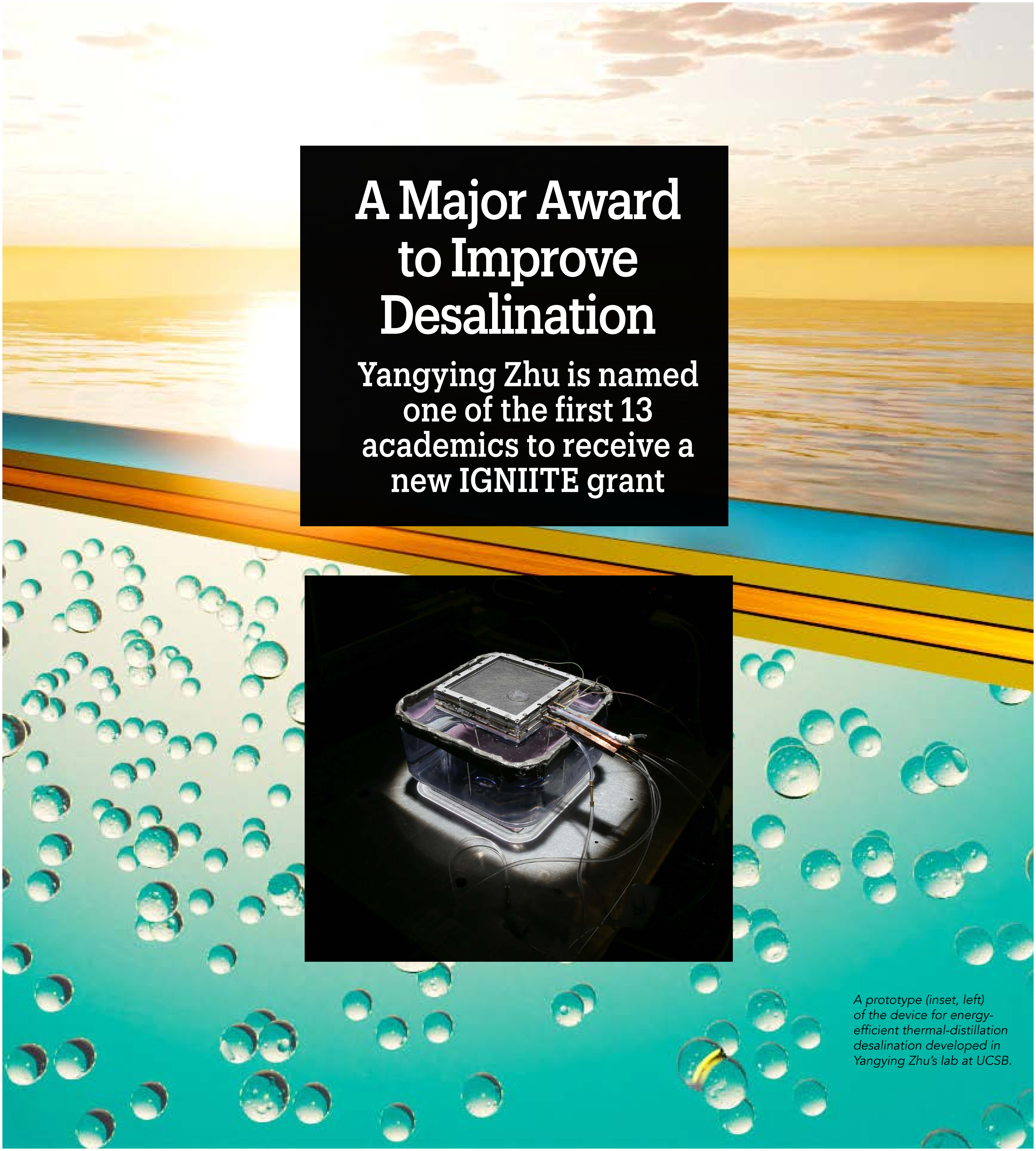
A Major Award to Improve Desalination

Yangying Zhu is named one of the first 13 academics to receive a new IGNIITE grant



A prototype (inset, left) of the device for energy-efficient thermal-distillation desalination developed in Yangying Zhu's lab at UCSB.

With freshwater becoming scarce, desalination of ocean water is increasingly being employed to bridge the gap between the amount of freshwater that is needed and what's available. Desalination is an energy-intensive process, however, one often powered by fossil fuels, so meeting the need for freshwater can exacerbate the challenge of reducing atmospheric CO_2, the main driver of climate change.

Yangying Zhu, an assistant professor in the Mechanical Engineering Department at UC Santa Barbara, is addressing that conundrum thanks to a two-year, $500,000 seed grant from the Advanced Research Projects Agency-Energy (ARPA-E) within the U.S. Department of Energy (DOE). The grant was provided as part of Inspiring Generations of New Innovators to Impact Technologies in Energy (IGNIITE 2024) a new ARPA-E program supporting early-career scientists and engineers to convert disruptive ideas into impactful energy technologies and bringing them to market.

"This is the first time the agency has funded early-career single-investigator research," Zhu says. "Instead of being solely focused on fundamental discoveries, as are NSF Early CAREER awards [which Zhu has also received previously], this one is focused on supporting ideas that align with the ARPA-E mission of improving energy efficiency and sustainability for the United States." The agency received 400 applications for the highly competitive grants, selecting only 23 for funding. Of those, just 13 were from academia, with the rest in industry, startups, and national labs.

Zhu (left) and graduate students Emily Spitaleri (front) and Patrick Babb examine an evaporator membrane made in Zhu's lab for the ARPA-E project.

> Zhu, who has expertise in heat and mass transfer, plans to develop a novel architecture to potentially reduce energy consumption of the desalination process by half.

Zhu has two main objectives in her project: to improve the energy efficiency of the thermal distillation desalination process, and to use renewable energy — either solar or waste heat from industry, such as that from power plants and data centers — to power the process. "We are targeting both energy efficiency and reduced dependence on fossil fuels," she says.

There is no shortage of available industry waste heat, but it is considered "low-grade," because it has a relatively low temperature of around one hundred degrees Celsius. That is far below what's needed, says, to drive a power plant, so it gets wasted, but, Zhu notes, "It's fine for our purposes, since that is the boiling temperature for water."

Conventional thermal distillation methods usually require more than one hundred kilowatt hours (kWh) of thermal energy to produce one cubic meter of fresh water. Zhu, who has expertise in heat and mass transfer, plans to develop a novel architecture that would potentially reduce energy consumption of that process by half.

Using thermal energy to evaporate water requires three things: liquid, solid, and vapor — called *a three-phase contact line,* along which all three phases occur. Evaporation and condensation are most efficient at or near the contact line, where the overall thermal resistance is low.

Zhu uses a cup of coffee to illustrate a heat-transferring context lacking such a three-phase contact line, because there is only the liquid-vapor interface. The cup is the solid, but the contact line, where the three phases meet, runs only along its perimeter. "If I were to have a membrane on top of the cup, within each pore of the membrane I would have liquid, vapor, and solid, providing the three-phase contact line that makes evaporation much easier," Zhu explains. "When heat is provided to the porous-solid membrane, it transfers the heat to the liquid to evaporate it. That process is most efficient when the heated membrane is very close to the liquid-vapor interface."

In the case of the cup of coffee, only the perimeter of the cup and the coffee near it receives the heat. It then has to pass through the liquid (not a good conductor of heat) to warm the rest of the coffee. "If you had a membrane, each pore would be like a tiny cup of coffee," Zhu says. "The solid would receive the heat, which would then be carried to a very nearby microscopic vapor interface. That's what is meant by "thin film" in the title of the project — the liquid film is very thin and also very close to the solid. If each pore of the membrane is, say, one micron in diameter, then the heat from the solid has to travel only one micron to reach the liquid-vapor interface for evaporation.

"Ideally, the solid membrane would be made of a highly thermally conductive material, so that the heat will move through it easily, heating the whole membrane," Zhu continues. "There is a range of materials — mostly metals — that are already used for this, or you can have a hybrid system consisting of polymers supported by a metal. We're using commercially available materials, because desalination is a practical process, so you can't create something that's very expensive or hard to get, like platinum."

The other innovation in this project is that it involved not only thin-film evaporation, but also thin-film condensation. "It is really the same process, and equally as important as evaporation, but in reverse," Zhu says, "so we also need lots of three-phase contact to release the heat that builds up during the process. You need to absorb heat during evaporation and release it during condensation. You want that to occur at the liquid-vapor interface and then to move easily to the membrane, which can conduct the heat away."

In the above scenario, the solid will conduct the captured heat to another stage to evaporate more water, thus the phrase multi-stage desalination. "We're thinking of having ten to twenty stages," Zhu notes. "We need to develop a model to predict what the right number is, because at some point, the efficiency decreases, and the amount of distilled water you collect after each stage will decrease. We have already built a two-stage prototype in the lab and done some very preliminary tests on it. So far, it's working well."