter of solar panels in a day, the researchers claim this is more than is generated by fermenting biomass. They also say that future systems could generate as much as 3.2 W per square meter, which would allow a roof measuring 100 m2 to supply electricity to a house with an average consumption of 2,800 kWh a year.

1. What do you hope to learn by engaging in this project? Be specific. Don’t just say that you want to learn more about Engineering or Computer Science. Identify something that is a question in your mind, a recognition that there is something in the world that interests you but you know that you don’t have enough information to pursue it.

By engaging in this project, I hope to learn how biology and the concern for the environment are incorporated into engineering. I hope to go into the field of bioengineering, whether that has to do with biomechanical engineering or a more health-care skew regarding neural engineering or biomaterials. This project will allow me to learn more about biology, as the research shows, electrical circuits, fuel cells, and how people can implement bacteria to fit their needs. This project will increase my understanding of how ecosystems, biomes and biospheres function and how life is related and complex: bacteria use the waste products from plants to create their own energy.

1. Why is this the project that you want to do? Provide some personal information relating to your personal interests in this topic.

In this project, I hope to create a fuel cell that runs off of bacteria harnessing waste from plants. The Microbial Fuel Cell has a future in car technology as well as energy production in remote areas. This project will allow me to further my understanding of topics that I am interested in studying in college: biology and engineering.

1. How will this project benefit the world (other people)? We want you to investigate a REAL problem. We want you to think about something that is going to have some kind of meaningful impact. That doesn’t mean you have to try to solve world hunger, but it does mean that you shouldn’t make a “fart noise machine” because you think that would be funny.

This project will benefit other people by spreading the knowledge and innovation of the idea: few know about microbial fuel cells and the potential that they hold in the near future regarding widespread water purification, space exploration, and energy production. This project taps energy that is left unused by nature: this technology does not inhibit nature in any way; it does not take up space for plants, nor use energy that other organisms would use.

1. What kind of equipment and materials are necessary to complete this project? Please provide a general list of items that you think you might need, such as wireless moisture sensors, an electric golf cart, a high speed camera, etc. You do not need to be specific, but *think ahead!*

In order to complete this project, I would need to obtain a chemical that transfers electrons from the bacteria to the anode. However, the majority of these are expensive and toxic. Instead, I could use bacteria that use an anode as their final electron acceptor in their electron transport chain. I will also need an anode and a cathode. I will need a wire to transfer the electrons from the anode to the cathode and a system that uses this energy, such as a light, a phone charger, or a battery charger. I will also need plants and good soil in order to create a microbial fuel cell.

1. You need to provide the name of a potential *professional advisor* for your project. This can be a professor, a parent, a friend of the family, an employer, etc. It must be someone who is currently working in a field that interests you AND is relevant to your project. Your next task will be to contact this person and ask them to be your advisor. We will give you a document that you can use to give your potential advisor more information.

Potential professional advisors could be Mrs. Kalish and/or Mrs. Pikk. These teachers would further my understanding the biology and chemistry behind the project. They could assist me when I decide which materials to obtain: bacteria and a possible mediator chemical.