Metal-organic frameworks: Nobel-winning tiny ‘sponge crystals’ with an astonishing amount of inner space

Stavroula Alina Kampouri, Assistant Professor of Chemical and Biomolecular Engineering and Chemistry, Rice University

So far, scientists have synthesized over 90,000 MOFs, and computational chemists have predicted hundreds of thousands more. Few material families offer this much versatility.

I like to think of MOFs as puzzles or Lego sets, but on the atomic scale. You can replace a single piece, or change its color or shape, and end up with a material that behaves completely differently.

Add a new “decoration” – what chemists call a functional group – and the framework suddenly recognizes a new molecule. Stretch the organic bridges, and the same architecture inflates like a balloon, giving what we call isoreticular MOFs. These have the same structure, but bigger pores. In short, MOFs can come in almost every imaginable shape, size and texture.

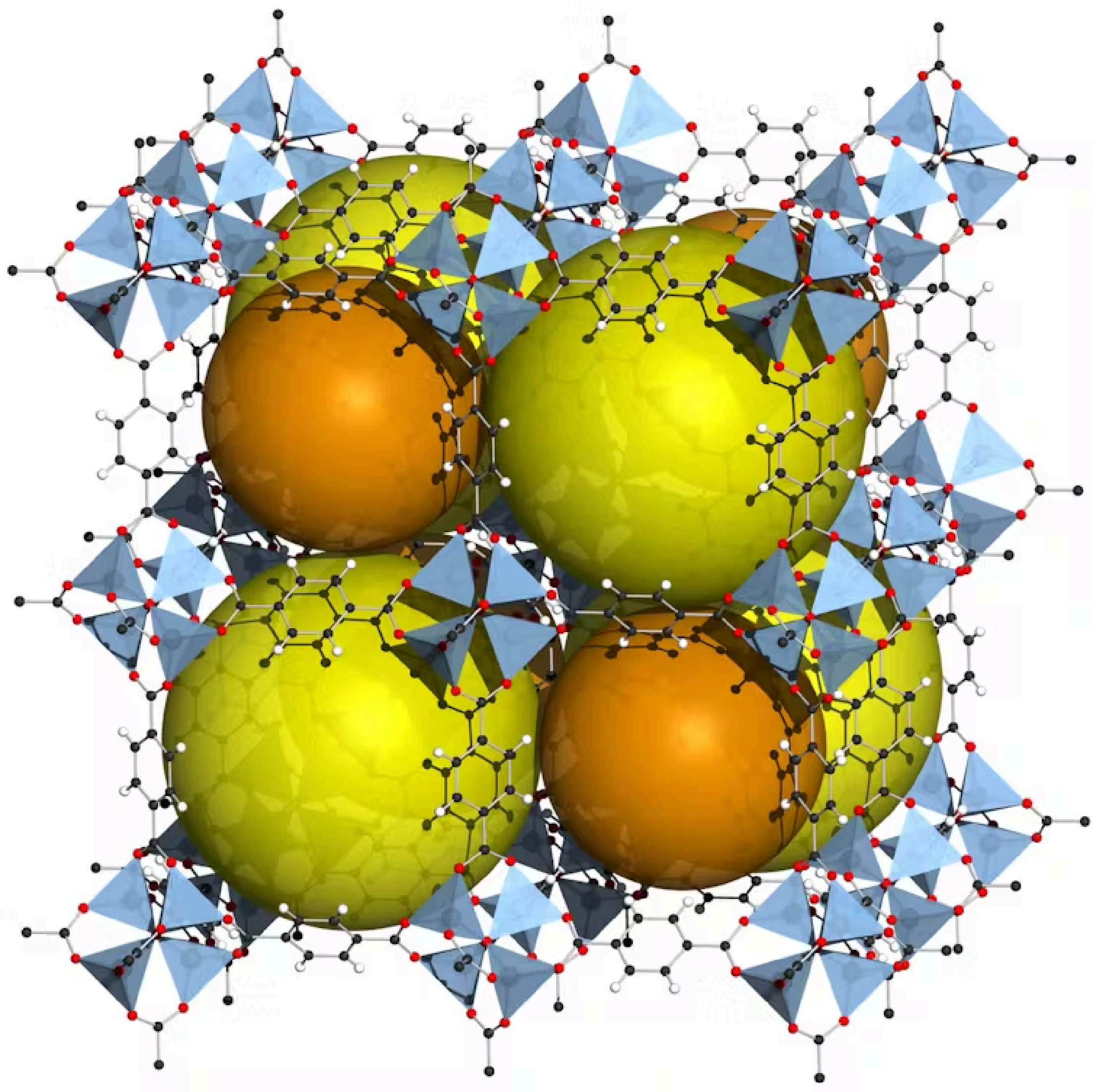
Pushing the boundaries of these materials

Beyond their scientific elegance, MOFs are incredibly promising for real-world technologies. Different structures and functionalities lead to different properties and, therefore, different uses.

Some MOFs act as molecular sieves, selectively capturing carbon dioxide from industrial exhaust or even directly from air. Others clean polluted water by removing heavy metals, dyes or “forever chemicals.”

Certain MOFs can also carry drugs or imaging agents inside the body for medical applications. In the energy world, they function as electrodes or electrolytes that make batteries safer and more efficient. And many serve as catalysts, accelerating chemical reactions that transform one molecule into another.

When I began my Ph.D., my senior colleagues warned me that MOFs might be too delicate – beautiful crystals that would crumble at the first hint of air or moisture. And indeed, some of the early frameworks were fragile curiosities, admired more for their elegance than their endurance. But that perception has changed dramatically.



Metal-organic frameworks, like MOF-5 shown here, have metal components, organic ‘linkers’ and a cavity which can allow in gases.

Many MOFs are now remarkably robust. The material I first worked on was a titanium-based metal-organic framework named MIL-125. It was first reported by Gérard Férey, one of the foundational figures in the MOF and porous framework community who sadly died in 2017. MIL-125 was not only stable, it was practically indestructible in my lab. After synthesizing two grams of it, I stored it on my bench in an open vial and used that same batch for every catalytic experiment throughout my Ph.D. No glovebox, no desiccator – just a jar of yellow powder sitting happily on my bench.

That experience taught me something important: While stability can be a legitimate concern, MOFs have grown up. Thanks to smart chemistry, we have materials that can withstand water, heat and repeated use. Since their foundation, researchers around the world have introduced new properties to these materials – from electrical conductivity to light responsiveness – and, crucially, made major progress in scaling up MOF synthesis for industrial applications.

Scaling is the key step in bridging the gap between fundamental discovery and large-scale deployment. Researchers are no longer content with studying MOFs in milligrams – we're often planning for grams, kilograms and beyond.

Some startups are turning these advances into real technologies – from storing gases more safely, to pulling clean water straight from desert air, to building more energy-efficient air conditioners. What once felt like science fiction – powders that breathe, trap and transform molecules – is now science fact.

Despite these advances, researchers will need to continue improving the stability and scalability of MOFs to fully realize these materials' potential in the real world.

A Nobel moment that honors creativity

The 2025 Nobel Prize in chemistry goes beyond honoring three remarkable scientists – it celebrates an entire community: a generation of chemists and engineers who transformed a single idea into a thriving field. The pioneering visions of Richard Robson, Susumu Kitagawa and Omar Yaghi laid the foundations for a vibrant discipline that has grown to encompass everything from gas storage and catalysis to energy and environmental technologies.

When I attended my first MOF conference as a second-year Ph.D. student, I listened in awe to many of the pioneers of this field, some of whom are now Nobel laureates. Back then, MOFs felt like magical sponges, and that sense of wonder never left me. It led me to continue my research on conductive MOFs: materials that can carry electricity. Now, in my own research group, we study how these frameworks can make batteries safer and more efficient, and how they can capture waste gases and turn them into useful chemicals using sunlight.

For me, this Nobel Prize celebrates more than a discovery, it celebrates a philosophy: Chemistry is creative, we can design and engineer matter with imagination, and sometimes emptiness can be the very essence of a material.

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