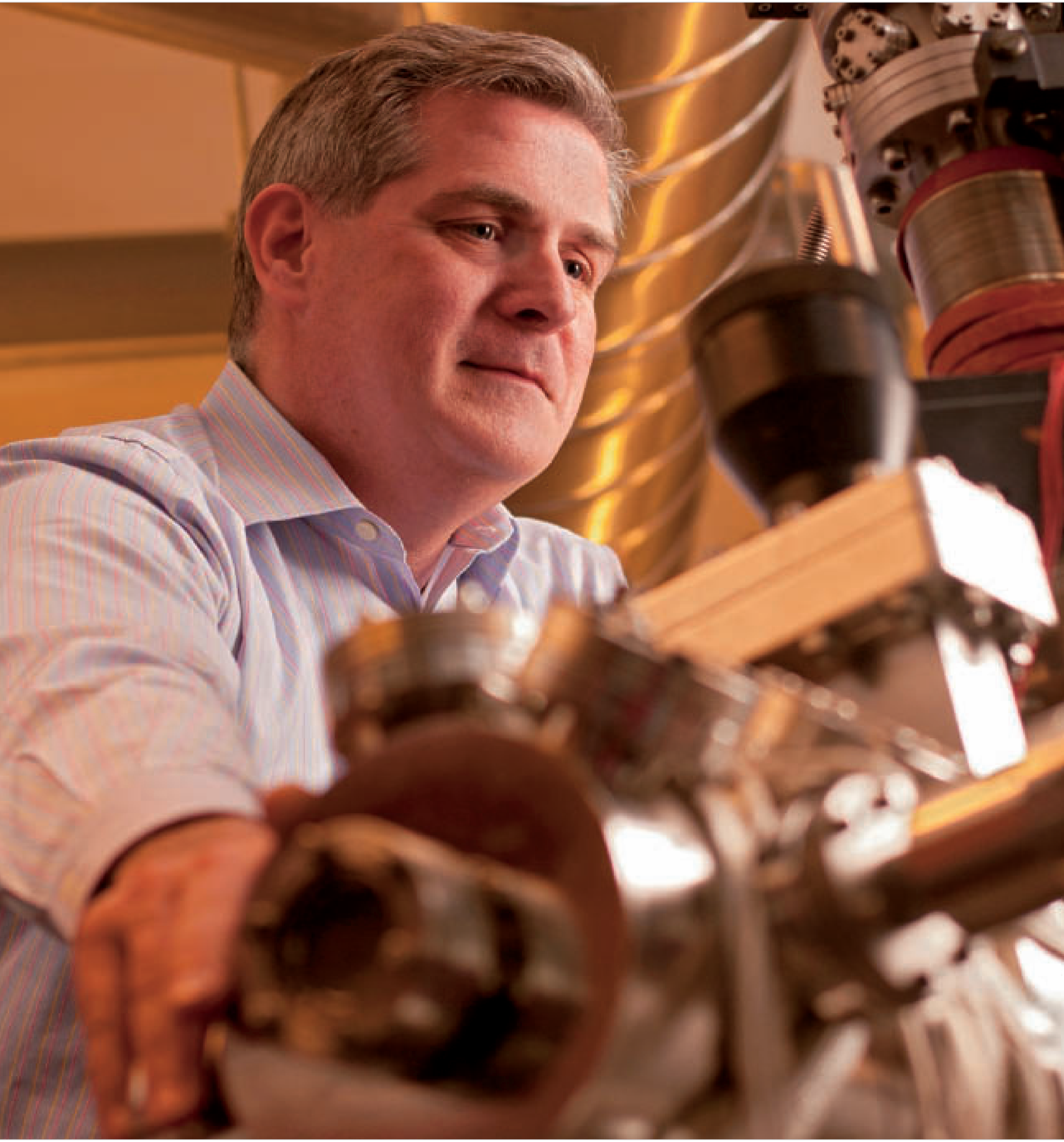
Building Better Fuel Cells

By Janelle Weaver

Fuel cells have been called the environmentally friendly energy source of the future because they generate electricity while producing fewer harmful emissions than coal-fired power plants. Solid oxide fuel cells in particular are very efficient, requiring much less fuel than an internal combustion engine to produce the same amount of energy, and they can handle a broad range of cleaner-burning fuels, including hydrogen and methane.

For the last 15 years, Raymond Gorte, the Russell Pearce and Elizabeth Crimian Heuer Professor of Chemical and Biomolecular Engineering and Professor of Materials Science and Engineering, and John Vohs, the Carl V. S. Patterson Professor of Chemical and Biomolecular Engineering, have been collaborating to design more efficient, durable and versatile solid oxide fuel cells. They have improved the materials making up these devices by studying their nanoscale structure and electrochemical properties.

Their efforts could help the United States transition toward using technology that can run on alternative fuels. This is an important goal, given that we annually produce about 6 billion metric tons of carbon dioxide emissions, the vast majority of which comes from burning fossil fuels, such as coal and oil. Electric power generation accounts for the most greenhouse gas emissions, which not only reduce air quality, but can also impact human health and ecosystems through climate change.



Dr. John Vohs

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"The work that has been carried out by Gorte and Vohs has revolutionized solid oxide fuel cell research in that they have developed a new method for fabricating fuel cells that allows electrodes to be made from a much wider range of materials," says Kathleen Stebe, the Richer and Elizabeth Goodwin Professor and Chair of Chemical and Biomolecular Engineering.

Ideal Ingredients

Solid oxide fuel cells are made up of a dense, ion-conducting layer known as the electrolyte, which is sandwiched between two electrodes—or electrical conductors—called the anode and cathode. Oxygen gas is channeled through the cathode, where electrons react with the gas to create oxygen ions. These ions travel through the electrolyte to the anode, where they react with gaseous fuel to produce electricity.

One way that Vohs and Gorte have improved solid oxide fuel cells is by replacing problematic metals in the electrodes. Nickel, for instance, is a traditional component of electrodes, but it causes the formation of carbon deposits when exposed to hydrocarbon fuels at high temperatures, which are required by solid oxide fuel cells. As a result, the electrodes become corroded and do not function properly. By swapping nickel for a conductive oxide and then adding dopant levels of a catalyst such as platinum, the scientists have reduced carbon buildup in the electrodes. "I like to say that nickel is not on my periodic table," Gorte says.

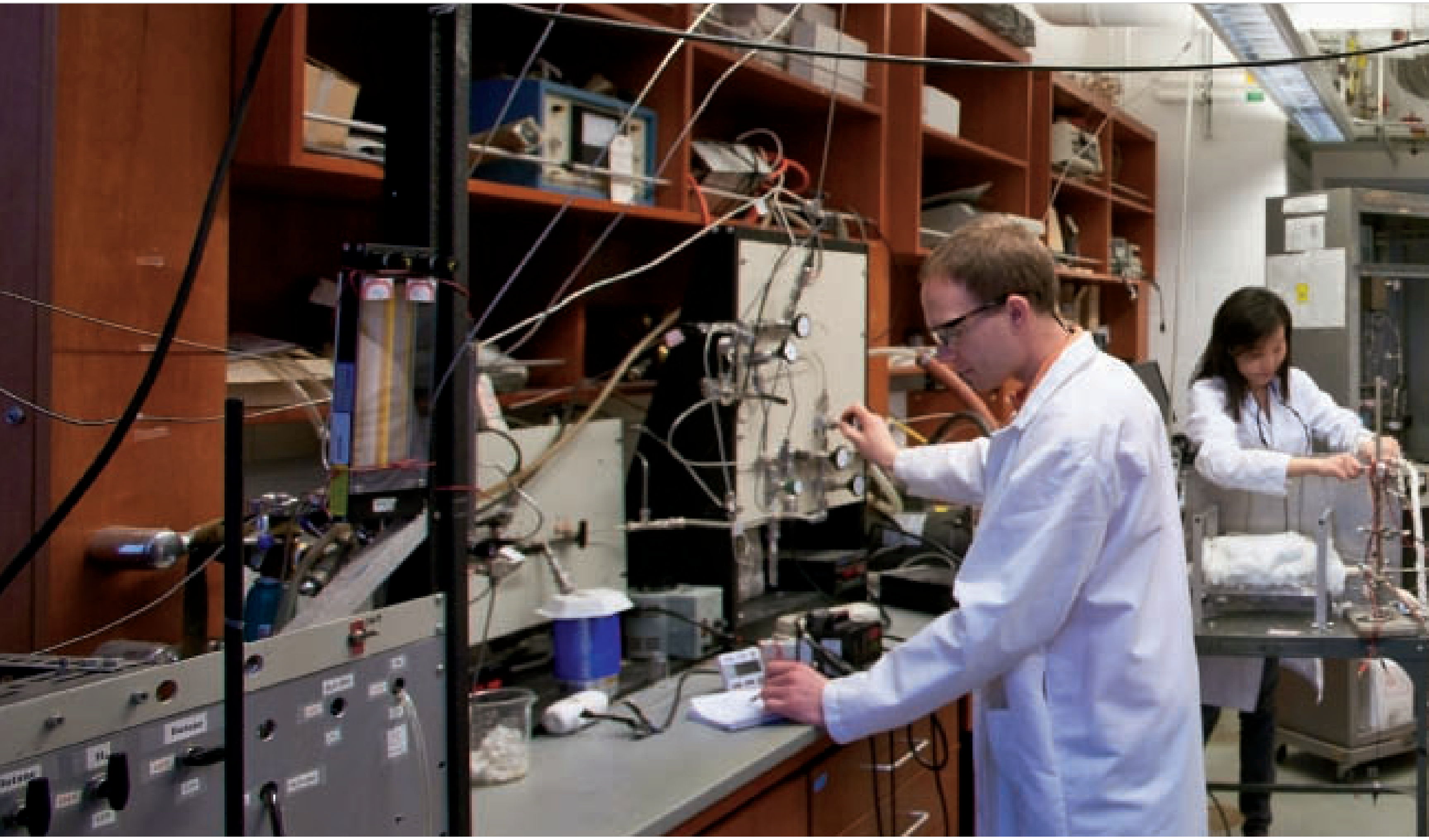
The researchers have also introduced a novel way of fabricating electrodes that allows them to precisely control and optimize the materials. They infiltrate salt solutions into a porous scaffold layer made of yttria-stabilized zirconia—a ceramic material used to make cheap jewelry—add catalysts, and apply heat to create electrodes with high electrical conductivity. This infiltration process reduces wasted energy and enhances the power output of ceramic fuel cells.

"Gorte and Vohs have gone above and beyond other experts in the field to advance solid oxide fuel cell technology using innovative approaches," says Eduardo Glandt, Dean of the School of Engineering and Applied Science.

Flexible Fuels

Most fuel cells are powered by hydrogen, which is extracted from hydrocarbon fuels with steam and high temperatures in an external device called a reformer. "The system that you have to develop to produce the hydrogen is far more complicated than the fuel cell itself, and there's energy lost in all sorts of stages during that production," says Gorte, who arrived at Penn in 1981, soon after receiving his Ph.D. in Chemical Engineering from the University of Minnesota.

Gorte and Vohs focus on solid oxide fuel cells because these devices do not require the external reforming process and can run on carbon-based fuels. "One major goal of our work has been to develop electrodes that will allow us to oxidize any combustible fuel," Gorte says, explaining that "carbon-based fuels are available, whereas hydrogen does not grow on trees."



One way the duo has met this goal is by replacing solid electrodes in fuel cells with molten electrodes—made of the metal antimony—that can operate on a variety of carbon-containing solids, such as sugar char, rice starch, graphite, and pyrolysis oil, "the gunk that messes up your chimney when you put logs on the fire," Gorte explains. "Grabbing a log and throwing it into the system and developing electricity is a much simpler process than a lot of what's going on to develop biofuels."

These robust fuel cells generate a substantial amount of power, and their electrodes have very high electrical conductivity. Gorte plans to work with a company to commercialize the devices into applications such as portable generators, which have a huge market in third-world countries lacking stable power grids. "I'm optimistic that they will find applications, initially in smaller-scale systems, particularly in places where electricity is expensive," he says.

Fueling Future Innovators

A recipient of the 2007 Catalysis Club of Philadelphia Award, Vohs uses sophisticated spectroscopic techniques to study the properties of fuel cells, while Gorte, who received the R. H. Wilhelm Award in Chemical Reaction Engineering in 2009, uses relatively simple approaches. "It has actually worked out well because we have methods of study that are very different and very complementary, so the collaboration has been extremely useful," Gorte says. "Our labs are essentially attached, so our students move freely between rooms."

"A hallmark of Penn Engineering is fostering the interdisciplinary nature of research, getting people

in different fields talking to each other, and having co-advised students," says Vohs, who joined the faculty in 1989, soon after earning his Ph.D. in Chemical Engineering from the University of Delaware. "The most satisfying part is actually working with these graduate students and seeing them succeed and go on to work in industry or take jobs in academia."

Vohs will soon have more opportunities to cultivate the next generation of Penn students and enable them to address the world's energy challenges, with the establishment of a new program that he is co-directing with Andrew Rappe, professor of Chemistry. The Vagelos Integrated Program in Energy Research (VIPER), endowed by Roy Vagelos (C'50) and his wife Diana, is a dual-degree program for talented and motivated undergraduates in the School of Engineering and Applied Science and the School of Arts and Sciences. The selected students will receive instruction on energy science and engineering and mentoring from faculty affiliated with the Penn Center for Energy Innovation (Pennergy). They will also participate in research to prepare for pursuing advanced degrees and eventually establishing their own research careers that focus on developing sustainable ways to harvest, convert and use energy.

"Energy and energy-related environmental issues are important global problems right now," Vohs says. "If we're going to solve these types of problems, we need well-educated scientists and engineers who have backgrounds in the technical fields needed to address these issues, so our goal is really to get students started on doing that as soon as possible."