

# The Alchemist

From his lab in the University of California, Berkeley, Jordan's Omar Yaghi is creating the formula for a greener future—before it's too late.

BY HELEN MORROGH

## Interest

• The upper safe limit for atmospheric carbon dioxide is 350 parts per million (ppm). In February, the global average surpassed the 400 ppm mark.

• Thomson Reuters' Top 100 Chemists is a ranking of chemists across the globe, based on the impact of their published papers from the years 2000 to 2010.

"Be less curious about people and more curious about ideas."

— Marie Curie



Jordanian chemist Omar Yaghi sits in his office in the University of California, Berkeley, casting his mind back to his childhood. He recalls afternoons spent in Amman poring over chemistry books, staring at drawings of molecules; discovering what he calls a "hidden world". The child was awestruck that these peculiar-shaped entities depicted on his library books were the building blocks of everything around him. "It's a beautiful world, and it's a feast for study," says the James and Neeltje Tretter Chair Professor of Chemistry. That childhood wonder led Yaghi to become one of the most important chemists of our time through the invention of metal-organic frameworks (MOFs), chemical compounds that can suck harmful gases from the atmosphere. And now, from his lab, molecule by molecule, he is demolishing scientific boundaries and formulating a greener future from the pieces.

A substance that can rid the air of toxic gases: it sounds extraordinary—and it is. In fact, the 50-year-old's work is so revolutionary, that even the science used to create MOFs required its own classification. The method is 'reticular chemistry': the stitching together of molecular building blocks to form porous structures that will maintain their original form while carrying out predetermined and specific functions.

Achieving this was a chemical first; a feat that has seen Yaghi's name frequently crop up in Nobel Prize predictions. Previously, the only constant scientists could rely on was that their molecular creations would not retain their original form during chemical processes, and

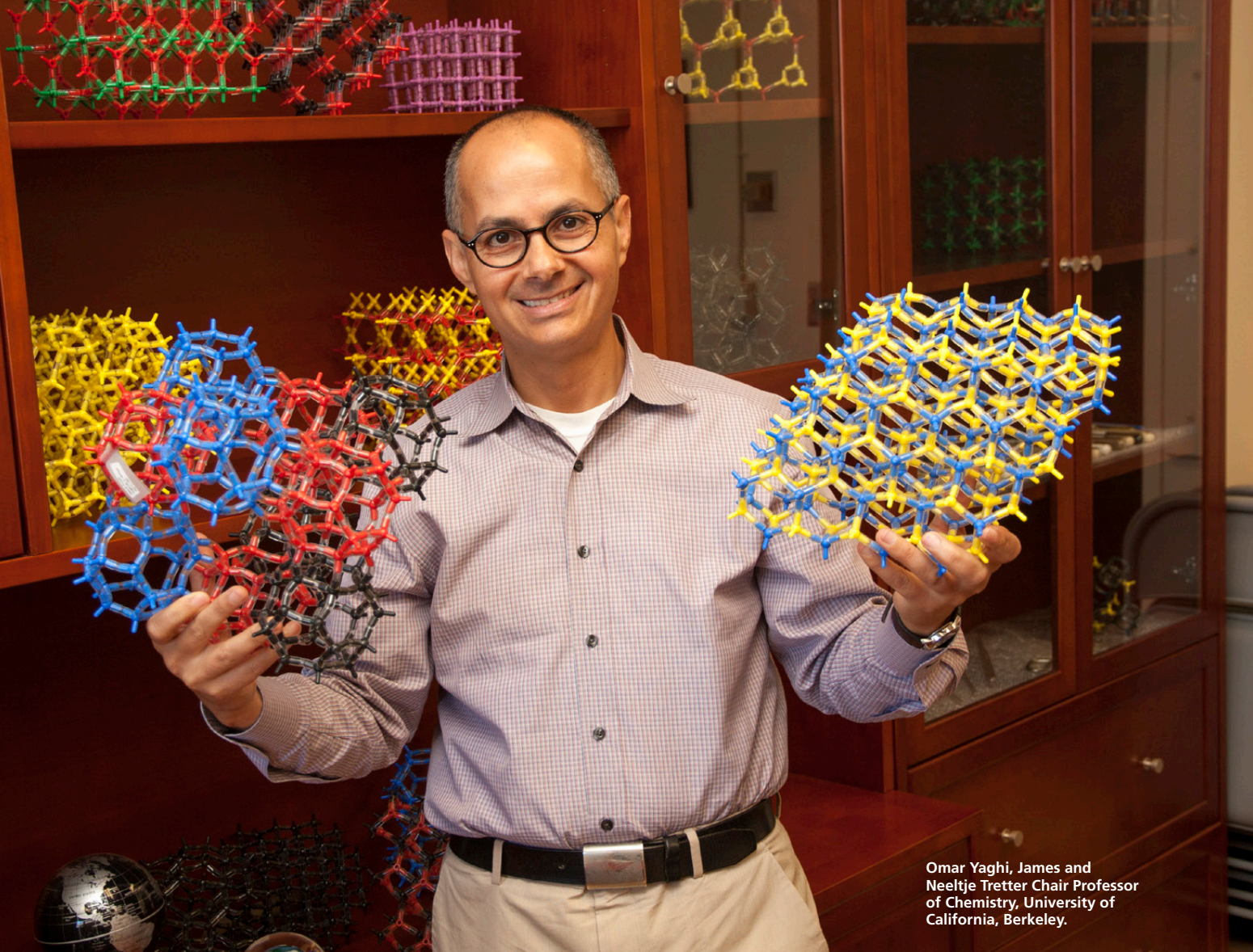
therefore their function could not be controlled.

Determined to achieve the then-impossible, the Jordanian, living in the States since the age of 15, dedicated his life—after earning a BS in chemistry from the State University of New York-Albany and a PhD from the University of Illinois-Urbana—to an independent career. His research began in 1992 in Arizona State University, where he spent long days in the lab experimenting, failing, carefully adjusting, until finally, in 1995: "Success came and the door opened, and it was a goldmine."

Yaghi had created sponge-like compounds—to the naked eye MOFs look like "baby powder"—which can be tailored to capture, compact and store specific molecules in the air, such as carbon dioxide or hydrogen, and essentially soak them up into large pores. "They have extremely high surface areas," explains Yaghi of the structures that broke a one-thousand-year record for porosity. "If you take one gram of these solids and spread it on the nanometer scale, you would easily cover a football field."

It sounds impressive. But what does all of this mean to the billions of non-scientists amongst us? The real world implications of MOFs are immense. "It is a breakthrough," says Yaghi, devoid of ego, but instead looking





Omar Yaghi, James and Neeltje Tretter Chair Professor of Chemistry, University of California, Berkeley.

through the un-blinkered, matter-of-fact lens of science.

German chemical producer, BASF, has shown how MOFs can benefit compressed natural gas (CNG) cars. Although a cleaner alternative to petrol or diesel-run automobiles, CNG vehicles do present considerable drawbacks. Large high-pressure cylinders—much bigger than those needed for petrol or diesel tanks—are required to compress and store enough gas for the vehicle to run efficiently. On top of that, there simply aren't that many natural gas stations in our cities where motorists can refuel.

Through equipping the cars with MOF-filled tanks, BASF found that those clunky oversized cylinders are no longer needed, while motorists can travel double the distance before needing to refuel. Now, manufacturers have the chance to produce CNG cars that make the practical sense they previously lacked—finally offering motorists an attractive alternative to their petrol-guzzling autos.

Unfortunately, the environment's woes don't

stop there. Yaghi moves onto the subject of carbon dioxide; by far the biggest contributor to greenhouse gases in the world. The professor explains that the more CO<sub>2</sub> we emit, the more acidified our oceans become and as a result, our coral reefs—the colorful flowerbeds of the sea, vital for the underwater food chain—are quite literally disintegrating. “That's damage that is irreversible in our lifetime,” says Yaghi. His words paint a grim picture.

While MOFs can't undo what's already been done—they won't unmelt the polar icecaps—Yaghi believes his work can certainly slow down the devastating and rapid effect of global warming on our planet through tracking and trapping CO<sub>2</sub> emitted by power plants and car exhausts.

This is something his laboratory works on in conjunction with other labs and institutions across the world, including King Abdulaziz City for Science and Technology in Saudi Arabia (KACST). Dr. Ahmad Alshammari, from the National Nanotechnology Research Center in KACST, says

advancements in carbon capture could greatly benefit the oil (and thus, emission)-rich Middle East. He says: “We plan to design and develop MOFs for various applications; it will help to limit emissions in the region.”

Instead of storing the waste gas underground—a common practice in carbon capture—Yaghi and his team are now working “extensively” on finding out how to turn it into a fuel. If his chemical wizardry is successful—past achievements mute doubting minds—it will spell an even more promising future for MOFs and their role in green energy practices. Yaghi explains: “If you take carbon dioxide and convert it into a hydrocarbon [found in crude oil]...and then take the hydrocarbon and use that as a fuel, and burn that, that goes to CO<sub>2</sub> and then the cycle continues.”

Using MOFs to capture carbon from the fumes released by power plants is for now, at least, only hypothetical. While it seems like an environmental no-brainer, there are inevitable cost considerations for re-fitting power plants. It is an issue that will have to be addressed by policy-makers sooner rather than later, says Yaghi. “People have not figured out the carbon dioxide capture policy yet,” he says. “Either the consumer pays for it, or the government helps—that has to be figured out.”

These are serious environmental issues being forced to the surface by Yaghi’s work. But is he an environmentalist? “I was more attracted by the idea of discovery...the intellectual aspects of learning how you can take different bits and pieces of matter and make new forms out of them; expanding chemistry beyond what we already knew,” says the professor.

However, the green repercussions of his inventions were by no means accidental. Yaghi recognized the immense potential of his work from the outset—leading him to be named the second-most influential chemist in the world by Thomson Reuters. He says: “Once you know how to twist and turn molecules in a very precise way, I knew—everybody knows in chemistry—that that’s a very powerful way of making useful materials.”

That passion for pure science has maintained Yaghi’s focus in the presence of the frequent, and inevitable, lucrative offers from big energy companies. “I would much rather enjoy the basic science and develop materials,” says the professor. Still, his work isn’t without financial—and distinguished—rewards. Most recently, in February, he became the joint winner

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of the 2015 King Faisal International Prize for Science. The honor saw Yaghi and Swiss chemist Michael Grätzel split \$200,000 in prize money.

Despite what must be a glistening awards cabinet, Yaghi is adamant that his focus has, and always will be, on discovering and sharing. And so, all of his inventions are patented—he estimates he has over 40 patents—and the formulae fully disclosed. “The

question was [when we made MOFs]: do you keep this technology in our lab, or do you teach the world? And I’m glad that we decided we would teach the world how to make them. That helps everybody jump in. Now there are—I don’t even know the number—it could be a hundred different labs around the world making MOFs. So you can imagine the scale of discovery. The science is immense.”

It was that dedication to science that motivated Yaghi, aged 15, to further his studies in the States—with encouragement from “a father and mother that were first loving, and second incredibly committed to education”—equipped with a dictionary and broken English. Though he had learned English in school, Yaghi admits he could barely understand a word coming out of the immigration officer’s mouth when he landed in JFK. He laughs: “I had my dictionary with me, but it wasn’t very helpful. I found out that I was learning a very different kind of English altogether.”

Despite the initial language barrier stateside, had he stayed in Jordan, Yaghi says his options would have been limited. It essentially whittled down to a choice of studying either engineering or medicine. The latter, he jokes, held little appeal: “I was not interested in blood and being in an operating room. I tried that for a summer internship and I didn’t like it at all.” And, to a shy teenager, the allure of chemistry didn’t stop at the fundamental love of science. “I really wanted a more solitary activity,” admits the professor. “I thought: wouldn’t it be wonderful to sit there and study these things without the constraints of society, and without the hassle of having to deal with the day-to-day things that we have to deal with? Now at an older age, you just realize that that was just fantasy.”

Omar Yaghi’s fantasies have served him well. Inspired by the odd shapes in a book, the chemist followed a mystical path into a hidden world. And as he continues to tread along the road, he is prizing open that secret realm, revealing a greener future of endless possibilities. **F**