Electromethanogenesis: the direct bioconversion of current to methane

Barbara Booth

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Methane can be a problem or a solution, depending on one’s viewpoint or circumstance. For Bruce Logan and co-workers at Pennsylvania State University, it’s both. It’s a problem when the researchers want to make hydrogen gas in microbial electrolysis cells (MECs), because making methane reduces hydrogen yield. The researchers have been studying the formation of methane in MECs in an effort to avoid it. To their surprise, they found that a microbe, most likely Methanobacterium palustre, can synthesize methane using electrons directly from current in addition to using hydrogen gas (DOI 10.1021/es803531g). This fundamental discovery could lead to an efficient way to generate methane, the main component of natural gas, from electricity and could have other environmental applications.

Despite its name, M. palustre is not a bacterium but an archaeon. It is also a methanogen, which means it can reduce CO2 to methane with H2 as an electron donor. Now, Logan and colleagues have found that this microbe appears to use electrons from current. “We think this is the first direct evidence that methanogens can accept electrons,” says Logan.

“Efficient methane production fueled by electrons directly from an electrode is an important discovery!” says Yuri Gorby, who studies electrically conductive appendages produced by bacteria (known as bacterial nanowires) at the J. Craig Venter Institute in San Diego. “What is significant about this publication is the reported efficiency of energy transformation; 80% efficiency is pretty darn good. As a microbial physiologist and ecologist, the questions become, ‘What is the mechanism, and does this occur in nature?’ Although this article does not address these questions, it provides hope that it is at least possible.”

“Methanogenic archaea have a unique biochemistry, employing cofactors and enzymes not commonly present in other types of microorganisms,” explain microbial physiologists Alfons Stams and Jeanine Geelhoed at Wageningen University (The Netherlands). Stams and Geelhoed note that, in the current paper, the authors’ interpretation of their results is based on the observation that little or no hydrogen is produced in a similar setup without microorganisms. Although the authors show convincingly that methanogens are essential, Stams and Geelhoed believe that the study does not unequivocally rule out the possibility that hydrogen is formed first and is the electron donor for CO2 reduction. They note that bacterial and/or archaeal enzymes may mediate electron transfer between the electrode surface and cells. They also suggest that a possible role for hydrogen could be ruled out experimentally by using a compound that inhibits methanogenesis. “Further research is clearly necessary to obtain insight of the molecular mechanism of electromethanogenesis and electrohydrogenesis,” they say.

The direct transfer of electrical current, or more precisely, electrons, to methanogens suggests that it may be possible to generate methane from wind or solar power sources; the methane could then be stored as fuel for later use, says Logan.

At the moment, you can make biofuels from about anything that’s biodegradable, but it’s a...
complex process, explains Logan. First, CO$_2$ is fixed into an organic compound by plants or microbes. Next, the organic compound is consumed by microbes. Eventually, methane is emitted. To make methane electrochemically directly from CO$_2$ is difficult because there is a big overpotential. But methanogens can do it very easily and have been for eons. What the paper implies is this: if you have a source of current, you have a source of electrons, and you can make methane electrochemically.

"Let's say the sun is shining during the day, and you are making solar energy, great! Then nighttime comes; what do you do?" asks Logan. "If you had a big capacitor or battery you could store the energy, or you could make a fuel like hydrogen or methane. Some people say hydrogen is too difficult to compress and to store, [but] nobody says that about natural gas. We've got pipelines of natural gas all over the world, and it's used in conventional engines. It's no problem to use at all," Logan concludes.

Korneel Rabaey, who is at the University of Queensland (Australia) and is an expert on bioelectrical systems, believes that while the discovery that methanogenic archaea can perform extracellular electron transfer is exciting, it's mainly interesting from a scientific rather than a practical viewpoint. The next step is to demonstrate this with an isolated methanogen, and that is a worthwhile challenge, according to Rabaey. Logan's group is already working on it.

Researchers Shaoan Cheng, Bruce Logan, and Defeng Xing (left to right) examine a two-chamber microbial electrolysis reactor.

DAVID JONES, PENNSYLVANIA STATE UNIVERSITY