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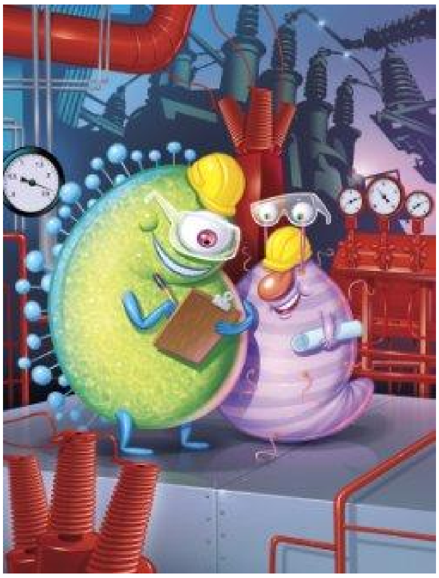
Microbial Moxie

Bacteria-based fuel cells provide power

Aimee Cunningham

Anglers casting their lines last September into a Montana creek may not have noticed, but a diminutive power plant was churning away in a shallow spot by the shore. The device generated electricity—with the aid of river-dwelling bacteria—to power a sensor system that wirelessly transmitted data to a receiver about 10 miles away. The underwater device, small enough to fit in a person's hand, was the first attempt to power such a system with a microbial fuel cell.

Microbial fuel cells take advantage of the long-known fact that some microbes produce electricity when they break down organic matter. Only recently, however, have scientists discovered that they could tap into this energy in a practical manner and use it as an alternative energy source.



MICROBIAL POWER PLANT. Bacteria that release electrons during their metabolism are the workers in microbial fuel cells, devices that could someday power remote sensors, wastewater-treatment plants, and portable devices.
Dean MacAdam

Today, microbial fuel cells are being explored primarily as a power source for remote sensors and for wastewater treatment, in which the bacteria that break down sewage generate sufficient electricity to run the treatment plant. But the role that the fuel cells could eventually play will depend on whether certain limitations can be overcome.

For starters, the prototype fuel cells don't produce power fast enough to do much more than juice up a clock. "These systems can be very efficient, but they are slow, in terms of the rate that organic matter is converted to electricity," says microbiologist Derek Lovley of the University of Massachusetts at Amherst.

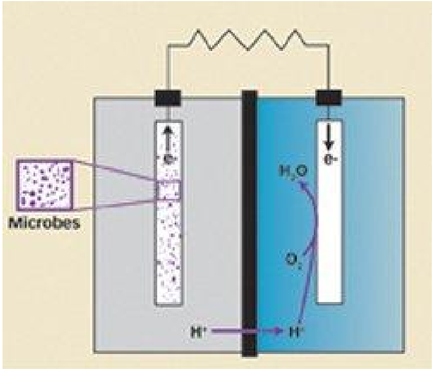
Still, the potential payoff is too good to pass up. "Once the device is constructed, it's basically working for free," says Zbigniew Lewandowski of Montana State University in Bozeman, whose group set up the Montana-stream system.

Electrifying events

Among the entities zipping along a microbe's metabolic pathways are electrons, which hop from molecule to molecule in the course of various biochemical reactions. When microbes metabolize organic matter in aerobic conditions, they tend to deposit these electrons onto oxygen, an exchange that provides the microbes with chemical energy.

By putting the bacteria in a microbial fuel cell under anaerobic conditions—that is, with no oxygen present—researchers "are stealing some of the energy and harvesting it as electricity," says Lovley.

A basic microbial fuel cell has two chambers, one containing an anode and the other a cathode. The microbes reside under anaerobic conditions on the anode. There, they break down their food, such as glucose, acetate, or the organic compounds in wastewater. Lacking oxygen, these microbes transfer their electrons to the anode. This exchange gives the microbes a small amount of energy to fuel their growth.



POWER BASICS. Microbes on the anode (in left chamber) deposit electrons (e–), which travel along a wire to the cathode (in right chamber). Protons (H+) move through a selective membrane from anode's chamber to cathode's chamber, where they combine with electrons and oxygen to form water.
E. Roell

A wire connects the anode to the cathode. The cathode chamber harbors oxygen dissolved in water. The electrons travel to the oxygen, generating a current as they move from one chamber to the other.

There is also a selective membrane between the two chambers that enables protons, another product of the microbe's biochemical reactions, to travel from the anode to the cathode. In the cathode chamber, the electrons and protons combine with oxygen to form water.

A different type of fuel cell can operate in a river or a lake. Local microbes colonize an anode stuck into the oxygen-poor sediment. Their electrons travel along a wire connected to a cathode suspended in the overlying water, which contains oxygen (SN: 7/13/2002, p. 21: Available to subscribers at http://www.sciencenews.org/articles/20020713/fob5.asp).

While electrifying, all this microbial activity doesn't yet translate into much power. There may be room for improvement in both the materials and the microbes.

For the anode, many researchers use a form of carbon called graphite, which conducts electrons. But "that may not be the best material to interact with whatever protein it is that's transferring electrons to the [anode] surface," says Lovley.

At the cathode, meanwhile, the transfer of the electrons to oxygen is slow. Researchers have used various catalysts and electron shuttles to improve cathode performance, but they tend to be expensive or toxic.

The microbes themselves are another limiting factor. Although some microbes, when deprived of oxygen, will ferry their electrons to an anode, says Lovley, they "aren't optimized for electricity production—they've had no evolutionary pressure to do this."

To speed electron transfer, Lovley's group is studying bacteria from the family Geobacteraceae, originally discovered in the sediment of the Potomac River in Washington, D.C. When these common microbes break down organic matter, they transfer their electrons to iron oxides, which makes them adept at using an electrode as their final electron acceptor.

By comparing electrode-dwelling and natural colonies of Geobacteraceae, Lovley's group has identified genes that are more active in the electrode-dwellers and thus likely to be important for transferring electrons to an electrode. In an attempt to increase energy production, the team is now genetically engineering Geobacteraceae to produce more of their electron-transferring proteins.

Wastewater wattage

Researchers with an eye toward a self-sustaining wastewater-treatment plant are moving forward with prototype microbial fuel cells, says Korneel Rabaey of Ghent University in Belgium.

About 5 percent of U.S. electricity production goes into water and wastewater treatment, says Bruce Logan of Pennsylvania State University in University Park. His team was the first to demonstrate that a microbial fuel cell could produce electricity as it cleans household wastewater (SN: 3/13/2004, p. 165: http://www.sciencenews.org/articles/20040313/fob5.asp).

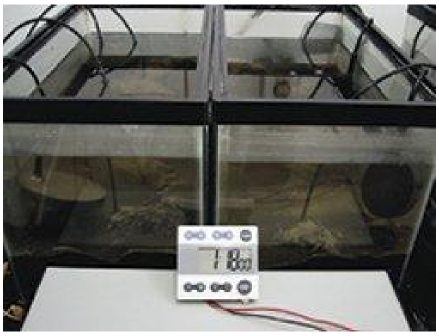
Along with providing energy savings for developed countries, microbial fuel cells could "revolutionize how we do wastewater treatment" worldwide, Logan says. He points out that 2 billion people live in areas without wastewater-treatment plants.

An inherent difficulty with using domestic wastewater as a raw material, however, is that it contains a lot of matter that biodegrades slowly, says Rabaey. This decreases the rate at which the microbes can pass along their electrons, so it reduces the power they produce. Also, the systems need to deal with a continuous stream of wastewater because it would be impractical to hold wastewater in a tank, notes Largus T. Angenent of Washington University in St. Louis.

In the July 15, 2005 *Environmental Science & Technology (ES&T)*, Angenent and his colleagues described a microbial fuel cell in which the wastewater flows from the bottom to the top of a tubular system. The team fed the fuel cell continuously with artificial wastewater—a sucrose solution spiked with nutrients and metals—for 5 months.

Rabaey and his colleagues reported another tubular-fuel cell design in the Oct. 15, 2005 *ES&T*. The anode chamber contains porous, graphite granules that are 1.5 to 5 millimeters in diameter and packed to permit liquid to flow through channels among them. Microbial biofilms cover the granules, which serve as the anode surface.

The researchers tested three such fuel cells, each fed continuously for about a year with a solution of a different raw material: acetate, glucose, or household wastewater. The acetate-fed fuel cell generated 90 watts per cubic meter (W/m^3), while the glucose consumer put out 66 W/m^3. The wastewater-fed fuel cell achieved a maximum of 48 W/m^3.



BUG TIME. Microbes from the family Geobacteraceae, living in sediments collected from Boston Harbor, provide power to a digital laboratory clock.
Lovley

Neither Rabaey's laboratory system nor Angenent's system is self-sustaining. Both rely on a regular supply of a toxic electron shuttle, which gets used up as it acts in the cathode. Logan's systems use an expensive platinum catalyst to speed the final transfer of electrons to oxygen. In the Jan. 1 *ES&T*, his team describes much cheaper metal catalysts containing little or no platinum.

All the researchers report that as they make adjustments to their designs, they continue to increase the power outputs of their laboratory systems. But much work needs to be done to make such systems economically feasible, increase the amount of electricity harvested from the organic matter, and prove that the systems can handle the volumes of a large treatment plant.

Currently, Logan's laboratory system generates 16 W/m^3 as it breaks down wastewater. His goal is 100 W/m^3 in a sustainable system, which he estimates could produce 0.5 megawatt of energy, enough to power a treatment plant for a town of 100,000.

Sensor success

Powering a remote temperature sensor also requires technical advances to boost the meek wattage now generated by the microbes.

Microbial fuel cells are an ideal solution for remote sensors, says Lewandowski, because they avoid the logistical difficulty of changing batteries in dense wilderness areas or at the bottom of the ocean. Future microbial fuel cells might chug along for years, opening the way to a "drop-it-and-forget-it type of probe," he says.

When Lewandowski's group set up its microbial fuel cell in Hyalite Creek near Bozeman, Mont., the scientists adopted a fuel cell design that differs from the basic approach. The anode is not stuck in the sediment, and the microbes reside on the cathode instead of on the anode. The electrons carrying the current come not from the microbes but directly from the anode, a slab of magnesium alloy, as it slowly corrodes in the water and releases magnesium ions and electrons.

The microbes, which settle on the stainless steel cathode, capture manganese ions present in the water and oxidize them to form encrustations of manganese oxide on the cathode's surface. The electrons then reduce some of the manganese oxides, switching them back to manganese ions, and the cycle continues.

To demonstrate that the fuel cell could power a wireless system, Lewandowski's group housed electric components in a nearby shed. The creek-based fuel cell supplied the entire system with electricity.

By the team's design, energy generated by the fuel cell built up in a capacitor and discharged in short bursts when needed, as a camera flash does. The team also included a component called a DC-DC converter to increase the voltage potential. The converter relayed power to a transmitter, which sent the sensor's water temperature readings wirelessly to a receiver roughly 10 miles away. In the July 1, 2005 *ES&T*, the researchers described the scheme, which ran in the field until September of last year.

Lewandowski's group plans to incorporate into its system a longer-lasting, traditional anode—one that uses electricity-producing microbes on a noncorroding surface—and the researchers say they'd like to scale up the system to power multiple sensors.

Where to?

While researchers say that microbial fuel cells hold great promise, they don't expect them to become major power producers. "You're not going to run an entire city" with them, says Angenent.

But the technology could become a convenient power source for portable electronics, says Lovley. He notes that powering a cell phone during continuous talk mode would require a power-production rate 10 to 100 times as great as that of current microbial fuel cell technology, but he thinks that increase is feasible. With such a system, "10 grams of sugar could theoretically produce power for nearly 2 days of talk time," he says.

Lovley also suggests that the technology could be beneficial for developing countries that don't have well-established power grids.

"There are probably a lot of new opportunities to use this technology—we're still trying to figure out what those are," says Logan. "As it develops and we understand the economics, we will be able to find and define systems. ... I see a future with lots of [energy] technologies, and there is room for this technology."

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Sources:

Largus T. Angenent
Department of Chemical Engineering
Washington University
St. Louis, MO 63130

Zbigniew Lewandowski
Department of Civil Engineering
Montana State University
Bozeman, MT 59717

Bruce E. Logan
Department of Civil and Environmental Engineering
Pennsylvania State University
University Park, PA 16802

Derek R. Lovley
Department of Microbiology
University of Massachusetts
Amherst, MA 01003

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