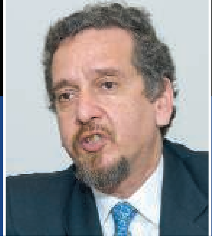

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CHEMISTRY

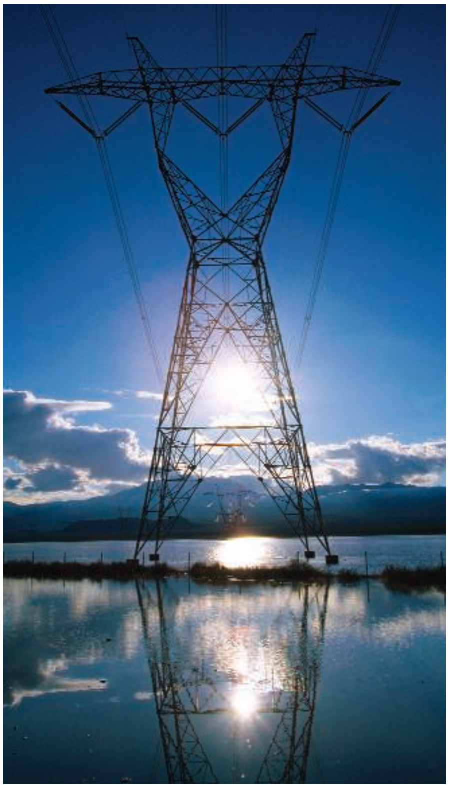
New Catalyst Marks Major Step in The March Toward Hydrogen Fuel

Climate change concerns, high gas prices, and a good deal of international friction would fade if scientists could learn a trick every houseplant knows: how to absorb sunlight and store its energy in chemical bonds. What's needed are catalysts capable of taking electricity and using it to split water to generate hydrogen gas, a clean fuel. Unfortunately, the catalysts discovered so far work under harsh chemical conditions, and the best ones are made from platinum, a rare and expensive metal.

No more. This week, researchers at the Massachusetts Institute of Technology (MIT) in Cambridge led by chemist Daniel Nocera report online in *Science* a new water-splitting catalyst that works under environmentally friendly conditions (www.sciencemag.org/cgi/content/abstract/1162018). More important, it's made from cobalt and phosphorus, fairly cheap and abundant elements. The new catalyst needs improvements before it can solve the world's energy problems, but several outside researchers say it's a crucial development.

"This is a great result," says John Turner, an electrochemist and water-splitting expert at the National Renewable Energy Laboratory in Golden, Colorado. Thomas Moore, a chemist at Arizona State University in Tempe, goes further. "It's a big-to-giant step" in the direction of powering industrial societies with renewable fuels, he says. "I'd say it's a breakthrough." Meanwhile, on pages 671 and 676, other groups report related advances—a cheap plastic fuel cell catalyst that converts hydrogen to electricity, and a solid oxide fuel cell catalyst that operates at lower temperatures—that affect another vital component of any future solar hydrogen system.

English chemists first used electricity to split water more than 200 years ago. The reaction requires two separate catalytic steps. The first, the positively charged electrode, or anode, swipes electrons from hydrogen atoms in water molecules. The result is that protons (hydrogen atoms minus their electrons) break away from their oxygen atoms. The anode catalyst then grabs two oxygen atoms and welds them together to make O_2. Meanwhile, the free protons drift through the solution to the negatively charged electrode, or cathode, where they hook up with electrons to make molecular hydrogen (H_2).



Water power. Cobalt-phosphorus catalyst opens the way to using sunlight to extract hydrogen from water.

The hard part is finding catalysts that can orchestrate this dance of electrons and protons. The anode, which links oxygens together, has been a particularly difficult challenge. Platinum works but is too expensive and rare to be viable on an industrial scale. "If we are going to use solar energy in a direct conversion process, we need to cover large areas," Turner says. "That makes a low-cost catalyst a must." Other metals and metal oxides can do the job but not at a neutral pH—another key to keeping costs down. In 2004, Nocera's team reported in the *Journal of the American Chemical Society* a cobalt-based catalyst that did the reverse reaction, catalyzing the production of water from O_2, protons, and electrons. "That told us cobalt could manage multielectron and proton-coupled reactions," Nocera says.

Unfortunately, cobalt is useless as a standalone water-splitting anode because it dissolves in water. Nocera and his Ph.D. student Matthew Kanan knew they couldn't get over this hurdle. So they went around it instead. For their anode, they started with a stable electrode material known as indium tin oxide (ITO). They then placed their anode in a beaker of water, which they spiked with cobalt (Co^{2+}) and potassium phosphate. When they flipped on the current, this created a positive charge in the ITO. Kanan and Nocera believe this initially pulls electrons from the Co^{2+}, turning it first to Co^{3+}, which pairs up with negatively charged phosphate ions and precipitates out of solution, forming a film of rocklike cobalt phosphate atop the ITO. Another electron is yanked from the Co^{3+} in the film to make Co^{4+}, although the mechanism has not yet been nailed down. The film forms the critical water-splitting catalyst. As it does so, it swipes electrons from hydrogen atoms in water and then grabs hold of lone oxygen atoms and welds them together. In the process, the Co^{4+} returns to Co^{2+} and again dissolves into the water, and the cycle is repeated.

The catalyst isn't perfect. It still requires excess electricity to start the water-splitting reaction, energy that isn't recovered and stored in the fuel. And for now, the catalyst can accept only low levels of electrical current. Nocera says he's hopeful that both problems can be solved, and because the catalysts are so easy to make, he expects progress will be swift. Further work is also needed to reduce the cost of cathodes and to link the electrodes to solar cells to provide clean electricity. A final big push will be to see if the catalyst or others like it can operate in seawater. If so, future societies could use sunlight to generate hydrogen from seawater and then pipe it to large banks of fuel cells on shore that could convert it into electricity and fresh water, thereby using the sun and oceans to fill two of the world's greatest needs.

–ROBERT F. SERVICE

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