Microbial Fuel Cells 1
Bacterial Power

Objective

To understand how bacteria and other living organisms can be use to produce energy?

Skill Level: High school	**Class time:** 45 min

Materials

Per group:

- Anaerobic soil. Digging down in a riverbank, shallow pond, or other wetland to the black stinking mud is the best option. Anything characterized as “dirt'” probably doesn't have enough organic matter or anaerobic bacteria to work well.
- One container per soil collection. Use a mason jar.
- Two stainless steel wires per container.
- One carbon cloth circle for the cathode.
- One carbon dusted carbon cloth circle for the anode.
- One resistor per container.
- A voltage meter

Next Generation Science Standards

Disciplinary Core Idea:
PS3: Energy in chemical processes
LS2: Ecosystems: Interactions, energy, and dynamics

Performance Expectations:

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

Practices	**Crosscutting Concepts**
☐ Asking questions / defining problems	☐ Patterns
☐ Developing / using models	☐ Cause and effect: Mechanism / explanation
☒ Planning / carrying out investigations	☐ Scale, proportion, and quantity

☐ Analyzing / interpreting data	☐ Systems and system models
☒ Math / computational thinking	☒ Energy / matter: Flows, cycles, conservation
☐ Constructing explanations / design solutions	☐ Structure and function
☐ Engaging in argument from evidence	☐ Stability and change
☐ Obtaining / evaluate / communicate	

Background Information

Introduction:
It may seem hard to believe that bacteria could produce electricity, yet some bacteria have managed to do just that. In labs, *Geobacter sulfurreducens* have displayed a talent that has enabled them to produce tiny electrical currents. The feedstock for these bacteria is decaying organic matter—the stuff of septic tanks. If these bacteria can be useful for electricity production from wastewater plants. An electric current simply consists of electrons that are moving through or in a conductor. When we use electricity to power a motor or heat the filament of a light bulb, we don't actually "use up" any of these electrons. We just use some of their energy to do something we find useful. Bacteria produce electricity in much the same way that a battery uses chemical reactions to produce electricity. Batteries have two poles, or terminals; these are as electrodes. One is positive, and one is negative. Electricity flows from the negative terminal to the positive terminal. For example, when you start your car, turning the key connects the two terminals of the battery via an electrical pathway that goes through the starter motor's coils. Current–electrons immediately flow from the negative to the positive terminal. The following activity helps you explore how this phenomena with students.

Background:
Car batteries are classified as lead acid batteries like 60% of the batteries in the world. This can serve as an example for our bacteria fuel cell (the difference between fuel cells and batteries is explained in the Microbial Fuel Cells 2 activity). At each terminal, plates are bathed in sulfuric acid. The plates in the negative pole, which supply electrons for the current, are made of lead. The plates in the positive pole, which absorb the electrons, are made of lead oxide. When the terminals are connected, at the negative pole the lead reacts with the sulfuric acid to produce lead sulfate and electrons.

$$\mathbf{Pb + SO_4{}^{2-} \rightarrow PbSO_4 + 2e-}$$

Those extra electrons then flow to the positive pole, where the following reaction takes place:

$$\mathbf{PbO_2 + 4H+\ \ SO_4 +\ \ 2e- \rightarrow PbSO_4 + 2H_2O}$$

The consistent flow of electrons from anode to cathode (negative pole to positive pole) creates a current that then can be used to power devices electronically. A car batteries initial function is to start the engine via electrical energy and therefore must be capable of generating high voltage, a variable dependent on the current. In a bacterial fuel cell the voltage output will not be as high but a current is still created and therefore electrical energy is being produced. The bacteria grow naturally on the negative surface, forming a highly stable colony called a biofilm, much like the colony that grows on your teeth when you forget to brush them. The other terminal is placed in the clear waters above. The bacteria on the anode feed off of decaying plant material provided by the dirt. They oxidize multiple organic compounds including acetate, described below, into carbon dioxide, hydrogen ions and electrons. The chemical equation for the breakdown of acetate is:

$$CH_3COO^- + 2H_2O \rightarrow 2\ CO_2 + 7H^+ + 8e^-$$

G. sulfurreducens have unique physical properties that allow them to transfer these electrons out of their cell walls to the anode. Once delivered to the anode, these electrons continue to flow through the wire to the positive pole, the cathode, where the electrons combine with protons and oxygen to produce water:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

This combined reduction and oxidation at different sites means that electrons will always be freed and consumed at different poles, enabling the consistent flow of electrons through the wire and mimicking the lead acid car battery. To define the power generated one must examine how thick the biofilm growth is and how fast oxidation is occurring at the cathode, ultimately examining how fast electrons are moving though the wire. The Figure 1 represents this process. A simple microbial fuel cell that produces power by the creation of a biofilm of *G. sulfurreducens* bacteria on the anode combined with oxidation at the cathode. The "waste" inlet at the anode is a mixture of organic components including acetate.

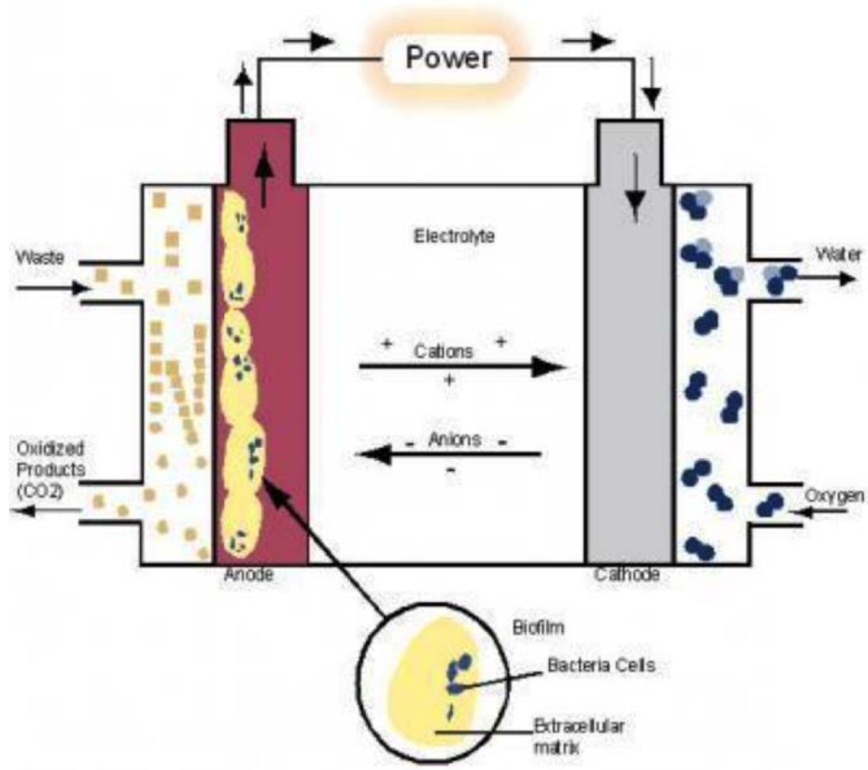

Figure 1. A simple microbial fuel cell. Reference

Engage

How can bacteria be used to create power? This is a concept that may be foreign to students. This activity introduces students to alternative ways to produce power. Alternative power production can be a way to interest students in science and technology.

Explore

Experiment Questions:
What can voltage data tell you about the differences between soils and biofilm growth?

Procedure:

1. Collect mud and dirt from local places, preferably near a water source such as a pond or river. (Collect the soil from a few feet below the surface)

2. Attach one 8" stainless steel wire to the carbon cloth circle, this will be the cathode. Attach one 8" stainless steel wire to the carbon dusted carbon cloth circle, this will be the anode.

3. Fill the container halfway with soil placing the anode underneath the soil, making sure it is well buried, and fold the wire so that it comes out the top of the container. It is important that the anode be in an anaerobic environment.

4. Fill the container the rest of the way with water and let the cathode rest on top of the water, again bending the wire so that it comes out the top of the container.

5. Wrap one end of the resistor around the end of the anode wire, and the other end around the end of the cathode wire. (Closing the circuit)

6. Measure the voltage across the resistor periodically and record.

*One example of a mud bacteria fuel cell is the picture above; this was created with graphite electrodes in a mason jar.

Explain

- Have students draw a picture of what is happening in the bacterial fuel cell. Showing that organic materials provided by the dirt are being consumed by the biofilm on the anode. The bacteria's metabolism release protons, which move through the water, and electrons, which move through the wire, ultimately ending at the cathode where oxidation is taking place. Because we are using carbon cloth for the cathode rather than a metal, the oxidation reaction is quite complex but the general concept should be well thought out; e.g. O_2 (g) + $4H^+$ (l) + 4e- → $2H_2O$ (l).

- Although most organisms utilize oxygen for their metabolic processes, in principle any substance that readily undergoes reduction could conceivably be the basis for an organism's metabolic requirements. It might be both challenging and fun to have knowledgeable and creative students consider different possible reduction reactions (from a table of reduction potentials, for example) and then try and create a theoretically viable metabolic system that might be used by an organism. Some considerations would include the availability of the requisite materials, the energy release that might be anticipated, and the properties of the metabolic products.

- At the basis of this project are the fundamentals of electrical circuitry. Connecting positive and negative terminals through wires and resistors creates a functioning circuit. It may be useful to shortly discuss what a circuit is before or after this activity if the students are having trouble understanding how the electrons pass through the wire/resistor combination. For more information on circuits and batteries visit Trojan Battery.

Elaborate

- Have students read this article about bacteria batteries. (Click links)

- Have students toggle with the resistor and voltage settings in this Phet simulation; examine what happens to the current as both things change. Introduce Ohm's Law, V = IR.

- Once voltage readings are measured, connect multiple bacteria batteries in series across one resistor and measure the voltage. This activity can be used as an intro to electrical circuit fundamentals, i.e. series vs. parallel connections.

- This activity was adapted and modified from this Chem Matters: Have students read the article enclosed and discuss the possibility of bacteria as an energy source.

- A college student gets creative and makes a microbial fuel cell song.

Resources

Additional Resources:

- How to create microbial fuel cell – A six part video of high school student making a homemade fuel cell. (Click links)

- Chem Matters
- Bacteria used in bioreactors.