Working Class Bacteria

SCIENTISTS OFTEN USE SMALLER SCALE SYSTEMS TO CONDUCT EXPERIMENTS. SEEN IN CLOSE UP IS A BUNDLE OF HOLLOW FIBER MEMBRANES USED IN BRUCE RITTMANN'S MEMBRANE BIOFILM REACTOR.

If we can think like the microorganisms, then we can create a system that works for the microorganisms so that they can be put to work for us

::: by Linley Erin Hall

Each day brings more news about the state of our environment. Water pollution. Global warming. Disappearing species. Bruce Rittman is one of many researchers at Arizona State University working to find new solutions to long-term environmental dilemmas.

Rittmann is a professor of civil and environmental engineering. During his early college years he got interested in the environment, particularly water pollution, after a summer job at a local wastewater treatment plant. Today he is director of the Center for Environmental Technology at ASU's Biodesign Institute. He works on a number of projects that use naturally occurring bacteria to clean up waste.

"Bruce's research has always had direct application to our most basic societal needs. We all want clean water and clean air. And we want to make the optimal use of limited resources," says Paul Johnson, executive dean at ASU's Ira Fulton School of Engineering. "Imagine a more sustainable future in which our wastes are detoxified and converted to useful products and energy. Imagine when all our water supplies can be purified for use. Bruce's research is leading us there."

Rittmann and his colleagues are working to develop a membrane biofilm reactor. The device uses microorganisms and hydrogen gas to remove contaminants from water. Another work in progress is focused on the development of an efficient microbial fuel cell. This device will use bacteria to extract energy from organic waste and turn it directly into electricity.

"We do research so that we can understand the microorganisms and think like the microorganisms," Rittmann says. "If we can think like the microorganisms, then we can create a system that works for the microorganisms so that they can be put to work for us."

Those microorganisms are working hard.

Some bacteria use materials that we consider pollutants as food or fuel for their biological processes. During the process of extracting what they can use, microorganisms sometimes convert pollutants into less harmful molecules.

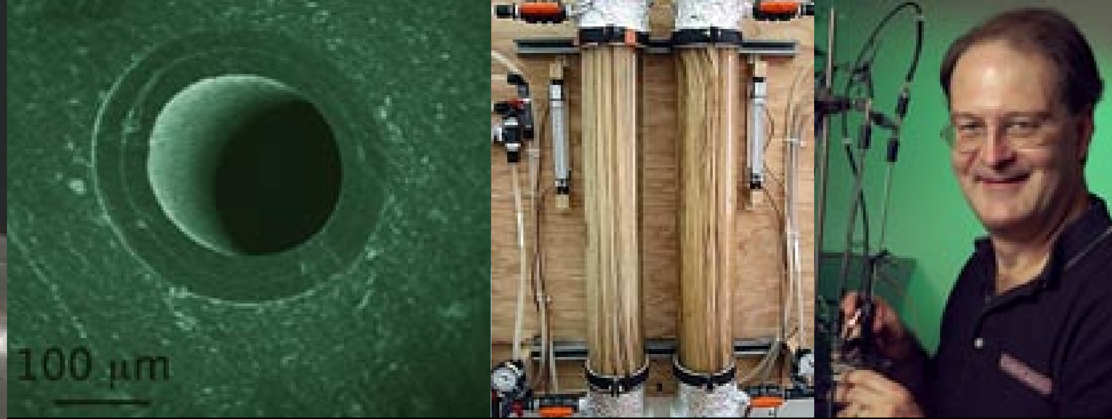
Often, however, bacteria need a source of electrons to make use of pollutants. Electrons are the negatively charged components of atoms that make up all matter. Hydrogen gas is an excellent electron donor source.

About eight years ago, Rittmann had an idea for a device that would use hydrogen and microorganisms to convert contaminants in water into harmless chemicals. But he had a problem. "Nobody believed me," Rittmann explains. "I had a great idea. I knew it would work. But it was hard to get research funding. Of course, today, membrane biofilm reactors have become very popular."

Biofilms are thin layers of bacteria that build up on surfaces. In Rittmann's membrane biofilm reactor, the layer of microorganisms forms on the outside of a hollow fiber. The fiber is made of a membrane, a thin sheet of material that allows some substances to pass through. Others cannot.

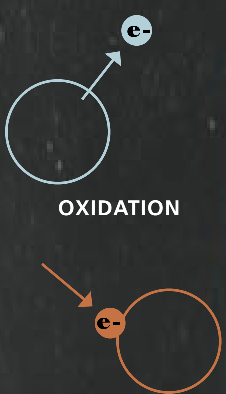
The exterior of the fiber is immersed in polluted water, while the interior is filled with hydrogen. The gas penetrates through the membrane to the biofilm. The bacteria then use the hydrogen's electrons to convert harmful compounds into safe ones.

Scientists in Rittmann's lab have tested the biofilm reactor with more than a dozen different contaminants. The bacteria quickly cleaned up every single one. "It's not surprising that it works. What surprised us is how fast it works," Rittmann says. "The biofilm usually begins processing waste within a couple of hours. It reaches peak efficiency only a few hours or days after that."



Bruce Rittman (right) tested two pilot-scale membrane biofilm reactors in La Puente, Calif. Each column is about 5 feet tall and has about 7,000 fibers. (center) At the time the picture was taken, groundwater containing nitrate and perchlorate was treated by these systems operating in series. The water first passed up through the one on the right and then up through the one on the left. The brown color on the fibers is visual evidence of the biofilm that formed. (Above left) A scanning electron microscope image shows a fiber in cross section. The inside of the fiber is hollow. Outside the fiber is the glue. John C. Phillips photo

Redox Reactions



The membrane biofilm reactor and the microbial fuel cell are based on simple scientific principles. Both devices work using a class of chemical reactions that involve the transfer of electrons from one molecule to another.

Everything is made up of atoms. Atoms, in turn, are composed of protons, neutrons, and electrons. The protons and neutrons are bunched together in the center of the atom to form a nucleus. Electrons orbit around the nucleus in a cloud. Some of the electrons in the cloud can be used to make chemical bonds with other atoms. Molecules are the result.

One class of chemical reactions is known as oxidation-reduction. Scientists and chemistry students refer to them as redox reactions. Redox reactions involve a transfer of electrons from one atom to another. Atoms or molecules that lose electrons during a redox reaction are said to be oxidized. Those that gain electrons are reduced.

"The world is full of oxidized materials that are big problems. Reduce those oxidized materials and they are big problems no longer," says Bruce Rittmann, an ASU professor of civil and environmental engineering. Reducing problem materials is the simple idea behind the membrane biofilm reactor developed by researchers in Rittmann's laboratory.

Hydrogen gas is an electron donor; it loses electrons. These electrons react with oxidized contaminants in the water to form reduced compounds that are not dangerous to human health. The microorganisms in the biofilm make this reaction happen.

The situation is a bit different inside a microbial fuel cell. The electron donors are organic materials in waste that is pumped into the fuel cell. The micro-organisms perform half of a redox reaction. They free electrons from the waste compounds. But those electrons are sent through a circuit instead of being immediately transferred to other molecules. This circuit provides power for the device containing the fuel cell.

At the other end of the circuit, the electrons react with oxygen in the second half of the redox reaction. Clean water is the final product. **Linley Erin Hall**

> "All the potential for generating electricity is right there in a pool of wastewater.

So why hasn't anyone done this before?

One reason is because hydrogen can be difficult to work with. Most often, microorganisms use molecules that are dissolved in water. Hydrogen, however, dissolves very poorly. When mixed with oxygen in the air, on the other hand, hydrogen gas creates a combustible atmosphere. Rittmann solved both problems by supplying the gas through the fiber's membrane. The hydrogen doesn't have to be dissolved in the water and transported to the bacteria. It also is kept separate from sources of oxygen.

Rittmann's team has completed one pilot study of the technology. Several more are in the works. The completed pilot study tested some pretty harsh conditions, not all of which were part of the study design. For example, the test site lost power, and no one realized it until the next day. Surprisingly, the membrane biofilm reactor was hardly affected at all.

The ASU researchers also tested harsh methods to clean the membrane. If too much biofilm builds up on the membrane, the reactor becomes clogged, and the contaminants can't reach the biofilm. In almost every case, the biofilm remaining after a cleaning immediately started working again as well as it did before cleaning became necessary.

Other questions remain. Rittmann's group wants to know which bacteria are cleaning up which contaminants. The answers may allow researchers to customize biofilms so that they focus on different types of pollutants. The scientists also want to know how well the bacteria work when multiple contaminants are present. "Of course, many water sources are polluted with multiple contaminants. The membrane biofilm reactor seems to have a major advantage because it can remove many of those contaminants at the same time," Rittmann says.

Rittmann admits that he was stumped when graduate student Andrew Marcus first asked him about doing research on microbial fuel cells. He'd never heard of them. It did not take long for the professor to share his student's enthusiasm for the topic.

Fuel cells generate electricity directly from a source of electrons without a combustion step. First, a chemical reaction removes electrons from the fuel. The electrons travel through a circuit, producing electricity. At the end of the circuit, the electrons react with oxygen to produce water.

Fuel cells are gaining in popularity because they do not involve any combustion, a process that emits a variety of air pollutants. However, most fuel cells use hydrogen as fuel. Hydrogen is currently produced from petroleum, a fossil fuel, rather than from a renewable source.

The beauty of the microbial fuel cell is that it can use organic waste as the fuel. Microorganisms remove electrons from the organic compounds and transfer them to the electric circuit. "Organic wastes that become fuel are a renewable resource that doesn't contribute to net emissions of carbon dioxide," Marcus explains. "If people use organic waste for fuel, they can lower our dependence on fossil fuels that contribute to global warming."

Researchers in Rittmann's lab are testing different types of organic waste to see which ones can be used as fuel. Currently, the waste must be dissolved in water. This means that it isn't as concentrated a fuel source as compressed hydrogen gas.

Because of this fact, microbial fuel cells are unlikely to end up in cars as a future power source. They are best used for situations that don't have a large power demand but need to run for a long time, such as a sensor in a remote area. Rittmann also has funding from NASA to create a microbial fuel cell for future space missions.

"A long-term space mission requires that everything be recycled. You might as well get energy out of it during the process," Rittmann says.

One of the challenges facing Rittmann's group is finding the best materials for building microbial fuel cells. For example, the electrode mediates the transfer of electrons from the bacteria to the circuit. The best electrode should provide as much surface area as possible on which bacteria can grow. However, porous materials with high surface areas generally don't have very good electrical conductivity. Finding a material that balances both needs is crucial.

Marcus is also trying to find the best bacteria to use in the microbial fuel cell. Different types of bacteria are able to remove electrons from organic wastes. But some are much better than others at transferring the electrons to the circuit.

"It's amazing when you think about it. All the potential for generating electricity is right there in a pool of wastewater," Marcus adds. "By creating a good environment for bacteria, we can harness that resource."

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