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Working together: Bacteria join forces to produce electricity

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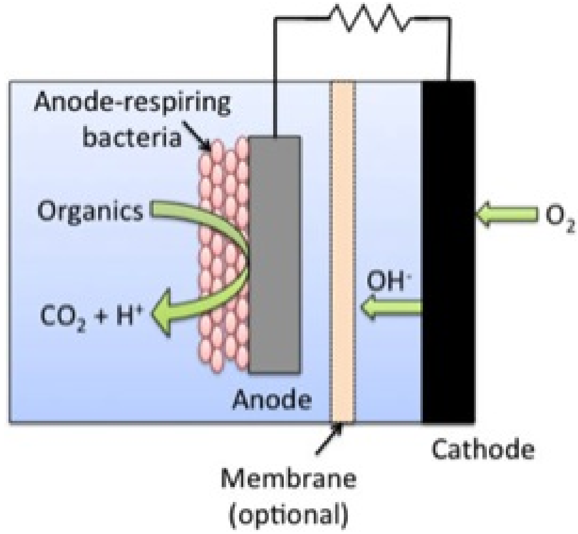

An MFC consists of an anode, a cathode, a proton or cation exchange membrane and an electrical circuit. In the left compartment, anode-respiring bacteria (like *Geobacter*) attach themselves to the anode, forming a sticky residue or biofilm. In the course of their metabolic activity, these bacteria strip electrons from organic waste. The electrons then flow through a circuit to the cathode, producing electricity in the process, in addition to CO2 and water. Hydroxide or OH- ions are transported from the cathode into the surrounding electrolyte. Note: in an experimental set-up lacking organic waste, an electron donor -- typically acetate -- is supplied in the growth medium, as a nutrient source for the anode respiring bacteria. Credit: The Biodesign Institute At Arizona State University

Bacterial cells use an impressive range of strategies to grow, develop and sustain themselves. Despite their tiny size, these specialized machines interact with one another in intricate ways.

In new research conducted at Arizona State University's Biodesign Institute, Jonathan Badalamenti, César Torres and Rosa Krajmalnik-Brown explore the relationships of two important bacterial forms, demonstrating their ability to produce electricity by coordinating their metabolic activities.

In a pair of papers recently appearing in the journal *Biotechnology and Bioengineering*, the group demonstrates that the light-sensitive green sulfur bacterium *Chlorobium* can act in tandem with *Geobacter*, an anode respiring bacterium. The result is a light-responsive form of electricity generation.

"*Geobacter* is not light responsive in its own right because it's not a photosynthetic organism," says Badalamenti, lead author of the two new papers. In contrast, photosynthetic *Chlorobium* is unable to carry out the anode form of respiration necessary for electricity production. "But when you put these two organisms together, you get both a light response and the ability to generate current."

The electrons *Geobacter* acquires from its photosynthetic partner *Chlorobium* can be measured and collected in the form of electricity, using a device known as a microbial fuel cell (MFC)—a kind of biological battery. A basic schematic for a conventional MFC is shown in figure 1.

Microbial fuel cells may one day generate clean electricity from various streams of organic waste, simply by exploiting the electron-transfer abilities of various microorganisms.

The research was carried out at the Swette Center for Environmental

Biotechnology, which is under the direction of Regents' Professor Bruce Rittmann. The goal of the Center is to exploit microorganisms for the benefit of society. These efforts typically involve the use of bacteria to clean up environmental pollutants or to provide clean energy. In the case of MFC research, bacteria can assist in both of these activities, generating useable electricity from energy-rich waste.

In the new studies, the researchers explore the possibility of enhancing electricity production in MFCs by examining the function of light-responsive *Chlorobium*, a photosynthetic green sulfur bacterium. The resulting experimental configuration, in which light responsive bacteria play a role in energy generation, is known as a microbial photoelectrochemical cell (MPC).

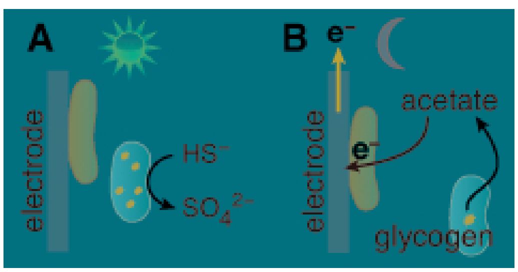

Figure 2 shows a coculture model for current production in the dark. A: In the light, *Chlorobium* photosynthetically accumulates glycogen (red particles) using electrons derived from sulfide oxidation. B: In the dark, *Chlorobium* ferments glycogen to acetate, which is consumed by *Geobacter* to produce electric current. Credit: The Biodesign Institute at Arizona State University

To explore the behavior of photosynthetic bacteria in a MPC, the team first used a clever means of selectively enriching phototrophs such as *Clorobium* in a mixed culture, by poising the device's anode at a particular electrical potential that was favorable for phototrophic growth, yet unfavorably low for the growth of non-photosynthetic anode respiring bacteria.

The researchers then noted an intriguing result: electricity production measured at the anode was linked to phases when the MPC was in total darkness and dropped during periods when the bacterial culture was exposed to light.

The group detected the presence of *Chlorobium* in the enrichment cultures using pyrosequencing and reasoned that the observed negative light responsiveness was either due to photosynthetic *Chlorobium* directly transferring electrons to the anode during dark phases or instead, transferring these electrons to a non-photosynthetic anode respiring bacterium like *Geobacter*, through an intermediary reaction.

Phototrophic organisms like *Chlorobium* are not known to carry out direct anode respiration. As Krajmalnik-Brown explains: "The follow up sceintific question was to disern if we had discovered a novel phototrophic anode respiring bacteria or if the phototroph was giving something to the anode respiring bacteria *Geobacter* and that was the response we were reporting."

In subsequent experiments, pure cultures of either *Chlorobium* or anode-respiring *Geobacter* were examined as well as co-cultures combining the two. In the case of *Chlorobium* alone, light responsive electricity generation was not observed. Similarly, pure *Geobacter* cultures failed to produce electrical current when deprived of an electron donor like acetate in the medium.

Only when the photosynthetic *Chlorobium* were combined with anode respiring *Geobacter* in co-culture experiments did electricity generation occur and it did so in a negative light-responsive manner—increasing in periods of darkness and falling off during light phases.

Figure 2 shows the interplay of anode-respiring *Geobacter* and light-responsive *Chlorobium* during light and dark phases.

The experimental results of the co-culture study suggest the following scenario: *Chlorobium* bacteria gather energy from light in order to fix carbon dioxide and fuel their metabolism. During dark phases however, they sustain themselves by switching from photosynthesis to dark fermentation, using energy they have stored. Acetate is produced as a metabolic byproduct of this dark phase fermentation.

During periods of darkness, anode respiring *Geobacter* gains electrons from the acetate produced through *Chlorobium* metabolism, transferring them to the MPC anode, thereby producing the observed rise in electrical current. "In this second study, we deliberately removed any sources of electrons that were present in the growth medium," Badalamenti says. When the two bacterial communities were forced to interact, it was clear that *Chlorobium* was helping to provide food for the *Geobacter*, in a light-responsive manner.

The authors note that one of the attractive advantages of their study is that electricity generation measured at the anode can be used as a highly accurate surrogate for the complexities of bacterial metabolism taking place in the MPC culture. "Unlike having to measure metabolites or cell growth either microscopically or through chemical intermediates, we are able to construct a co-culture system in which one of the readouts is electricity," Badalamenti says. "We can then monitor metabolism in the system in real time."

Further questions concerned whether the presence of *Chlorobium* may provide benefits for *Geobacter* in naturally occurring cultures, not confined to MFC devices. In anode-free experiments the group showed that the very survival of *Geobacter* in the absence of alternative sources of electrons was contingent on the presence of *Chlorobium*-derived acetate.

In addition to establishing a mechanism for light-responsive electricity generation in MFCs, the research points to the power of similar co-culture studies for elucidating a range of energy-producing microbial interactions.

Provided by Arizona State University

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