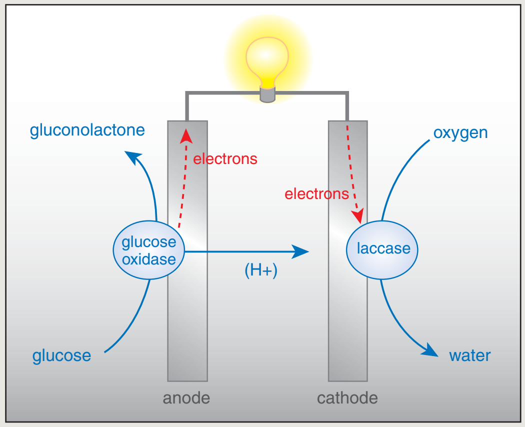
Biofuel Cells

While companies are battling to shrink fuel cells down to cell phone size, nature has already done them one better. Enzymes in creatures from bacteria to people extract energy from compounds such as glucose to power life. Now researchers are looking to borrow a page from biology's manual to create rice grain–sized fuel cells that run on chemicals inside our bodies. Such cells, they say, could someday power futuristic implantable sensors that monitor everything from blood glucose levels in diabetics to chemicals that signal the onset of heart disease or cancer.

Researchers can already make glucose-detecting sensors as small as a millimeter across. "But you cannot make a submillimeter-sized battery at a reasonable cost," says Adam Heller, a chemical engineer and biofuel cell pioneer at the University of Texas, Austin. "That's where we see the use for miniature biofuel cells."

Biofuel cells are much further from commercial development than their larger cousins. But recent progress has been heady. Last August, for example, Heller and his Texas colleagues reported in the *Journal of the American Chemical Society* that they had created a miniature glucose-powered cell that puts out 600 nanowatts of power, five times the previous biofuel cell record and enough to power small silicon-based microelectronics. Heller's lab has already developed millimeter-sized glucose sensors, which are currently being commercialized by a company called TheraSense in Alameda, California. And the new biofuel cells may one day keep such implantable sensors running for days to weeks at a time.

Like traditional fuel cells, biofuel cells use catalysts at two oppositely charged electrodes to strip hydrogen atoms of their electrons and then combine the leftover hydrogen ions with oxygen to form water (see figure). The siphoned-off electrons are then used to do work. In traditional fuel cells, reactants at the two electrodes are kept apart by a thin plastic membrane. But such membranes would be impractical to make on the size scale of biofuel cells, so Heller and other teams have settled on another approach: They use enzymes to carry out the reactions and tether those enzymes to the two different electrodes to ensure that the proper reactions occur at the right spots. At the negatively charged electrode, or anode, copies of an enzyme called glucose oxidase strip electrons from hydrogen atoms on glucose, converting the sugar molecule to gluconolactone and a pair of hydrogen ions. These ions then travel to the positively charged electrode, or cathode, where an enzyme called laccase combines them with oxygen and electrons to make water. The tethers are made of osmium-containing polymers that ferry electrons between the electrodes and enzymes.



Lifelike. By drawing fuel from the body and processing it with enzymes, researchers hope to build fuel cells that imitate the power plants in living organisms.

Heller's cells do have their drawbacks. Because laccase enzymes typically work best in environments much more acidic than the neutral pH of blood, laccase-based fuel cells implanted in the body likely wouldn't produce much power. "Nature didn't evolve proteins to work with circuitry," says Tayhas Palmore, a chemist at Brown University in Providence, Rhode Island.

But Palmore has been working to improve matters here as well. At a fuel cell conference in Washington, D.C., last month, Palmore reported that her group had used standard molecular biology techniques to reengineer the laccase enzyme so that it retains about 50% of its activity at physiological pH. And Palmore and her colleagues are now working on incorporating the reengineered laccase into a prototype fuel cell that could extract power from circulating fluids such as blood.

All biofuel cells still face considerable challenges, however. Most important, blood and other complex bodily fluids contain numerous compounds that can deactivate or block the enzymes essential to fuel-cell function, causing them to stop working within hours or days. But if researchers can improve their stamina, biofuel cells could pave the way to a new generation of implanted devices powered by the body itself.

–R.F.S.

strip them of their electrons. The electrons are siphoned off to an electrical circuit where they are used to do work. The leftover protons, meanwhile, are drawn through the electrolyte—typically a plastic mesh that blocks free electrons from passing to the other side—to the positively charged electrode (cathode). There they combine with electrons returning from the circuit and oxygen molecules from air to form water, which is usually vented off as steam.

Future co-pilot? Fuel cells will have to get much smaller to replace batteries in devices such as PDAs.

Although such hydrogen-consuming fuel cells can be extremely efficient, pure hydrogen must be stored in pressurized tanks—a drawback that makes it a "nonstarter" as the fuel source in mini fuel cells, says Kurt Kelty, who directs business development at Panasonic's Battery Research and Development Center in Cupertino, California. The alternative most micro fuel cell companies prefer is methanol. This liquid fuel has a high energy density and is plentiful and cheap, explains Mark Hampden-Smith, a vice president for catalyst supply company Superior MicroPowders in Albuquerque, New Mexico. The catalysts used in methanol fuel cells can also strip hydrogen atoms from methanol without the need for another step. What's more, he explains, in a fuel cell methanol breaks down into CO_2 and water vapor without any leftover byproducts that could foul up the fuel cell over time.

Reactions and regulations

Getting methanol fuel cells to work at high efficiency, however, hasn't been easy. One problem lies in the fuel itself. Methanol can cross through the plastic electrolyte to the cathode, where it will block the reactions that form water, thus reducing the overall efficiency of the cell. To lessen the problem, researchers often dilute the methanol with water. Yet this solution creates problems of its own, as it tends to lower the overall power output of the cell.

Numerous groups are working overtime