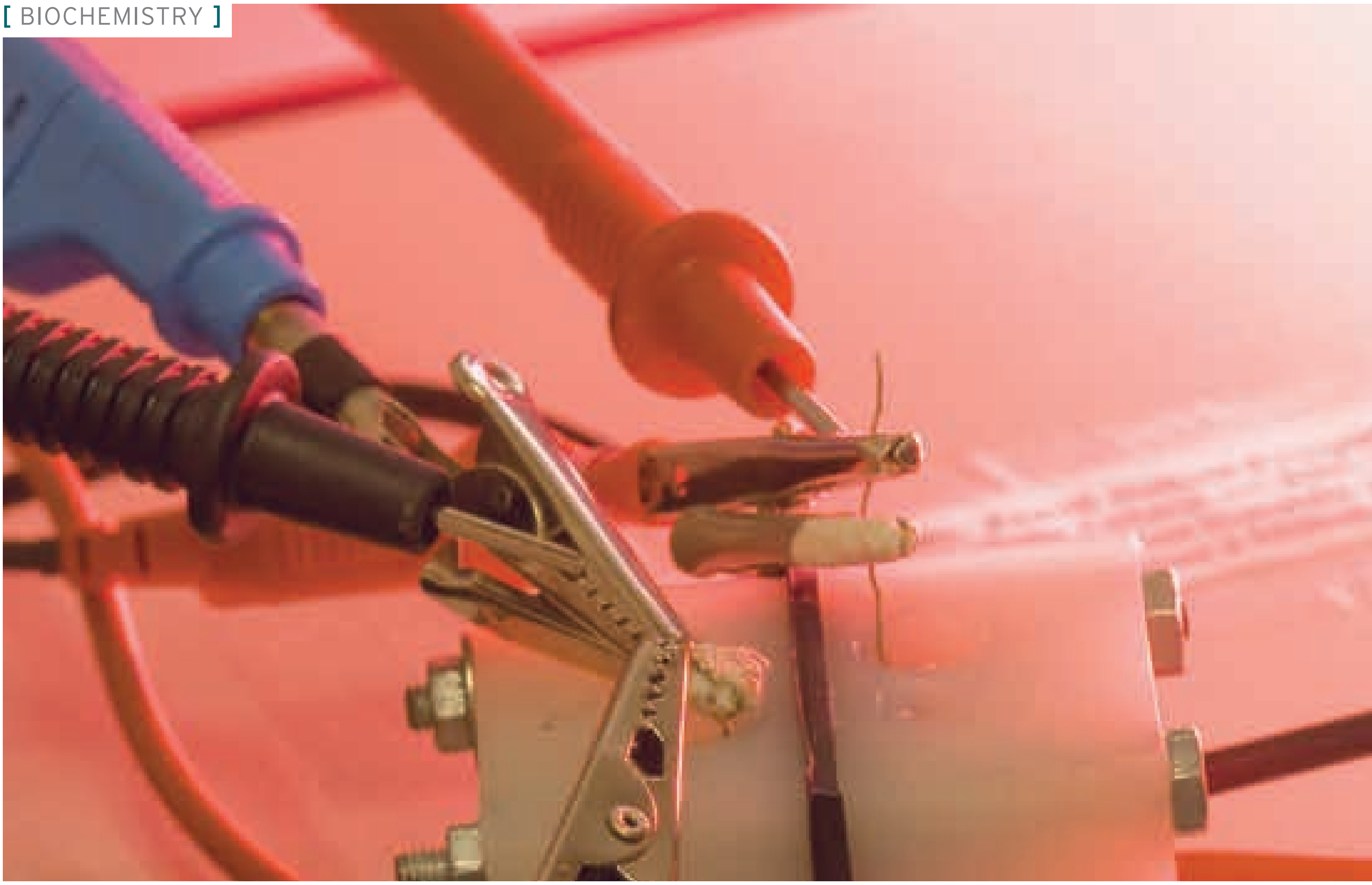

PHOTOS EDUARDO CESAR

Sugarcane juice in biocells

Energy alternative to produce electric power

Marcos de Oliveira

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Sugarcane juice, which people in São Paulo often drink when eating deep-fried pastries at street markets, is a strong candidate as a source of electric power in a small plastic box that can be used as a battery for mobile devices, MP3 players and even notebook computers. The device that allows sugarcane juices to act as a fuel, called a biocell, is one of the latest developments in the field of alternative energy sources. In 2007, Sony displayed one of these prototypes – there are various such prototypes around the world – using it to supply power to a small music player fueled by glucose. In addition to sugars, other fuels such as ethanol, methanol, and sewage water can be used for this purpose. With respect to sugarcane, the first demonstration was conducted by a research team from the Federal University of the ABC Region (UFABC), in the city of Santo André, located in the Metropolitan Region of São Paulo, Brazil. The team was able to produce electric power from sugarcane juice by synthesizing an enzyme in the laboratory. This enzyme increases the chemical reaction that converts the sugar into electric power.

Biocell with sugarcane juice is measured at UFABC laboratory

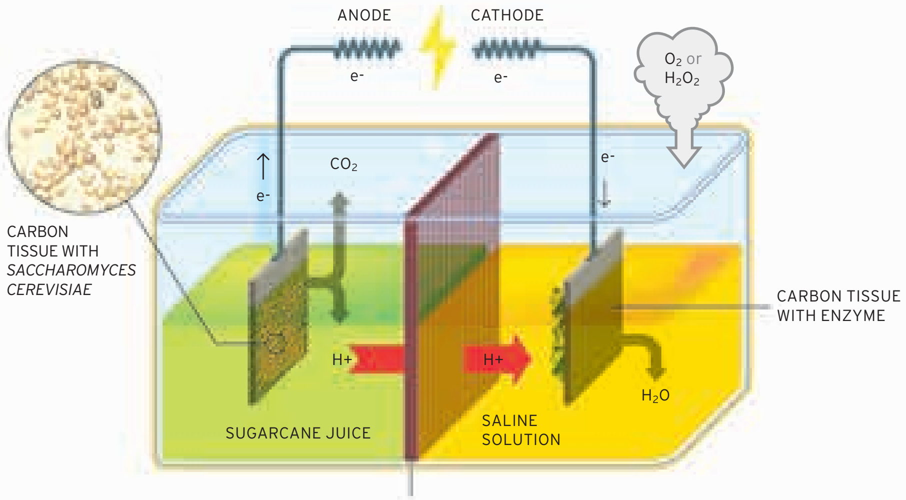
Fuel biocells have gained scientific and technological importance in the last few years. Studies involving these devices, which began in the early 1990s, increased from five articles published in scientific journals in 1989 to 240 articles in 2010, according to a survey by Professor Adalgisa de Andrade of the Chemistry Department at the School of Philosophy, Sciences and Letters of Ribeirão Preto at the University of São Paulo (USP). These studies are usually conducted jointly by several institutions. For example, Andrade, who works on the development of ethanol-fuelled biocells, has partnered with Professor Chelley Minteer from the University of Utah in the United States. Professor Minteer is the coordinator of a group that has conducted several studies in this field. Frank Nelson Crespilho, coordinator of UFABC's Materials and Advanced Methods Group, which uses sugarcane juice in biocells, has partnered with the University of South Korea, the University of Grenoble in France, and the Federal University of Piauí under the National Institute of Organic Electronics Science and Technology (Ineo).

One of the challenges of the studies on fuel biocells is that the power generated by biocells is still too low, which is an obstacle for commercial implementation. For example, the UFABC study finds that sugarcane and its new enzyme generate 60 milliwatts (mW) per square centimeter (cm^2) running at 0.39 volt (V), which is equivalent to 26% of the voltage of a AAA 1.5-volt battery. "The voltage can be increased by placing various cells to function sequentially," states Professor Crespilho, coordinator of the study. This was the formula that Sony used in its prototype, which generated 1.5 milliwatts per cm^2 and a total of 0.8 V. The company's experiment enjoyed the scientific support of Professor Kenji Kano of Japan's University of Kyoto.

The current technological challenge is to increase the power and the operating time of biocells, which can currently run for more than 10 hours. Other lines of study in the field include electric power generated by sewage, in which electrons are extracted from the organic material and then miniaturized, a process that would enable installing these cells in humans. In this case, the fuel might be blood glucose

Biocell with a membrane

Electrodes with microorganism and enzyme dipped in sugarcane juice and solution



Injecting sugarcane juice into biocell

INFOGRAPHICS MARIO KANNO

rather than sugarcane juice. "One of the current challenges concerning biocells is to put them into microchips, to produce a micro biocell or nanobiocell that could be implanted to work like a pacemaker battery, to release medication in the body or to detect glucose levels," says Crespilho, who, at the age of 32, is also the head of the Intellectual Property Division of the Technological Innovation Center at UFABC. To measure very low currents of tiny biocells, Crespilho and his team developed a software program and, with FAPESP funding, purchased equipment that eliminates noise from the cables of electronic appliances.

High efficiency - The biocells work like batteries; that is, they convert chemical energy into electric power in a manner akin to fuel cells that produce electric power. The related equipment can be made to order by several companies, including in Brazil, and it is hydrogen-fueled. The power of this equipment corresponds to more than five kilowatts, which is enough to provide electric power for a home that comfortably houses four people. The fuel biocells currently undergoing scientific and technological research have the potential to become an alternative form of electric power, since, like their older cousins, they are highly energy-efficient and use little fuel to convert energy, as compared to gasoline or diesel-fueled engines, for example. This conversion is silent and does not produce large amounts of gases or pollutants.

THE PROJECTS

1. *Interaction between biomolecules and cell systems with OD, 1D, 2D nanostructures, using electrochemical methods - nº 2009/15558-1*
2. *Development of a fuel biocell using ethanol dehydrogenases enzymes immobilized by self-assembly - nº 2008/05124-1*

TYPE

1 and 2. - Ordinary Research Grant

COORDINATORS

1. Frank Nelson Crespilho - UFABC
2. Adalgisa Rodrigues de Andrade - USP

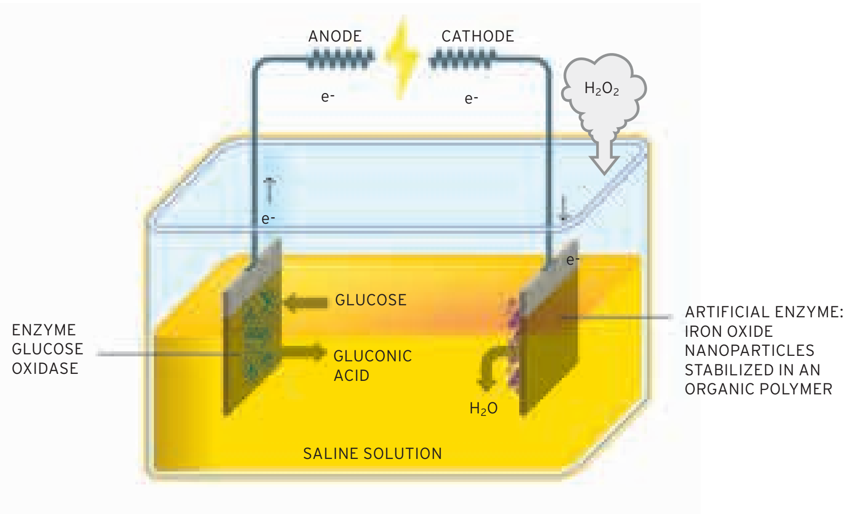
INVESTMENT

1. R$ 92,262.80 and US$ 50,821.57 (FAPESP)
2. R$ 73,622.30 and US$ 29,031.76 (FAPESP)

The benefit of these small devices is the biological aspect found in organic catalysts produced with enzymes or microorganisms. They produce the necessary chemical reaction to generate electric power and can replace the expensive platinum used in fuel cells. Crespilho's team has developed a synthesized enzyme in the form of a compound comprised of iron oxyhydroxide nanostructures and an organic polymer called poly diallyl dimethyl ammonium chloride (PDAC). This compound is applied in the cathode, one of the terminals of an electrolytic system, similar to a battery, that produces electrons or allows them flow. The electrons, in this case, are extracted from the sugars of cane juice on the anode (*see illustration*). The group also used polyamide in the structure of the cell To understand this bioelectrochemical area of study, which is being referred to as nanobioelectrical chemistry because it uses nanotechnological compounds, one must keep in mind that the fuel and biocells need oxidizing and reducing elements to gain and lose electrons. A polymeric membrane called a proton exchange membrane is sandwiched between the biocell's anode and cathode. Given that the current is direct, the electrons flow from

Biocell without a membrane

Solution with electrodes and enzymes produces electric power



one side to the other and are received at the other end. Only the protons – the non-electron atoms – pass through the membrane. Crespilho also studies biocells without membranes between the two terminals. "In this case," he explains, "we produce a biocell in which the electrons are placed in a solution of glucose, water, hydrogen peroxide (H_2O_2), and two kinds of natural enzymes – a glucose oxidase and our enzyme with iron oxide nanoparticles. The biocell proved to be effective, as the electrochemical reaction achieved a higher speed than some cells described in scientific literature," says Crespilho.

"The synthetic enzyme that we developed mimics the natural mechanism of enzymes of the peroxide class. When electrons are extracted from the sugars for the anode, other electrons are injected into the cathode and the synthetic enzyme accelerates the breaking of the hydrogen peroxide molecules." According to the researchers, a biomimetic enzyme is cheaper, more stable and more efficient than natural enzymes. The work, which was developed by Marccus Victor Martins, a doctoral student, consists of coating the iron oxide with a layer of a synthesized organic polymer in the shape of needles. The immobilized enzyme, placed over an electrode containing carbon tissue fibers, is placed inside a saline solution with sugarcane juice and other additives that then form the enzyme's natural environment. "The biggest problem is to maintain the enzyme's stability for more than 10 hours. If it degrades, the current weakens," says Crespilho.

Without disturbing – The experiments conducted by Crespilho's group also focus on another possibility of the biocell world, namely, the use of microorganisms such as the *Saccharomyces cerevisiae* yeast, which is used to ferment ethanol, bread and beer. "They digest the sugar," says Crespilho. "The biggest difficulty is to extract the electrons without disturbing or killing the *Saccharomyces*." By means of various chemical strategies, the researchers were able to maintain the microorganism and to produce electric power while the organism was immobilized in a carbon electrode. According to the scientific literature, more than 20 microorganisms, especially bacteria, have already been used successfully in experiments with biocells.

The use of electrodes with microorganisms was not part of the studies conducted by Professor Andrade of the USP at Ribeirão Preto, author of an article that summarized the worldwide activities conducted in 2010 concerning enzyme biocells. She develops ethanol-fueled biocells comprised of enzymes that break up the alcohol, such as the dehydrogenases found in the liver to digest alcoholic beverages. Her group's most recent accomplishment is the development of anodes with immobilized nanostructures. These anodes, which contain more stable organic polymers and dehydrogenases, have a higher electric current density and function for as long as 90 days.

"Our work consisted of mixing the enzymes and the polymers and placing them on a carbon surface prepared to receive electrons; we guided the electrons so that the electrode would become more stable and powerful," says Andrade. A postdoctoral student, Juliane Forti, also participated in the study. As a result of these new arrangements, Andrade's group produced a battery with 0.28 milliwatts per cm^2 that worked with ethanol. Adalgisa and Crespilho are among a select group of researchers who inherited the development of biocells from Professor Michael Potter of the University of Durham in the United Kingdom. In 1912, Potter demonstrated the production of electric power by *Escherichia coli* bacteria in an organic substrate. The first biocell with enzymes was announced more than 50 years later, in 1964, by a group of researchers from the Space-General Corporation, California, United States. It has been a long journey, one that might lead to a new power alternative in the not very distant future. ■

Scientific articles

1. MARTINS , M. V. A.; BONFIM, C.; SILVA, W. C.; CRESPILHO, F. N. Iron (III) nanocomposites for enzyme-less biomimetic cathode: A promising material for use in biofuel cells. **Electrochemistry Communications.** v. 12, n. 11, p. 1.509-12. 2010.
2. AQUINO NETO, S.; FORTI, J. C.; ZUCOLOTTO, V.; CIANCAGLINI, P.; ANDRADE, A. R. Development of nanostructured bioanodes containing dendrimers and dehydrogenases enzymes for application in ethanol biofuel cells. **Biosensors and Bioelectronics.** v. 26, p. 2.922-26. 2011.