

# Taming Electricigens

How electricity-generating microbes can keep going, and going – faster

By Derek Lovley

**E**lectricigens, the microbes that can completely oxidize organic compounds to carbon dioxide and then transfer the electrons derived from that oxidation onto the anode of a microbial fuel cell, are the Energizer Bunnies of the microbe world. They gain energy to support their growth and metabolism from the electron transfer to anodes, resulting in low-maintenance, self-sustaining fuel cells that can run indefinitely. But for many proposed applications of microbial fuel cells, the rate at which electricigens convert organic matter to electricity will need to be substantially increased.

As far as we know there has been no evolutionary pressure on electricigens to generate electricity in natural environments. Their electricigenic abilities are likely a fortuitous benefit of growing in anoxic soils and sediments with insoluble Fe(III) and Mn(IV) oxides as the electron acceptor. It is not clear whether proteins that have evolved for extracellular electron transfer onto minerals would necessarily also be optimized for electron transfer onto graphite or other anode materials. Furthermore, most Fe(III)-reducing microorganisms have evolved to be competitive in soils and sediments where selection is likely to favor slow-growing microbes that efficiently utilize limited resources, rather than favoring organisms that can rapidly oxidize large quantities of organic fuel. These considerations suggest that we may be able to develop electricigens that produce electricity faster.

One optimization strategy may be genetic engineering of electricigens to increase or improve their electrical contact with the anode or accelerate their rate of respiration. For such studies we have focused on the electricigen, *Geobacter sulfurreducens*, in part because it is closely related to the electricigens that naturally colonize anodes harvesting electricity from various organic wastes. Furthermore, the complete genome sequence, a genetic system, and a genome-based in silico model of the bacterium's metabolism are available, all of which have made it possible to study its physiology on electrodes in detail.

To date, we have identified several possible electrical contacts between the cell and the anode, including microbial nanowires, the electrically conductive pili

that permit long-range electron transfer onto surfaces. However, our attempts to produce strains with more electrical contacts or faster rates of extracting electrons from organic fuels have had only minimal success.

For example, adding a gene to overproduce one of the membrane proteins thought to serve as an electrical contact between the cell and the anode had no impact on power production. This may be because the oxidation of organic compounds coupled with extracellular electron transfer is a complex, highly regulated process, and the introduction or deletion of only a small number of genes may not be able to make a significant beneficial difference in the overall process.

An alternative strategy that may be more appropriate for such a complex process is adaptive evolution in which selective pressure is put on the microorganisms to convert fuels to electricity faster or at more desirable potentials. This approach is potentially suitable for improving the functioning of multispecies communities or pure cultures. Initial results with this approach are encouraging, though it remains to be seen whether the observed improvements are the result of changes in the expression of existing genes or whether beneficial mutations are taking place.

Better understanding of the mechanisms for increasing microbial electricity production will also contribute to better electrical engineering of the microbial fuel cells. For example, empirically testing a wide range of materials might reveal the anode composition that best promotes electron transfer between microorganisms and electrodes, but a better approach may be to rationally design materials based on an understanding of how microorganisms establish electrical contact with the anode.

Although we do not yet fully understand how electricigens make electricity, it is clear that they were the first nanoelectronic engineers. Even if microbial fuel cells are not a short-term solution to our energy needs, further elucidation of this elegant system for conducting electrons may well make other contributions to the electronics industry as well as reveal some fascinating biology. ■



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