Protonic ceramic fuel cells are highly durable, fuel flexible

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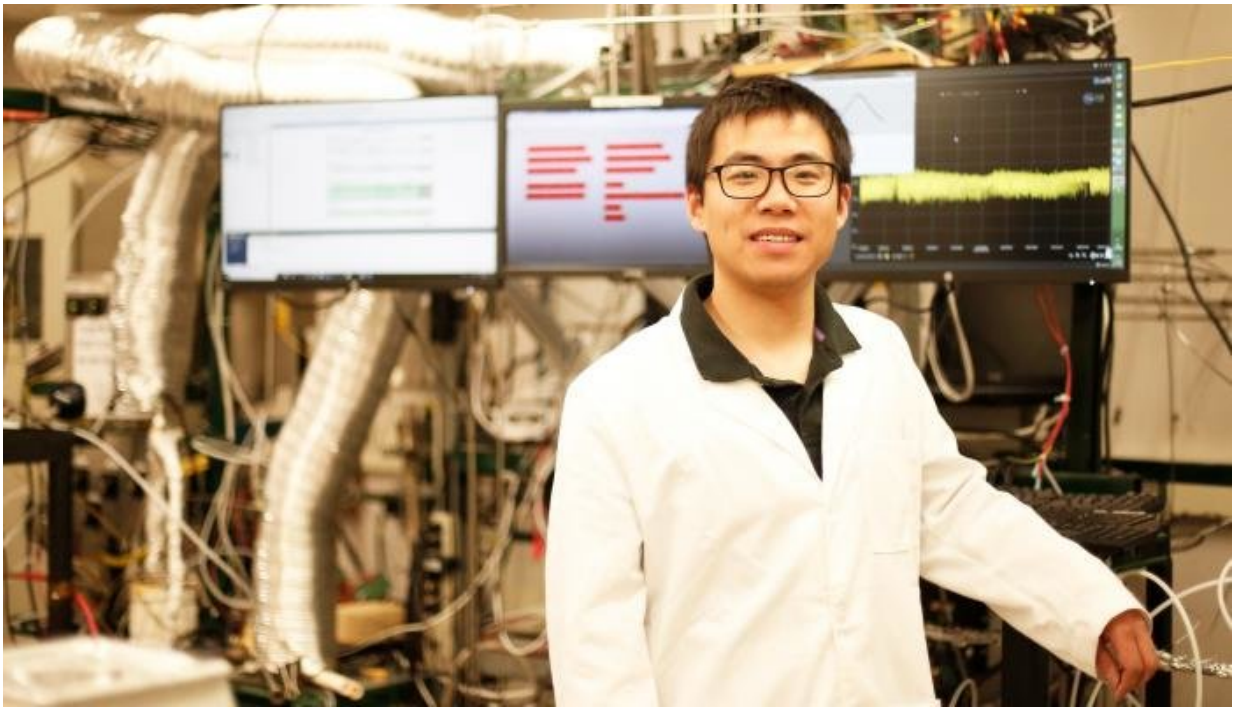

Chuancheng Duan, the paper's co-lead author, will graduate from Mines this week with a PhD in Material Science. Credit: Colorado School of Mines

Protonic ceramic fuel cells could one day be used to power off-the-grid cabins in remote locations, backup generators during natural disasters and more.

In the first long-term study of its kind, researchers from Colorado

School of Mines have shown that the relatively new class of fuel cells exhibit both the long-term durability and fuel flexibility needed to become a viable commercial alternative to other existing fuel cell technologies.

In all, researchers tested 11 different fuels – hydrogen, methane, domestic natural gas (with and without hydrogen sulfide), propane, n-butane, i-butane, iso-octane, methanol, ethanol and ammonia – demonstrating excellent performance and exceptional durability across all fuel types over thousands of hours of operation. Their findings, "Highly durable, coking and sulfur tolerant, fuel-flexible protonic ceramic fuel cells," were published today by the journal *Nature*.

"Protonic ceramic fuel cells (PCFCs) are very fuel flexible. We can feed them all sorts of different real-world fuels and make electricity," said Ryan O'Hayre, professor of metallurgical and materials engineering and co-lead author of the paper with Mines Ph.D. candidate Chuancheng Duan. "That's very different from other fuel cells that only work on hydrogen. Some high-temperature solid oxide fuel cells (SOFCs) will also run on other fuels but they're very finicky – if you feed them fuels other than hydrogen, they are susceptible to contamination and degradation, and their performance drops rapidly with time. Our fuel cells didn't face those problems with long-term testing."

"No one can get hydrogen delivered to their door very easily," O'Hayre added. "But you can go down the road to the 7-Eleven and pick up a tank of propane."

Protonic ceramics are a relative newcomer in the fuel cell world, the material having only been discovered in Japan in 1980. It wasn't until the late 1980s and early 1990s, though, that the technology began to gain acceptance, and in just the last eight or so years, researchers have made major inroads in addressing stability issues and how to make the dense

membranes necessary to power a device, O'Hayre said.

The performance tests conducted at Mines were 10 times longer in duration than any previous effort, O'Hayre said. For the tests, Duan designed and built a fuel-cell testing system where he could simultaneously test seven cells using different fuels for thousands of hours. The setup required careful monitoring for the better part of two years.

"The longest test was 8,000 hours, which is almost a whole year," Duan said. "The degradation rate of most of the fuel cells was less than 3 percent per 1,000 hours, which meets the requirements of commercial products."

Developing a highly durable fuel cell technology that can directly use natural gas and hydrocarbons is critical when it comes to commercialization, Duan said.

Mines researchers are now working with Fuel Cell Energy, a Connecticut-based fuel cell company, to scale up the lab-scale technology and develop a pre-commercial prototype that could deliver the amount of electricity needed to power a RV or remote cabin, with funding from the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E).

"Based on our current work and achievements, it is time to collaborate with an industrial partner to make commercial products," Duan said. "In three years, there will be a 500-watt direct-natural gas PCFC stack developed based on our technology. In less than 10 years, there will be a 1-kilowatt PCFC stack that could serve as a house power supply, the backup power supply for offices or mobile base stations."

"This is an excellent example of the fruitful collaborations between

Mines and CoorsTek catalyzed in part by their lead support for the new CoorsTek Center for Applied Science and Engineering on campus," O'Hayre said. "David Hook at CoorsTek spearheaded high-temperature XRD studies that helped us better understand the high-temperature behavior of our protonic ceramic membrane."

More information: Chuancheng Duan et al. Highly durable, coking and sulfur tolerant, fuel-flexible protonic ceramic fuel cells, *Nature* (2018). DOI: 10.1038/s41586-018-0082-6

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