Objective

Investigate how adding urine to a microbial fuel cell changes its power output.

Introduction

Each year, people make about 6.4 trillion liters of urine worldwide! That is a lot of waste that needs to be collected and then properly treated and/or disposed of. But it may not need to just be seen as "waste" — it might be able to serve a useful purpose while it is being processed. Urine is full of nutrients, primarily nitrogen (in the form of urea), along with other compounds, including chloride, sodium, potassium, and creatinine. Because of this, human urine has sometimes been used as a fertilizer for plants. (For more on this, see the Science Buddies science project idea Growing Great Gardens: Using Human Urine as a Fertilizer.)

Among other uses, the nutrients in urine can also be used to feed microbes (microscopic organisms), like bacteria. Why would this be useful? As it turns out, in the early 1900s, scientists showed that microbes could make electricity, which is the basis of microbial fuel cell (or MFC) technology. As natural resources are being depleted, scientists’ attention has shifted to pursuing alternative energy sources, such as MFCs, even more than before.

A microbial fuel cell, also known as a biological fuel cell, is a device that can use microbial interactions to generate electricity. It is a renewable, clean source of energy, making it quite appealing. An MFC has an anode, a cathode, and an area that separates the two (called a membrane). Anodes and cathodes are both electrodes. An electrode is something that conducts electricity, with electricity either flowing into, or out of it. Specifically, an anode has electricity flowing into it, whereas a cathode has electricity flowing out of it. So, for an MFC to function, electricity must be made to flow into the anode and then leave from the cathode. How is this accomplished?

To answer this question, we will look at MFCs that use microbes from the soil to generate electricity. When you think of electricity, and how it can be made in nature, you may think of lightning and electric eels, though you probably do not think about microbes! But some types of soil bacteria can help generate electricity, too. These bacteria, known as electrogenic bacteria, include the Shewanella species, which can be found in almost any soil on Earth and are shown in Figure 1, below, and the Geobacter species, which prefer living in soil deep underground or even under the ocean, where no oxygen is present. How can these bacteria help make electricity? The soil bacteria eat what is in the soil, such as microscopic nutrients and sugars, and in turn, produce electrons that are released back into the soil. Electrons are subatomic particles that have a negative electric charge. These electrons can be harnessed and used to create electricity, which is a form of energy. For example, if a lightbulb has enough electricity flowing through it in the correct way, the lightbulb will light up.

Figure 1. This is a high-magnification image of Shewanella bacteria, specifically the species S. oneidensis. The bacteria are the cylindrical-shaped rods scattered in this image. (The other parts of the image are ice pieces that the bacteria were submerged in to take this picture.) (Image credit: PLoS Biology)

In an MFC using these soil bacteria, the anode is buried in the damp soil. Down there, the bacteria multiply and cover the anode (creating a biofilm on it), supplying it with a lot of electrons. At the same time, electrons are taken away from the cathode. How does this happen? While the anode is buried in the soil, the cathode sits on top of the soil, leaving one of its sides completely exposed to the air. Electrons from the anode travel up a wire to the cathode and, once there, they react with oxygen (from the air) and hydrogen (produced by the bacteria as it digests the nutrients in the soil) to create water.

The anode is buried deep enough, where there is no oxygen, so this reaction could not take place right next to the anode. See Figure 2, below, for a visualization of this process. The more electron-producing, soil-munching bacteria are in the soil, the more electricity the MFC produces.

Abstract

Every day, we produce a lot of sewage (wastewater full of feces and urine). In fact, it adds up to 6.4 trillion liters of urine alone produced worldwide each year! The sewage is collected and then treated or disposed of. But what if, along the way, there was a way to make that sewage do something useful? It turns out that human urine is rich in nutrients, and some bacteria actually thrive on eating those nutrients. There are also devices called microbial fuel cells that can generate electrical power by using certain bacteria. Could human urine be used to generate electricity in a microbial fuel cell? Find out for yourself in this science project.

Summary

Prerequisites

Previous experience using a voltmeter/multimeter is helpful, but not required.

Safety

Be sure to wear the gloves supplied with the kit when handling the microbial fuel cell's electrodes (its cathode and anode). The electrodes are made of a conductive material called graphite fiber and should not be placed near electronics or power plugs, or have their fibers dispersed in the air. The fibers will cause electrical shortages when they come in contact with electronics. Use caution when handling human urine. Wear gloves when working with human urine. Adult supervision is recommended.

Frequently Asked Questions

Figure 2. This diagram shows the reactions taking place in a microbial fuel cell (or MFC) that make it generate electricity. (Wikimedia Commons, 2010, MFCGuy2010)

In this environmental science project, you will investigate how adding human urine to an MFC changes its electrical power output. Are you shocked that you will be using human urine? Do not be — even NASA has experimented with using urine as a fertilizer! Urine is actually relatively clean. In fact, human urine in the bladders of individuals without bladder and kidney infections is sterile. At the beginning of urination, the flow takes with it any bacteria in the urethra, cleaning the urethra but contaminating the urine. While this means the initial flow might not be sterile, the mid-flow urine will be sterile. And as we mentioned, human urine is continually being made in large amounts, making it a renewable resource, and it is rich in nutrients (mainly nitrogen) that bacteria like Shewanella and Geobacter species can eat. And the more Shewanella and Geobacter bacteria that are in the soil of an MFC, the more electricity it makes. How do you think adding urine to an MFC will affect its power output? Do you think a certain amount needs to be added for the power output to increase? Is it possible to add too much and cause the bacteria to die? There are all sorts of interesting questions you can ask in this science project; get ready to figure some of the answers out!

Terms and Concepts
- Urine
- Nitrogen
- Microbes
- Bacteria
- Alternative energy sources
- Microbial fuel cell (MFC)
- Renewable
- Electrode
- Shewanella
- Geobacter
- Electrons
- Electricity

Questions
- What nutrients can bacteria eat in human urine?
- How does an MFC work?
- How do soil bacteria help make electricity in an MFC?
- How do you think adding a small amount of human urine to the MFC will affect its power output? How about adding a much larger amount of urine?

Bibliography
These resources will give you more information about microbial fuel cells and using waste to create power:

For more information about electronics terms and using a voltmeter/multimeter, use this tutorial:

This project idea was adapted from Keego Technologies LLC, and additional resources can be found through the company's website:

Experimental Procedure

Working with Biological Agents

Setting Up the Microbial Fuel Cell
The first thing you need to do is assemble your microbial fuel cell (MFC).
1. First watch the video below to see how to assemble your MFC.
2. Prepare your topsoil mud.
   a. Pour about 2 cups (about 500 milliliters [mL]) of your topsoil into a large mixing bowl.
      i. Make sure to remove any small, hard particles (such as rocks, pebbles, twigs, etc.) from the soil because these can aerate the soil and inhibit the desired bacteria from growing (they do not want to be exposed to oxygen).
   b. Add distilled water and mix it in until your topsoil mud feels like cookie dough. Add more water if the mud is too crumbly, or add more topsoil if the mixture feels too wet.
      i. If you are using Scotts Premium Topsoil, you will likely need about ½ cup (120 mL) of water.
   c. When you have prepared your topsoil mud, set it aside and wash your hands.
3. Carefully take the MFC pieces out of the box and lay them out. Identify the different components.
4. Put on the gloves that came with the MFC.
5. Remove the MFC cathode from its bag. (The cathode is the black, felt-like circle with the red wire sticking out.)
   a. Safety Note: The MFC's cathode and anode (its electrodes) are made of a conductive material called graphite fiber. Do not put the cathode or anode near electronics or power plugs, and do not disperse the fibers in the air, as the fibers will cause electrical shortages when in contact with electronics.
6. Take the cathode's red wire and put it through the hole in the "donut disk" (the transparent disk). Arrange the donut disk so that its tab is facing up and away from the cathode.
7. Then put the cathode's red wire through one of the holes in the "dome lid" (the white, dome-shaped plastic part with two holes in it). Gently pull the red wire so that its rubber bumper is up against the whole in the dome lid. Do not worry about it staying in place or completely sealing the hole yet.
8. Remove the MFC anode from its bag. (The anode is the black, felt-like circle with the green wire sticking out.)
9. Repeat steps 6 and 7 using the anode's wire instead of the cathode's wire. Note: In step 7 for the anode, put the anode's wire through the other hole in the dome lid.
10. Once the wires are in place, with each one sticking out of the dome lid, twist the wires together between the dome lid and the donut disk one full turn.
    a. This can be a bit tricky, but just take your time turning the wires together.
    b. Doing this should help keep the wires in place, but do not worry if they get moved around in the next steps. You will adjust everything a little in step 17.
    c. Set this anode-cathode assembly aside for now.
11. Put the ruler sticker on the MFC vessel (the plastic jar). Do this by lining up the top of the sticker with the rounded top edge of the vessel.
12. Take the topsoil mud that you prepared in step 2 and use it to fill the vessel up to the line next to the "1" on the ruler (marking 1 centimeter [cm]). Once filled, pat the mud so that its surface is smooth.
    a. Tip: You may want to cover the surface you are working on with old newspapers to prevent mud from getting on it.
    b. When you are finished, rinse the mud off your gloves and dry them (but do not take them off yet).
13. Take the anode-cathode assembly you set aside in step 10 and put the anode on top of the mud in the vessel.
    a. The green wire from the anode should be sticking out of the top side of the anode. The green wire should not be stuck down in the mud.
    b. Gently press the anode flat against the mud so that no air bubbles are under the anode.
14. Use more topsoil mud to fill the vessel up to the line next to the "4" on the ruler sticker (marking 4 cm). Once filled, again pat the mud so that its surface is smooth.
    a. Run the green wire along the side of the vessel.
    b. Rinse the mud off your gloves and dry them.
15. Gently press the cathode flat against the mud.
    a. The red wire from the cathode should be sticking out of the top side.
    b. Do not let any mud or liquid cover the top of the cathode.
    c. Let the mud rest in the vessel for a few minutes. Then carefully pour off any excess liquid.
16. Use a clean paper towel or rag to wipe any mud off the vessel's rim.
17. Set the donut disk on top of the vessel and place the dome lid on top of that.
    a. Adjust the wires if needed so that they are loosely twisted together between the donut disk and dome lid.
    b. Gently pull on the ends of the wires sticking out of the dome lid so that their rubber bumpers are up against their holes in the dome lid.
18. Put the "sealing ring" (the white plastic ring) around the dome lid and screw the ring in place.
19. Take out the hacker board (the small green circuit). Locate the "+" and "-" ports on the top.
20. Attach the hacker board to the top of the dome lid using the piece of Velcro® included in the kit. Attach the hacker board between the wires, with the "+" near the cathode (red) wire and the "-" near the anode (green) wire.
21. On the hacker board, plug the cathode (red) wire into the "+" port and plug the anode (green) wire into the "-" port.
22. Locate ports 1 and 2 on the hacker board. Place the jumper (the small, black, rectangular-shaped item with two small metal prongs) so that its prongs plug into these ports.

Note: Some versions of the hacker board do not require a jumper. If your hacker board has "KeegoTech" written on the bottom of it, like the one shown in Figure 3, below, then you will need to use a jumper with it. However, if your hacker board does not have "KeegoTech" written on it, then you will not need to use a jumper. Either version of the hacker board will work for this science project.

23. Plug the capacitor (the small, cylinder-shaped item with two longer metal prongs) into ports 3 and 4, just below the jumper. The capacitor's longer prong should go into port 3 and the shorter prong into port 4.
    a. Note: You may need to bend the capacitor's longer end slightly so that the capacitor's prongs fit into the ports well.
24. Plug the red LED right below the capacitor into ports 5 and 6. The LED's longer prong should go into port 5 and the shorter prong into port 6.
    a. Note: You may need to bend the LED's longer end slightly so that the LED's prongs fit into the ports well.
25. Make sure that the wires, jumper, capacitor, and LED are all securely in place. The top of the MFC should look like Figure 3 below.
26. Set the MFC indoors, at normal room temperature (about 19 to 25°C Celsius [C], or 66 to 77° Fahrenheit [F]), in a place where it will not be disturbed. The MFC should remain in the same location the entire time after you set it up because if it is moved this could disrupt the growth of the bacteria. It should take between three and ten days before the red LED on the hacker board starts blinking, but you will start taking measurements before that, as described in the next section.

Measuring Power Output and Adding Urine

You will measure the power output of your MFC every day. Once the power output seems to have stabilized, you will add a small amount of urine. The urine should change the power output of the MFC. How do you think the MFC’s power output will be affected?

1. One day after setting up your MFC, check to see if the LED is blinking. Most likely, it will not be, but check to make sure. Watch the LED for 2 minutes to see if it is blinking.
   a. If the LED is blinking, time how many seconds apart the blinks are.
      i. To do this, start a stopwatch as soon as you see the LED blink and stop the stopwatch when the LED blinks again.
      ii. If the LED is blinking faster than once every 5 seconds, do not time the seconds between blinks, but instead time the blinks per second. Time a 10-second interval and count how many times the LED blinks in this period and then divide this by 10 to get blinks per second.
      iii. Repeat step 1.a.i. or 1.a.ii. two more times so you have made three counts total.
      iv. Record your results in your lab notebook in a data table like Table 1 below. (If you counted blinks per second, as in step 1.a.ii., change the heading from "Seconds Between Blinks" to "Blinks per Second." Calculate the average for your three counts and record that, too.

2. Next measure the power output of the MFC using a voltmeter/multimeter. If you need help using a multimeter, consult the Science Buddies’ Multimeter Tutorial (http://www.sciencebuddies.org/science-fair-projects/multimeters-tutorial.shtml), as well as the instruction manual that came with your multimeter.
   a. To measure the MFC's power output, first remove the jumper, capacitor, and LED from the hacker board.
      Note: Leave the cathode and anode wires plugged in to the hacker board - only ports 1-6 should be empty.
      Doing this switches the hacker board to open circuit mode.
   b. Leave the MFC like this for 30 minutes.
   c. Place a resistor between ports 1 and 4.
      i. Several resistors come in the MFC kit. Start with the largest-capacity resistor, which will probably be a 1 KΩ resistor. (Ω, the capital Greek letter Omega, is the symbol for ohms, the unit used to measure resistance. 1 kilo-ohm, or 1 kΩ, is 1000 ohms.)
      ii. Resistors’ values are labeled using color-coded bands. Use the pictures in the hacker board booklet that comes with the kit to determine the resistance for each resistor.
         Tip: If you want, you can confirm the resistance of any resistor using your multimeter by setting it to measure resistance (usually a "Ω" symbol for ohms) and placing the multimeter’s leads on the wire ends of the resistor.
      iii. Leave the resistor plugged in for 5 minutes.
     d. After the resistor has been plugged in for 5 minutes, use your multimeter to measure the voltage across the two test pads (the small metal circles on the bottom of the hacker board).
   i. Set the multimeter to measure DC voltage. (On a multimeter, this is usually marked as "DCV" or "V" with a straight line above it.)
   ii. Hold the multimeter’s red lead on the test pad with the "+" next to it and hold the multimeter’s black lead on the test pad with the "-" next to it.
   iii. If the voltage seems to be changing a little, such as decreasing slightly over the period of a few seconds, watch the readings on the multimeter for a few seconds more until they stabilize (and stay the same for a few seconds). Use the stabilized value.
      • If the readings are still changing after several seconds, come back in another 5 minutes and repeat step 2.d.
   iv. Record your results in your lab notebook in a data table like Table 2 below.

<table>
<thead>
<tr>
<th>Day</th>
<th>Count #1</th>
<th>Count #2</th>
<th>Count #3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Each day check the MFC to see if the LED is blinking. If it is, record how many seconds elapse between the blinks (or how many blinks there are per second), making three separate counts. Record the results in a data table like this one in your lab notebook.

<table>
<thead>
<tr>
<th>Resistance (ohms)</th>
<th>Voltage (V)</th>
<th>Power (µW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>470</td>
<td></td>
<td></td>
</tr>
<tr>
<td>220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. In your lab notebook each day, create a data table like this one to record your voltage measurements. Do not forget to write down the date and the time you started taking measurements on the top line.

e. Remove the resistor.
f. Repeat steps 2.c.–2.e. until you have tested the MFC with all of the resistors in the kit. Start with the resistor with the largest resistance value and end with the resistor with the smallest resistance value.

3. Once you have finished taking your voltage measurements, plug the jumper, capacitor, and LED back into the hacker board, as described in steps 22–25 in the "Setting Up the Microbial Fuel Cell" section above.

4. Calculate the power output (in microwatts, or µW) for each resistor. You can calculate this by using a derivation of Ohm’s law shown as Equation 1 below.
   a. Note: It is important to convert the voltage measurements into power output measurements. The power output depends on the resistors you use, so you cannot determine how well the MFC is performing by just looking at the voltage measurements alone; they need to be converted into power for them to be meaningful.
   b. Using Equation 1, your answer will be in watts (W). Convert watts to microwatts by dividing your answer by 1,000,000.

   \[ P = \frac{V^2}{R} \]

   - \( P \) is the power in watts (W).
   - \( V \) is the voltage (V).
   - \( R \) is the resistance in ohms (Ω).

   c. Once you have calculated it, record the power for each resistor in the data table (such as Table 2 above) in your lab notebook.

5. Determine what the peak power of your MFC is.
   a. In the second data table in your lab notebook, look at the power produced using each resistor. The peak power is the highest power produced by any of the resistors.
   b. If you want to visualize this, you can plot your data for the day on a graph, putting the resistance of the resistors on the x-axis (horizontal axis) and the power on the y-axis (vertical axis). Sample graphs are
shown in Figure 3 below.

i. You may see a curve, with the peak power being at the top of the curve, as shown in sample graph #1 in Figure 3 below.

ii. It is possible that instead of a curve you will just see the power increasing with resistance, creating a nearly straight line sloping upward, as shown in sample graph #2. This means that finding the peak power may require using larger resistors. But do not worry if this is the case — for this science project, just use the power produced by the largest-capacity resistor as your peak power (it should be the highest power produced by any of the resistors).

c. Make a note in your lab notebook of what the peak power is each day, by circling or highlighting this value in your data table.

d. You can investigate peak power more in the Make It Your Own section. Although it will not be explored in this science project, you might like to know that the peak power tells you what the internal resistance of your MFC is. The resistor that gives the peak power is closest to the internal resistance of the MFC. This may change a little over time.

6. Repeat steps 1–5 each day until it looks like the power output (the peak power) is stabilizing.

a. Take these measurements around the same time every day. This will limit variables affecting your results (such as changes in temperature).

b. For step 1, it should take 3–10 days for the LED to start blinking. However, even if the LED never blinks, you may still be able to do this science project; be sure to continue to take the power output measurements every day.

i. Tip: See the Frequently Asked Questions section for what to do if the LED does not blink, or if it was blinking and unexpectedly stopped blinking.

c. For step 2, you should see the power output slowly increase.

i. For each day, make a data table like Table 2 above in your lab notebook to record your results and use them to determine the peak power.

ii. The peak power will probably be found with the same resistor each day.
After about 10–12 days, the power output should stabilize.

i. If it stabilize anywhere between 5 µW to 200 µW or more. A lot depends on the topsoil you are using and other factors. Wherever it stabilizes, it should make enough power to blink the LED at least once every 30 seconds.

ii. Tip: If the power output seems low, see the Frequently Asked Questions (FAQ) section for suggestions on what to check and try.

iii. It stabilizes, the peak power should not change by more than about 0.5 µW for at least 3 days in a row.

iv. Do not worry if your peak power changes by a little more than this (such as by 1 µW or 2 µW).

v. If it has been at least 10 days and when you graph the peak power (as described in step 6.i.d., below) it looks like it is stabilizing (i.e., it is not steadily increasing or steadily decreasing from day to day), then it has probably stabilized enough.

vi. Keep this in mind, if it still does not look like your peak power is stabilizing, see the Frequently Asked Questions (FAQ) section for suggestions on what to check and try.

vii. Do not worry if your peak power changes by a little more than this. If it has been about ten to 12 days and the peak power is not steadily increasing each day, then it has probably stabilized enough.

viii. Tip: Making a graph of your data as you collect it may help you see if the power output is stabilizing. If you do this, put the date on the x-axis and the power output (peak power) for each day on the y-axis. Does the peak power appear to be stabilizing?

ix. The time between LED blinks should also stabilize.

7. Once it appears that the power output has stabilized, carefully open up the MFC and add 1 milliliter (mL) of urine, one drop at a time (i.e., drop-wise).

a. Go and harvest your urine. This step is similar to collecting a urine sample at the doctor’s office.

i. Make sure the glass jar and its lid are clean. Be sure to rinse the jar thoroughly with water (to get rid of any antibacterial soap residue that could harm the soil bacteria) and then let it dry before using it to collect urine.

ii. Urinate into a toilet for a few seconds (to get rid of any contaminated urine) and then capture the rest of the urine in a clean, approximately 25 ounce glass jar. The mid-flow urine should be sterile. See the Introduction for an explanation of why. When you are done, cover the jar with the lid.

1. Note: If you need to clean any spills on the outside of the jar, be sure the lid is on tight before using any cleaning solutions so they do not come into contact with the urine sample in the jar and potentially harm the soil bacteria in the MFC.

iii. You can use the urine for up to one week if it is stored in a refrigerator. Be sure it is clearly labeled and kept away from food. When you want to add the urine to the MFC, set it out at room temperature for 2–3 hours to allow it to reach room temperature.

b. Unplug the anode and cathode from the hacker board, unscrew the sealing ring, remove the dome lid, and carefully take off the donut disk, being careful to untangle and leave the anode and cathode attached to the MFC.

c. Put your gloves on and gently lift up the cathode, being careful not to get any mud on top of the cathode.

i. Safety Note: The MFC’s electrodes are made of a conductive material called graphite fiber. Do not put the cathode near electronics or power plugs, and do not disperse the fibers in the air, as the fibers will cause electrical shortages when they come in contact with electronics.

d. Use a clean medicine dropper to suck up some urine from the jar. Add 20 drops of the urine to the top of the mud, spread out evenly across the mud’s surface. Note: 20 drops equals approximately 1 mL, so you are adding a total of 1 mL of urine to the MFC.

e. Wait 5 minutes to let the urine soak into the mud a little. (If you immediately put the cathode back on the mud, the cathode will likely soak up much of the urine.)

f. Then assemble the MFC exactly as you put it together before, following the instructions from the “Setting Up the Microbial Fuel Cell” section above to make sure that the wires are twisted together properly and everything is reconnected to the hacker board correctly.

i. Specifically, this will be following steps 6–7, 9–10, and 15–25 from the previous section.

ii. Do not get any mud on the top of the cathode. If you do, carefully wipe it off, being careful not to grind it into the cathode.

8. Starting the day after you add the urine, repeat steps 1–5 each day until it looks like the power output (the peak power) is stabilizing again (as described in step 6). Shortly after it stabilizes, the power output may then clearly change again.

a. Take these measurements at the same time every day.

b. For each day, make a data table like Table 2, above, in your lab notebook to record your results and use them to determine the peak power. Note: It is possible that the resistor you use to determine the peak power will change slightly. Make a note of this in your lab notebook if it happens.

c. Depending on the exact conditions of your experiment—which can be affected by the soil you use and the urine used—the power output could take anywhere from several days to over a week to stabilize after adding the urine.

i. When the power output is stabilized, the peak power may not change by more than about 0.5 µW to 15 µW for at least three days in a row. How much the power varies when it is “stabilized” can depend on the amount of power being produced by the MFC:

1. If the power output is relatively small (<100 µW): The change in power when it is stabilized may be about 0.5 µW, but do not worry if your powers changes by a little more than this (such as by 1 µW or 2 µW).

2. If the power output is large (>100 µW): The change in power may be larger when it is stabilized, such as changing by 10 µW to 40 µW (or even more) from day to day.

ii. Overall, if it has been about two weeks after adding the urine and the peak power has not been steadily decreasing or increasing each day for at least the last week, then it has probably stabilized enough.

iii. After it has stabilized, the power output may then clearly change again (steadily decreasing or increasing each day).

iv. Tip: Making a graph of your data as you collect it may help you see if the power output is stabilizing. If you do this, put the days on the x-axis and the power output (peak power) on the y-axis. Does the peak power appear to be stabilizing?

v. The time between LED blinks should also stabilize.

Analyzing Your Results and Continuing Explorations

1. Make two graphs of your data, one showing how the power output changed over time and one showing how the frequency of LED blinks changed over time.

a. For the graph showing power output over time, put the number of days after setting up the MFC on the x-axis and the peak power output (in µW) on the y-axis.

b. For the graph showing the frequency of LED blinks over time, put the number of days after setting up the MFC on the x-axis and the blinks per second on the y-axis.

i. If you recorded the time between blinks in your data table, convert this to blinks per second by taking the data for the average seconds between blinks that you collected each day and calculate what 1 divided by this number is. For example, if your LED blinked an average of once every 15 seconds, 1 divided by 15 is 0.067, which is the number of blinks per second it made.

2. Analyze your graphs.

a. What happened to the power output and frequency of the LED blinks the day after adding urine? Was there an increase or decrease in power output? How large of a change was it?

b. How quickly did the measurements stabilize after adding urine? When they stabilized, were they higher or lower than they were originally, before adding the urine?

c. When was the power output and blinking frequency the highest? What was the peak power at this time?

d. Based on your results, do you think it would be feasible to use urine (and/or other human waste) to help generate power? Why or why not?

3. At this point in your experiment, there are several ways to continue your explorations. Here are a few starting points:

a. You could try repeating the entire experiment at least one more time. Is the change in power similar each time?

b. You could try adding 1 mL of urine each time the MFC stabilizes (or right when the power output starts to change after it has stabilized). Is there a change in power each time the urine is added? Is there a point at which additional urine does not change the power output?

c. You could repeat the entire experiment, but this time use a larger amount of urine (such as 7 mL). Does the size of the initial amount of urine affect the power output? If so, how?

Variations

- In this science project, you tested how the addition of urine affects the power output of the MFC, but other factors may affect and improve the power output as well. Investigate other factors, such as temperature or the addition of other substances, like salt, sugar, or cow manure. Develop a well-reasoned hypothesis for what you think will happen when this factor is changed and create a way to test it. How does changing other factors affect the MFC’s...
power output? Can you change something that greatly improves the MFC's power output? If your MFC is generating between 80 μW and 199 μW, it is doing really well, and if it is generating 200 μW or more, it is doing amazingly well!

Hint: You may want to look into what the soil bacteria (discussed in the Introduction) like to eat and the environments they thrive in.

- An unusual potential application for MFCs is using them to power medical devices that are implanted in a person. It is possible that the MFCs could run using sugar and oxygen from the person's blood. This is appealing because MFCs can run for a very long time, unlike batteries that would need to be replaced more often. You could investigate how well adding something similar to blood, such as blood meal (a plant fertilizer), affects the power output of the MFC. For more information on this type of application, see page 903 of this scientific paper:


- How well do different topsoils work in the MFC? Try collecting some different types of soils from different locations (such as from a yard or park compared to the bottom of a stream), or purchasing different soils. Test the soils, one at a time, over a set period of time. Which soil is best, resulting in the MFC generating the most power? Which soil is worst? If multiple soils work well, what do they have in common? What factors do you think help make a soil "good" or "bad" for an MFC?

Note: Carefully clean the MFC between testing different soils. To do this, we recommend using tap water to rinse the electrodes while gently rubbing them (with gloves on) until the dirty water runs clear. Also completely rinse out the vessel with tap water. See the end of the Frequently Asked Questions for details.

Note: If you use a soil with perlite, Styrofoam balls, or vermiculite pieces, strain these particles out before using the soil, as they may damage the MFC or severely inhibit bacterial growth.

- What is the lifespan of the MFC you tested in this science project? If you want to test a long-term science project, you can try this out. The MFC may produce power for years (as long as the MFC stays sealed and moist). But exactly how long will it keep reliably producing power? Does the power output slowly decrease over time, or does it abruptly stop? Can you see a decline long before the MFC completely stops? Can you do something to make it have a longer lifespan?

- How does adding urine to the MFC, as you did in this science project, compare to adding nothing to the MFC and just letting it continue to run as you originally set it up? To try this out, you can purchase a second MFC as a control to run at the same time as the one that you add urine to, or alternatively you can run the original MFC again after your urine trial but only add topsoil to it the second time. How does the power output of the MFC that has no urine added compare to the one that you added urine to?

Note: Carefully clean the MFC between testing different soils. We recommend using tap water to rinse the electrodes while gently rubbing them (with gloves on) until the dirty water runs clear. Also completely rinse out the vessel with tap water. See the end of the Frequently Asked Questions for details.

For additional ideas focusing on the electronics aspects of the microbial fuel cell, see the Science Buddies science project Turn Mud into Energy with a Microbial Fuel Cell — and a Dash of Salt! (http://www.sciencebuddies.org/science-fair-projects/project_ideas/Elec_p071.shtml) and Its Make It Your Own section (http://www.sciencebuddies.org/science-fair-projects/project_ideas/Elec_p071.shtml#makeityourown).

For additional ideas focusing on using human urine as a resource or other waste products to create energy, see these related Science Buddies science project ideas:

- Growing Great Gardens: Using Human Urine as a Fertilizer (http://www.sciencebuddies.org/science-fair-projects/project_ideas/Pandio_p046.shtml)
- From Trash to Gas: Biomass Energy (http://www.sciencebuddies.org/science-fair-projects/project_ideas/Energy_p027.shtml)

Related Links

- Science Fair Project Guide (http://www.sciencebuddies.org/science-fair-projects/project_guide_index.shtml)
- Other Ideas Like This (http://www.sciencebuddies.org/science-fair-projects/search.php?F=world&f=EnvSci_p081)

If you like this project, you might enjoy exploring these related careers:

Environmental Scientist

Have you ever noticed that for people with asthma it can sometimes be especially hard to breathe in the middle of a busy city? One reason for this is that the exhaust from vehicles, cars, buses, and motorcycles add pollution to our air, which affects our health. But can pollution impact more than our health? Cutting down trees, or deforestation, can contribute to forest fires, which carry off valuable topsoil. But can erosion alter more than the condition of the soil? How does oil spill harm fish and aquatic plants? How does a population of animals interact with its environment? These are questions that environmental scientists study and try to find answers to. They conduct research or perform investigations to identify and eliminate the sources of pollution or hazards that damage either the environment or human and animal health. Environmental scientists are the stewards of our environment and are committed to keeping it safe for future generations. Read more (http://www.sciencebuddies.org/science-fair-projects/science-engineering-careers/EnvSci_environmentalscientist_c001.shtml)

Microbiologist

Microorganisms (bacteria, viruses, algae, and fungi) are the most common life-forms on Earth. Help us digest nutrients; make foods like yogurt, bread, and olives; and create antibiotics. Some microbes also cause diseases. Microbiologists study the growth, structure, development, and general characteristics of microorganisms to promote health, industry, and a basic understanding of cellular functions. Read more (http://www.sciencebuddies.org/science-fair-projects/science-engineering-careers/Microbio_microbiologist_c031.shtml)

Fuel Cell Engineer

Most of the world's energy comes from fossil fuels. However, the amount of fossil fuels is finite, and many people are concerned about where our energy will come from in the future. We can turn to alternative, renewable sources of fuel, such as our sun (solar energy) and the winds (wind energy). But what happens when the sun doesn't shine or the winds don't blow? Would we be stuck? Well, that is where the fuel cell comes in. A fuel cell is an electrochemical device that generates electricity through a reaction between a fuel, like hydrogen, and an oxidant, like oxygen. This reaction produces few greenhouse gases or water vapor. The job of the fuel cell engineer is to design new fuel cell technology that improves the reliability, functionality, and efficiency of the fuel cell. Do you like the idea of using your math and science skills to work on mankind's future energy needs? Then start "fueling your future" and read more about this career. Read more (http://www.sciencebuddies.org/science-fair-projects/science-engineering-careers/Energies_fuelcellengineer_c031.shtml)

Electrical & Electronics Engineer

Just as a potter forms clay, or a steel worker molds molten steel, electrical and electronics engineers gather and shape electricity and use it to make products that transmit power or transmit information. Electrical and electronics engineers may specialize in one of the millions of products that make or use electricity, like cell phones, electric motors, microwaves, medical instruments, airline navigation system, or handheld games. Read more (http://www.sciencebuddies.org/science-fair-projects/science-engineering-careers/Elec_electricalandelectronicsengineer_c031.shtml)

Credits

Teisha Rowland, PhD, Science Buddies

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This project was adapted from a Keego Technologies LLC.™ kit.

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Contact Us

If you have purchased a kit for this project from Science Buddies, we are pleased to answer any question not addressed by the FAQs on our site. Please email us at help@sciencebuddies.org after you have checked the Frequently Asked Questions for this PI at http://www.sciencebuddies.org/science-fair-projects/project_ideas/EnvSci_p061.shtml#help

In your email, please follow these instructions:

1. What is your Science Buddies kit order number?
2. Please describe how you need help as thoroughly as possible:

Examples

**Good Question** I'm trying to do Experimental Procedure step #5, "Scrape the insulation from the wire..." How do I know when I've scraped enough?

**Good Question** I'm at Experimental Procedure step #7, "Move the magnet back and forth..." and the LED is not lighting up.

**Bad Question** I don't understand the instructions. Help!