A new way to fight 'forever chemicals'

ASU researchers develop technique that can capture and destroy ubiquitous PFAS, instead of just filtering them out

By Richard Harth, ASU News
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They can turn up in a nonstick frying pan, a waterproof jacket, a takeout food wrapper or the foam used to fight fires.

Known as “forever chemicals,” these substances are ubiquitous in modern society, prized for their extreme durability and versatility. However, their charm comes with a curse: They are so durable they resist degradation, posing threats to human health and the environment.

Per- and polyfluoroalkyl substances, or PFAS, gained early widespread use in products such as Teflon, a coating that resists oil, heat, stains, grease and water. Today, they are everywhere, from paints and adhesives to furniture, carpets, cosmetics, semiconductors and waterproof fabrics. Unfortunately, they are also in our water, soil, food, and even us.

Now, researchers at Arizona State University and their international colleagues are attacking the problem in a new way. Rather than filtering these harmful chemicals out of contaminated water, they have developed a technique to destroy them.

Most conventional PFAS treatments separate the chemicals from water. Activated carbon, ion exchange and membrane filtration can capture PFAS, but the contaminants remain in spent filters, brines or concentrated waste that must still be handled or disposed of. The new approach is designed to go a step further by breaking the chemicals apart rather than simply moving them somewhere else.

“PFAS are hard to break down, and normal processes that we use don't work,” said Bruce Rittmann, director of the Biodesign Swette Center for Environmental Biotechnology, who led the study.

He is joined by collaborators from Rice University, Texas; Tongji University, China; National University of Singapore; and Nanjing University, China.

The research appears in the current issue of the Proceedings of the National Academy of Sciences.

Why forever chemicals endure

PFAS owe their notorious persistence to the carbon-fluorine bond. In many of these compounds, a chain of carbon atoms is almost completely surrounded by fluorine atoms, creating an exceptionally tough chemical structure.

“It’s called the strongest bond in organic chemistry,” Rittmann said.

With fluorine effectively shielding the carbon backbone, conventional biological and chemical processes have trouble finding a place to begin breaking the molecule apart.

“There’s really no place to get a start to break it down,” Rittmann said.

The breakdown is difficult, but not impossible. Hydrogen can provide the power needed to attack the carbon-fluorine bonds, but first it must be activated. The researchers use palladium nanoparticles as catalysts to convert hydrogen gas into a highly reactive form capable of stripping fluorine from the PFAS molecule. To deliver the hydrogen efficiently, the researchers coated tiny membrane fibers with palladium nanoparticles and fed hydrogen gas through them.

A related membrane technology developed by Rittmann and his colleagues delivers hydrogen to pollutant-degrading bacteria. In the current research, the microbes are replaced by palladium, which uses the hydrogen to attack PFAS.

The new study tested the method across six PFAS of regulatory concern.

“We showed that this mechanism worked for all six,” Rittmann said. “It’s a universal mechanism.”

A lasting environmental legacy

PFAS contamination is widespread in groundwater, wastewater and soil. Particularly high concentrations are often found around wastewater-treatment facilities, landfills, airports and military bases where PFAS-containing firefighting foams have been used. The chemicals can also enter crops and accumulate in fish, livestock and wildlife, creating additional routes of human exposure.

“We all have PFAS in us,” Rittmann said. “They stay in the environment. They move up the food chain, and so they’re a big legacy problem.”

That persistence means PFAS contamination can outlast the uses that created it.

Exposure to some PFAS has been associated with cancers, thyroid disease, immune-system effects, reduced fertility, pregnancy complications, developmental problems, obesity and elevated cholesterol. Two types of PFAS — PFOS and PFOA — have been listed under the Stockholm Convention on Persistent Organic Pollutants. But the risks posed by the broader PFAS family remain difficult to assess because thousands of compounds exist and only a small fraction have been thoroughly tested for toxicity.

Why this research matters

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Molecular matchmaking

The catalytic membrane works by bringing the PFAS molecules and highly reactive hydrogen together at the surface of the palladium catalyst. Hydrogen travels through the membrane and is attracted to the palladium, where hydrogen-gas molecules split into individual hydrogen atoms. PFAS molecules approaching from the surrounding water also attach to the palladium surface.

“The palladium attracts the PFAS molecule, and the palladium attracts the hydrogen and puts them together,” Rittmann said.

With the pollutant and the reactive hydrogen side by side, the palladium acts as a catalyst, enabling a speedy reaction that breaks the stubborn carbon-fluorine bonds.

The way the hydrogen is delivered is also critical. Rather than simply mixing hydrogen into the water, the researchers feed it from inside the membrane directly into the base of the palladium layer.

This inside-out delivery is one of the study’s key advances: The membrane does more than capture PFAS at its surface. It also supplies the reactive hydrogen needed to chemically dismantle the molecules once they arrive there.

For nearly two months, the system continuously treated water containing a mixture of six PFAS. It removed more than 90% of each compound and stripped away about 83% of the fluorine overall, showing that the pollutants were being chemically dismantled rather than merely filtered out.

Toward real-world use

The 58-day test showed the system could operate continuously, but translating the technology into practical water treatment will require further engineering. One practical hurdle is cost. Rittmann said reducing the amount of palladium needed is one of the group’s top research priorities.

“Palladium is expensive,” he said. “It’s around $50,000 a kilogram.”

The technology could eventually complement existing PFAS-removal systems. Conventional treatment could first concentrate the contaminants from large volumes of water into a smaller waste stream, which could then be treated to destroy the PFAS rather than simply store or dispose of them.

The same membrane platform may also have broader uses. Rittmann’s group is developing hybrid versions that combine palladium nanoparticles with pollutant-degrading bacteria. The palladium and microbes attack contaminants in different ways, giving the system two routes for breaking them down.

“We’ve shown that this works too,” Rittmann said.

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photoelectron spectroscopy.

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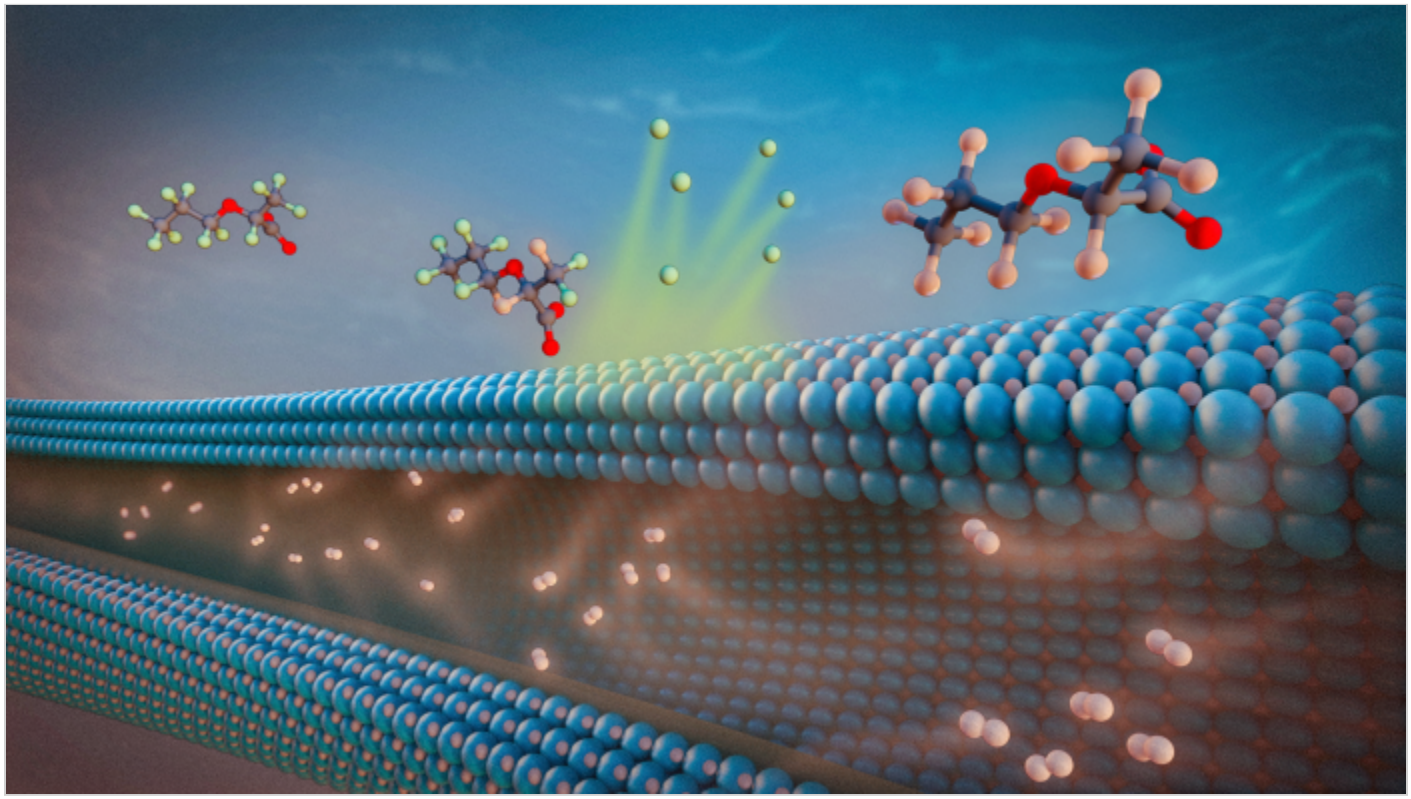
Main image



A palladium-coated membrane uses hydrogen to help break down PFAS, or “forever chemicals.” Graphic by Jason Drees

Text image(s)



Bruce Rittmann