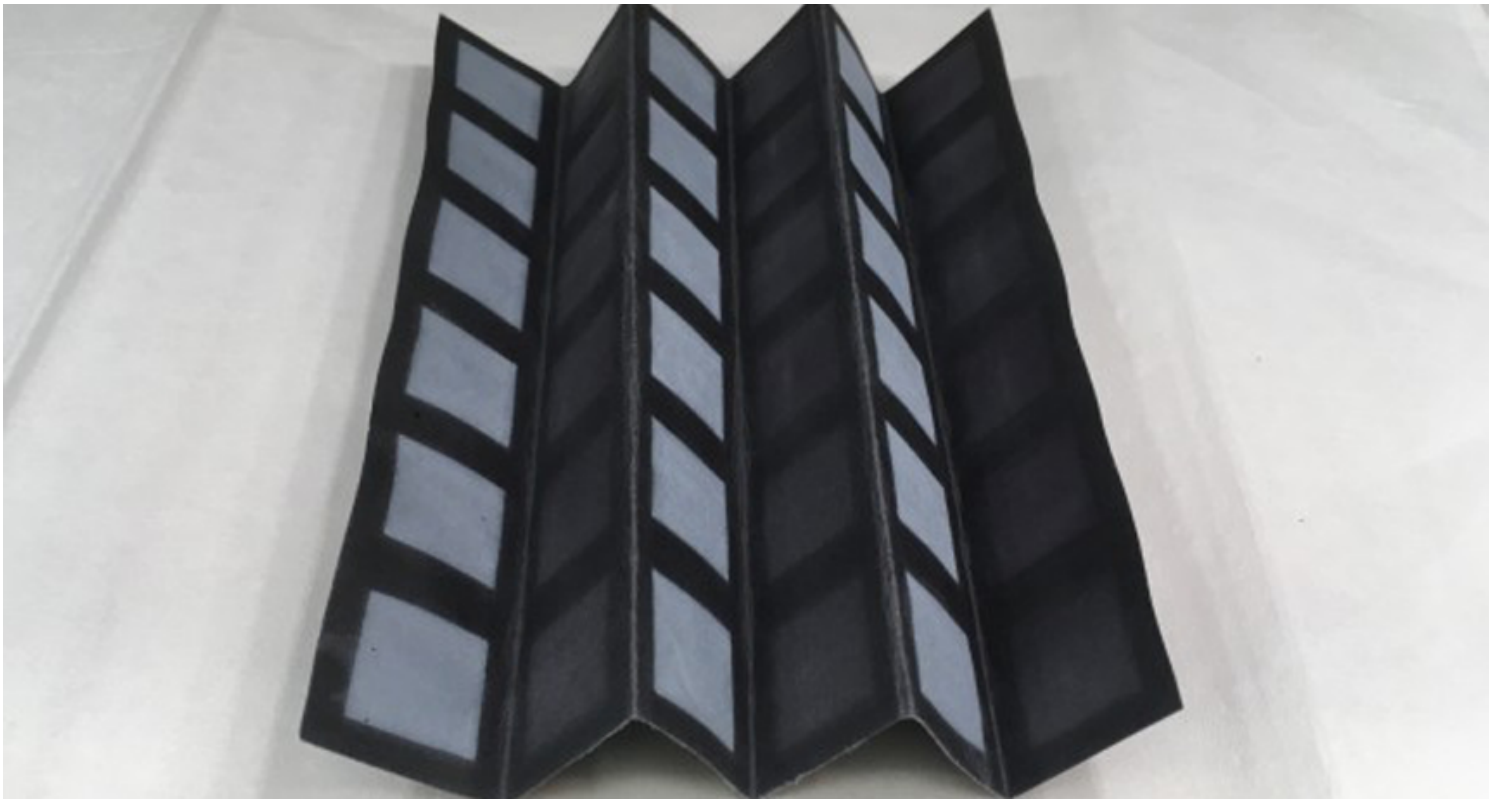
ScienceNews for Students

COMPUTERS & ELECTRONICS MICROBES

Germs power new paper batteries

These 'papertronics' power systems may be especially useful in remote or dangerous places, scientists say

BY STEPHEN ORNES MAR 3, 2017 — 7:10 AM EST



What looks like a folded piece of a paper is actually a battery powered by bacteria.

Seokheun "Sean" Choi

This is one in a series presenting news on technology and innovation, made possible with generous support from the Lemelson Foundation.

Engineers in upstate New York have invented a folded paper device that looks like a decorated art project. But don't be fooled. This is actually a paper-based battery. No, it doesn't look like any of those metal batteries running flashlights or smartphones. This alternative to electronics is based on paper. It represents a step forward in the field of *papertronics* (short for paper electronics). In these systems, the battery can be printed on a page. Well, most of it can: The battery's power consists of living bacteria.

Paper electronics are simple to make and inexpensive, notes study leader Seokheun Choi. He's an engineer at Binghamton University, part of the State University of New York system. These batteries also would be flexible and disposable, he adds. And powered by germs, they need no

electrical outlet to recharge. They just need more bacteria, which can be found everywhere — including in dirty water.

Most batteries use chemicals to generate electricity. Substituting bacteria can be an advantage, Choi says. "They are cheap, self-repairing and self-maintained," he notes. What paper-based batteries *won't* do is generate much power. They do, however, create enough to run small devices in faraway or dangerous places — such as a battlefield. They might also find use in medicine. For instance, they might power tiny sensors, such as the types used to measure blood sugar.

Choi and Yang Gao, also at Binghamton, describe their new invention in the January 2017 issue of *Advanced Materials Technology*.

Such devices are based on an observation made more than a century ago — that microbes produce a trickle of electricity as they digest food. Scientists refer to the bio-batteries based on this principle as *microbial fuel cells*.

Explainer: How batteries and capacitors differ

(https://www.sciencenewsforstudents.org/explainer-batteries-capacitors)

A fuel cell generates electricity like a regular battery. But a regular battery stops producing electricity when its internal chemical reactions stop. A fuel cell uses fuel that can be replenished. In this case, bacteria serve as the fuel. By replenishing more germs, as needed, scientists can keep these fuel cells running.

Papertronics' advantages

Ordinary electronics often contain toxic materials. Paper-based bacterial batteries may offer a safer choice, says Derek Lovley. A biologist, he works on bacteria and batteries at the University of Massachusetts, Amherst. A battery powered by germs may never run out of juice. "It can go on forever," he says, as long as the bacteria have enough to eat.

Ordinary batteries convert chemical energy into electrical energy. They have three main parts. One is the anode (AN-ode). It produces negatively charged particles called electrons. (Flowing electrons make electricity.) Another is the cathode (KATH-ode). It receives electrons from the anode. The third is a chemical electrolyte. It is usually found between the anode and the cathode. Chemical reactions among the materials cause electrons to leave the anode. They travel along a conductor to the cathode. From there they can move on to power a connected device.

In the battery made by Choi's team, the scientists used wax to hold everything in place. The wax also made the paper hydrophobic. (That means water won't soak in and weaken it.) Their anode was an electricity-conducting material painted on one side of the paper. Silver, sprayed onto the paper's bottom, provides the cathode. The anode and cathode are separated by the wax and paper. Choi says that paper layer also acts like a small container where the bacteria can dwell.

Here's how: To power the battery, a user adds water to the reservoir that contains bacteria and organic compounds. (Organic compounds contain carbon. Choi says a simple sugar, such as glucose, would be a good choice here.) As bacteria digest their meal, they release electrons. Those electrons pile up at the anode. Then, when a device or wire connects to the anode and cathode, the electrons flow to the cathode. To recharge the battery, someone need only add water hosting more bacteria. Even wastewater would work, Choi says.

In past projects, scientists have shown that it's possible to print metal or other materials on paper. That means they can print circuits — even parts of a battery. Those manufacturing techniques could be used for Choi's paper-based battery, too.

Lab tests have shown that the new battery can produce a trickle of a current. Now, Choi and his team are looking at ways to increase the power. They're studying different shapes and materials for the anode and cathode. They're also looking for the best ways to combine batteries for more power.

"The beauty of the paper devices is that you can simply stack them or fold them to connect them," he says.

Power Words

anode The negative terminal of a battery, and the positively charged electrode in an electrolytic cell. It attracts negatively charged particles. The anode is the source of electrons for use outside the battery when it discharges.

bacterial Having to do with bacteria, single-celled organisms. These dwell nearly everywhere on Earth, from the bottom of the sea to inside animals.

battery A device that can convert chemical energy into electrical energy.

blood sugar The body circulates glucose, a type of simple sugar, in blood to tissues of the body where it is used as a fuel. The body extracts this simple sugar from breakdown of sugars and starches. However, some diseases, most notably diabetes, can allow an unhealthy concentration of this sugar to build up in blood.

carbon The chemical element having the atomic number 6. It is the physical basis of all life on Earth. Carbon exists freely as graphite and diamond. It is an important part of coal, limestone and petroleum, and is capable of self-bonding, chemically, to form an enormous number of chemically, biologically and commercially important molecules.

cathode The positive terminal of a battery, and the negatively charged electrode in an electrolytic cell. It attracts positively charged particles. During discharge, the cathode attracts electrons from outside the battery.

cell The smallest structural and functional unit of an organism. Typically too small to see with the naked eye, it consists of watery fluid surrounded by a membrane or wall. Animals are made of anywhere from thousands to trillions of cells, depending on their size. Some organisms, such as yeasts, molds, bacteria and some algae, are composed of only one cell.

chemical A substance formed from two or more atoms that unite (become bonded together) in a fixed proportion and structure. For example, water is a chemical made of two hydrogen atoms bonded to one oxygen atom. Its chemical symbol is H_2O. Chemical can also be an adjective that describes properties of materials that are the result of various reactions between different compounds.

chemical reaction A process that involves the rearrangement of the molecules or structure of a substance, as opposed to a change in physical form (as from a solid to a gas).

compound (often used as a synonym for chemical) A compound is a substance formed from two or more chemical elements united in fixed proportions. For example, water is a compound made of two hydrogen atoms bonded to one oxygen atom. Its chemical symbol is H_2O.

conductor (in physics and engineering) A material through which an electrical current can flow.

current (in electricity) The flow of electricity or the amount of electricity moving through some point over a particular period of time.

digest (noun: digestion) To break down food into simple compounds that the body can absorb and use for growth. Some sewage-treatment plants harness microbes to digest — or degrade — wastes so that the breakdown products can be recycled for use elsewhere in the environment.

electricity A flow of charge, usually from the movement of negatively charged particles, called electrons.

electrolyte A non-metallic liquid or solid that conducts ions — electrically charged atoms or molecules — to carry electrical charges. (Certain minerals in blood or other bodily fluids can serve as the ions that move to carry a charge.) Electrolytes also can serve as the ions that move positive charges within a battery.

electron A negatively charged particle, usually found orbiting the outer regions of an atom; also, the carrier of electricity within solids.

electronics Devices that are powered by electricity but whose properties are controlled by the semiconductors or other circuitry that channel or gate the movement of electric charges.

engineer A person who uses science to solve problems. As a verb, to engineer means to design a device, material or process that will solve some problem or unmet need.

environment The sum of all of the things that exist around some organism or the process and the condition those things create for that organism or process. Environment may refer to the weather and ecosystem in which some animal lives, or, perhaps, the temperature, humidity and placement of components in some electronics system or product.

fuel cell A device that converts chemical energy into electrical energy. The most common fuel is hydrogen, which emits only water vapor as a byproduct.

germ Any one-celled microorganism, such as a bacterium, fungal species or virus particle. Some germs cause disease. Others can promote the health of higher-order organisms, including birds and mammals. The health effects of most germs, however, remain unknown.

glucose A simple sugar that is an important energy source in living organisms. As an energy source moving around the bloodstream, it may be known as "blood sugar." It is half of the molecule that makes up table sugar (also known as sucrose).

hydrophobic Repelling (or not absorbing) water.

microbe Short for microorganism. A living thing that is too small to see with the unaided eye, including bacteria, some fungi and many other organisms such as amoebas. Most consist of a single cell.

microbial fuel cell A device that relies on microbes to initiate a chemical reaction to generate electricity. These devices can use waste materials, including sewage and manure, to produce energy cleanly. (see also fuel cell)

organic (in chemistry) An adjective that indicates something is carbon-containing; a term that relates to the chemicals that make up living organisms. (in agriculture) Farm products grown without the use of non-natural and potentially toxic chemicals, such as pesticides.

reservoir A large store of something. Lakes are reservoirs that hold water. People who study infections refer to the environment in which germs can survive safely (such as the bodies of birds or pigs) as living reservoirs.

sensor A device that picks up information on physical or chemical conditions — such as temperature, barometric pressure, salinity, humidity, pH, light intensity or radiation — and stores or broadcasts that information. Scientists and engineers often rely on sensors to inform them of conditions that may change over time or that exist far from where a researcher can measure them directly. (in biology) The structure that an organism uses to sense attributes of its environment, such as heat, winds, chemicals, moisture, trauma or an attack by predators.

toxic Poisonous or able to harm or kill cells, tissues or whole organisms. The measure of risk posed by such a poison is its toxicity.

wastewater Any water that has been used for some purpose (such as cleaning) and no longer is clean or safe enough for use without some type of treatment. Examples include the water that goes down the kitchen sink or bathtub or water that has been used in manufacturing some product, such as a dyed fabric.

Readability Score:

8.3

NGSS:

- MS-LS2-3
- MS-LS2-5
- MS-ETS1-3
- MS-ETS1-4
- HS-PS3-3
- HS-LS2-4
- HS-ETS1-1

Citation

Journal: Gao Y and Choi S. **Stepping toward self-powered papertronics: Integrating biobatteries into a single sheet of paper (http://onlinelibrary.wiley.com/doi/10.1002/admt.201600194/abstract).** . *Advanced Materials Technology*. Vol. 2, January 2017. doi: 10.1002/admt.201600194.
