Green Cleaner Tech

Startups Are Racing to Make Water Out of Thin Air

Materials that are bigger on the inside than the outside provide a futuristic solution to supply water to an increasingly arid planet.

Omar Yaghi is the founder of Atoco and a chemistry professor at the University of California at Berkeley who pioneered materials that can harvest water from air.

Image courtesy of Atoco

By Todd Woody

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At a laboratory in a Southern California warehouse, scientist Heng Su unveils what could be a world-changing solution to the global water crisis. The small handheld object looks unremarkable, consisting of stacked white fins that resemble a miniature old-fashioned apartment radiator. But when Su puts the device on a scale, it silently gains weight within seconds. As the minutes pass, it gets heavier and heavier. That's because the gadget is invisibly gathering water molecules from the surrounding air.

A few feet away, four of the water harvesters sit inside a plastic enclosure shaped like a transparent birdhouse. The warm air inside dislodges the H2O molecules from the harvesters and a condenser transforms the water vapor into liquid, which is dripping into a beaker. The technology, called metallic organic frameworks (MOFs), doesn't require electricity and can produce water with just ambient sunlight. It's Irvine-based startup Atoco's vision for how to provide water in an increasingly arid world.

This is a lab prototype designed to only produce a few milliliters of water as scientists work to perfect the technology. The company plans on building a full-scale commercial version that could produce thousands of liters of ultrapure water a day for a community. A unit the size of a residential air conditioner could supply water to your home.

"You can harvest water from air anywhere in the world, at any time of the year regardless of the level of humidity, without a carbon footprint," says Omar Yaghi, who founded Atoco in 2021 and is a chemistry professor at the University of California at Berkeley who pioneered MOFs.

Half the world's population experiences water scarcity and 25% endure extremely high levels of water stress, according to a 2024 United Nations analysis. Even in a wealthy place like California, which boasts the world's fifth-largest economy, nearly a million residents lack access to clean drinking water, a June report found.

Climate change-fueled heat waves and droughts, meanwhile, are exacerbating water shortages across the world, sparing neither rich nor poor, and more intense and frequent storms can knock water treatment plants offline.

The company envisions building a full-scale commercial version that could produce thousands of liters of ultrapure water a day for a community *Illustration courtesy of Atoco*

But even the driest skies contain water. The US Geological Survey estimates that the atmosphere contains 12,900 cubic kilometers of water or about 14% of what's found in the world's lakes. MOFs offer a unique way to harvest some of it.

Like Doctor Who's Tardis, the material is bigger on the inside. A gram of MOFs can have the surface area of a soccer field. Imagine, says Atoco Chief Executive Officer Samer Taha, you take a piece of paper and crumple it as much as you can. It's now a fraction of its original size but retains the same surface area within the folds.

That's what Atoco is doing on the molecular level, engineering nanoscale crystalline structures filled with porous cavities. Its MOFs are made of elements that attract specific molecules, such as H2O.

The company starts to cook up its MOFs in a small room off the main lab at its headquarters. There, an amber liquid boils in a beaker next to a centrifuge that will reduce it to a fine powder. This is where chemists are creating organic "linker" molecules, which connect metallic molecules and provide stability to the MOF's crystalline structure. The inorganic molecules form cavities that serve as microscopic water tanks for H2O molecules drawn from the atmosphere. The first water molecules that attach themselves to the insides of the cavities become "seeds" to which others bind.

MOFs are made from mostly common elements such as carbon, nitrogen, hydrogen, copper and aluminum. But Taha says that some of the specialized molecules Atoco needs can be expensive due to their scarcity, and its scientists are working to synthesize them in-house in an effort to drive down costs. In an adjacent room, several barrels sit on the floor. Senior scientist Jacob Kanady opens the lid on one, which is filled with a white powder made from identical nanoscale crystalline structures. When a binder is added, the powder solidifies so it can be fashioned into fins for the lab water harvester.

Conventional methods of harvesting water from the atmosphere rely on cooling the air until water vapor liquifies, a process that consumes large amounts of electricity. It's also not effective in environments with low humidity. Another option for producing water in arid regions, desalinization requires immense energy, affects marine life and leaves behind brine waste.

MOFs sidestep those obstacles, producing purified water on site using no or little electricity. They are, in Yaghi's view, a transformational technology. "For the first time in human history, you can modify materials on the atomic and molecular level and you can design them with precision to be suitable for a particular application," he says.

Other startups are developing MOFs for atmospheric water harvesting. Atoco has an edge, though: Yaghi developed the material and has continued to perfect it while working in a field known as reticular chemistry. "The advances that Professor Yaghi has made over the past decade keep us ahead of the competition," says Taha. He declined to say when Atoco would bring its technology to market but notes "it's not far."

The challenge Atoco and its competitors face is developing cost-effective processes to mass-produce MOFs, according to Laura Gagliardi, a professor of chemistry and molecular engineering at the University of Chicago who has collaborated with Yaghi. Atoco declined to comment on the price to make its MOFs at scale but says the company is on track to harvest water for 1 cent or less per liter.

In August 2022, Yaghi and UC Berkeley colleagues tested a prototype of a handheld water harvester in California's Death Valley National Park, one of the hottest, driest places on the planet. *Image courtesy of Atoco*

"I worked with these people long enough to understand that this technology works very well, and it has been demonstrated in the field," Gagliardi says.

In August 2022, Yaghi and UC Berkeley colleagues tested a prototype of a handheld water harvester in California's Death Valley National Park, one of the hottest, driest places on the planet. At night, the harvester adsorbed water molecules from the atmosphere. During the day, they were released as the sunlight warmed the harvester and a condenser then liquified the water vapor. With temperatures at ground level hitting 60C (140F) and an average humidity of 14%, the harvester produced between 4 ounces (118 milliliters) and 7 ounces (207 milliliters) of water a day, according to a 2023 paper the scientists published in the journal *Nature Water*. Though it's not nearly enough to serve an average person's daily needs, it illustrates the promise of the technology.

Water from air could be a gamechanger for increasingly arid and impoverished regions of the world where desalinization isn't an option and conventional atmospheric water harvesting is ineffective due to low humidity. Traditional harvesters also collect air pollution along with water vapor, requiring the captured water to be purified at additional expense. MOFs, on the other hand, are engineered to nab only H2O molecules, filtering out contaminants and producing water free of nanoplastics, PFAS chemicals and other toxics.

“Initially, we are focusing all our efforts on tackling water scarcity and trying to operate in arid conditions, which is actually our competitive advantage because we can harvest water even in dry conditions, while others cannot,” says Taha.

Atoco is designing water harvesters that need only sunlight to operate or that can be powered by renewable energy. That would allow a harvester to operate when the sun isn’t shining as well as employ fans to draw more molecules into the MOFs, producing more water in the process.

The US military has boosted such efforts by establishing an Atmospheric Water Extraction program. In 2020, the Defense Advanced Research Projects Agency awarded a $14 million grant to General Electric to develop MOF technology that could supply water to troops, and GE enlisted Yaghi and Gagliardi to advise and work on the project.

“The electrified device that GE is now delivering to DARPA is delivering 22 liters of water per day, using only two kilograms of MOFs,” says Gagliardi. “So I think that this is all very promising.”

In March, GE Verona, a spinoff of GE’s energy business, announced a joint venture with startup Montana Technologies called AirJoule to commercialize the technology. AirJoule has developed a MOF atmospheric harvester that also provides energy efficient air conditioning through evaporative cooling. One of AirJoule’s innovations is to tap the heat generated by MOFs adsorbing of H2O molecules to extract them for condensation. A proprietary vacuum compressor and condenser transforms the water vapor into liquid.

Montana Technologies Chief Executive Officer Matt Jore says two big potential markets for AirJoule's atmospheric harvesting technology are the US military, which must currently truck water to troops deployed in remote locations, and rapidly expanding data centers, which consume staggering amounts of water and electricity for cooling, and have become flashpoints in drought-stricken regions.

"Data centers are not getting permitted because of water consumption so we have a huge opportunity," he says.

Jore says the cost of the MOFs it uses has fallen from $5,000 a kilogram to less than $50 a kilogram. The company has built pre-production models of the machine and intends to begin manufacturing the devices in 2025 for the air conditioning market.

While AirJoule sees specific industries as potential customers, Atoco's Taha is thinking bigger. The market, he says, is anyone "that wants to have a consistent, stable and pure water supply and doesn't want to rely on water coming from the government."

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