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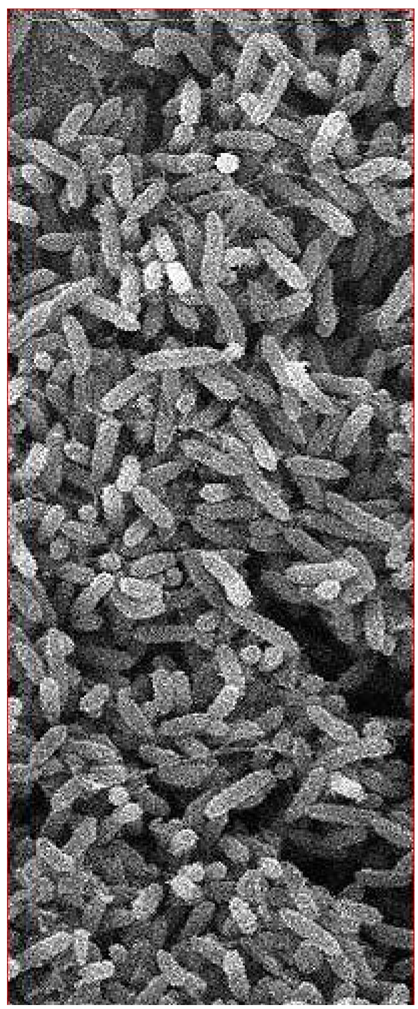
Bact to basics

Need energy? So do bacteria. Like every other form of life, these single-celled critters must gather energy and find a way to use it. But could bacteria help get us out of the vise that that has clamped humanity between energy shortages and global warming? Two new developments give a glimmer of hope.



Like yeast, bacteria can convert glucose (simple sugar) into ethanol, a trick that wine-makers and brewers have been using since the dawn of civilization. These days, baker's yeast Saccharomyces cerevisiae converts glucose into ethanol, powering about half of the auto fleet in Brazil.

Brazil is awash in glucose-rich sugar cane. But in many places, including the United States, cellulose is more abundant than glucose, as it's found in the dregs after crops are harvested. Currently, biofuel companies make ethanol from cellulose in two steps. First, enzymes from fungi convert it into glucose. Second, bacteria ferment the glucose into alcohol.

In May, Susana Romero, a graduate student at Mexico's National Autonomous University (UNAM), told the American Society for Microbiology about a genetically engineered

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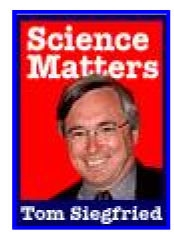

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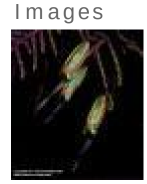

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Microbiology about a genetically engineered form of the bacteria Bacillus subtilis, that can ferment 88 percent of glucose into ethanol.

Geobacter bacteria living on a graphite electrode. Geobacter must dispose of electrons to live; those electrons are picked up on the electrode, forming an electric current. Courtesy Geobacter Project

That's only slightly below the level industrial fermenters get while using bacteria to make ethanol for car fuel. But B subtilis has some advantages: This soil bacterium is safe enough to be used in food factories, she says, and it is already used to biodegrade detergent spills. But it does not normally make ethanol, so Romero had to add two genes from another bacterium.

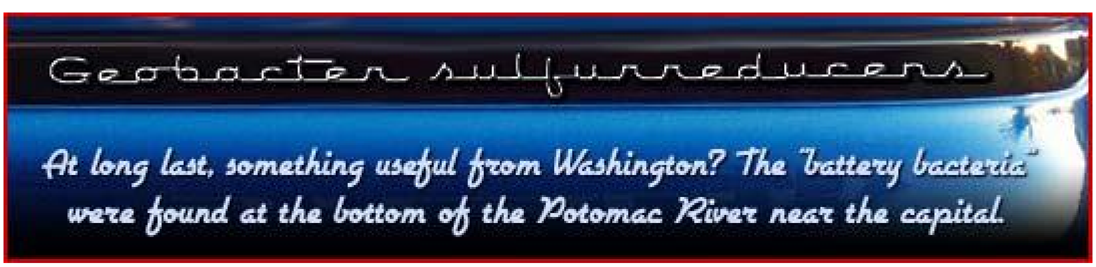
Having forced B subtilis to do what doesn't come naturally, Romero wants to give the bug another talent. The fungal enzymes now used to degrade cellulose for ethanol are expensive, she says. Why not create one bug that could both convert cellulose into glucose, and then ferment glucose into ethanol? "We think we can produce a cellulase enzyme that can break down cellulose into glucose, and obtain a microorganism that will be able to degrade cellulose, and transform it into ethanol." That's called getting a two-fer.

Bacteria battery

Instead of using bacteria to make fuel, what about using them to make electricity? The ability of bacteria to make an electric current has been known since 1910, but only in the past couple of years has the microbial fuel cell been taken seriously. (Fuel cells, you'll recall, convert a fuel's chemical energy into electricity, without burning anything.)

Microbial fuel cells use a variation on a common metabolic process that oxidizes carbon and reduces oxygen. As energy is released, the atoms bond, making carbon dioxide.

Electrons are a byproduct of this process, says Derek Lovley, a professor of microbiology at the University of Massachusetts in Amherst, and the reaction grinds to a halt unless the electrons can be dumped. In aerobic organisms like people and plants, the electrons are transferred onto oxygen, forming water. But anaerobic organisms, including many bacteria, must find an alternate "home" for the extra electrons.



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Enter Geobacter, a type of bacteria that Lovley discovered in 1987 in the mud of the lovely Potomac River near Washington, D.C. (a historic first: Something Good from Washington!). Now widely used for biological cleanups, the bacterium "evolved to transfer electrons onto iron minerals," says Lovley. "Most soils are depleted of oxygen, so they can use iron the same way we use oxygen in metabolism."

A wiring problem?

While oxygen can get inside a cell, iron minerals cannot, so Geobacter "had to evolve a strategy to get the electron outside," Lovley says. Geobacter transports those electrons on ultra-fine structures called pili. These bio-wires are just three to five nanometers in diameter, and 10,000 to 20,000 nanometers (10 to 20 microns) long. These extraordinarily slender protein structures are conductive, also a first. "Such long, thin conductive structures are unprecedented in biology," said Lovley. "This completely changes our concept of how microorganisms can handle electrons."

Bacteria in these flasks are making enough current to run this calculator. Courtesy Geobacter Project

Pili normally serve as attachment structures, used to move a microbe along a surface through "twitching mobility," Lovley says. "They extend and retract, and this moves the bacterium along surfaces."

At first, Lovley says he, "assumed Geobacter was using the pili as an attachment to iron oxide, but we jokingly called them wires." Then a study with an atomic force microscope proved that the pili really were conducting electrons. The actual mechanism remains a mystery, Lovley told us.

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Selling the cell

After discovering that Geobacter can make electricity, Lovley's group worked to improve the design and output of the fuel cell. "The bacterial cells started stacking up into a thick biofilm," Lovley said. This slippery goo of bacteria makes the grut that builds up on your teeth.

With the biofilms present, power output increased 10-fold, and all the bugs were contributing to the output. "The interesting thing was that the cells at substantial distance from the anode were just as efficient in electricity production as the closer cells," Lovley said, "so there had to be long-range electron transfer."

The answer appeared in the pili, which were apparently conducting electrons to the graphite electrode of the fuel cell. To prove that the pili are conducting, his research group used genetic engineering to knock out genes for the pili. The cells quit producing nanowires, and stopped generating juice. When the genes were restored, generation resumed.

Geobacter sulfurreducens cells make pili (arrows). These tiny structures conduct electricity.
Courtesy Gemma Reguera and Dale Callaham, Geobacter Project

Once electrons start moving without anything burning, people who are psyched about alternative energy tend to pay attention, but these bacteria work a whole lot slower than a power plant. Already, one test microbial fuel cell is being used to power a remote sensor system in Montana. Later, they may be used to power remote villages in the developing world. Ample organic fuel is also available is in wastewater treatment plants, which use oodles of electricity to drive pumps.

Although power output is still low, advances are expected, says Lovley, who heads the Geobacter Project at UMass. One reason for optimism, he says, is that evolution has not "selected" the bacteria for optimum electric production, so mutants may already exist that give more output. His research group is using a strategy called "directed evolution" to select and multiply the best strains.

In environmental terms, the microbial fuel cell is close to perfect, since it oxidizes organic carbon, making energy without pollution. The carbon dioxide will be recycled into plants that could become more fuel, so the system won't contribute to global warming. And the bacto-gadget works, Lovley says. "It's a self-sustaining, perpetual system, with long-term reliability. One has already been going in the lab for a year-and-a-half with exactly the same power output. We just need to supply the fuel, which is basically anything that the microorganism can degrade."

-- David Tenenbaum

Bibliography

• Bug Juice: Harvesting Electricity with Microorganisms, Derek R. Lovley, in press, Nature Reviews Microbiology.

• "It's Electric!"