PROFILE: DANIEL NOCERA

Hydrogen Economy? Let Sunlight Do the Work

Looking for a clean way to produce hydrogen, Daniel Nocera wants to run a fuel cell backward, powered by sunlight

Hydrogen seems like an ideal fuel. Combine it with oxygen in a fuel cell, and it produces water and electricity, without the noxious pollutants that accompany the burning of most fossil fuels. But it has a dark side: Although there is plenty of hydrogen around, it's bound with other atoms in complex molecules, and it takes large amounts of energy to strip it free. Moreover, most hydrogen today is made from fossil fuels, releasing vast quantities of carbon dioxide in the process. Daniel Nocera is hoping to change that. The Massachusetts Institute of Technology (MIT) chemist is looking for new ways to use sunlight to split water into oxygen and hydrogen. In essence, Nocera is trying to run a fuel cell in reverse. "Why can't we reengineer the fuel cell backwards?" he asks. "Conceptually, it's very easy."

His quest had a colorful start. Like many fellow Grateful Dead fans with their tie-dyed T-shirts, Nocera, 49, was fascinated by colors when he was growing up—not by the colors themselves, however, but by the processes that lie behind them. "I wanted to understand the colors of materials," Nocera says. And that sparked his interest in chemistry. In between going to some 80 Dead shows, he learned that the colors we see are driven by which frequencies of light are absorbed and reflected by materials. When that light is absorbed, it kicks electrons out of their relaxed state, sending them into a dancing frenzy. As they return to their relative rest, they give off heat. By the time Nocera was a graduate student at the California Institute of Technology in Pasadena, he was wondering how he could design systems to capture electrons excited by sunlight and use them to make fuel. "Right out of the blocks, I was interested in solar energy conversion," Nocera says. Or, as Deadheads might put it, finding a way to hold onto the light.

Plants do this by photosynthesis: Two massive protein complexes split water and carbon dioxide and forge new energy-storing bonds in sugar molecules. At the heart of the process is the harnessing of electrons excited by sunlight. Nocera is looking for novel catalysts that will perform some of these tasks more efficiently.

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Uphill battle. Nocera hopes to find new catalysts that harness sunlight to make hydrogen fuel.

Five years ago, he and then–graduate student Alan Heyduk designed a ruthenium-based catalyst that uses light energy to strip protons and electrons from an acid and stitch them together to make H_2 molecules. (They're still trying to find a cousin that does the same thing with water rather than an acid.) But that was the easy step. It's even more difficult to grab lone oxygens liberated by splitting water and link them together to form O_2—a step that would be needed to complete the water-splitting reactions and maximize the efficiency of the process. "That requires a certain organization," says Heyduk, now a chemistry professor at the University of California, Irvine. And it's one of the reasons there's been so little progress in recent decades in devising catalysts that turn out O_2.

But there could soon be a new glimmer of progress. Nocera says his group is close to publishing results with a new ruthenium-based catalyst that absorbs light and uses the energy to stitch oxygen atoms together to make O_2. The new catalyst isn't very efficient yet. But it works the way he expected it to, Nocera says, which gives him confidence that they're beginning to understand how to control the motion and bonding of different atoms with their new catalysts. Although Heyduk says he hasn't heard the details of the new catalyst yet, "any system where they can turn water to O_2 is a huge advance because of the difficulty of the problem."

Nocera acknowledges that even this and other advances his group has made are baby steps compared to what's needed for an industrial version of the technology. One problem is that Nocera's catalysts thus far contain ruthenium, a rare and expensive metal. But Nocera is hoping to find cheaper materials that work as well. He recently launched a new project with MIT colleagues to synthesize a multitude of novel metal oxide compounds for testing as possible water-splitting catalysts.

A handful of other groups around the world are engaged in related efforts. One approach pursued by researchers at the National Renewable Energy Laboratory in Golden, Colorado, for example, uses semiconductors to absorb sunlight and create electrical charges that are then used to split water. Although this approach is currently more efficient than Nocera's catalysts, the semiconductors needed are still too costly to be commercially viable. At this point, Nocera argues, all such strategies are worth pursuing. "I'm not sure what the winner will be that is able to make energy without adding extra CO_2 to the atmosphere," Nocera says. "A failing of energy R&D for the last 30 years in the United States has been that it has been treated as an engineering problem, with a little 'r' component and a big 'D.' There needs to be an 'R' bigger than the 'D.' There are whole new areas of science and engineering that need to be discovered to solve this problem."

Still, Nocera is convinced that the broad community of researchers now being inspired to find a carbon-neutral source of energy will succeed. "I'll guarantee it," he says. "I think science can deliver a cheap and efficient solution. I believe it deeply."

–ROBERT F. SERVICE

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