Khalifa University Science and Tech Review

A quarterly science magazine published by Khalifa University

The Water Issue

The Future Of WATER

Lessons from the desert beetle

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Khalifa University Science and Tech Review

KUST Review is dedicated to publishing authoritative, reliable and accessible information about science, innovation and technology news and trends. Although we report on news from around the world, we highlight advances, innovators and topics of interest from the Middle East and North Africa region.

Our mission is to spread knowledge of and enthusiasm for science and technology in the Arab world and beyond through responsible and trustworthy journalism.

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LETTER FROM THE EDITOR

If the events of the COVID-19 pandemic have taught us anything, it is that a public well-versed in science is vital to a strong and healthy community.

Science literacy gives us the tools we need to make smart decisions for our health and families. It helps us distinguish between fact and fiction amid a cacophony of conflicting opinions. And it provides a better understanding of the powerful forces – both natural and human-made – shaping the world and how we can each play a part in making sure the future is bright, sustainable and equitable for all.

That is why H.H. Sheikh Hamed Bin Zayed Al Nahyan, chairman of the Board of Trustees of Khalifa University, directed us to create the *KUST Review*.

We built this magazine under his leadership to share our enthusiasm for science and technology with our neighbors around the world and here in the MENA region, where researchers and innovators at Khalifa University and beyond are doing exciting work that will help us meet serious challenges now and in the future.

Water issues are among the most pressing in the United Arab Emirates and the surrounding region. Water scarcity is not new to our area. But increased, settled populations and changing climates are putting unprecedented pressures on water supplies. Water tables are falling. Agricultural requirements are rising. Rain is sporadic. In short: The Middle East is thirsty. And it's going to get only thirstier.

But although the issue of water scarcity may be especially acute in the UAE and MENA region, it's of international concern. Nearly 1 million people die each year because they don't have access to good-quality water; and 4 billion people, about two-thirds of the world's population, live with severe water scarcity at least one month of the year, according to the United Nations.

And the World Health Organization reports that by 2050, half of the planet will suffer even more from water scarcity, whether because of climate change driving devastating floods and droughts, pollution's effects on water quality, or expected growth in the demands of manufacturing and increasing populations.

This doesn't even take into account the staggering effects of severe water shortages on the environment and vulnerable species.

That's why in the premiere issue of the *KUST Review*, we're investigating some of the ways researchers and innovators are looking at the future of water: how to better manage the resources we have; measure and predict the weather changes that will shape our new world; access sources previously believed out of reach; and power these efforts without adding to the carbon-dioxide emissions driving climate change to begin with.

You'll find even more stories, videos and images at our website, www.KUSTReview.com, and on Facebook, Instagram, LinkedIn, Twitter and other favorite social-media sites @KUSTReview. So page, click and follow to get the best of our coverage of science in the Middle East and around the world in the ways you like to see it most.

Dr. Arif Sultan Al Hammadi
KUST Review Editor-in-Chief

READ IN THIS ISSUE

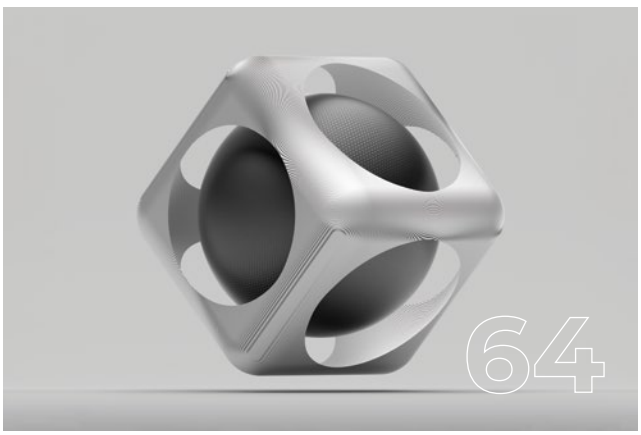
THE FUTURE OF WATER

The world faces growing populations; increasing pollution threats; and climate change driving unprecedented floods, storms and droughts. Clearly, conserving and finding new sources of clean water is more important than ever.

In the premiere issue of *KUST Review*, we investigate ways researchers and innovators are addressing the need to protect the Earth's water resources and provide for more than 8 billion people.

In these pages you'll find stories about a UAE scientist who uses nanotechnology to coax rain from the clouds; an innovator who grows tomatoes in the desert with seawater; a desert beetle that is teaching humans how to collect water from thin air and much more.

REGULAR CONTENT



IN SPACE
no one can hear you flush

Ensuring the accessibility of water on Earth is a priority for science in the coming years to be certain. But so is making sure it's available in space.

By: **KUST Review Staff**

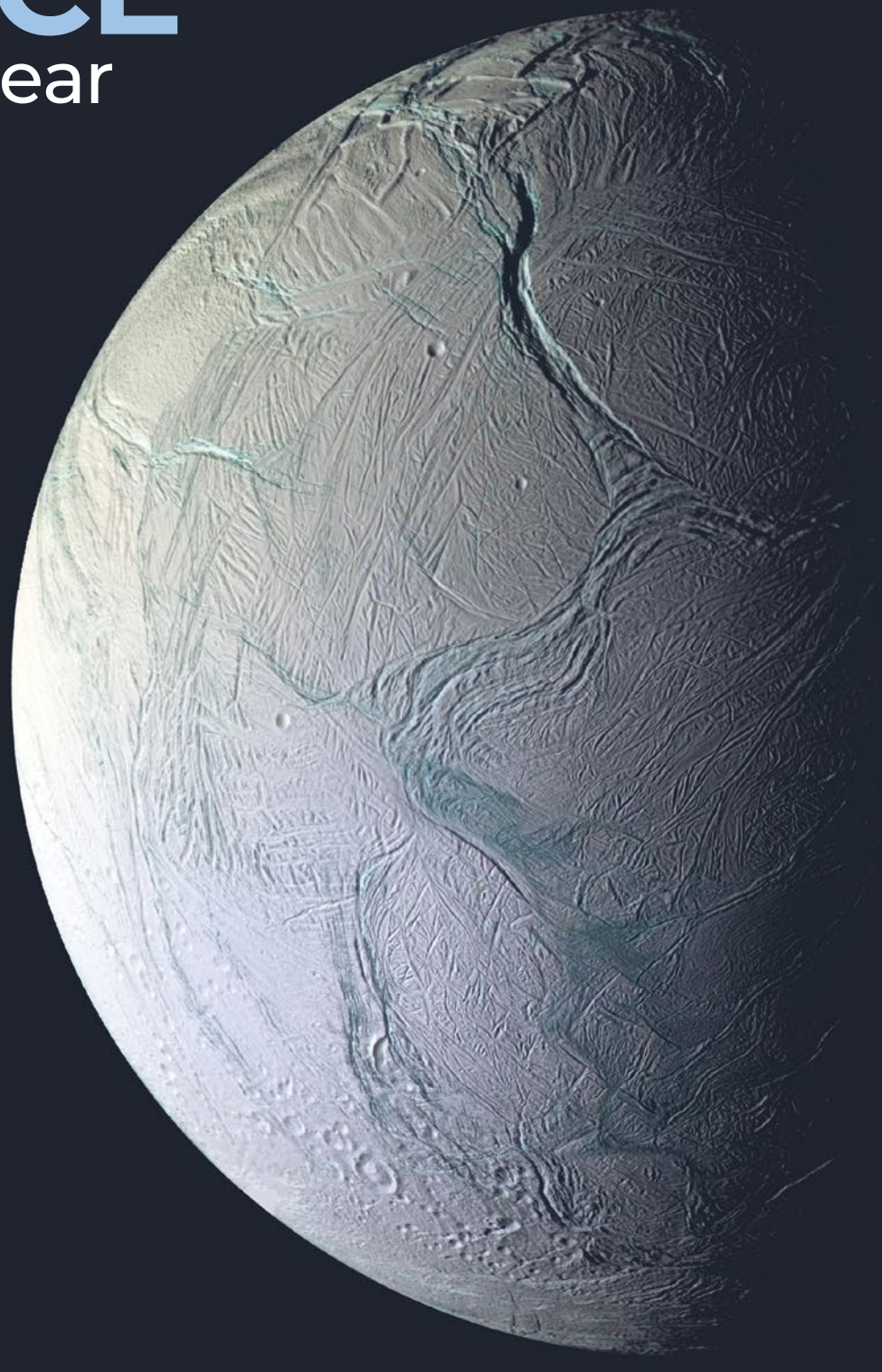


PHOTO CREDIT: NASA/JPL/Space Science Institute

⊙ **PHOTO:** Enceladus, the sixth moon of Saturn, is covered with ice. Perhaps someday humans in space will be able to tap it and other sources of extraterrestrial water. But until then, space voyagers will need to bring along their own supplies from Earth.

It isn't like finding water in space is impossible. The chemical elements that make water – hydrogen and oxygen – are abundant in space.

"NASA science activities have provided a wave of amazing findings related to water in recent years that inspire us to continue investigating our origins and the fascinating possibilities for other worlds, and life, in the universe," says Ellen Stofan, a chief NASA scientist, on NASA.gov. NASA points to the four giant planets in our solar system – Uranus, Jupiter, Saturn and Neptune – as being likely to contain large amounts of water. There is also evidence that five moons of Jupiter and Saturn contain oceans under their surfaces.

In 2020, NASA announced the discovery of H2O in sunlit areas of the Earth's moon, suggesting that the water molecule is widely distributed across the lunar surface.

And scientists have discovered a huge cloud of water vapor about 30 billion miles away that contains at least 140 trillion times the amount of water in all of the seas and oceans on Earth. In fact, all of the water here came from out there as ice piggybacking on the comets and asteroids that plowed into a hot and dry young Earth. That's right: Water is alien.

But ensuring a steady supply for humans venturing out into space is a bit more complicated right now than steering into a vapor cloud or drilling into a frozen moon. Explorers will have to ensure they bring and manage whatever they need.

"We recycle about 90 percent of all water-based liquids on the space station, including urine and sweat," says astronaut Jessica Meir on NASA.gov. "What we try to do aboard the space station is mimic elements of Earth's natural water cycle to reclaim water from the air. And when it comes to our urine on (the International Space Station), today's coffee is tomorrow's coffee!"

Part of the liquid-recovery process is accomplished with NASA's new space toilet: The $23 million Universal Waste Management System launched to the ISS in 2020. The toilet, designed for male and female astronauts, aids in recycling more urine for tomorrow's coffee. The water in fecal content is not currently being recycled, but NASA scientists are looking into it.

That could help them do better than their current 90 percent recovery rate. NASA wants to bring that recycling rate to 98 percent before humans board a proposed Mars transport vehicle for missions expected to last two years round-trip. NASA is aiming for the Mars missions to begin in the 2030s.

PHOTO CREDIT: NASA

⊙ **ABOVE:** NASA astronaut and Expedition 65 Flight Engineer Mark Vande Hei services components on an advanced new toilet installed inside the International Space Station's Tranquility module.

⊙ **BELOW:** For privacy, the toilet is located inside a stall just like in a public restroom on Earth.

⊙ **COVER:** Desalination, renewables, energy, and climate change are all connected

GRAPHICS: Anas Albounni
PHOTOS: Shutterstock

Desalination's BRIGHTER FUTURE

Solar-powered plants could help achieve water security globally with a surprising benefit in energy storage

By: **Jade Sterling**

If you're ever lost in a desert, finding a water supply is key to your survival. Understandably, this is difficult in a desert as there is neither enough rainfall nor open-water sources, such as rivers or lakes, to reliably support the people inhabiting these areas. What many desert regions do have, however, are coastlines with access to plenty of salty seawater.

Enter desalination

Desalination is a brilliant way to make fresh water. Seventy percent of the world is covered with water, but only 1 percent of that is potable. The solution? Take the salt out of the sea.

In the United Arab Emirates, even the groundwater is saline, in some cases up to eight times as salty as the surrounding seawater. Although this brackish groundwater can be used in irrigating salt-tolerant plants like date palms, everything else needs that water to be desalinated.

In many ways, the Middle East is on the cutting edge of sustainability because the governments there were forced to confront water scarcity from the get-go. The evolution of water conservation and sustainability in this region is a result of a multi-pronged approach, involving rethinking city planning, efficient water use and innovative solutions to providing clean water. »»

A perfect fit

Desalination plants are found in abundance in the Middle East: The U.S. Geological Survey says 70 percent of the world's desalination plants are located in this area, found mostly in Saudi Arabia, the UAE, Kuwait and Bahrain.

This makes sense: These countries are water-strapped but oil-rich. An energy-intensive clean-water-production technique is a perfect fit.

This oil won't last forever, though. And the world is already feeling the effects of global warming and climate change thanks to rampant use of fossil fuels in applications including desalinating water for desert populations. The solution? "Renewabilize" it. And luckily, the Middle East also has plenty of renewable energy to spare: sunshine.

But first, how does desalination work? The most popular method is reverse osmosis, where large quantities of seawater are pushed through a semipermeable membrane to remove the salt from the water. Think of this membrane as a very fine sieve that catches salt and other impurities.

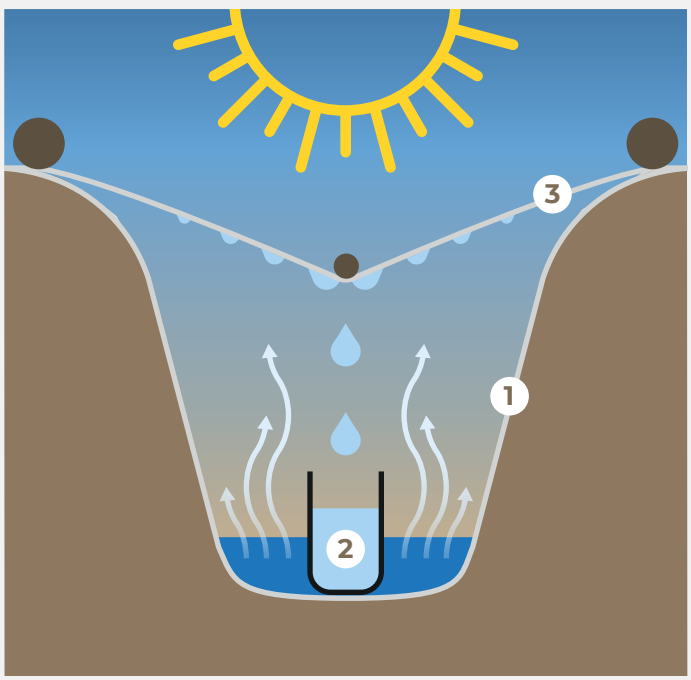
Although this is an effective means to desalinate seawater, it is driven by very high hydraulic pressure and requires robust pumping and expensive pretreatment. In Saudi Arabia's Eastern Region, for example, the seawater first needs to be filtered for oils, greases and jellyfish.

Seawater: See water

Desalination is an energy-hungry process. According to Richard Muller, professor of physics at the University of California, Berkeley, it will always take one kilowatt hour or more of energy to desalinate a cubic meter of seawater.

But Corrado Sommariva, founder and CEO of the Middle-East-based Sustainable Water and Power Consultants, says the desalination sector has been experiencing a revolution in the past five years and believes the process can be powered by renewable energy, particularly solar.

The cost of desalination from reverse osmosis has fallen dramatically in recent years, he notes, with much of this decrease in price stemming from streamlining processes and cheaper electricity, and as solar power looks set to become the cheapest form of electricity, moving to a renewable-power supply seems inevitable.

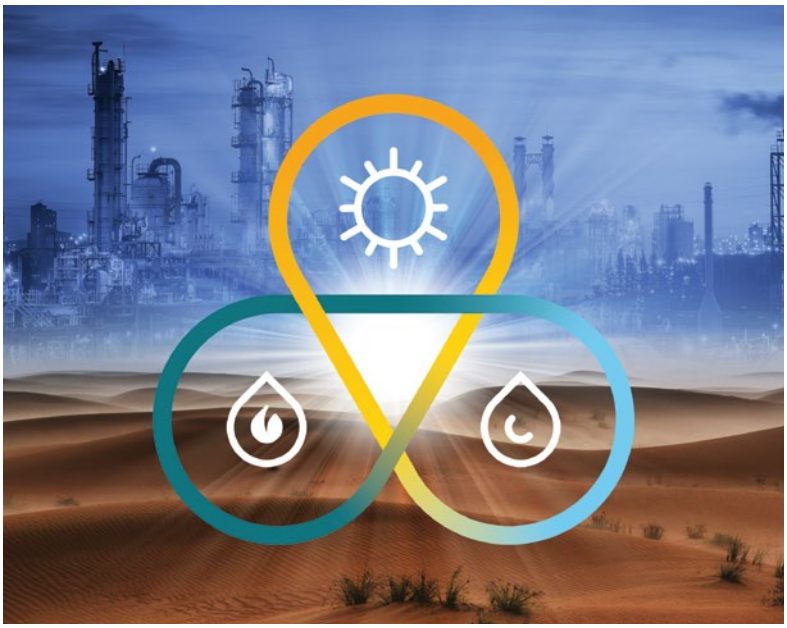


Solar stills

A classic solution: Sometimes the old ways are the best ways. The oldest desalination technology is the solar still, a simple device that uses sunlight to purify water. Salt water is placed in the still and an angled piece of glass or plastic is placed above.

The sunshine evaporates the water, which then condenses on the surface above before running down the surface to collect in a separate trough. The impurities and salt remain in the bottom of the still and the water in the trough is clean, pure drinking water.

If you do find yourself lost without clean water, you can make a solar still with a sheet of plastic (1) lining a hole in the ground, a mug (2) to collect the clean water, and another plastic sheet (3) on top anchored with a rock to create the angled surface.



Tom Pankratz, editor of the US Water Desalination Report, confirms: "Desalination is more energy-intensive than other water-treatment processes, so there's a growing interest in using renewable energy to reduce a plant's operating costs and its environmental footprint. In many places, especially in the Middle East where desalination is the primary source of water, renewable energy is often much less expensive — even with the abundance of fossil fuels in the region.

"In theory," he says, "any form of renewable energy could power desalination, but solar power is generating the most attention. Helpfully, the arid regions that need desalination the most are also the ones blessed with abundant sunshine.

"Solar farms are sprouting up in more and more areas in the Middle East, and their power generation gets priority to feed into the grid," Sommariva says. "For at least six hours a day, power tariffs as low as 1 U.S. cent per kilowatt hour are available to utilities from photovoltaic plants as the amount of electricity being generated by these plants will shortly outstrip grid demand during certain hours of the day. »»

⊙ **ABOVE, THE DESALINATION TRIANGLE:** When the oil runs out, can the sunlight step in to power the process?

1000 Wh+

It will always take **one kilowatt hour or more** of energy to **desalinate a cubic meter of seawater.**

As demand for water grows, **so does the need for better management.**

Previous poor water management and unsustainable agriculture practices in the Middle East have exacerbated desertification, and water scarcity is becoming severe in countries including Jordan and Yemen. Agriculture, industry, urbanization and population growth are all fueling the demand for more water, while climate change decreases supply day by day.

As the UN Food and Agriculture Organization points out, for **every 1 degree Celsius of global warming, 7 percent of the world could see 20 percent of renewable water resources dry up.** More frequent and severe droughts, combined with crops needing more water in higher temperatures, will put further pressure on dwindling water supplies.

According to the Water Project, other concerns with the future of desalination plants in the Middle East focus on the improper dependency they will cause, instead of encouraging alternate forms of water and energy to be explored and conservation of fresh water.

Photovoltaic power offers the chance to both operate desalination plants as potable-water generators and grid-energy absorbers and buffers."

A tough balance

The journey of electricity from the power plant to our homes and businesses is not always a smooth one. Grid operators are faced with the complex task of balancing the amount of electricity fed into the grid against the amount of electricity consumed to keep the power system stable. But as more intermittent renewable-energy sources of electricity, like solar and wind, are fed into the grid, this balancing act becomes even more challenging.

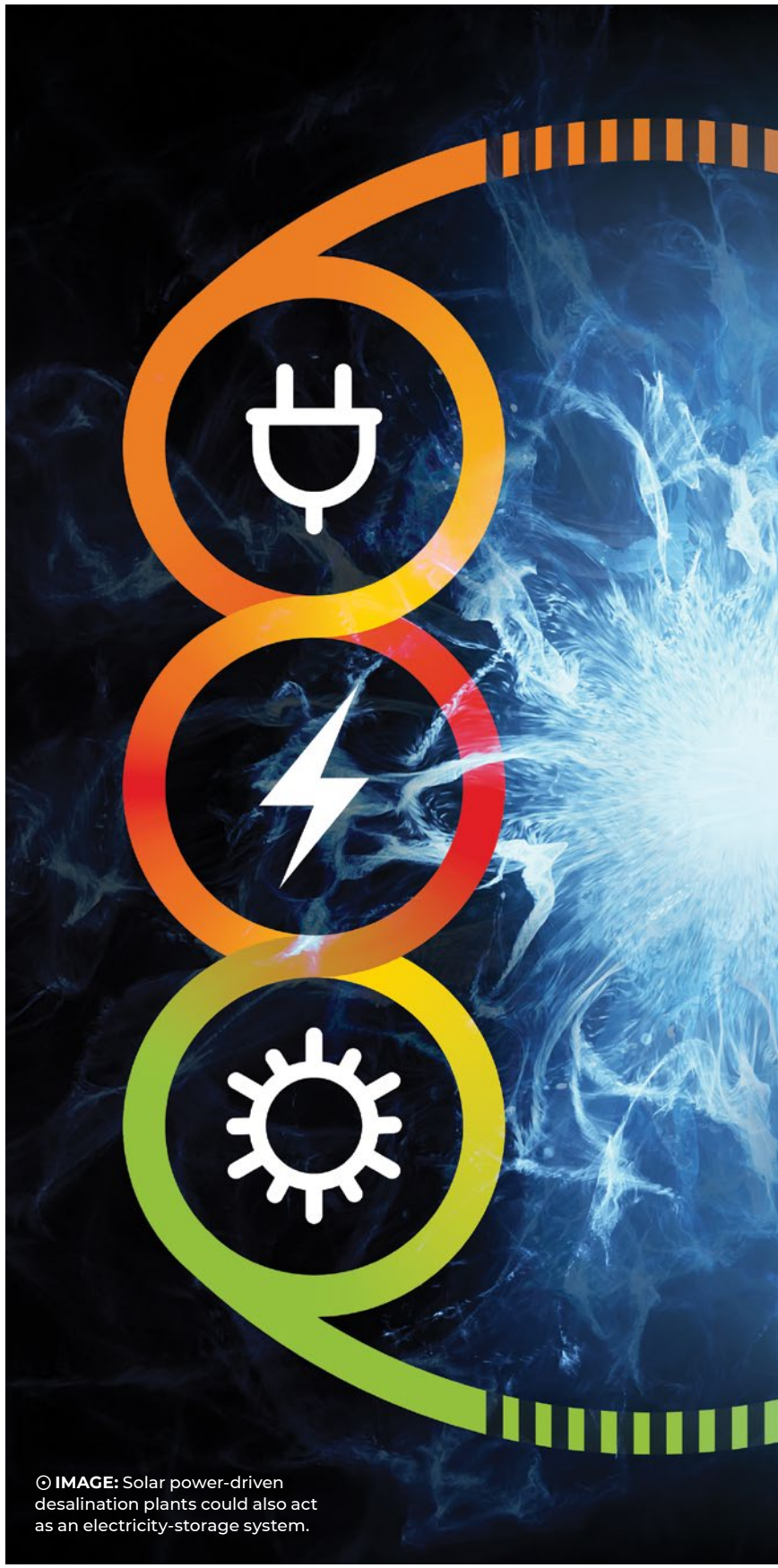
Pankratz notes that it's no coincidence renewable-energy desalination plants are being implemented in Saudi Arabia and the UAE, where some of the largest solar photovoltaic power plants are also being built.

"For larger plants, it is often infeasible to locate a large wind- or solar-energy power plant near a coastal seawater desalination plant. In these cases, it is usually more practical and cost-effective to build the wind or power plant farther inland, and feed the energy into an electrical grid that can be distributed to the desalination plant and other facilities," Pankratz says.

"This approach not only ensures that the desalination plant and energy plants are located where they are most cost-effective, but it also eliminates, or lessens, the need for large batteries to store the energy during the night or low-wind conditions."

An ingenious battery

Sommariva believes solar-power-driven desalination plants could also act as an electricity-storage system, using the excess electricity produced by photovoltaic plants, rather than continuously running fossil-fuel plants, to desalinate water. Connecting the desalination plant to the renewable-power grid could be the solution to two problems facing the region: renewable-energy storage and drinking-water shortage. »»



⊙ **IMAGE:** Solar power-driven desalination plants could also act as an electricity-storage system.

What to do with the BRINE?

Brine is a high-concentration solution of salt in water and is a byproduct of many industrial processes, including desalination. The simplest way to dispose of brine is to return it to the ocean, but high localized brine concentrations raise seawater salinity and alkalinity, creating an environmental risk.

Another common way to dispose of brine is to use evaporation ponds, where the water is evaporated and the salt is collected for use in other processes. Unfortunately, neither method is a fully environmentally friendly approach, and untreated brine can be corrosive and toxic if disposed of improperly.

A collaborative work between King Abdullah University of Science and Technology, Saudi Arabia, and Khalifa University of Science and Technology, UAE, saw the design of a solar crystallizer that uses solar energy as the main energy source to heat and evaporate the brine. This follows the same concept as an evaporation pond, except the condensate from the evaporated brine is collected as fresh water.

This sounds like an obvious solution to reducing the water loss, but the amount of salt in the water can affect the performance of the materials in the crystallizer, so the team needed to design a new device in which the water-evaporation surface and the light-absorption surface are separated by an aluminum sheet with high thermal conductivity. The bottom and inner walls absorb the solar energy, while the outer wall performs the evaporation and crystallization parts of the process.

The research team says the high thermal conductivity of the aluminum separator conducts the heat generated at the bottom of the device to the walls for water evaporation, resulting in a "high solar-to-vapor performance." They believe this is a simple but promising strategy to provide a low-cost and sustainable solution for treating industrial brine, especially in small- to medium-size applications.

"If the industry could simply move away from the traditional concept of steady water generation mainly dictated by a lack of storage, we could imagine a desalination plant able to operate in a sustainable and flexible manner: producing when excess power is available in the grid from photovoltaic production and curtailing desalination when the grid is in peak mode," Sommariva says.

Additionally, producing water when excess power is available from solar power and curtailing production when the grid is in peak mode does not require any dramatic changes to infrastructure, except an increase in storage capacity for the resultant potable water. As Sommariva points out, additional water-storage capacity is part of the strategic development in the region anyway.

"It is necessary that policy makers start seeing desalination not only as a water producer but also a potential energy buffer and indirect storage system," he says, adding that all of the desalination plants in the Gulf region and worldwide have the opportunity to smart retrofit and develop a net-zero-energy operational process.

Continued improvements

The potential use of renewable energy for desalination is hardly a new idea. Reported since the mid-1990s, a few conventional water-treatment plants in the United States have integrated solar power for water treatment, including a Massachusetts plant in 2009.

New renewable-energy technologies are becoming available for desalination applications as well. For example, an Australian pilot project utilizing wave-power technology for seawater desalination using submerged buoys began operating in 2015.

Despite the challenges, many researchers are working to improve desalination so it can reach more people and address climate change without contributing to it. The Global Clean Water Desalination Alliance has set a goal for 20 percent of new desalination plants to be powered by renewables between 2020 and 2025. Currently, the global share of renewable energy used in desalination is just 1 percent.

"It is necessary that policy makers start seeing desalination not only as a water producer but also a potential energy buffer and indirect storage system."
- Corrado Sommariva

Sommariva does point out that the main challenge in pivoting to renewable-energy-powered desalination is retiring or converting traditional thermal-desalination assets.

"These plants have a residual economic life of several decades," he explains. "Not to mention they are substantially energy-intensive. But desalination is a technology that is fast developing." There haven't been any major recent breakthroughs in the technology, he adds, but the process is seeing a steady rate of improvements that are fine-tuning the process for ever-increasing efficiency.

A growing approach

Already, stakeholders in the desalination industry are beginning to turn to renewables. Dubai Electricity and Water Authority is planning to power its desalination plants with solar power by 2030, pushing for increased efficiency and large-scale integration of renewable energy in its water-production processes.

In Port August, Australia, one desalination plant uses solar power to provide potable water for its tomato farm. In fact, in Western Australia, all new desalination plants must use renewable energy. "All of the large Australian seawater desalination plant operators have contracts with renewable energy providers who supply energy into the local grid in an amount equal to that required by the desalination plant, in a cost-offset arrangement," Pankratz adds.

Both the King Abdullah Economic City and the King Abdulaziz City for Science and Technology in Saudi Arabia are supplied by solar-powered seawater desalination plants, taking water from the Red Sea.

Also in the United Arab Emirates, one Masdar plant in Ghantoot produces desalinated water using a solar-powered solution. The company behind this plant, Mascara Renewable Water, is now developing similar projects in Mauritius, Cape Verde, South Africa, Morocco and Vanuatu.

Other projects

There have also been several small-scale trials across the Middle East, Spain and India bringing together concentrated solar power and seawater desalination. Pankratz says there are on-going research projects looking into using other forms of renewable energy too, including those from wave power, geothermal and biomass sources, and even from the energy contained within salinity, chemical and pressure gradients.

"There is absolutely a real future for this, and it's happening now," he says. "Renewable-powered desalination is proving itself in plants in the GCC and around the world. It's happening on a local scale too, with hundreds of small, renewable-energy desalination plants under construction in island communities and off-grid locations in developing countries such as Kenya, Madagascar, Mozambique and Nigeria."

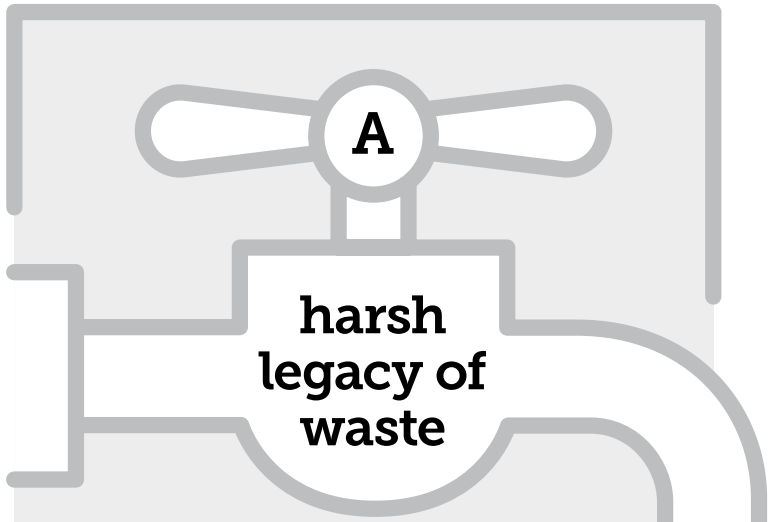
As the planet faces an uncertain water future, desalination will continue pumping out freshwater for thirsty cities.

And as renewable energy becomes increasingly mainstream and technology prices continue to decrease, renewable energy sources will become an economically viable option as well as the environmentally friendly solution.

All the benefits

Desalination can provide sufficient quantities of water as and when needed, which can significantly enhance the water security of a nation, while also supporting regional stabilities by evading any conflict over water resources. This also means there are a plethora of opportunities for society to benefit from desalination technologies.

Local employment opportunities during the construction and operation of desalination plants are one such benefit, but easy access to cheap water also means more work and education opportunities for women, who otherwise typically bear the often expensive, time-consuming and physically taxing burden of collecting and carrying water in the poorest communities.



"Historically, water availability has always been considered fundamental for human civilizations to evolve and flourish, from the early Mesopotamian age to the current rapidly growing cities in the Middle East. Over time, wasteful water use, mismanagement and significant environmental challenges have triggered severe depletion and degradation of the available freshwater resources, with adverse effects on human health, living conditions, and social and economic prosperity."

Tom Pankratz,
Global Water Intelligence

Desalination has social benefits - and costs, too

Desalinating water to meet growing global needs has many challenges, from energy demands to environmental issues. Often overlooked, however, are the sociopolitical factors impacting the adoption and proliferation of this technology.

By: **Jade Sterling**

A team from the United Arab Emirates, which has limited natural water resources and uses desalination to make seawater drinkable, looked at cases from several countries to identify these factors and their influence on desalination around the world, publishing their findings in the journal *Desalination*.

"Although the economic and environmental factors have received more attention, there is evidence to suggest that the use of desalination technologies and their associated impacts would most likely exacerbate the existing inequalities in a society," says Yazan Ibrahim, a former graduate student and research engineer at Khalifa University who joined New York University, Abu Dhabi, for his Ph.D. in 2021.

"This was attributed to the increased greenhouse-gas emissions, increased water prices, urban-growth motivation, shifting geopolitical relations related to water security and increased chemical pollution," he says.

The research team used a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis as the framework for a critical review of the sociopolitical factors that impact the adoption and proliferation of desalination.

A SWOT analysis is typically employed to help gain insights into the strengths and opportunities of an initiative or concept as well as the associated weaknesses and threats.

"We defined 'sociopolitical' factors as factors with a significant social dimension, which have either underlying social, economic or political root causes and consequences within those spheres," Ibrahim says. "We identified eight strengths and opportunities, and seven weaknesses and threats."

The strengths and opportunities include fast deployment and low physical footprint that comes with some desalination technologies with the potential to help remote communities and tourist facilities flourish.

Desalination can significantly enhance the water security of a nation, while also supporting regional stabilities by evading conflict over water resources.

Local employment opportunities during the construction and operation of desalination plants are another benefit, but easy access to water also means more work and education opportunities for women who might otherwise be tasked with the time-consuming work of sourcing and carrying water.

Most-cited weaknesses include the visual impacts, noise and land-use issues. Beyond this: the unintended consequences of excessive reliance on desalination and the potential impacts of poor mineralization of desalinated water on human health.

Freshwater contains minerals that may offer health benefits, and it's not yet understood if desalinated water that has not been re-mineralized could have adverse health effects.

Threats to desalination also stem from social tension among those who mistrust the technologies as well as the wide range of human and natural threats to operation ranging from cyberattacks to natural disasters and oil spills.

The team's research makes it clear that aside from political stability, water security and economic growth, desalination can also boost tourism, agriculture and education. "Since its inception, desalination has delivered a range of benefits to societies in arid regions and supported their economic development and political stability.

It must be recognized, however, that many factors are at play when it comes to the sociopolitical dimension of desalination. A holistic approach to this subject is essential," Ibrahim says.

X MARKS THE SPOT FOR CLEAN WATER

X, the “moonshot factory” for Google parent company Alphabet, in 2020 began its first tests on a design to harvest drinking water from the atmosphere using solar power.

IMAGERY: AI, KUST Review

Now, in a paper published in Nature, the team has calculated the number of people such a device can potentially help around the world.

Using WHO/UNICEF datasets, the X team mapped out where the people who have the least access to safe drinking water live and compared those locations to the areas with the best climate conditions (relative humidity at 30 percent to 90 percent) for using its atmospheric water harvesters.

The result? Up to 1 billion people without access to safe drinking water live in places with enough atmospheric moisture (in the form of dew or fog) may benefit from this type of water harvester.

Study author Jackson Lord notes that larger infrastructure projects such as desalination plants can take years to build. “This (model) can (potentially) leapfrog a lot of that and go directly to the source with a small device that’s solar-powered,” says Lord, who previously worked at X on the project.

“Net-zero water production is possible if such AWG systems are coupled to renewable-energy sources, such as hydrogen or solar power,” says Khalifa University’s Ludovic Dumee, who was not involved in the study. “In that context the footprint of the technologies, which may be decentralized, may become competitive with reverse osmosis. However the kWh requirements are still much higher for AWG than for RO.”

It is estimated that 1 in 3 people around the world drink unsafe water. Illnesses caused by untreated water include cholera, dysentery, typhoid and polio. About 485,000 people die every year from diarrhea alone, according to the World Health Organization.

The X lab began with the development of Google’s self-driving car.

A framework for INNOVATION

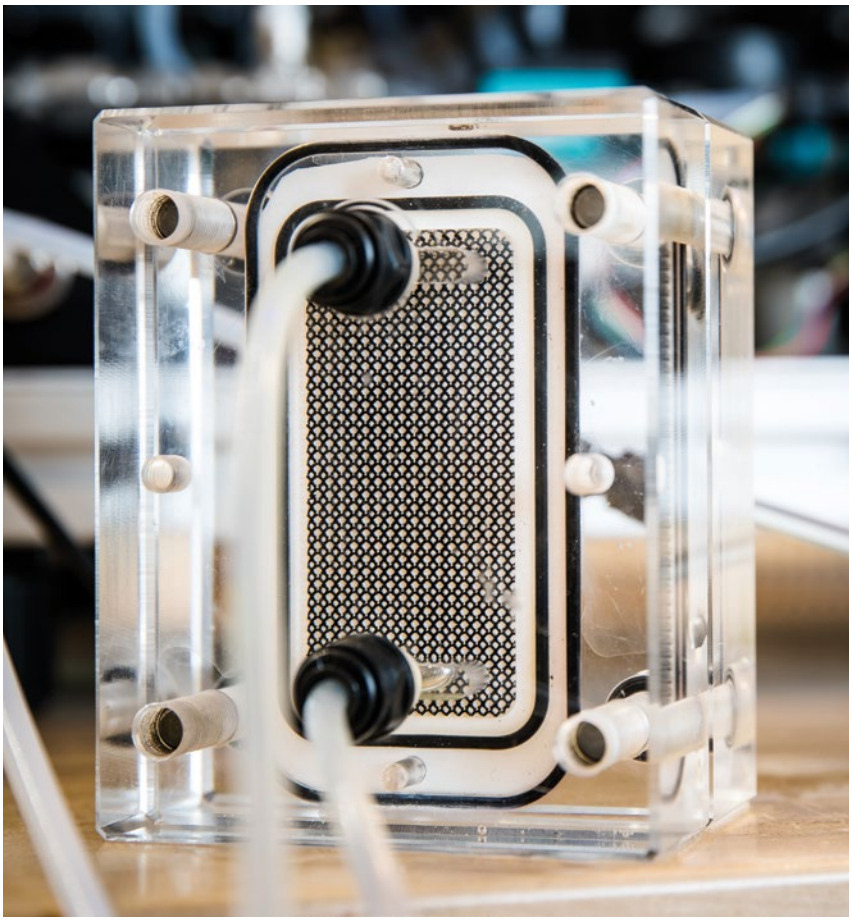
KU's Center for Membranes & Advanced Water Technology incubates research, development and more.

By: **Hassan A. Arafat**

As the availability of natural fresh water sources rapidly declines globally, a result of world population growth, lifestyle changes and climate change, countries around the world have turned to non-traditional water sources such as wastewater reclamation and desalination.

In fact, over the past 20 years, the total global desalination capacity has increased by more than 1,500 percent.

The United Arab Emirates (UAE) and other Gulf Cooperation Council (GCC) countries particularly have grown to rely on desalination, which now provides more than 90 percent of total potable water supply in those Gulf countries.



Hassan A. Arafat is the director of the Center for Membranes & Advanced Water Technology at Khalifa University.

⊙ **LEFT:** Khalifa University's Center for Membranes & Advanced Water Technology supports research to help generate a sustainable potable-water supply.

⊙ **FAR LEFT:** The center's research aims to develop innovative technologies for desalination, reclaiming wastewater and more.

This tremendous growth was catalyzed by a plethora of innovations that helped improve energy efficiency and cut the cost of desalination. These include new membranes, energy-recovery devices and effective membrane-based pre-treatment technologies.

However, the sustainable provision of potable water through desalination and the treatment of industrial and domestic wastewater effluents is still a significant challenge, both for the UAE and globally. The UAE's leadership has emphasized that securing a sustainable fresh water supply for the country is a top priority. This is indeed a grand challenge that must be met with grand, innovative solutions. To create such holistic solutions, multidisciplinary efforts are a must.

This is why Khalifa University (KU) created the Center for Membranes & Advanced Water Technology (CMAT). The Center's main goal is to create a framework for well-coordinated research efforts that have a clear, common goal: generating a sustainable potable-water supply for the UAE and the globe.

At the forefront of the Center's research goals are developing innovative technologies for desalination, wastewater reclamation and relevant membrane processes. This framework takes full advantage of KU's tremendous accumulated research capacity to develop innovative technologies for desalination, wastewater reclamation and relevant membrane research.

CMAT also allows KU to engage UAE industry and government in research, development, demonstration and deployment of innovative water-related technologies. It focuses on research that addresses ensuring adequate availability of water to meet society's needs while addressing concerns of environmental integrity and economic viability.

The result: The Center is a viable ecosystem for relevant technology development and intellectual-property transfer, driving interdisciplinary novel-membrane and water-technologies research to secure sustainable sources of water for the UAE and the world now and into the future. ⭘

PHOTOS: KU Center for Membranes & Advanced Water Technology (CMAT)

Harvesting technologies could someday let people even in dry climates get clean water straight from the atmosphere.

By: **Jade Sterling**

Out of Thin Air

On a desert planet in a galaxy far, far away, the land is hot, dry and devoid of any large bodies of surface water. It is a parched world, desolate in that way only a planet illuminated by a pair of binary stars can be. Fantastical, yes; a pop culture icon, also yes.

But there are two reasons to start with a description of Tatooine, the desert planet that appears in the Star Wars franchise: The technology seen here has become a reality, and we can test it in the real-world places that inspired the fictional landscape.

We're talking moisture farming.

The moisture vaporators, also known as vapor spires in the Star Wars lingo, are devices used on Tatooine moisture farms to capture water from the atmosphere. Tall and slender, they were stationed at ground level and used refrigerated condensers to pull water from the air around them.

Captured water was then pumped or gravity-directed into a storage cistern. These devices could collect 1.5 liters of water every day, even when the relative humidity of the air was only 1.5 percent. An amazing idea, and now becoming real as new technologies and materials emerge to harvest previously untappable water from the atmosphere.

The basic concept is simple. If you take an ice-cold glass of water outside on a hot day, you'll quickly notice water droplets forming on the outside of the glass. If you cool warm, humid air, it loses its capacity to maintain its water content and you can produce and collect condensation, whether it's on the outside of your glass or in a moisture vaporator straight out of science-fiction. »»

⊙ **MAIN IMAGE:** For now, plants supplying cities with water from the air are science-fiction. But researchers are making progress.

ALL IMAGES: AI, KUST Review.

Rather than waiting, bring the rain to you

When clean drinking water comes out of the tap at home, it's easy to think that it will always be plentiful, but fresh water is actually incredibly rare. Only 3 percent of the world's water is potable, and two-thirds of that is stored away, frozen in glaciers, or otherwise unavailable for our use.

As a result, more than 1 billion people worldwide lack access to clean water year-round. Global warming may be melting those glaciers, but as humans continue to pump carbon dioxide into the atmosphere, weather and water patterns will change, combining to make less water available for people around the world. By 2025, predicts the World Wildlife Fund, two-thirds of the world's population may be facing water shortages.

Technologies such as filtration, desalination and solar purification have been developed to use seawater or wastewater. However, because they depend on terrestrial water sources, these technologies are feasible only in coastal areas.

Atmospheric water, however, is present everywhere, and the global water cycle enables a sustainable supply of water to the air, providing a resource equivalent to about 10 percent of all the fresh water in lakes on Earth.

At 100 percent humidity, the air at 40 degrees Celsius contains about 51 milliliters of water per cubic meter of air. For the same humidity at 10 degrees Celsius, the air contains only 9.3 milliliters. Bring that 40-degree air down to 10 degrees and you should be able to extract that water difference. Scale that up and you could produce an awful lot of water on one of those sticky, hot Arabian Peninsula days.

Technologies already exist to catch fog or collect dew that condenses overnight, but pulling water directly from the air, without consuming lots of electricity, is still under development.

Still, Ruzhu Wang, professor at Shanghai Jiao Tong University, says atmospheric water harvesting is accessible everywhere and can be easily co-operated with a renewable energy source for local needs.

The problem, Wang writes in *Joule*, is that there are few commercial water-harvesting systems available. But when those systems do become available? "In general, any viable atmospheric water-harvesting technology must satisfy five primary criteria: It should be efficient, cheap, scalable, wide-band and stable enough to operate for a whole year or at least a monsoon season," Wang writes.

None of the existing commercial atmospheric-water generators meets all five criteria. Wang says this is mainly due to the energy inefficiency of the process.

So, the ideal moisture harvester has a high water uptake, low-energy demand for water release, fast water capture/release cycling, high cycling stability and a low cost — a tall order but one that could be achieved with advances in material science.

BELOW: Desert countries especially would benefit from atmospheric water harvesting.

Living in a material world

Atmospheric water harvesting based on moisture harvesters captures vapor from the air via adsorption, where water molecules adhere to the surface of a material through chemical or physical interactions. For chemical adsorption, the surface needs to adsorb water through strong chemical bonding; releasing the water requires a large energy supply.

Physical adsorption needs pores in the surface, where water molecules can pool and collect. Energy is still required to release the water, but at a significantly lower rate than chemical adsorption. Porous materials capture the water from the atmosphere, but said pores need to be perfect; you can't just place a sponge in the desert and expect water to collect. Enter the metal-organic framework (MOF): a network of metal and organic materials that can easily trap water vapor, which is then released using energy captured from the sun. »»

⊙ **ABOVE:** Researchers are looking at materials such as hydrogels and zeolites, as well as porous materials similar to this AI-generated image.

Combining the two

fog & moisture farming

The United Arab Emirates has all the necessary ingredients for fog as dry desert conditions exist next to the warm seas of the Arabian Gulf, with moist air carried inland by the afternoon sea breeze cooled by the night desert surface.

Tendrils of fog snake their way through the dunes in the early morning and could be captured by the fog-farming technologies already available.

At the same time, the humidity that plagues the region during the hot months makes atmospheric-water generation viable. Combining both approaches could reduce dependency on desalination and provide clean water for the many farms found far out in the desert.

Water load of options

MOFs work great in areas with lower humidity, but they have a finite number of pores. Fill those, and your harvesting device stalls until they can be emptied.

Hydrogels, on the other hand, can expand to hold more water. The soft, pliable and thin material that makes up more than 90 percent of contact lenses prescribed in the United States is a hydrogel: a water-swollen polymeric material that maintains a 3D structure.

The 3D network of hydrophilic polymers can swell in water while maintaining its structure and is tunable, dynamic, biodegradable and, most importantly, capable of encapsulating huge amounts of water.

Let's just use hydrogels, then. Well, they're not the best in low-humidity areas — they like it muggy outside.

Although they may not be suited to the deserts of the Middle East, there are plenty of places with high humidity that are also water-stressed. Lima, Peru, is one such place.

Just south of Lima is the village of Bujama. Despite being in an area where air humidity reaches 98 percent, Bujama is almost a desert, and its people live in tough conditions with little access to clean water.

Researchers from the University of Engineering and Technology in Lima installed panels in advertising billboards that trap the humidity and transform it into drinking water for the people on the ground.

ABOVE: Atmospheric water is everywhere. The trick is finding energy- and cost-efficient ways to tap it.

These panels comprise filters and condensers and produced 96 liters of water a day in 2013.

People here may already have one solution to water scarcity, but that doesn't mean hydrogels couldn't also work in Bujama.

Zeolites are often considered "molecular sieves" as they can selectively sort molecules based primarily on a size-exclusive process.

They are easy to manufacture and have a large internal surface area full of pores to adsorb the tiny quantities of water held in desert air — another contender for the low-humidity application.

The zeolite can collect water vapor overnight, and heat from the sun can then be used to extract the water for use. However, compared to MOFs and hydrogels, the water capacity of zeolites is relatively low, and releasing the water requires a high energy consumption that, even when supplied by solar power, make zeolites a less efficient option.

In areas where water scarcity is a problem — and climate change is putting more areas at risk — it's important to consider different technologies and approaches.

Condensing the problem

The billboard in Bujama is just one example of the condenser approach. Michael Rutman is co-CEO of Watergen, a company creating drinking water from air. Based in Israel, "which has a very similar climate to the UAE," Watergen uses a system involving food-grade polymer condensers and filters to draw water out of the air around us.

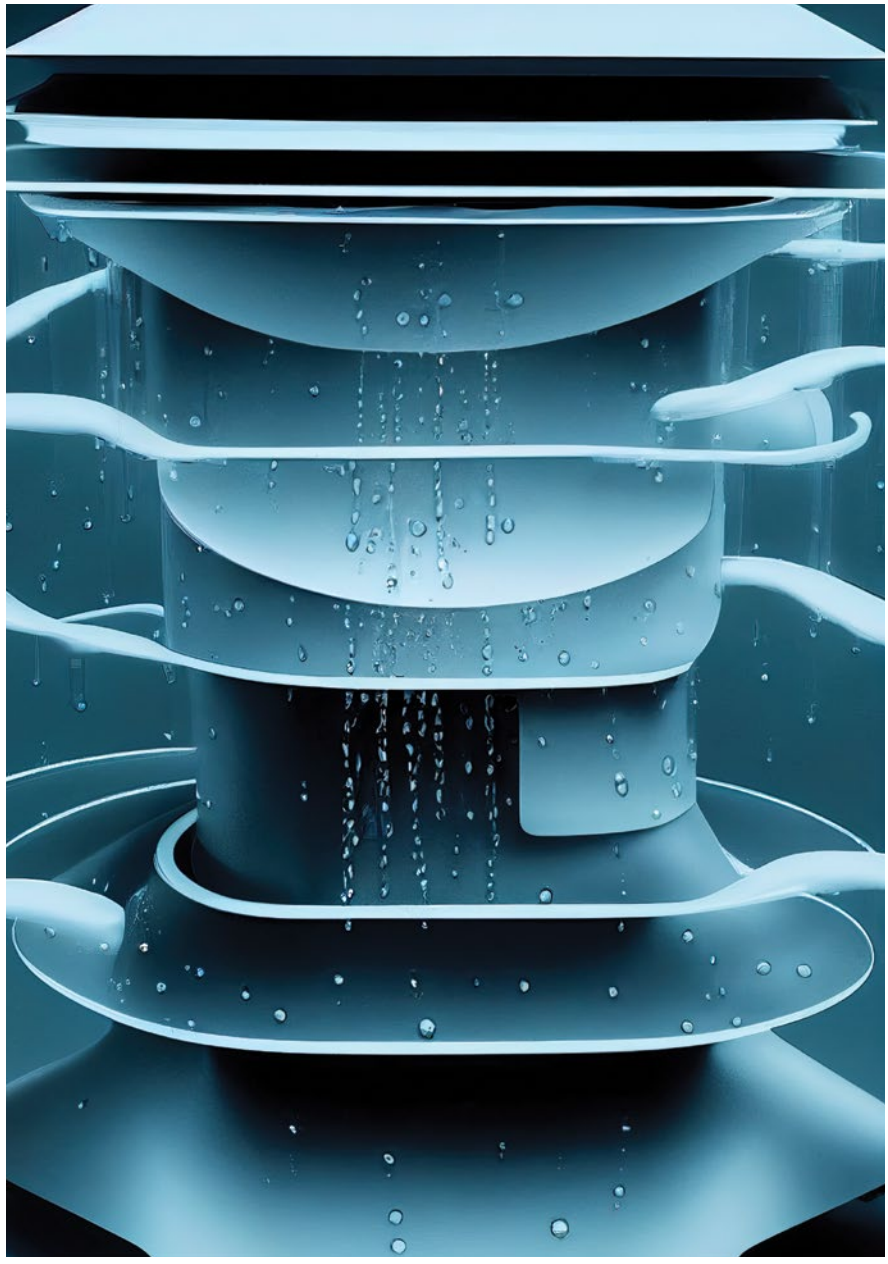
"Adsorption can only generate so much water," Rutman explains. "It also requires a much larger resource footprint than condensation, and much more energy. Metal-organic frameworks that don't need quite so much energy input to draw the water out are under development, but the metal part of a MOF should also be a concern."

Rutman points out that an air-conditioning unit does much the same thing as a Watergen condensing system: pull warm air out of the environment and cool it, producing water as a by-product. However, the heat exchanger material in an AC unit is usually made of metal, and that metal leeches into the resulting water.

"That's why you don't drink from your AC," Rutman says, laughing. "An AC unit produces tons of water, but that water is contaminated with heavy metals. The Watergen systems use food-grade polymers in the heat-exchanger technology, so the water produced is immediately potable, but we also add minerals to further improve the quality." Watergen didn't set out to save the world from its water problem; the company started by trying to make dehumidifiers more efficient and less power-hungry.

It was Michael Mirilashvili, an Israeli-Georgian businessman, who declared they were wasting this technology. Now president of Watergen, Mirilashvili realized these highly efficient polymers could be used to solve the world's biggest problem and spent the past five years pivoting the company to producing water from the air for everyone.

Their system works, too. It works in areas of high humidity, such as Colombia and South Africa, but it also works in the driest of places, like Arizona in the U.S., where the average relative humidity is 38.5 percent. Rutman says he believes mass use of atmospheric water generation is the future. »»



⊙ **RIGHT:** An air-conditioning unit in the future might be made with a food-grade polymer to also collect potable water.

"Water is running out and we know that desalination is not the solution. It's not just drinking water, it's all the water used in industry, in agriculture.

It can take 160 liters of water to make a pair of jeans, and 60 liters for a loaf of bread. All this water can be replaced by water produced from the air. I believe we're less than ten years away from this point. Our pilot technology works, and it'll work everywhere."

Speaking of everywhere, we should also start thinking about portability. Conventional water supply starts with a large centralized plant that distributes water to the population, but if a device were small enough to incorporate into a home, gaps in water supply could be plugged. Make them smaller and they could travel to now-uninhabitable regions: the middle of the desert, the polar extremes, Mars?

DO NOT EAT THIS PACKET

Almost everyone has bought something and found a packet of silica gel beads placed inside to absorb moisture while items are waiting to make their way to the customer. Silica is commercially available, inexpensive and a highly effective desiccant. Silica can also be also used in water production via the conventional condensation approach.

Silica gel is one of the most commonly used materials in moisture harvesting, and Lisa Klein, professor of materials science and engineering at Rutgers University, has investigated using patterns on silica gel to facilitate water-droplet formation.

She conducted a series of experiments to condense water vapor on the hydrophilic pattern of silica gels. Although the pattern was hydrophilic, the gel itself was hydrophobic so the water droplets slide down the surface and collect in a container rather than absorb into the gel. This represents another potential area of investigation for harvesting water from the atmosphere.

Klein points out that silica is experiencing considerable growth in use in the dominant oil, gas and petrochemical industries of countries in the Middle East, and favorable government participation in the expansion of these industries will further stimulate the silica-gel market.

"This expansion could potentially allow more silica gels to be utilized for atmospheric water harvesting in addition to their regular uses," Klein says.

Back down to earth options

Understandably, research institutes in the Middle East are particularly invested in this new type of technology. Many of the projects showing promise in the U.S. were funded by Saudi Arabia's King Abdulaziz City for Science and Technology, including projects designed by Omar Yaghi, pioneer in the MOF space, and his teams.

Similar technology is behind an industry-funded project at Masdar City, a hub for sustainability research and innovation in the MENA, with whom Khalifa University does research.

"As freshwater scarcity is becoming a global challenge, a promising route to overcoming water shortage is to extract water from air with innovative atmospheric water production (AWG) technologies," says Samuel Mao, director of Masdar Institute at Khalifa University.

Almost half of all people on Earth live in water-threatened conditions, with demand growing drastically, while supply remains constant, according to the World Health Organization. The United Nations recognizes that access to clean water and sanitation is at the core of sustainable development, and ensuring access requires innovation. Atmospheric water generation could be the solution, and it's already here.

⊙ **BELOW:** As the climate changes, accessing clean water will become even more of a challenge. New technology might help by pulling moisture directly from the air.

Dehumidification or something new?

Atmospheric-water generation sounds a lot like using a giant dehumidifier. There's a big difference though: The water produced in a dehumidifier isn't potable. It could be cleaned and filtered and made potable, but that's an extra step when water pulled from the atmosphere is fresh straight away. Plus, dehumidifiers need a constant power supply and a lot of it, unlike moisture harvesting.

MAKING IT Rain

Cloud seeding does more than bring precipitation to the desert, and new materials make the technology viable in a broader range of conditions.

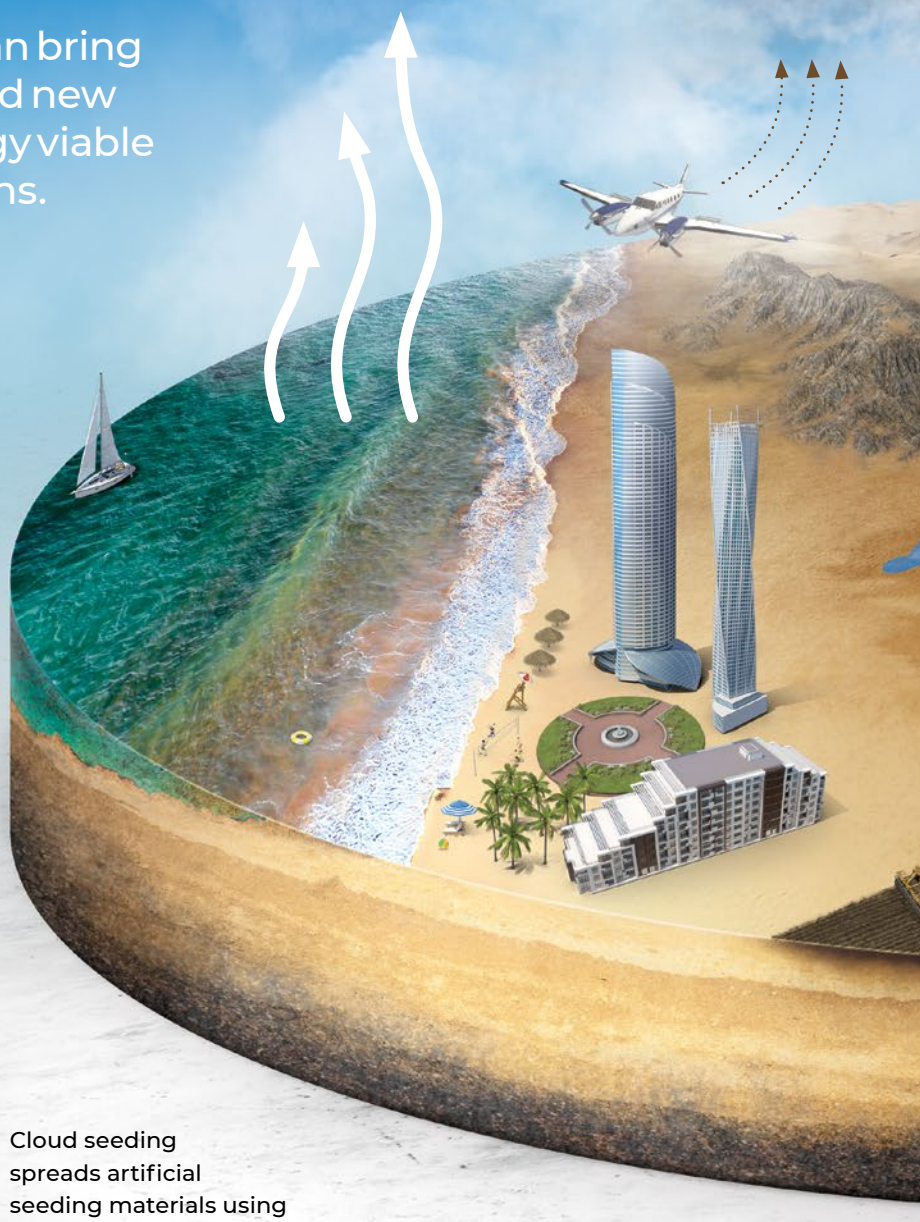
By: **Suzanne Condie Lambert**

Linda Zou is a UAE researcher who uses nanotechnology to develop new materials for cloud-seeding, a weather-modification technology that improves the chances a cloud will produce rain. **We talked to her about her work.**

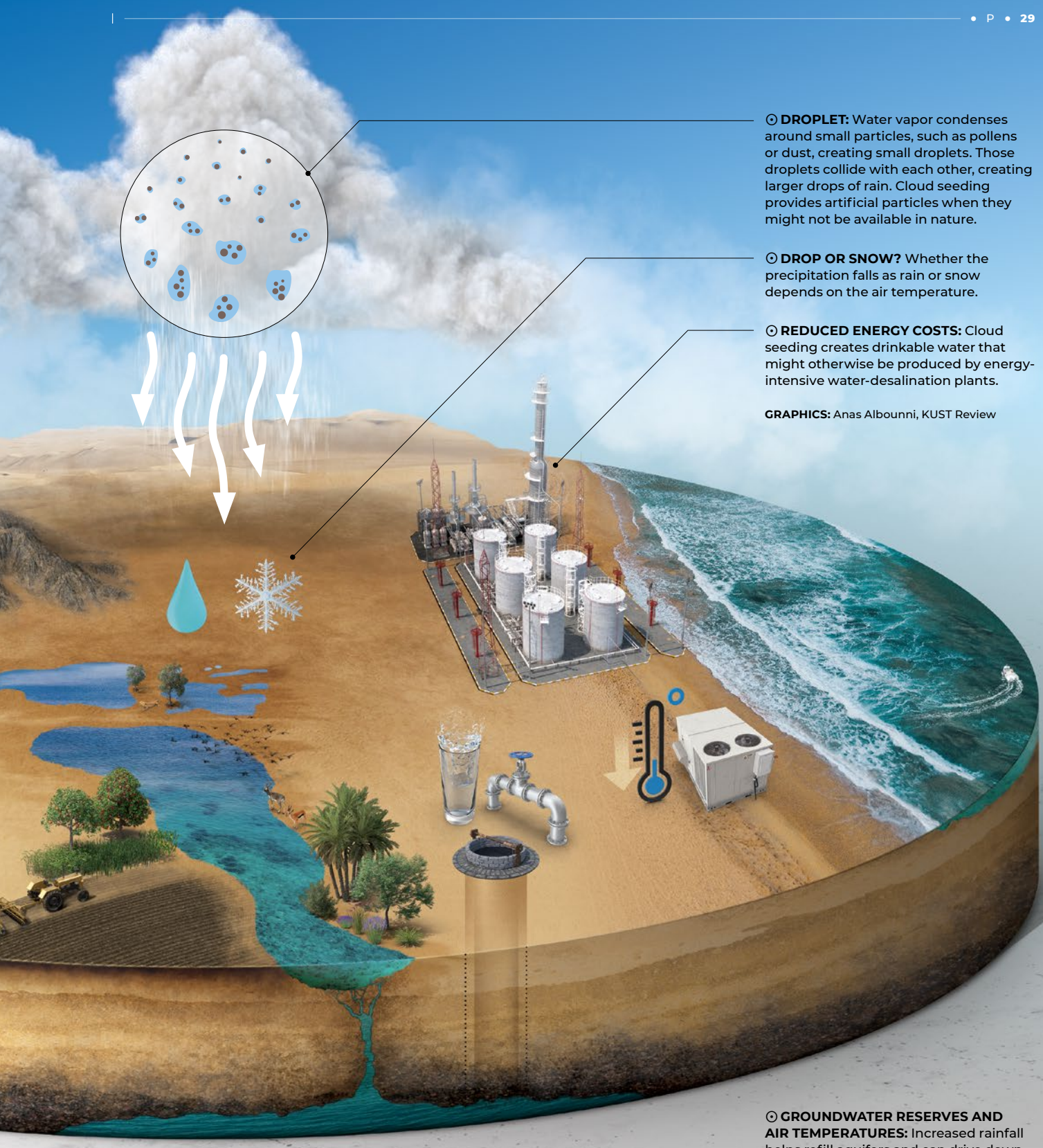
Q: Walk us through the basics of cloud seeding.

The sun shines and water vapor rises up from the Earth's surface, and these tiny water vapors will keep on rising and finally condense to become either rain or snow.

In the presence of small particles as nuclei, water vapor condenses, turning into small liquid droplets. And that droplet will hit another small droplet during the falling process, and then they form a larger droplet. The size grows and grows. When the drops reach the lower part of the atmosphere, they're too big and too heavy, and they fall as rainfall. And unfortunately the availability of this sort of small seeding nuclei in the atmosphere is unpredictable. It could be natural occurring particles such as volcano ashes, dust particles or pollens. But when you need it you can't guarantee you'll get it.



Cloud seeding spreads artificial seeding materials using aircraft, flying over the bottom of suitable clouds and releasing the seeding materials. An updraft will carry them into the cloud, to start the condensation process and turn the water vapor into water droplets artificially. »»



⊙ **DROPLET:** Water vapor condenses around small particles, such as pollens or dust, creating small droplets. Those droplets collide with each other, creating larger drops of rain. Cloud seeding provides artificial particles when they might not be available in nature.

⊙ **DROP OR SNOW?** Whether the precipitation falls as rain or snow depends on the air temperature.

⊙ **REDUCED ENERGY COSTS:** Cloud seeding creates drinkable water that might otherwise be produced by energy-intensive water-desalination plants.

GRAPHICS: Anas Albounni, KUST Review

⊙ **GROUNDWATER RESERVES AND AIR TEMPERATURES:** Increased rainfall helps refill aquifers and can drive down surface temperatures, reducing the need for air conditioning. Zou sees cloud-seeding as part of a broader spectrum of strategies to mitigate the rising issue of climate change.

Linda Zou is a professor in the Khalifa University Department of Civil Infrastructure and Environmental Engineering and the head of the Nano and Water Laboratory. This interview has been edited for space and clarity.

> **Over longer periods of application, silver iodide may pose some toxic effects. It is not used in my research project.** - Linda Zou

Q: How important is it for the world to tap that atmospheric moisture?

The World Meteorological Organization (WMO) did a survey and reported more than 45 countries are practicing some sort of weather modification. Cloud seeding is one of the major (weather-modification) technologies. This implies advances in cloud-seeding materials could have a wider impact to combat the water-shortage problem globally.

Q: Is cloud seeding used primarily in desert countries or are a broad range of countries practicing it?

(Cloud seeding) is technology-driven; commonly you need aircraft fleets. Countries like the U.S., South Africa and some European countries are very active, particularly in agricultural protection as well. (Countries may have) a different purpose: Russia is more interested in hail-suppression. China has dry regions.

For many decades, the science behind this water-related process hasn't had much innovation, but the UAE is driving innovation through its UAE Rain Enhancement Science Program.

Q: That leads into the next question: What are the problems and limitations that your work is looking to solve?

The kind of seeding material adopted around the world heavily depends on atmospheric relative humidity. That means the seeding material released is only activated or useful at very high relative humidity.

So, in a lot of cases you release (the seeds), and if it isn't very humid conditions, it's not useful. So because I'm thinking on the science of the interactions between materials and atmospheric relative humidity, I can see that there's room to improve.

Q: And your proposal is to change the seeding material?

Yes. I proposed three ideas: Each has been investigated and concept is realized. The first is to change the surface of the material to make it more reactive (so it can work) at a lower relative humidity. Instead of 75 percent or higher, now we can use it at 65 percent.

To achieve this, we used nanotechnology to engineer a material that is activated in much broader relative-humidity conditions. Because

the structure is so porous, water will melt easily, forming larger droplets, increasing the probability that it will work. Secondly, a bioinspired hydrophilic/hydrophobic pattern was created on the seeding material to enhance the interaction with water vapor; thirdly, a porous 3D nanocomposite was developed to promote ice nucleation and growth for cloud-seeding in cold clouds.

Q: Old-technology cloud-seeding materials might be harmful to the environment. That's another problem you're looking to solve?

There are different types of seeding material used. Various salt particles are used for warm clouds; their environmental effect is less of concern. But the one you hear about is mostly silver iodide, which is mostly for cold clouds – for ice- and snow-making.

Over longer periods of application, silver iodide may pose some toxic effects. It is not used in my research project, as we design novel seeding material to steer away from potential harmful materials.

Q: Some of your materials are inspired by natural adaptations in biological organisms assisted by nanotechnology. What would you say is the value of looking to nature to solve problems?

Nature has evolved over millions of years. Every biological system that thrives today is the positive result of evolution. Modern analytical tools enable scientists to look at the details of biology at the biochemistry level and have more understanding on how they work.

This newly gained knowledge helped us to mimic the biological mechanism in designing nanomaterials. Although we're not able to replicate biological mechanisms, I can be inspired and learn from their principles.

Q: What would you say are the biggest challenges to seeding clouds?

One of the major problems is all cloud-seeding operations are carried out in the open atmosphere. All the conditions cannot be controlled as in a closed system. »»

⊙ **RIGHT:** UAE's National Center of Meteorology is in discussions to manufacture the novel cloud-seeding material in the Emirates.

⊙ **BELOW:** The materials are spread by airplanes but can also be released by balloons and drones.

PHOTOS: NCM

Secondly, all clouds are different at a time and they're also varied and unpredictable. This makes the evaluation of cloud-seeding effects difficult. But we accept this unpredictability. And if the seeding materials become more and more efficient, the probability (of success) is higher for any given cloud conditions.

PHOTO: Shutterstock

Q: Some of your works focuses on ice and snow instead of rain. How are these approaches different?

It's different and it's the same in some regions. Clouds that form at a few thousand meters above us are in sub-zero temperatures. Precipitation at that altitude will be ice. But when ice falls down to the earth, if it falls down in cold region it will be snow. If it falls down to warm regions such as the UAE it will melt into rain.

So for clouds with sub-zero temperatures, different techniques have to be used. The sub-zero cloud conditions are different. The water vapors are oversaturated in some cold clouds, so their relative humidity is like more than 100 percent but they stay as supercooled water vapor.

So at this stage if (the supercooled vapor meets) a suitable ice nuclei it will form ice crystals and grow rapidly as an ice explosion, an avalanche of ice crystals.

So I also investigate how to develop this type of ice nuclei. The ice nucleus is often silver iodide. Why? The possible theory behind is that its crystal structure is similar to the ice. So crystal grows on the other crystal due to their crystal framework lattice matching. So it's very different from the droplets, a different mechanism.

And as we said with the silver iodide there are some problems but there aren't many alternatives. So I designed an alternative material. This material can also help create artificial snow at ski resorts. It works well in cloud-chamber experiments.

Q: Can you describe that material?

The novel cloud-seeding material has a shell/core structure, with a sodium chloride core, which is covered by a nanometer-thick layer of titania particles. This structure offers a synergistic effect on condensation at lower relative humidity and forms larger water droplets: Both are important to increase the probability of rainfall.

Q: Is this the sort of technology that would be used to control undesirable weather, like preventing hail?

Yes. That's the case in some European countries, to protect agriculture industry from extreme weather attack, such as hail and frost.

Q: What impact would you say cloud seeding will have on climate change?

I think this is a very important question. It is in the broader spectrum of climate-change strategies. If we got more water as rainfall through cloud seeding, it would cool the weather and replenish the ground-water aquifer. There would be less demand for air-conditioning, less demand for desalinization. It has very positive effects.

Q: So what's the next frontier? What's the next exciting development?

The next frontier will be scaling up the production, making the seeding materials more available. Apart from airplanes, the seeding materials can be released by other methods such as balloons, or drones. In addition, it can also migrate into surface-water-harvesting applications, like catching fog.

> **I designed an alternative material. This material can also help create artificial snow at ski resorts. It works well in cloud-chamber experiments.** - Linda Zou

Q: Is there anything we haven't covered that you want people to know?

The UAE Rain Enhancement Science Program is appreciated because they provide us funding on my research project. I really wish that this will have a ripple effect.

We need to transform the novel seeding materials into commercial-scale production and wider application. We have started working on that. I need government and industry support on this direction. If this becomes a commercially viable technology, more countries and regions will benefit. ●

AI & NOWCASTING

Cloud seeding can increase a region's rainfall, but knowing when the conditions for cloud-seeding are optimal can be difficult.

Now, researchers who recently won a U.S.$1.5 million grant from the UAE's National Center of Meteorology think they can help by tapping into artificial intelligence. Luca Delle Monache, deputy director of the Center for Western Weather and Water Extremes (CW3E), Scripps Institute of Oceanography at the University of California, San Diego, in March received the three-year grant of the UAE Research Program for Rain Enhancement Science (UAEREP) for the project using a hybrid machine-learning framework for enhanced precipitation nowcasting. Nowcasting in meteorology is describing the present or predicting the very near-future weather conditions.

Khalifa University professors Ernesto Damiani, Linda Zou and Hussam Al Hamadi will gather data and create a prototype artificial intelligence system for data fusion and weather nowcasting for the project. Alya Al Mazroui, UAEREP director, says the work will continue the organization's role in advancing rain-enhancement technology, as well as "promoting the UAE's status as a prominent hub for rain-enhancement research and helping the world tackle the challenges posed by the scarcity of potable water."

Polluted oceans: LET THE TRASH TAKE ITSELF OUT

By: **KUST Review staff**

Up to 12.7 million tons of waste makes its way into the world's oceans each year, forming massive "plastic islands" in oceanic gyres and devastating birds and marine life in the process.

Cleanup, in which plastics are currently collected at sea, stored and shipped to shore for disposal, is estimated to take from 50 to 130 years with annual costs expected by some at nearly US $37 million. In the meantime, the trash is degrading faster than it can be gathered, disintegrating into harmful and even more difficult to mitigate microscopic forms (see Page 44 for Dr. Ludovic Dumee's essay on the dangers of microplastics).

Now a team of researchers from Massachusetts in the United States is suggesting a new approach: self-powered cleanup vessels that turn the trash they harvest from the seas into the fuel they use for the job.

The "blue diesel"-powered ships could reduce the amount of fuel and roundtrips needed to remove ocean waste, the researchers write in a paper published in the Proceedings of the National Academy of Sciences of the United States of America.

The researchers, representing Harvard University, the Woods Hole Oceanographic Institution and the Worcester Polytechnic Institute, suggest using high temperatures and high pressure in a process called hydrothermal liquefaction to depolymerize the plastics into a harnessable energy, creating self-powered cleanup that eliminates the need to refuel or unload plastic waste and potentially reduces total cleanup times.

IMAGE: Plastic trash is degrading in the oceans faster than it can currently be cleaned up. Researchers think they may have solutions.

CREDIT: Unsplash

Of course, it isn't enough to clean up the oceans faster and with less fuel waste. The world needs to address the amount of garbage that makes it into the oceans in the first place, the researchers write. "Reducing or eliminating the amount of plastic waste generated is critically important, especially when the current loading may persist for years to even decades," they say.

COVID's toll on the oceans

Meanwhile, researchers from China's School of Atmospheric Sciences at Nanjing University

and the Scripps Institute of Oceanography at the University of California-San Diego say the COVID-19 pandemic is making an already bad situation in the oceans even worse.

Also writing in the Proceedings of the National Academy of Sciences of the United States of America, the scientists say that of the 8 million tons of plastic waste generated until recently in the fight against the virus, about 25,000 tons of medical waste, mostly from hospitals, has entered the world's oceans. And more is expected to come, not only damaging marine species but potentially spreading contaminants including the COVID-19 virus.

The hospital trash, they say, dwarfs the amount of waste from discarded personal-protective equipment (PPEs) and plastic packaging produced by a surge of online shopping in the wake of the pandemic. For a little perspective, the authors cite another study estimating that 1.56 million face masks made it to the oceans in 2020.

Five of the top six rivers associated with medical-waste discharge are in Asia (Shatt al Arab, Indus, Yangtze, Ganges Brahmaputra and Amur). The other, the Danube, is in Europe.

The authors call for increased public awareness of plastics' environmental impacts; better collection, treatment and recycling of plastic waste; and improved waste-management practices at pandemic epicenters, particularly in developing countries.

Microbots to the rescue?

A solution to microplastics in water might come in an equally small package: microbots.

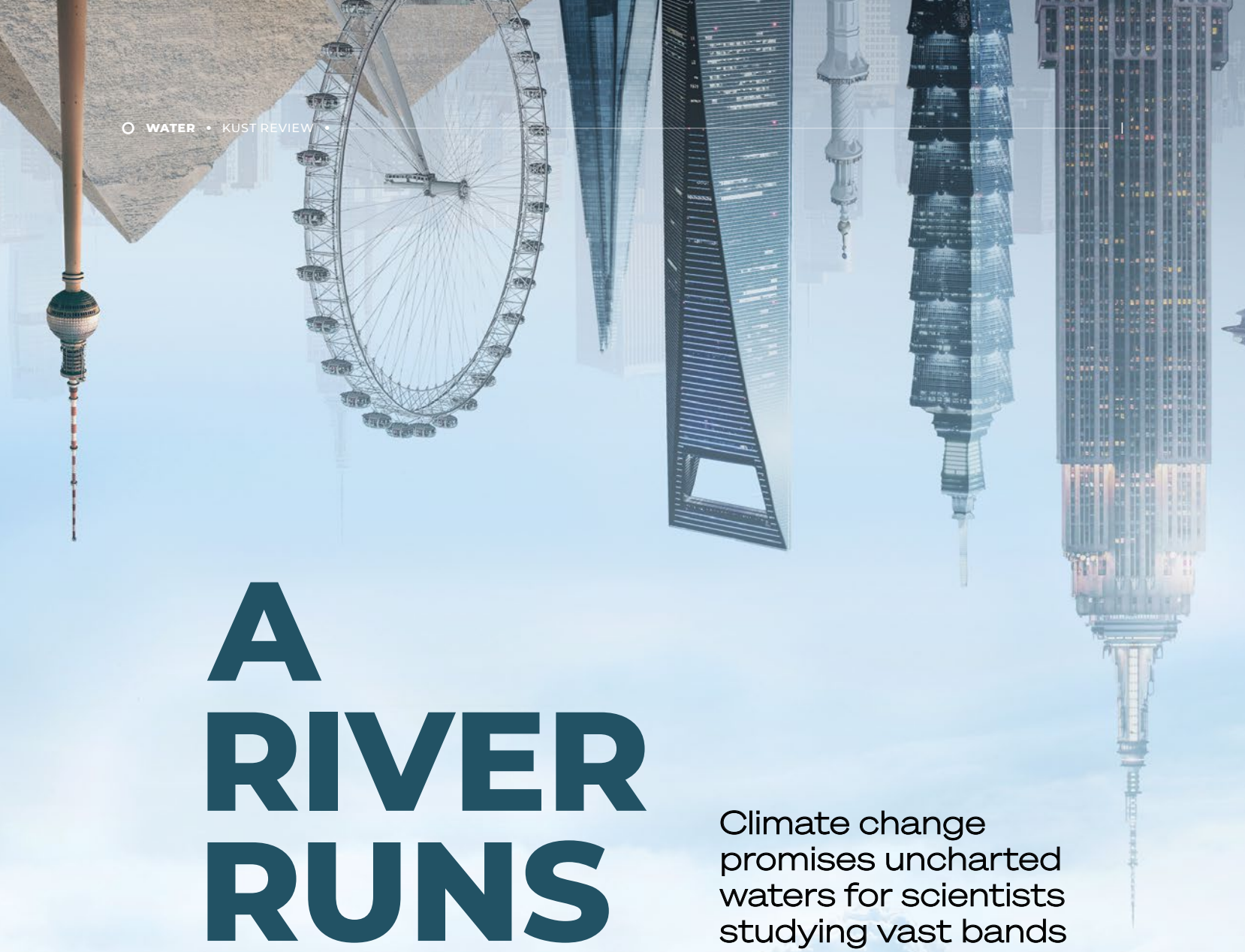
The bacterium-size bots when added to water with a little hydrogen peroxide attach to microscopic bits of plastic and begin to break them down. The research was recently published in ACS Applied Materials & Interfaces.

"They can sweep a much larger area than you would be able to touch with stationary technology," says study co-author Martin Pumera, a researcher at the University of Chemistry and Technology, Prague.

Pumera envisions setting the microbots loose in the oceans to collect microplastics, but Win Cowger, an expert in plastic pollution at the University of California, Riverside, who was not involved with the study, tells Scientific American that closed systems such as those for drinking-water or wastewater treatment would probably be better potential targets. ●

⊙ **IMAGE:** Researchers say the world must reduce the amount of plastic it produces in the first place if it hopes to clean up the oceans.

CREDIT: Unsplash



A RIVER RUNS OVER IT

Climate change promises uncharted waters for scientists studying vast bands of vapor in the sky.

By: **Jade Sterling**

Think the Amazon River is the largest river on Earth? Technically, you'd be right because the river with twice the amount of water than the Amazon can be found in the sky.

Atmospheric rivers are long, narrow bands of concentrated water vapor that produce major amounts of rainfall. They exist on a global scale, transporting moisture from the tropics to the higher latitudes. And they can have a huge effect on the way you live. "Atmospheric rivers are responsible for important impacts throughout the Earth's middle and polar latitudes, such as flooding, influence on water resources, and melting of polar ice sheets," explains Kyle Mattingly of the University of Wisconsin. »»

ARTWORK DESIGNS: Anas Albounni
PHOTOS: Unsplash, Shutterstock

A 1998 paper from Yong Zhu and Reginald Newell, the researchers who coined the term, says on any given day, atmospheric rivers account for over 90 percent of the global north-south water-vapor transport.

There are typically three to five rivers present within a hemisphere at any given time, and any single one can carry a greater flux of water than the Amazon River.

For context, that's about 6,592 cubic kilometers of water every year, or more water than the next seven largest independent rivers combined. It's just water vapor instead of liquid water.

These rivers in the sky help replenish reservoirs and redistribute water in the Earth system, but they can also be detrimental to the places they deposit water.

Extreme weather events such as severe flooding and high winds are now found to be associated with atmospheric rivers.

These elongated tendrils of moisture stretching from the tropics poleward act as conveyor belts, feeding huge amounts of tropical moisture into existing weather systems, intensifying the rainfall. Record-breaking rainfall is often associated with an atmospheric river making landfall.

However, this water content doesn't just fall out of the sky on a whim. The rivers pass through various atmospheric conditions on their journey, and where conditions are right for precipitation, water is released as rain or snow.

Mountainous regions are particularly effective at squeezing moisture out of these sky rivers as wind travels up their sides.

A NEW ANCIENT PHENOMENON

Despite earning a name only in 1998, atmospheric rivers have been meandering through the skies for millions of years — they're not new. So why are atmospheric rivers making a splash in the current zeitgeist? Climate change, of course. Plus, it's a useful and versatile term, says Mattingly. "The 'rivers in the sky' metaphor helps to vividly communicate these scientific ideas to the public.

> **Atmospheric rivers are projected to grow longer, wider and wetter in a warming climate.**

In places such as California, where they have major impact, the concept helps people connect weather they experience personally with processes operating at much larger scales in the climate system."

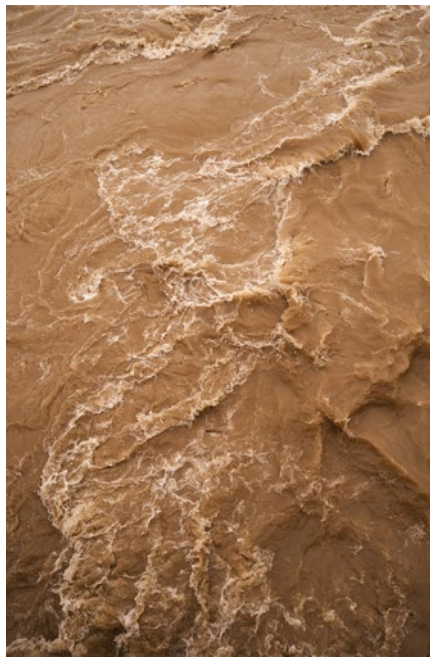
Understanding atmospheric rivers is key to improving weather forecasts for better managing water resources and predicting flood risk. However, atmospheric rivers are also influenced by climate change. Previous work has examined the relationship between weather patterns and atmospheric-river development, but with climate change, these features may become more variable — and therefore harder to predict.

This could mean a less reliable source of precipitation for those areas depending on the water redistribution, but could also mean extreme flooding in other places. To those living in the Middle East, huge amounts of rainfall are pretty rare and would likely be welcomed to recharge oases, water crops and wash away the dust that accumulates in cities. The reality can be much more detrimental than beneficial, unfortunately.

Although a large body of research has shown the impacts of atmospheric rivers on weather-related natural disasters over the western United States and Europe, little is known about their mechanisms and contribution to flooding in the Middle East. However, a rare atmospheric river was found responsible for the record floods of March 2019 in Iran that damaged one-third of the country's infrastructure and saw the death of 76 people. This river started its 9,000-kilometer journey in the Atlantic Ocean before making landfall over the Zagros Mountains.

It needed special conditions to make this trek across North Africa, including anomalously warm sea-surface temperatures. What do we know is a symptom of global warming? Rising sea temperatures. The moisture transported by this rare atmospheric river was equivalent to more than 150 times the accumulated flow of the four major rivers in the region: the Tigris, Euphrates, Karun and Karkheh. Even now, people are still wrestling with the aftermath.

It was a rare atmospheric river for 2019. But like hurricanes, atmospheric rivers are projected to grow longer, wider and wetter in a warming climate. Studies have modelled how atmospheric rivers will change in the coming decades: The planet warms, more water evaporates and a wetter atmosphere makes for stronger storms.



⊙ **IMAGES:** A global phenomenon, atmospheric rivers have far-reaching influences on weather patterns and natural disasters.

BLOWING HOT AND COLD

Challenging our understanding of atmospheric-river genesis is the increasing activity in the polar regions. Atmospheric rivers developing near the poles transport large amounts of moisture and heat and have been playing a significant role in short-duration but high-volume melt events over the Arctic and Antarctic in recent years.

There are several reasons for this, explains Mattingly. “Research to date has shown that atmospheric rivers can increase ice melt by enhancing the water-vapor greenhouse effect, releasing condensational latent heat into the air over the ice, forming bands of cloud that reflect heat back to the surface, and providing more water to the cyclones ahead of which they develop. In addition, atmospheric rivers are closely related to the atmospheric fronts over the Southern Ocean, which, in turn, reinforce subantarctic cyclone dynamics.”

The number and intensity of cyclones around Antarctica over the past few decades have increased as the storm tracks shift toward the pole under enhanced greenhouse-gas concentrations. In the largest calving event from the Amery Ice Shelf since 1963, an iceberg 1,636 square kilometers with an estimated weight of 315 billion tons broke away from its glacier in September 2019. Melting polar ice is concerning enough, but global warming and atmospheric changes could lead to more such calving events.

Cyclogenesis, the formation of cyclones, is a major factor in this, and an increase in the frequency and intensity of atmospheric rivers in the region will only exacerbate the problem. It's not just calving events we need to be worried about. “Our analysis of the polynya event in September 2017, where a body of unfrozen ocean appeared within a thick body of ice during Antarctica’s winter, shows that the atmospheric rivers that initiated this were the most intense on record,” Mattingly says.

“Surprisingly, these atmospheric rivers resulted in the highest amount of snowfall on record over the study area, but because of the warm temperatures, it was this warm snow that enhanced the ice melt and inhibited refreezing.”

It may be rare now, but under a warmer climate, atmospheric-river activity is expected to intensify considerably: a scary thought when we now know it can melt the sea ice in the middle of the Antarctic winter. It’s not all bad, though. Within the sea-ice zones of both hemispheres these polynyas act as oases, enabling marine mammals such as walruses, narwhals and belugas to overwinter.

Some polynyas, such as the North Water Polynya between Canada and Greenland, occur at the same time and place each year. Animals can adapt their life strategies to this regularity, with polynyas in McMurdo Sound in the Antarctic providing a vital winter feeding place for the Cape Royds penguin colony. »»

The problem arises in the intensification of the atmospheric rivers affecting a larger area than that of the natural polynya, which may prevent sea-ice growth around the polynya and contribute to keeping it open even after the river moves on. Jonathon Wille, postdoctoral researcher at the Université Grenoble Alpes, is also investigating the impacts of atmospheric rivers on Antarctica.

"The Antarctic continent, like many deserts in the world, receives a large percentage of its yearly precipitation from just a few intense events," Wille explains. "They may be rarer here, but they still have a major influence on the surface-mass balance of the ice sheet and are responsible for 10 to 20 percent of the total snowfall across East Antarctica.

"This may seem a modest percentage, but this contribution to the snowfall budget has been driving parts of the positive annual snowfall trends in some areas and the negative trends in others. Atmospheric rivers also control the year-to-year variability of precipitation across most of the ice sheet." Given this link, increased future atmospheric river activity would result in higher snowfall accumulation on the Antarctic continent. Combine this with Mattingly's results showing it was snow that melted the sea ice, and we have a problem.

CLOSER TO HOME

If Antarctica feels too far flung to worry about, you can always turn your attention to the European Alps.

Over the past four decades, there has been a pronounced reduction in the snow depth in the Alps, says Diana Francis, senior research scientist at Khalifa University, and, for once, it's not a warming planet that is directly to blame. A new atmospheric river route has appeared, originating in the eastern Atlantic Ocean and drifting over the Sahara Desert on its way to Europe, bringing desert dust with it.

"Dust may actually play a bigger role in melting snow than ambient air temperature," Francis explains. "It's estimated that a single dust event in March 2018, where Saharan sand blew in over the Caucasus Mountains, may have shortened the snow-cover duration by up to 30 days, with this effect even more pronounced at higher elevations."

The dust magnifies the snowmelt in a number of ways. For starters, airborne dust enhances the radiative effects of the water vapor in the atmospheric river, meaning the air can hold higher amounts of moisture, and the dust particles can act as cloud-condensation nuclei, promoting the development of clouds that then rain on the mountain snow. »»

Atmospheric rivers are not big hurricanes. Although they share many features (high winds and lots of rain originating from the tropics), atmospheric rivers are sustained, moving bands of moisture with wide-spread impact. Think a jet stream, but wet, and closer to the ground.

Hurricanes, on the other hand, are rapidly rotating storm systems that concentrate their water content into precipitation over a much smaller area. Hurricanes take heat from the tropics to the poles, which plays an important role in regulating global climate; atmospheric rivers take moisture out of the tropics and spread it around the world.

⊙ **IMAGE:** Despite their distance, the sand dunes of the Sahara and the ice caps of the Antarctic are linked by global atmospheric phenomena.

Then, there's the dust that is deposited on the snow. Dust on the snow impedes the albedo effect, where the white snow reflects the UV radiation back, reducing the heat and keeping things cool.

Dust-covered snow can't do this, with the darker surface absorbing a larger fraction of the incoming solar radiation, causing it to melt. Drastically, in fact, as Francis confirms the snow-albedo feedback in response to Saharan dust can lead to the snow melting up to 38 days earlier than normal.

THAT'S NOT ALL

Mineral dust on snow and ice can provide nutrients to the microalgae that grow there. That might not sound so bad, but when microbes grow in abundance they can cause holes in the ice and snow cover, called cryoconite holes.

The microalgae tend to concentrate at the bottom of these holes, creating a dark mass, which further reduces the albedo effect. As the snow melts, more of the darker material is exposed on the surface, creating a vicious circle.

The jet streams that zoom over the Earth often bring dust to northern latitudes, but with new atmospheric rivers lending a hand, alpine skiers won't get much opportunity to enjoy the slopes.

But again, it's not all bad. In a world without atmospheric rivers, drought would reign supreme.

Atmospheric rivers are crucial to rebalancing water distribution around the planet, and while an increase in rain may be devastating, no rain at all would be just as bad. A better understanding of the future of rivers in the sky may also help water-resource managers on the ground.

THE GOOD NEWS

Mehry Akbary, assistant professor at the University of Tehran, thinks her findings on the development of atmospheric rivers in the Middle East and North Africa could be used to compensate for the shortage of water resources in this desert region.

The MENA region lies at the interface of the subtropics and mid-latitudes, and its geographical location means there is significant uncertainty about the magnitude of future changes to precipitation in much of the region.

However, because atmospheric water vapor will increase with increasing temperatures, researchers from Jet Propulsion Laboratory, University of Balamand Dubai, University of California and California State University say in their 2020 paper, confidence is high that precipitation extremes will increase in frequency and intensity throughout the MENA region.

Akbary thinks this could be more beneficial than detrimental, though. "As the most arid deserts of the world are located in the MENA region, atmospheric rivers can be counted as good sources of precipitation.

Among the 21 countries in the MENA region, Iran, Egypt and Saudi Arabia have benefited the most from this phenomenon."

Atmospheric rivers account for more than 30 percent of the total rainfall across the MENA region, with some areas seeing almost half their precipitation from rivers in the sky. "I believe if water storage systems are suitable, this huge amount of rainfall could be stored for coming droughts," Akbary says.

In models simulating the year 2100, calibrated to represent a high-emissions future, we can see increases in atmospheric-river frequency in the North African coast, Turkey and Iran. This doesn't mean the rest of the region will dry up: on the contrary, there is an expected increase in precipitation for the Arabian Peninsula.

From the Horn of Africa to the United Arab Emirates, more rain is coming. More water for a parched land can only be welcomed, but locals need to prepare for the accompanying high winds and flooding potential.

Mattingly thinks the largest impact from more frequent atmospheric rivers will be their effects on flooding and water resources. "More intense atmospheric rivers will lead directly to more intense floods in the future, and we are already seeing examples of extreme floods in recent years that were likely exacerbated by the fact a warmer atmosphere can hold more water vapor.

⊙ **IMAGE:** Desertification may be kept at bay by the life-giving moisture in atmospheric rivers.

Although more rainfall might help replenish water resources in some areas, wetter and warmer atmospheric rivers will also present challenges to water managers in the future.

For example, in areas such as the western US that are heavily dependent on snow pack for their water resources, atmospheric rivers are expected to bring more rain to the region, rather than snow, which will likely result in depleted snow packs and stressed water resources during the dry summer months."

It's not all doom and gloom, though, Mattingly is keen to point out. "I do think that in general, water managers are working to be more flexible in their approach to managing resources in the future.

California is a good example, because in the past few years they have had to deal with a few wet seasons against the backdrop of a long-term drought and overall warming that has depleted reservoirs and snow packs. The challenge seems to be to develop approaches that conserve the water delivered quickly during more intense rain events to help ride out drought years." Models from around the world agree: Atmospheric rivers will become more frequent and intense as the planet warms.

The researchers behind these models also agree: Knowing how atmospheric rivers develop and move – and what they may pick up along the way – is an important step toward accurately predicting them and their associated rainfall. ●

THE INVISIBLE THREAT

Microplastics pollution is a danger to industry, marine species and human health

By: **Ludovic Dumée**

Over 300 million tons of plastics are produced each year, out of which only up to 40 percent are recycled or incinerated. The majority end up in landfills or are improperly discarded in the environment, leading over time to their fragmentation into smaller plastic items.

Such “microplastics,” whose maximum dimension falls below 5 millimeters, are ultimately released into waterways and represent a major threat to global ecosystems, the entire food chain as well as many human industrial activities that rely on river or sea-water intake.

The fragmentation of such microplastics may also lead to the formation of nanoplastics, with dimensions below the micrometer level. These are much more difficult to quantify and identify, and they represent key challenges for engineers and researchers.

Why may microplastics enter the food chain and affect humans? Microplastics are reported in the guts of multiple avian or sea-life species that often mistake microplastics for food. Ingested microplastics may accumulate in their digestive system. Besides representing a major source of pain, it can lead to the animals’ premature death. Scavengers then feed on their carcasses, leading to further ingestion of microplastics up the food chain.

Over time microplastics contamination carries over to greater predators and human beings. It is estimated that humans ingest between 50,000 and 100,000 microplastics every year, arising from overusage of plastic bottles for soft drinks or packaged-water consumption, but also through uncontrolled fragmentation and release from packaging materials.

Examples of risks associated to plastic ingestion for human and their uptake by our body through diffusion in the blood system are multiple and daunting, not only due to the increased risk of cancer for exposed organs, but also because microplastics may carry over pathogenic contaminants, such as heavy metals or persistent organic pollutants. Such surface-contaminated microplastics, given the high buoyancy of plastic materials and their ability to float, may therefore act as cargos to further disseminate other contaminants over much larger distances than the single contaminants could achieve.

How can microplastics impact human industrial activities? Besides the food industry, a key area affected by the presence of micro or nanoplastics is the water industry.

The intake waters, feeding wastewater-treatment and desalination plants, may contain, depending on their location and origin, various levels of nano or

> **It is estimated that humans ingest between 50,000 and 100,000 microplastics every year**
> - Ludovic Dumée

microplastics, which may damage existing treatment processes.

For instance, the presence of microplastics in microbial-digestion bioreactors would disturb the microbial ecosystem and floc formation, that is the size of the colonies and their stability, thus reducing the efficiency of the process.

Deposits of nano or microplastics may directly damage membrane-separation steps, potentially leading to mechanical abrasion, as well as to accumulation onto the membranes, reducing the separation and flux performance. These phenomena were found to increase substantially the cost of water desalination and processing, sometimes detrimentally affecting the quality of produced water.

In addition, studies showed also that, depending on the treatment trains in place, microplastics may be further concentrated across the treatment units, leading to discharge of sludge or downstream waters richer in microplastics at the end of the water-treatment process.

How can you help? Discard your plastic wastes properly and ensure that you put them in the right bin without leaving a chance for discarded items to get into our beautiful waterways. Also privilege sustainable-packaging options and limit your usage of single-use items.

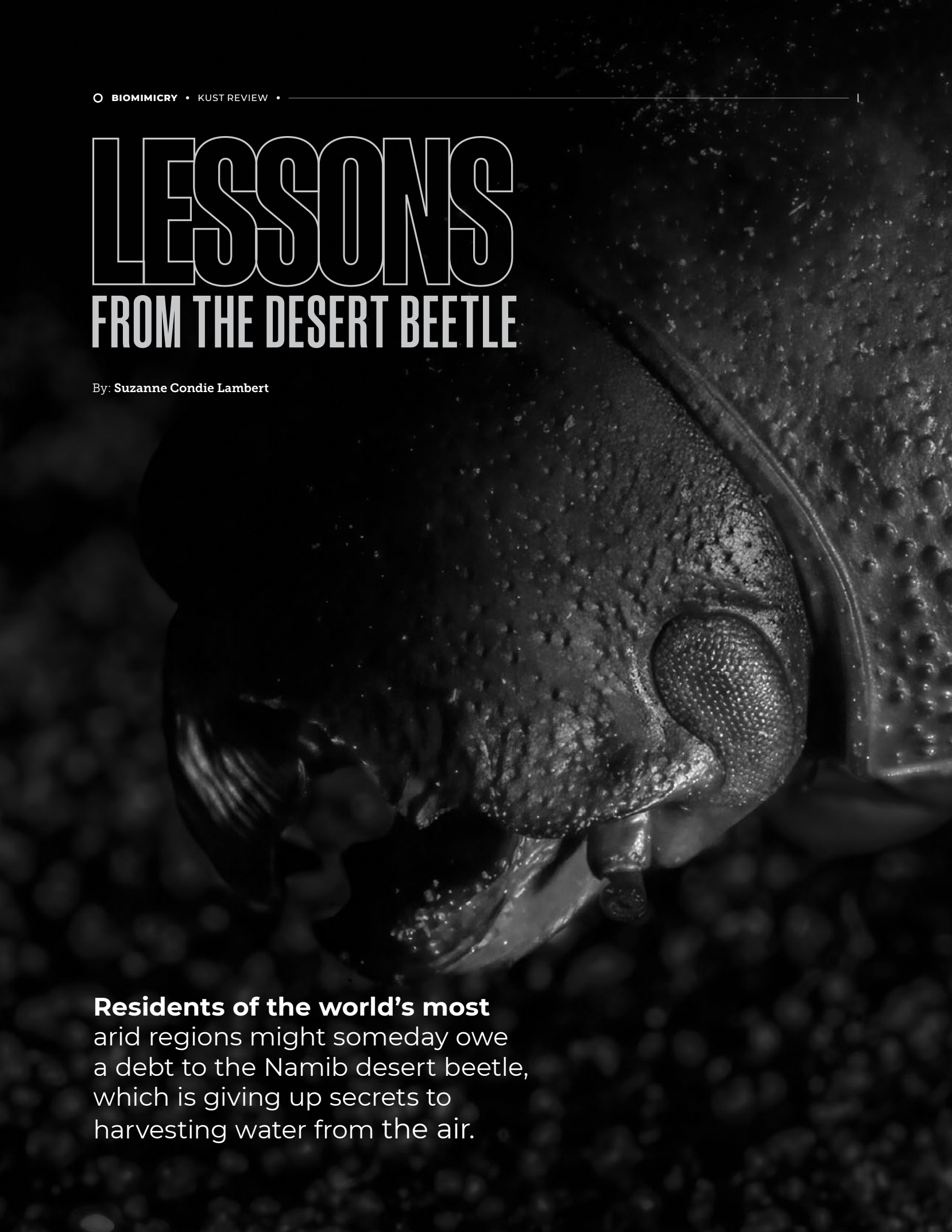
What is needed at this point to better understand risks? Researchers are developing advanced tools and platforms to detect nano and microplastics in wastewaters, to better understand their interactions with microbial organisms, water-treatment operations and assess their health and economic impact. We develop strategies to reveal the true extent of pollution within local ecosystems and understand the impact of plastic fragments of various sizes or shapes on the performance of separation systems. We also study the impact of microplastics on human health and their potential diffusion into our bodies to better prevent long-term diseases.

Ludovic (Ludo) Dumée: is an assistant professor within the Chemical Engineering Department at Khalifa University who leads the Advanced Separation Materials team. His research interests span from functional and reactive materials engineering to their application across environmental applications. In 2020, he received the Membrane Society of Australasia Science award for his work on microplastics separation. He can be reached at Ludovic.dumee@ku.ac.ae.

PHOTOS: Shutterstock, Envato

LESSONS FROM THE DESERT BEETLE

By: **Suzanne Condie Lambert**



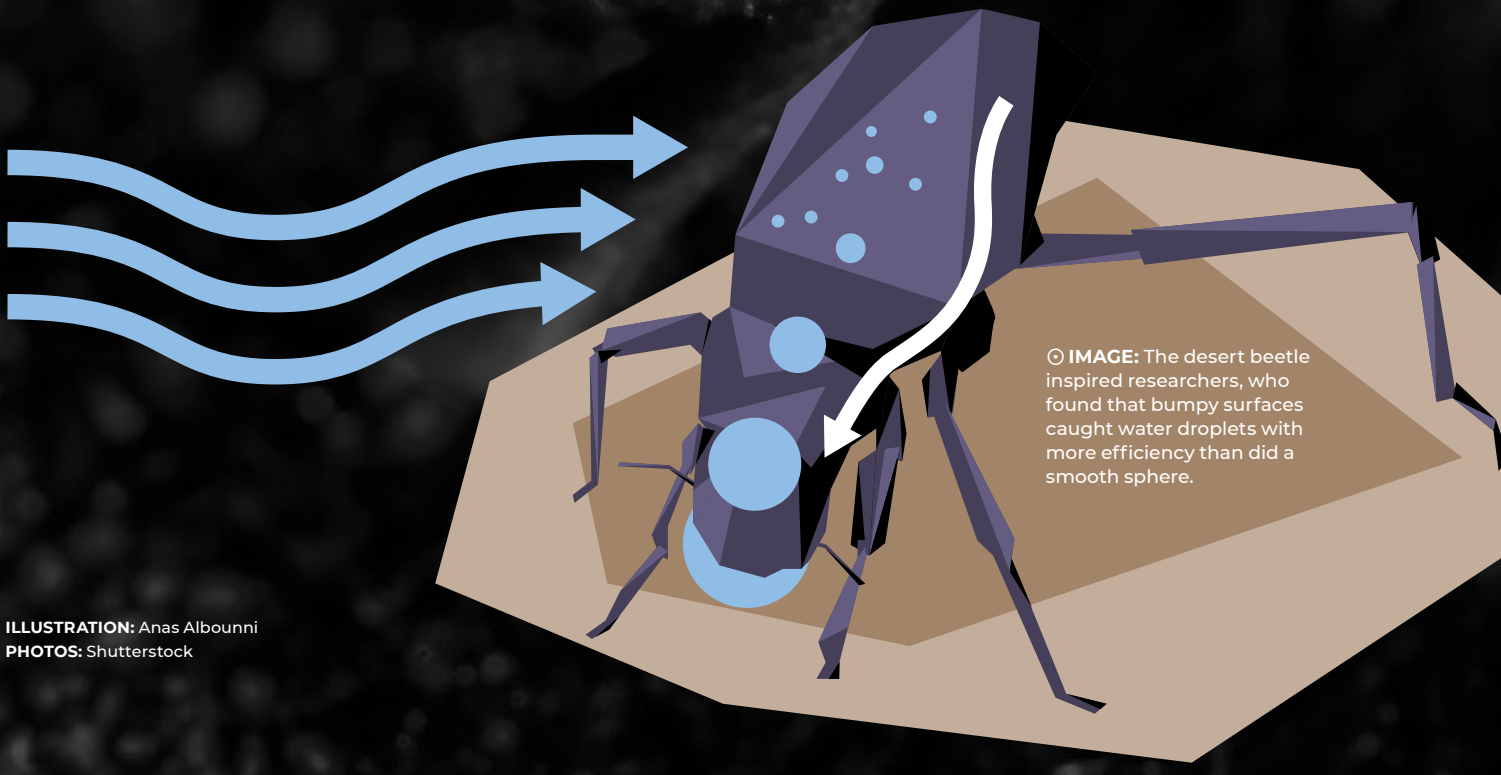
Residents of the world's most arid regions might someday owe a debt to the Namib desert beetle, which is giving up secrets to harvesting water from the air.

Several species of Namib desert beetles are native to an area of southwestern Africa without much ground water and rainfall averages of about 1.3 to 5 centimeters a year. To compensate, the beetles "fog bask," leaning into the fog that rolls in several times a week to collect the water they need to stay alive. Water from the air collects on the beetles' abdomens, then rolls into their mouths. Researchers have studied the beetles for decades, but several teams have peeled back more of their mysteries in recent years.

Hunter King, a physicist at the University of Akron in Ohio, USA, and his team took their cues from the bumps on the beetle's back and found that shape and texture could become a "fog magnet," with 1-millimeter bumps catching water with 2.5 times more efficiency than a smooth sphere with the same surface area. "We think the real take-away message is one of enhanced filtration of hard-to-catch, low inertia particles/droplets," King says.

> **We think the real take-away message is one of enhanced filtration of hard-to-catch, low inertia particles** - Hunter King

In 2021, researchers from Fuzhou and Soochow universities in China and Nanyang Technological University in Singapore reported on how they mimicked the beetle's exoskeleton, weaving superhydrophilic and superhydrophobic materials with copper particles to increase the water-harvesting rate of conventional fog harvesters. The researchers say their biomimetic material would be well-suited to large-scale production.



⊙ **IMAGE:** The desert beetle inspired researchers, who found that bumpy surfaces caught water droplets with more efficiency than did a smooth sphere.

ILLUSTRATION: Anas Albounni
PHOTOS: Shutterstock

A BOUNTY IN THE DESERT

Research scientist grows food in the harshest environments by harnessing sun and seawater

By: **Suzanne Condie Lambert**

PHOTOS: Red Sea Farms

Ryan Lefers started his Red Sea Farms project with partner **Mark Tester** to find better ways to bring food and water security to desert communities. Discovering new ways to save energy and reduce carbon emissions while doing it was a bonus.

Lefers, a research scientist at King Abdullah University of Science and Technology in Saudi Arabia whose unique agtech project uses sunlight and seawater to commercially farm produce indoors in otherwise harsh growing environments, grew up on a dairy farm in South Dakota in the American Midwest, where he learned early that a capricious Mother Nature could make or break a harvest.

"Checking the weather in the morning and evening was just part of life," he says, "and usually the question to be addressed was 'When are we going to get rain?'"

In his work studying sustainable agriculture and water usage, he brought that sensibility to the even harsher climate of the Middle East, where the answer to the question "When are we going to get rain?" is usually "Don't hold your breath."

"When your harvest is dependent on the whims of nature, there are significant risks of failure. Hail, drought, insects, weeds, floods and frost are just a few of the obstacles to success in open-field farming in the Midwest. In the Arabian Peninsula, you can add to that list sandstorms, excessive heat, poor-quality soils and excessive humidity," Lefers says. »»

⊙ **FAR LEFT:** Mark Tester (left) and Ryan Lefers are finding ways to save energy and lower carbon emissions while helping to bring food security to the desert.

⊙ **LEFT:** Vegetables grown in the Red Sea Farms greenhouses are selected for saltwater tolerance.

⊙ **BELOW:** Smart engineering design and smart control systems allow the greenhouses to use saltwater to both water crops and cool the greenhouses.

⊙ **FAR BELOW:** Lefers' technology allows crops to be grown close to markets, even in difficult environments.

Red Sea Farms
IN NUMBERS

Up to 95%

Up to 95 percent less freshwater use as compared with a traditional desert greenhouse.

Up to 90%

Up to 90 percent less energy use than mechanically cooled greenhouses.

3

Number of sites in Saudi Arabia where tech is deployed today.

7

Number of countries with active projects.

"We work around these challenges by putting most of our high-value crops indoors in protected controlled environments, and we do it in an energy- and water-efficient way using sensors and a growing database to get the best results for our planet, our crops, our communities and our bottom line."

Most traditional greenhouses in the desert region use grid energy and freshwater to water plants and keep the greenhouses cool. But Lefers and his team capitalize instead on desert resources – sun, saltwater, and a lot of both – to reduce operational expenses and grow crops close to the markets they serve. This in turn increases local food security and reduces the costs and challenges of shipping delicate produce long distances.

Red Sea Farms, based in Saudi Arabia, uses solar power and saltwater to both water crops and cool the greenhouses. Plants are selected for saltwater tolerance, and material selection, smart engineering design and smart control systems allow the cooling systems to weather saltwater's corrosive effects, Lefers says.

And the tomatoes? "A bit of salt in irrigation for crops like tomatoes actually increases physical properties like brix (often used as a measure of sweetness/taste) and vitamin and mineral content," Lefers says. "We find that our tomatoes irrigated with salty water taste amazing and have a longer shelf life as well."

⊙ **BELOW:** Using saltwater to irrigate tomatoes actually improves their taste, Lefers says.

Lefers thinks his approach is especially relevant in the wake of the COVID-19 pandemic that exposed serious weaknesses in traditional supply chains. "(It helps) build the case for why we should be looking at growing crops that have a short shelf life locally as much as possible," he says. "The big question is how can we do this? Our technologies enable these crops to be grown locally – providing resilience in the face of supply-chain disruptions.

Add to this the growing consumer awareness and demand for local and healthy food and we expect a bright future for local communities who will benefit from agriculture systems operating using our platform of technologies."

And which communities would benefit from this platform of technologies? One or more pieces of the Red Sea Farms technology platform can be used anywhere, but it's especially suited to communities in harsh environments globally, Lefers says.

"These environments may include deserts, island communities, regions with significant solar resources, coastal communities and regions and/or structures with significant humidity challenges." As for Red Sea Farms, the future is growth, Lefers says.

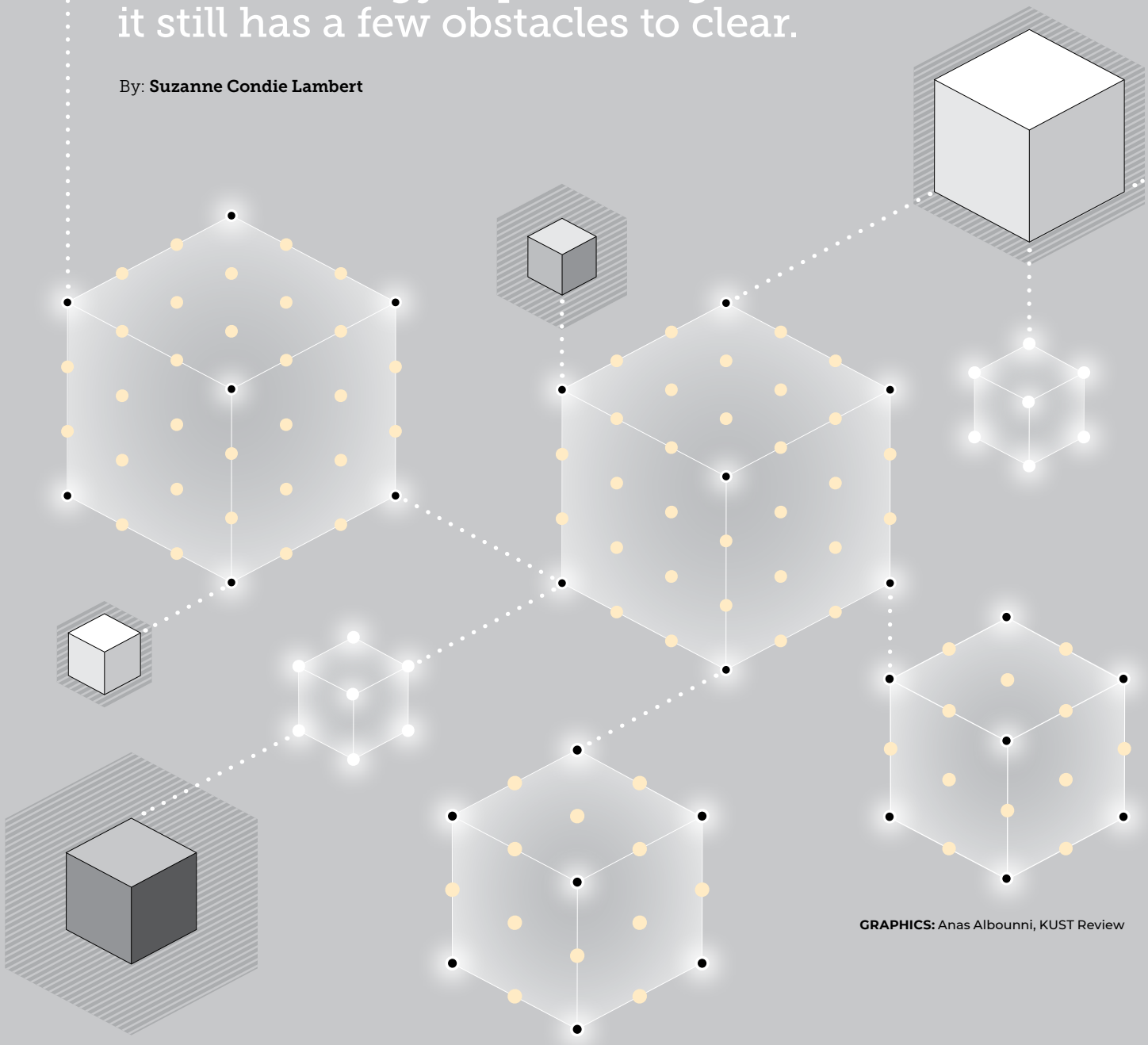
"We are aggressively pursuing opportunities for growth locally (in Saudi Arabia), regionally (in the near MENA region) and globally (with North America as our first step in this). We are excited about bringing our innovative platform of technologies for agriculture systems in harsh environments from Saudi Arabia to the world."

He adds: "On a personal note, I look forward to the day in the future when I can look back and see how we, as the Red Sea Farms team and as a global community working toward this common goal of food security, have managed to both improve the lives of people and protect/enhance the planet we live on for future generations." ⊙

WHAT'S CHAINING BLOCKCHAIN?

The technology is promising, but it still has a few obstacles to clear.

By: **Suzanne Condie Lambert**



GRAPHICS: Anas Albounni, KUST Review

Blockchain might be the most hyped technology relatively few people understand or actively use. Its earliest and perhaps most famous use – the cryptocurrency bitcoin – has become a household word, with other digital-currency companies such as Ethereum and Cardano gaining traction in the public consciousness and with investors.

Despite wild price volatility and scams that the United States' Federal Trade Commission says cost 7,000 people more than US $80 million between October 2020 and March 31, 2021, the crypto economy keeps rolling along, with market capitalization topping $2.4 trillion in May 2021, up from around $200 billion in 2019. And according to a 2021 Fidelity study, seven in 10 institutional investors expect to buy or invest in digital assets in the future.

But financial applications are just part of the hyped potential for blockchain. Boosters of the technology point to other uses such as securing medical data, tracking supply chains, facilitating votes and protecting personal-identity security.

Blockchain, however, still faces hurdles before it can be the game-changer it's been promising to be since the 2009 debut of bitcoin.

But first: What is blockchain?

Blockchain is a platform to store and transfer information in a way that is virtually impossible to change without other users knowing. It is secure because it is decentralized and its content is hashed. Users issue transactions to a public ledger that is managed and verified by a network of computers (called miners) without a third party such as a government, bank or other institutional intermediary getting involved.

A group of verified transactions is called a block, and the blocks are linked by complex puzzles solved by computers ("miners") which verify the transaction and are rewarded for their efforts. Any retroactive change to the log invalidates each block that follows. The result is a certified, transparent, decentralized, tamper-proof database or ledger.

Do we really need it, though?

There are difficulties on the way to blockchain world domination, however. Perhaps the first hurdle to the Age of Blockchain, as Jesse Frederik of the Correspondent asked in 2020, is whether blockchain is a solution in search of a problem. In other words, are the problems expected to be addressed by blockchain projects better suited to solutions we already have?

But hold up, says Dragan Boscovic, research professor and co-director of the School of Computing, Informatics and Decision Systems Engineering at Arizona State University. Blockchain may need to evolve and improve, but it's viable, solves real-world problems and is on a well-trod path to large-scale adoption.

"It is rather a common technology evolution, the same way you would upgrade from your iPhone 11 to iPhone 12 or 13," Boscovic tells KUST Review. "There are numerous examples of blockchain technology being deployed to solve practical problems: One example is the (IBM) Food Trust solution for the food-supply chain." (See sidebar on page 57). »»

Also, says Dr. Ramesh Ramadoss, co-chair of the Institute of Electrical and Electronic Engineers' Blockchain Initiative, it's important to note that "blockchain" isn't a monolith. It refers to a collection of various distributed ledger architectures. "Different architectures are used in different applications," he tells KUST Review, "so, it's very challenging to make a general statement about the actual usage or maturity level of the field."

An energy glutton

Another issue is that blockchain can have a heavy carbon footprint. According to the Harvard Business Review, Bitcoin alone consumes around 110 terawatt hours per year – 0.55 percent of the world's energy production.

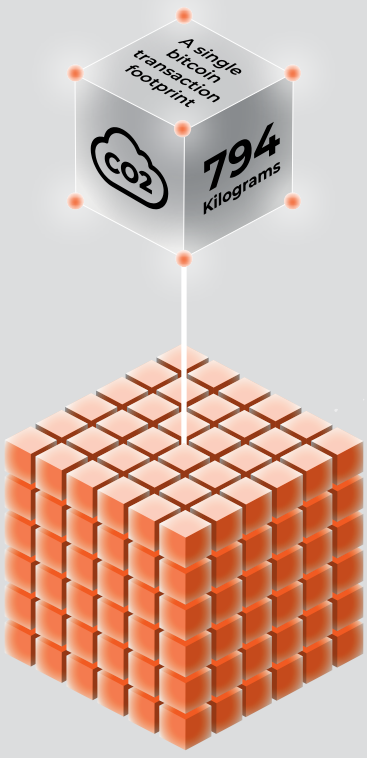
Together, Ethereum and Bitcoin annually eat up the same amount of energy as the residents of Belgium and Thailand, respectively, Digiconomist's Ethereum Energy Consumption Index reports. And each Bitcoin transaction, regardless of how big or small, represents $176 in electricity to power the mining, according to UK financial site MoneySuperMarket.

The technology needs the resources, but the industry is already beginning to correct itself, Boscovic says, noting "Ethereum 2.0," which completed its merge in September 2022. The initiative promises reduces its energy usage by 99 percent and be "more scalable, more secure and more sustainable."

And energy consumption for private blockchains, however, is generally not an issue, Ramadoss notes. Still, "blockchain by its design needs to have access to a large pool of distributed resources," ASU's Boscovic adds. "It is from there that it is able to extract value by enabling independent validation and real-time auditing of the transactions enacted across these resources.

Initial blockchain solutions made great strides in improving their scalability and throughput (e.g. speed of transaction) as well as energy efficiency. Cardano network is (another) example of new blockchain design that scales well and exhibits great energy efficiency."

CARBON FOOTPRINT



199,000+
Bitcoin transactions carried out in a single day as of July 2022.

57.67 million tons
Annual carbon footprint of bitcoin transactions in 2022.

56.13 million tons
Greece's annual carbon footprint in 2022.

Greece was ranked **59th** for carbon footprint by country in 2022, followed by Singapore at 56.11Mt.

More than Greece
The annual carbon footprint of bitcoin transactions is comparable to that of Singapore or Greece.

Out of the shadows

A feature for many users is blockchain's anonymous transactions, which is fine if you just don't want anyone to know you're really into collecting rare My Little Pony figurines, but it becomes a problem when that anonymity is used to launder money or for other nefarious ends.

But just because you don't have to show ID doesn't mean transactions are really anonymous. Identities can be tracked if you care to look hard enough, Boscovic says: "Blockchain is a rich source of digital information. With the right digital forensic tools, it is relatively easy to link a specific person to their digital identity used to transact on the blockchain."

The FBI followed that sort of forensic trail after cyber attackers hit the Colonial Pipeline in May 2021, shutting down the American oil-pipeline system and demanding a ransom of 75 bitcoin (about $2.8 million at the time), Boscovic notes. Most of the ransom (63.7 bitcoin) was recovered; the US government in November offered a $10 million bounty for information about DarkSide, the hacking group believed to be responsible.

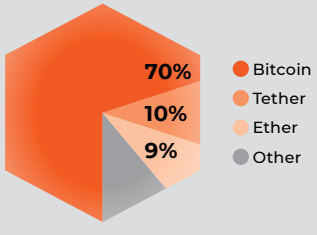
Of course, as law enforcement becomes more tech-savvy, users will find new ways to cover their electronic trails. The IEEE's Ramadoss points to blockchains such as Monero and Zcash that were designed with privacy in mind and are much more difficult to trace. »»

LEFT SOURCE: Digiconomist, World Population Review.

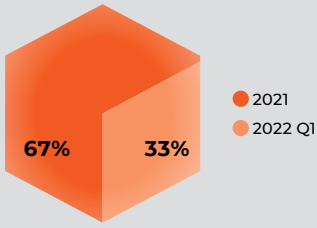
BELOW SOURCE: US Govt. Federal Trade Commission.

FRAUD LOSSES

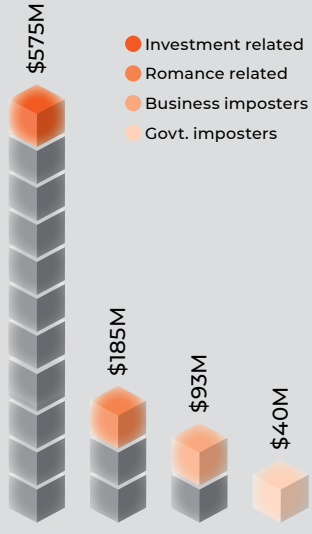
Top cryptocurrencies used to pay scammers Jan 2021 - Mar 2022



Cryptocurrency fraud losses % by year Jan 2021 - Mar 2022



Cryptocurrency fraud losses sum by subject Jan 2021 - Mar 2022



Blockchain linguistics

TERMS YOU SHOULD KNOW

Hash: The function that meets the encrypted demands needed to solve for a blockchain computation.

Non-fungible token (NFT): A unique bit of data stored on a digital ledger that can be sold or traded. It can be a photo, a video or any kind of digital file. Companies such as Nike, Walt Disney, Warner Bros., the NBA and Coca-Cola are issuing NFTs.

Nodes: The computers that make up the blockchain network. They store and update records of each transaction in real time.

Smart contract: A signed, unalterable digital agreement stored on blockchain.

Token: Unit of value that can be acquired through blockchain.

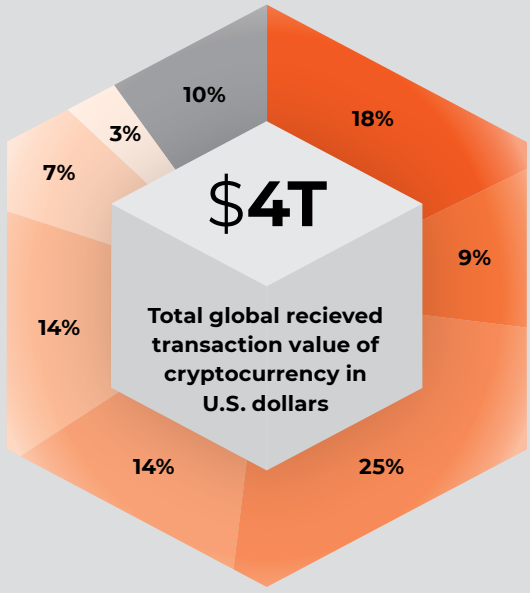
Wallet: A digital wallet that lets users store or transfer digital currencies.

Central Bank Digital Currency (CBDC): A digital currency issued on a blockchain/distributed ledger technology (DLT).

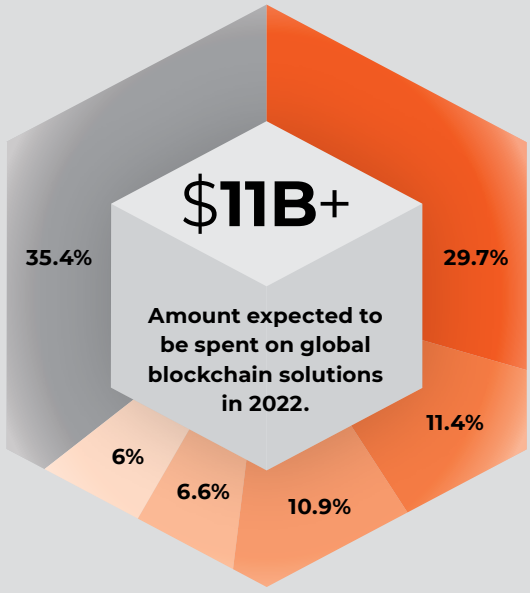
Governments across the globe are running pilot projects using CBDCs. A 2021 Banks for International Settlements survey found that 86 percent of the central banks worldwide are conducting research on CBDCs.

BLOCKCHAIN MARKET

Total cryptocurrency value received by region Jul 2020 - Jun 2021



Worldwide distribution of blockchain market value by sector 2020



SOURCE: International Data Corporation.

Eyes on the future

So what does a blockchain future look like? International regulation might not be a part of the puzzle.

Ramadoss thinks such agreements might be extremely difficult given the fragmented nature of the global regulatory landscape.

"Crypto regulation varies from country to country," he says. "Some countries are favorable (Singapore, El Salvador, Ukraine, Malta), some countries are working on a new regulatory framework (European Commission), and some countries outright banned cryptocurrencies (China)."

And ASU's Boscovic sees no need for international agreements in principle. "Blockchain solutions are international and borderless by their designs," he says.

"Rather, the national regulators will need to interpret and map international blockchain business opportunities onto local business ecosystems and help their economies be competitive in such a global environment."

Who's in the lead?

The experts disagree, however, on which regions are leading the way to a blockchain future. Ramadoss is betting on China (for non-crypto technology), which has been piloting the blockchain-based Digital Yuan project, and the European Union, whose European Commission "is funding the European Blockchain Services Infrastructure (EBSI) to serve as a single platform for issuance of identity, diplomas management, notarization of documents and trusted data sharing among the EU member states."

Boscovic, however, puts his money on North America. "It is primarily due to the entrepreneurial spirit of the young generation, its sharp focus on the global economy and easy access to the capital markets. Europe and Singapore are not far behind."

But both agree that the confusing nature of the technology isn't a problem at all. Just as most people don't have to understand exactly why the internet works to use it, blockchain users will access the technology through user-friendly apps, they say. And the blockchain future? When will it finally arrive? "It's already here," Boscovic says.

7 COOL OTHER USES FOR BLOCKCHAIN TECHNOLOGY

Most people think finance first when they consider the applications of blockchain. But here are seven examples of real-world uses you might not have expected.

Food safety

The United Nations estimates that 1.4 billion tons of food are wasted every year because of supply-chain inefficiencies. The IBM Food Trust looks to change that – and control other issues, including food safety, sustainability and fraud – with its blockchain program to help supply-chain users better communicate.

Avoiding spam calls

India's telecom authority insisted that providers use digital ledger technology to solve the problem of spam calls and texts to its more than 500 million mobile-phone customers. The result? Tech Mahindra created Hyperledger Fabric, which works with all of the service providers in India to manage unwanted calls.

Entertainment

Mediachain, which was bought by Spotify in 2017, is another use of smart contracts, helping musicians agree to rates and get paid.

Health care

BurstIQ's smart contracts help patients and doctors manage the transfer of sensitive identity information and data. Other blockchain-based systems for medical record-keeping and communication include Patientory, Immunity.Life and Medicalchain.

Marriage

Rebecca Rose and Peter Kacherginsky in April 2021 used Ethereum's blockchain to get married. The couple, both employees of crypto-based exchange Coinbase, wrote a smart contract and exchanged "rings," non-fungible tokens (NFTs) in the animated form of two circles merging into one.

The digital marriage was performed in conjunction with a traditional Jewish ceremony when the couple used their phones to exchange the tokens. The couple named their tokens Tabaat – the Hebrew word for ring.

Human rights

Coca-Cola, along with the US State Department and several crypto companies, is working on a plan to let workers use blockchain technology to report cases of forced labor.

The initiative was announced after the Know the Chain study in 2019 found that many food and beverage companies failed to address the issue of labor abuses in their supply chains.

Tracking vaccines

With the Covid pandemic bringing vaccines and vaccine safety to the forefront of the world's attention, IBM (again) is stepping up with a project aimed to make sure vaccines are trustworthy and distributed efficiently.

IBM promises that its distribution network will ensure speed, transparency and accountability as well as the ability to monitor for adverse events and facilitate quick recalls, if needed.

a non fungible

token of good faith

NFTS are the internet's answer to collectibles, but there are things to know before you start trading.

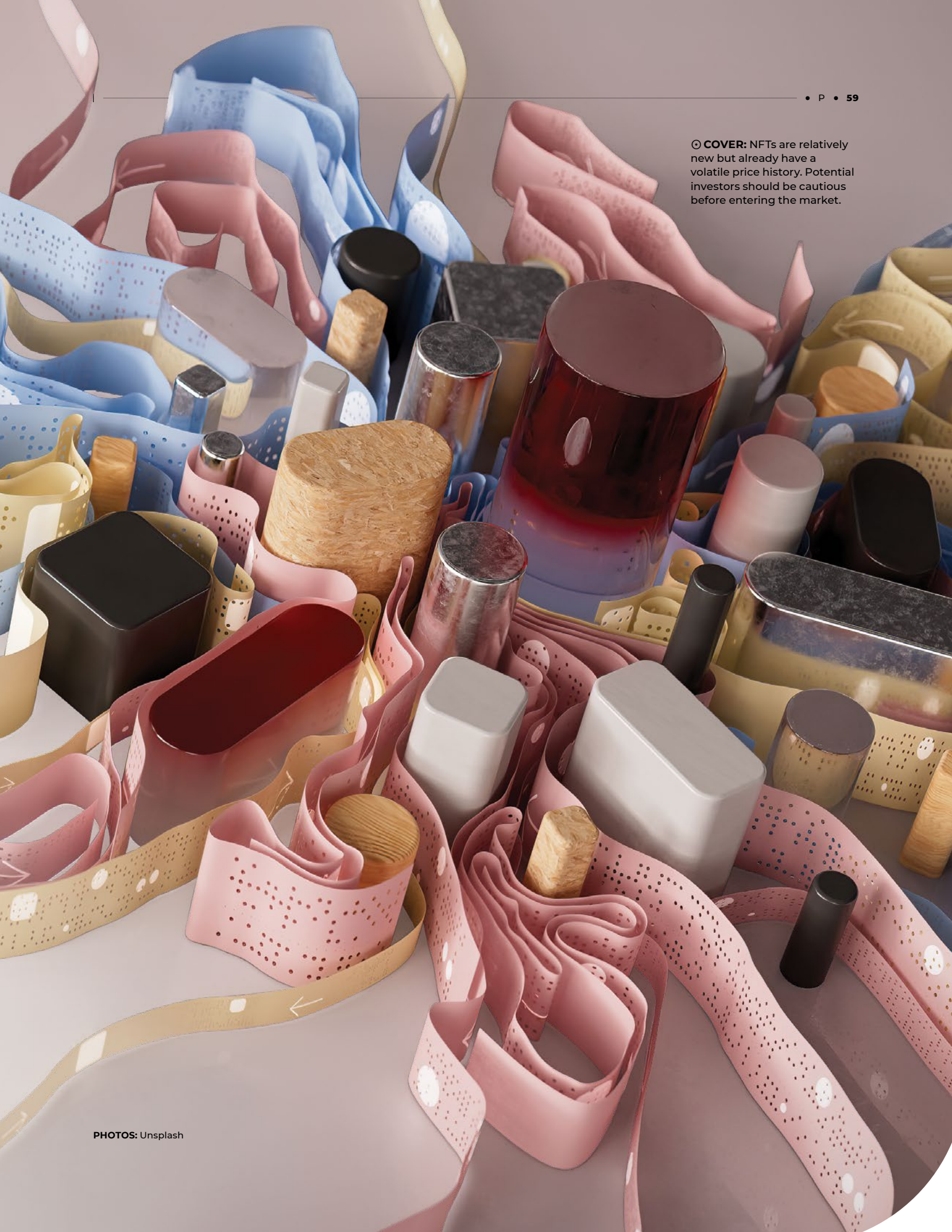
By: **Jade Sterling**

The internet is full of funny images, including cartoon images of animals by digital artists from all over the world. The Bored Ape Yacht Club is one such group producing digital cartoons of apes in hats. They're entertaining; they're cute; and one sold for USD 3.4 million last year.

These monkey pictures are examples of NFTs: non-fungible tokens. To explain NFTs, let's start with the concept of fungibility. Fungible assets are goods that can be readily interchanged for another of the same thing: a dollar bill is a dollar bill, regardless of its serial number.

That dollar bill is also four quarters or ten dimes, and so on. Its value remains the same. Stock operates in much the same way: One share of a company's stock is worth the same as any other share of that same company. It doesn't matter which one you personally own: The stocks are designed to be equivalent and interchangeable.

Go to any bookstore and buy a copy of any mass-market paperback. You now have a fungible copy of that text. But if you choose a first edition or a limited cover, things start to shift. »»



⊙ **COVER:** NFTs are relatively new but already have a volatile price history. Potential investors should be cautious before entering the market.

PHOTOS: Unsplash

Now, you have something of a limited run, and its value often increases because of that. People may pay a premium to get that unique cover or the historical first edition: The book hasn't actually got more to offer as a first edition. It's generally the same text that you'd find in the mass-market paperback.

Bringing it back to art, you could purchase a print of one of Monet's Water Lilies series for your wall; you could even print an image from the internet and hang that. But an original Water Lilies piece costs so much more than a printer-paper copy or even the most skilled reproduction. You're not just paying for the image, you're paying for the history and the provenance, for the fact that it's a Monet, an original.

If you want your item to be valuable, you often want it to be non-fungible. For physical items, non-fungibility makes sense. Certain things hold greater value than others even if they are fundamentally the same thing. Digital media, however, is infinitely reproducible.

⊙ **IMAGE:** Anything can be an NFT. The NFT isn't a digital image itself, but the receipt that shows that you own it. A blockchain record verifies the purchase.

My eBook copy of the mass-market paperback is identical to your copy, right down to the ones and the zeros. How can you have a collector's edition of those ones and zeros? How can you have something special when creating an exact copy is as simple as Ctrl+C?

Enter the blockchain

Blockchain is the technology that'll be powering everything, that new system we've all heard of yet barely anyone actually understands. Blockchain offers an immutable and tamper-proof ledger, where each record created forms a block, and each block is confirmed by the community among which the platform is shared before it can be paired up with the previous entry in the chain.

The blockchain is a shared database, validated by a wider community rather than a central authority, making it a public ledger that cannot be easily tampered with, as no one person can go back and change things.

If you purchase an NFT, you are the sole owner, and this fact is protected by the blockchain. No one can modify the record of ownership, and no one can copy/paste a new one into existence. Smart contracts assign ownership and manage the transfer of NFTs. When someone creates an NFT, they execute code stored in the smart contracts that conform to different standards, with this information added to the blockchain to be tamper-free forever.

Instead of a physical limited-edition copy of your favorite novel, your NFT is a token that says: "I bought one of only 500 limited-edition versions of this, and no matter how many times the piece is copied, there will only ever be 500 of these tokens." It's digital copyright; it's digital bragging rights. Sure, you have a piece of work by Monet, but do you have a Monet? Sure, you have a piece of digital art, but do you have an NFT?

Think of an NFT as a template. Although 2021 saw digital art sweep the mainstream, anything can be an NFT. The NFT isn't the asset itself, but a unit of data (or a digital asset) on the blockchain that confirms and represents ownership of the asset, whether that is digital or physical.

If you're purchasing a piece of digital art that has been listed as an NFT, the NFT is the string of numbers on the blockchain that says, "Yes, you own this now." It's like a digital receipt that no one can argue with.

An NFT could represent digital art, from GIFs to videos, and real-world items such as the deeds to a house, legal documents, tickets to a real-life event and so on. As the Ethereum website says, "It's not hard to imagine a world where your Ethereum wallet becomes the key to your car or home — your door being unlocked by the cryptographic proof of ownership."

Where's the money?

As with any good where only a limited number exist, you can often expect its value to increase over time. Bragging rights command a high price. The NFTs created by Bored Ape Yacht Club, a team of developers who created the 10,000 Bored Apes sitting in the digital repositories of such celebrities as Justin Bieber, Paris Hilton and Jimmy Fallon, also serve as tickets to an exclusive social club. And they're all sold out.

At the same time, there's money to be made anywhere people are willing to pay for something. Some people want to support their favorite creators by buying a "premium" version of a piece. Some people just want to own a piece of digital art.

There's also the concept of royalties, which is new to this marketplace, but powerful. Some NFTs have smart contracts that will automatically pay out royalties to their creators when they're sold. As their work is sold from person to person — as that NFT changes hands — creators can earn royalties automatically.

And the potential for those royalties could be rapidly growing. Andrea Baronchelli, reader of mathematics at City University of London, reports on what he describes as the "NFT revolution."

He investigated data concerning 6.1 million trades of 4.7 million NFTs between June 23, 2017, and April 27, 2021, and says the NFT market experienced a 150-fold growth in just eight months at the end of 2020 and into 2021.

"Following an initial rapid growth in late 2017, when the CryptoKitties collection gained worldwide popularity, the size of the NFT market remained substantially stable until mid 2020, with an average of around USD 60,000 traded daily," Baronchelli »»

⊙ **IMAGE:** Some NFTs have language built into the smart contract that automatically pays out royalties to the NFT creators when the asset is resold.

says. “Starting in July 2020, the market experienced dramatic growth, with the total volume exchanged daily surpassing USD 10 million in March 2021.”

How valuable is an NFT, really? Usman Chohan, economist at the University of New South Wales, says an NFT is just “as valuable as people express a willingness to pay for it.”

Same as anything, then.

It’s not perfect — yet

The blockchain itself is immutable; your information and your assets are safe when they’re on there. But with multiple NFT marketplaces and multiple individual blockchains, it’s feasible to screenshot an NFT from one platform and list it as something brand new and unique on a different platform.

Once it’s on that blockchain, have fun trying to delete it. Ultimately here, the fungibility applies to the specific blockchain instance of the thing, not the thing itself.

Chohan says this is part of what raises eyebrows among casual observers of NFT markets. “Anyone could, in theory, upload artwork onto an NFT, without proving that they are the original creator of the work,” he says. “This creates an evident real-world risk that fraudulent actors will upload NFTs to auction markets by posing as the original owners, or creators, of objects of value.”

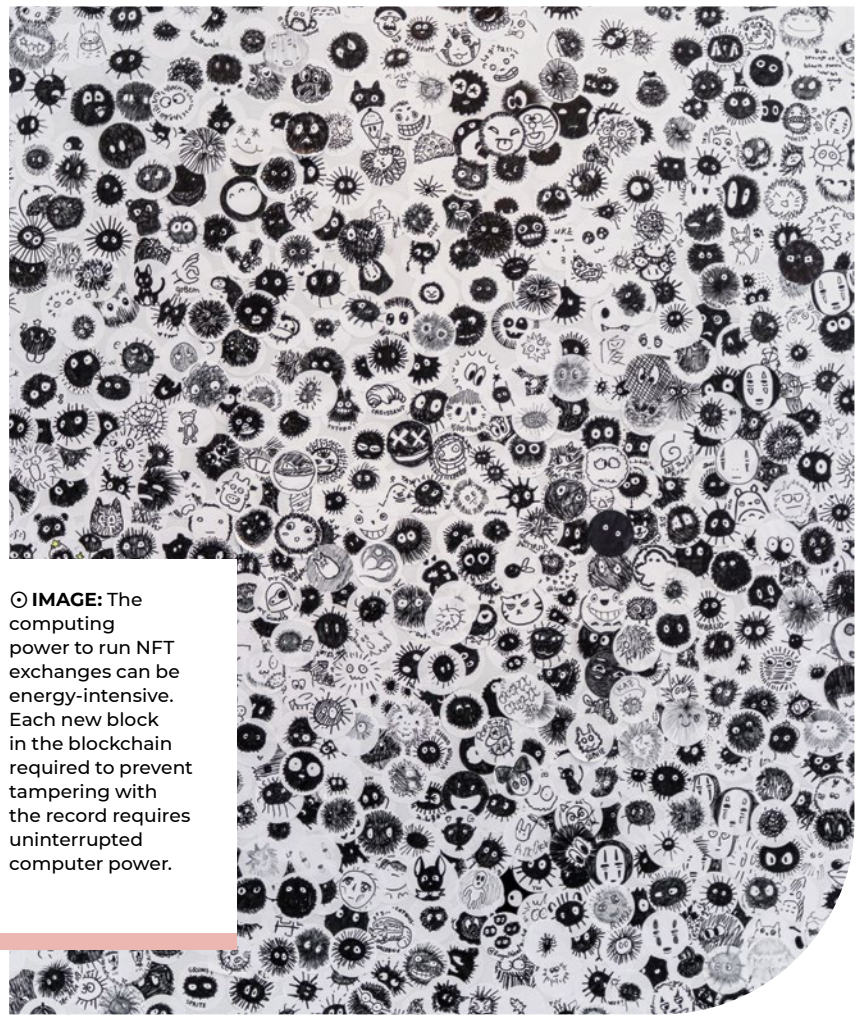
“In theory,” he continues, “there can be multiple NFTs created over an asset, claiming to be the ‘true’ token representing an idea, image or object.”

There are contracts that can help mitigate this. If you want to buy an NFT, you can ask a smart contract to run a ”node,” a piece of software that checks everything on a blockchain for fakes. This contract needs to be smart enough to find fakes, but if it does, you’ll realize the NFT is a copy and you can pull out of the purchase.

The whole system works because blockchain technology is decentralized and secure, but this comes at a cost. It takes a lot of computing power to create new blocks in the blockchain, and blocks are created constantly to keep everything tamper-proof. Even if blocks aren’t storing new data, the more blocks, the more secure the chain.

However, this means that uninterrupted computing power is required and that is energy-intensive, to say the least. According to the New York Times, mining bitcoin uses more electricity than some countries.

“The process of creating bitcoin to spend or trade consumes around 91 terawatt-hours of electricity annually, more than is used by Finland,” the paper reports. Blockchain companies like Ethereum are committing to making the process greener, but it’s likely that blockchain technology’s energy consumption will remain volatile.



⊙ **IMAGE:** The computing power to run NFT exchanges can be energy-intensive. Each new block in the blockchain required to prevent tampering with the record requires uninterrupted computer power.

The 'art' in fraud artist

Nothing is immune from exploitation and NFTs are no different. For those looking to launder money, the art world has long been a draw: Art typically commands a high price, and the industry allows large cash deals.

Many valuable artworks are housed in "freeports," high-security storage spaces for safekeeping. They are auctioned and purchased using dirty money, then anonymously sold on without ever leaving their place in the freeport.

The new buyer can retrieve their new artwork from the same freeport, and the original buyer, turned seller, has money from a seemingly legitimate business deal. NFTs could make this even easier.

There is nothing stopping you listing any asset as an NFT for huge amounts of money. An anonymous user who totally isn't you then buys that NFT, and you receive some nice clean cryptocurrency.

The anonymity of the whole affair is the key here: When your government wants to know where you got all your money, you can point to the transaction where an anonymous user paid for your NFT.

⊙ **IMAGE:** Have you bought THE *Mona Lisa* or A *Mona Lisa*? The value of your asset often depends on the exclusivity of the purchase.

It's all a bit tenuous

When you buy an NFT, you buy the certificate of authenticity that proves you own the NFT, not the thing itself, and a link pointing to that thing. That thing could be the original image, that Bored Ape you've wanted for so long.

But that link is only as good as the service keeping that link active. It's all very fragile and maintains value only as long as the people using it insist it has value. But then, that's how all money works, really.

As Baronchelli points out: "The NFT market is less than four years old. Overall, NFTs are a new tool that satisfies some of the needs of creators, users and collectors of a large class of digital and non-digital objects.

As such, they are probably here to stay or, at least, they represent a first step towards new tools to deal with property and provenance of such assets."

Ultimately, NFTs are a way to emulate physical uniqueness for digital assets. Even if there are a million other identical copies out there, the NFT says that you own the original one.

This is all secured using blockchain technology, which is the same method that digital currencies use to ensure that you can't make a million copies of your bitcoin.

There are countless copies of the Mona Lisa out there, but there's only one Mona Lisa. ⭘

The future of Hydrocarbons

Our experts predict the role of oil, gas and coal in an increasingly green world

Behaviors must start changing now

Michael Jefferson is a professor at ESCP Europe Business School (London campus). Formerly Group Chief Economist, Shell International (1974-1979), and other planning and oil supply and trading posts (1979-1990); deputy secretary general, World Energy Council (1990-1999); lead author, contributing author, IPCC reports; recipient of the IPCC's certificate for contributing to their award of the Nobel Peace Prize, 2007; chairman, Policies Committee, World Renewable Energy Network, 1991-2007; senior editor Energy Policy journal 2013-2019.

From the supply side there are a few problems facing us as we (or some of us) endeavor to move to "an increasingly green world." For example, the UK is Europe's windiest country, yet in the first 11 months of 2021 there were at least 85 days when wind energy failed to provide even 10 percent of the country's electricity grid load, leaving gas (and sometimes even coal) to come to the rescue.

Things are not helped by the fact that this sector has only just begun to invest in significant volumes of back-up storage, and wind energy producers who look as if they may produce electricity when not required are paid to shut down temporarily.

On the demand side there are serious issues arising about how societies will be able to cope as demand for electricity rises concurrently with pressure to reduce reliance on hydrocarbons.

The demands of re-charging electric vehicles is but one of these. There is also the rising opposition to plastics. We should all abhor plastic waste. But there are estimated to be up to 9,000 plastics products, all reliant on hydrocarbons (petro-chemicals is perhaps a more relevant term here).

You may gather that I believe we are still only in the early stages of realizing how great the challenges are of seeking to move forward along an increasingly green path. Hopefully a greater effort will be taken in using solar power, wind towers, learning from traditional architectural layouts to reduce dependence on hydrocarbons.

But we all need to be aware of the many basic needs provided for by petro-chemicals, realistic time horizons for moving off petroleum in the transportation sector, and the key contribution which gas will make to the needed energy transition. In many countries, the general population remains concerned about the safety of nuclear power, and perhaps insufficiently aware of the current constraints or challenges to wind and wave power, and modern biomass.

Readers of this may find me unduly pessimistic, so I had better point out that I believe human activities have raised near surface global temperature by just over 1 degree Celsius over the past 140 years, and I fear they could raise it by nearer 3 degrees (rather than 1.5 or 2.0) over the remainder of this century.

I have worked with climate research scientists for over 40 years, with the Intergovernmental Panel on Climate Change (IPCC) between 1991 and 2015 in various roles, and believe strongly in the need for sound precautionary policies and investments — as well as behavioral changes — now to counter climate change, even if the start of a new global solar minimum happened to be just round the corner. ●

Hydrocarbons remain significant

Mai Bui is a research associate at the Centre for Environmental Policy at Imperial College London.

Hydrocarbons have provided the majority of the world's energy needs for centuries. Employed in many areas of society, hydrocarbons have played an important role in the power, industry, transport, commercial and residential sectors, with 84 percent of the global primary energy consumption currently coming from fossil fuels. At a global scale, total anthropogenic CO2 emissions reached 36.4 Gt/year in 2019, which reduced to 34.07 Gt/year in 2020 due to the Covid-19 pandemic. It is now clear that in order to limit global warming to 1.5 degrees C and mitigate the harmful effects of climate change, the world urgently needs to reduce its greenhouse gas emissions significantly. »»

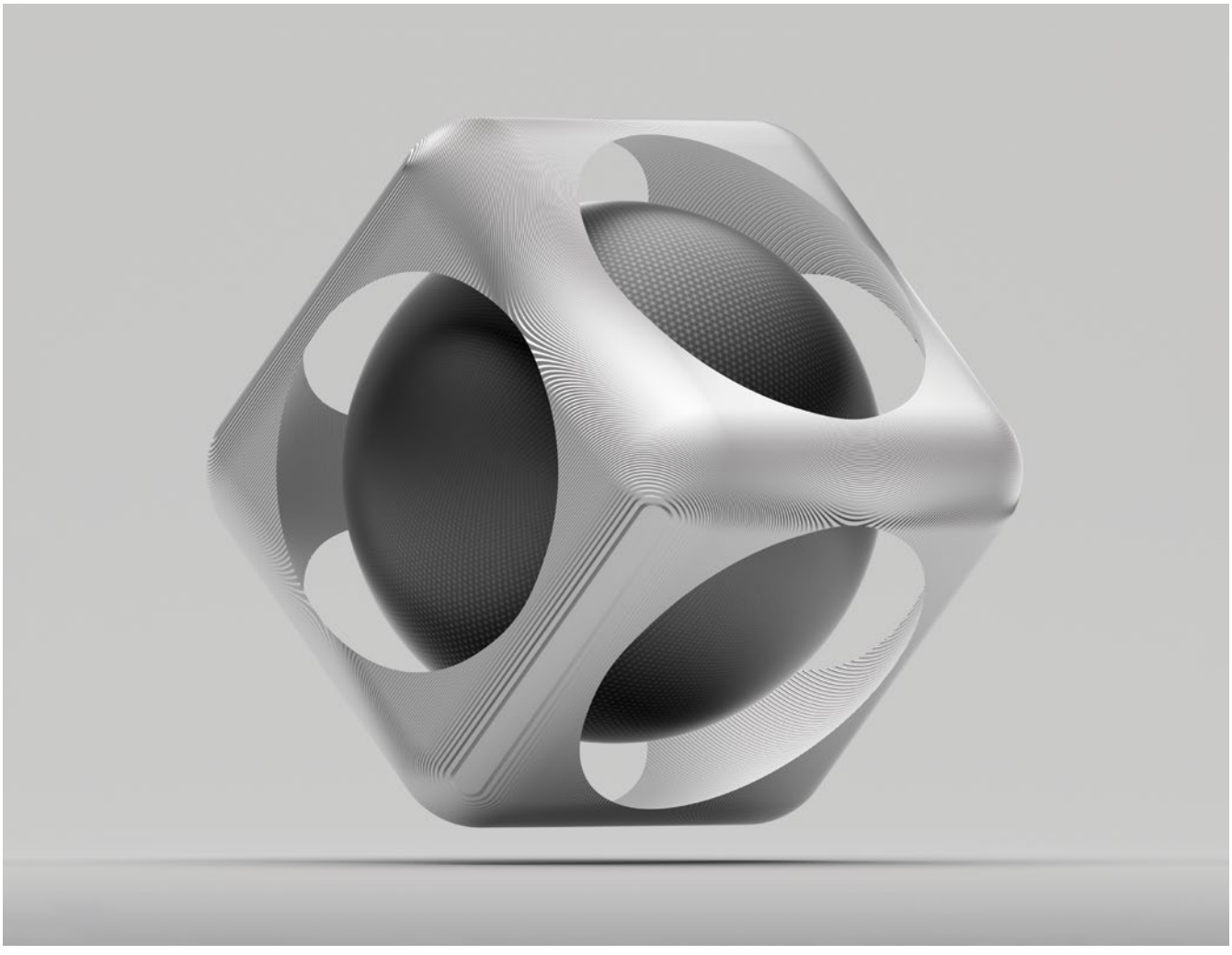
Subsequently, a growing number of countries and companies have recognized the need to commit to a target of net-zero emissions by 2050 (or 2060 as in China's case). Even at a national scale, reaching net-zero will be a major challenge, requiring unprecedented levels of greenhouse gas emissions reduction and removal from the atmosphere. The net-zero transition will employ a portfolio of different technology options, including renewable energy, hydrogen and energy-efficiency improvements.

Carbon-capture and -storage (CCS) technologies will also play an important role in reducing emissions associated with hydrocarbons in the power and industrial sectors, as well as generating low-carbon hydrogen (e.g. from natural gas or biomass) to use for transport or residential heating. CCS can also be used for CO2 removal from the atmosphere, which can be used to offset any residual CO2 emissions that are not captured.

It is highly likely that hydrocarbons will continue to have a significant role for the upcoming decades, particularly in countries and sectors that currently rely on carbon-based fuels. Although 2050 seems far into the future, reducing emissions at a gigaton scale will require major infrastructure changes and large-scale deployment of low-carbon technologies. Furthermore, governments will have an essential role in developing policy that will support and facilitate the transition to net-zero. Although urgent action is needed immediately, it is crucial that the transition to a green-oriented future is affordable and socially equitable.

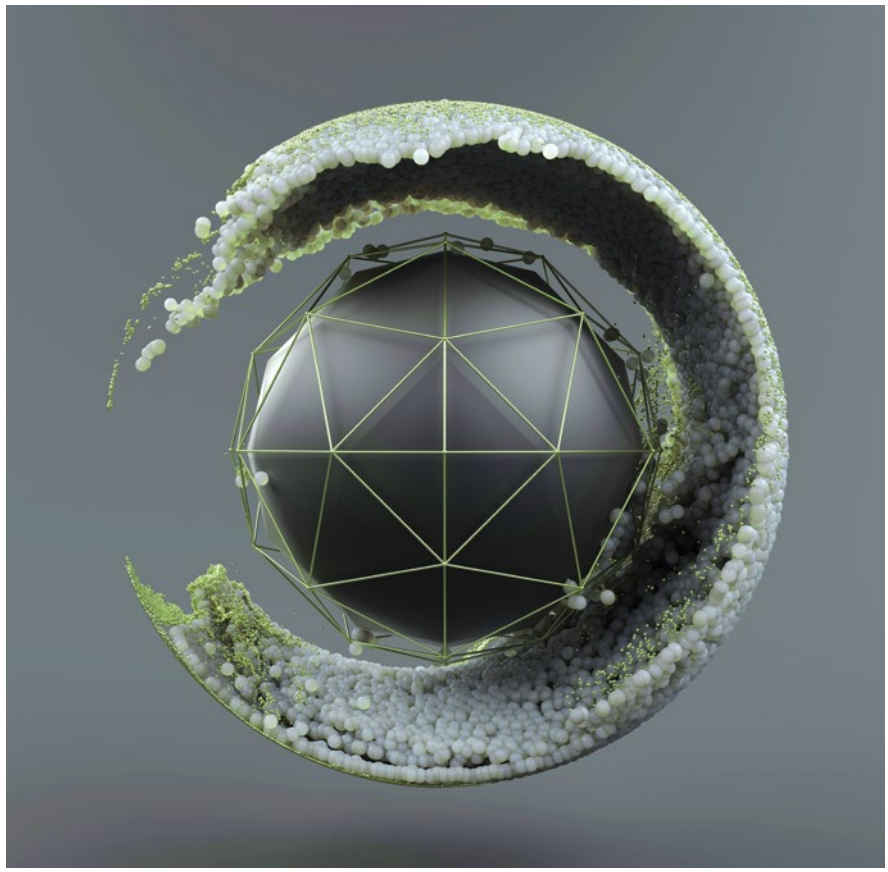
We need to strike the right balance between cost, energy security, meeting emissions-reduction targets, while also avoiding unintended negative impacts to society and the environment.

BELOW: Carbon capture and storage could be key to helping tackle global warming.



3 pathways to a net-zero future

Martin Haigh looks after the long-term energy modelling behind the Shell scenarios.



⊙ **ABOVE:** Going green means more than just reducing our energy consumption.

In the long run, we need to get to net-zero CO2 emissions to stop the world's temperature rising. That means that we need to be on a pathway to reduce our use of fossil hydrocarbons. In turn, that boils down to three options:

- fossil hydrocarbons are not burned but used to make products like plastics (in which case those need to be either recycled or disposed of responsibly);
- fossil hydrocarbons are burned and the emissions are captured;
- or fossil hydrocarbons are burned and the emissions are balanced by negative emissions elsewhere.

Then the debates start about how we achieve this. Because of the pervasive use of hydrocarbons across our economies and lives, the implications are profound: justice and equity. Which uses are seen as more legitimate? How much more time should developing countries have to decarbonize? Indeed, should developing countries' emissions rise for a period in order to continue meeting human-development goals?

- demand or supply of fossil hydrocarbons? Can you effect change by stifling production of fossil hydrocarbons, or do you need to address demand for any change to be lasting?
- economics and practicalities. How much change is realistic by 2030? What are the knock-on consequences of changes? Which policies are most effective in driving change?

These are just a few examples, but the "how" touches almost all areas of politics, economics, technology and society. We explored a range of alternatives in our scenarios: Waves, Islands and Sky 1.5, available here. These look at wider drivers of change and the implications for the whole energy system, hydrocarbon and non-hydrocarbon.

In the Sky 1.5 scenario, a stretching and rapid world of change across the energy system, we look at the most practical means of keeping the temperature rise to 1.5 degrees C above pre-industrial levels by 2100. All available options come into play, including negative emissions, and both technological (bioenergy with CCS) and natural (nature-based solutions).

In Waves, stronger demand combines with a widespread desire to drive the energy transition by focusing on elimination of fossil hydrocarbons as the root cause of climate change.

In common with Sky 1.5 is strong growth in renewables and hydrogen, but in this scenario, CSS does not play a material role. The result in ›››

Waves is that emissions take longer to peak and fall. In Islands, near-term energy (and hydrocarbon) demand grows more slowly than the other scenarios, as countries focus on trying to stimulate sluggish economies and address local concerns.

The flip side to factors leading to the slower growth in demand is that the pace of transition is slower and similar to historical norms. Here are our outlooks for the future of oil demand and supply. In the long-term, demand moves away from oil. The timing of the peak of demand for oil is quite different, possibly even this decade.

But there are very different trends underneath this, both regionally and across sectors. Some uses, notably the "non-energy use" sector (material products like plastics), continue to be robust throughout the century, while it moves away more rapidly in sectors like car travel.

Our data set provides the figures behind this graph, together with outlooks for other hydrocarbons (natural gas, coal and bioenergy, the non-fossil hydrocarbon), alongside other energy sources, and then how the uses of these different energy forms evolve.

Gulf countries need to take the lead

Dr. Adnan Shihab-Eldin is a senior visiting research fellow at the Oxford Institute for Energy Studies and a board member of both the Kearney Energy Transition Institute, Amsterdam, and Gulf Bank of Kuwait.

With increasing momentum in favor of switching to global clean-energy sources (net-zero emissions) by around 2050, the United Nations Climate Change Conference of the Parties (COP26) in November adopted a series of decisions embodied in the Glasgow Climate Act (GCA), which aims to achieve the Paris Agreement's climate-change goal of keeping the projected rise in global average temperature below 1.5 degrees C.

Renewable technologies, solar and wind in particular, are at the forefront of the clean-energy mix. Nuclear energy and clean, carbon-neutral fossil-energy fuels could competitively be part of the mix, but their roles and shares are uncertain due to multiple, and sometimes contradictory, views about the optimal path of the transition, its component technologies and who will bear investment costs estimated at about $5 trillion annually by 2030, according to the NZE2050 scenario from the International Energy Agency (IEA).

There remain significant differences among industrial countries over how to proceed with emissions reductions: Some vehemently oppose expanding nuclear energy and clean fossil-energy technologies and some European countries are against including such technologies in the list of clean-energy sources and products eligible for global trade, raising obstacles to plans to export and import fossil-based clean (blue) hydrogen and ammonia.

Those countries, and most environmental activists, are betting that renewable energy could provide most if not all of the clean-energy supply, despite technical and economic obstacles that prevent their share in electrical grids from exceeding, on average, about 30 percent.

A number of extreme energy-transition scenarios predict a sharp decline in the contribution of fossil energy to total demand, from the current 80 percent to about 20 percent by 2050 (e.g. IEA's NZE2050). However, such scenarios are idealistic, costly and difficult to realize.

Among a wide range of other scenarios, OPEC's latest annual World Oil Outlook report projects oil and gas demand to grow, albeit at a slower pace, until at least 2045, with the share of fossil sources falling to about 70 percent.

Regardless of the degree of optimism or pessimism of these scenarios, the goal and trajectory of all energy-transition pathways are unequivocal: a rapid transition to a clean-energy mix, with a wide range of component technologies. The growing enthusiasm for protecting the environment is sometimes shrouded in an increasingly negative outlook toward fossil sources, irrespective of how clean some can be.

This will no doubt drive an accelerating shift in policies, unless countries with large reserves of fossil sources, combined with low production costs, such as the Gulf states, start immediately making strategic investments to develop CO2 capture, use and storage technologies (CCUS, or CCS), including direct capture of CO2 from air (DAC).

The investments are huge but worth it, for they will help to maintain a robust role for fossil-energy sources. Although many CCS projects are being implemented by oil- and gas-producing countries, most of them are still of small capacity and their number is growing slowly due to their high cost.

In line with the GCA call to member states to make more ambitious and concrete pledges to reduce carbon emissions, the Gulf states should embrace an ambitious initiative: pledging to equip all fossil-based power plants with (CCS) systems by 2035. Such an initiative would be welcomed worldwide.

Furthermore, it will reduce Gulf countries' CO2 emissions by approximately 25 percent, or about 1 percent of total global emissions — a significant decrease given the size of their economies is about 1.8 percent of the global economy.

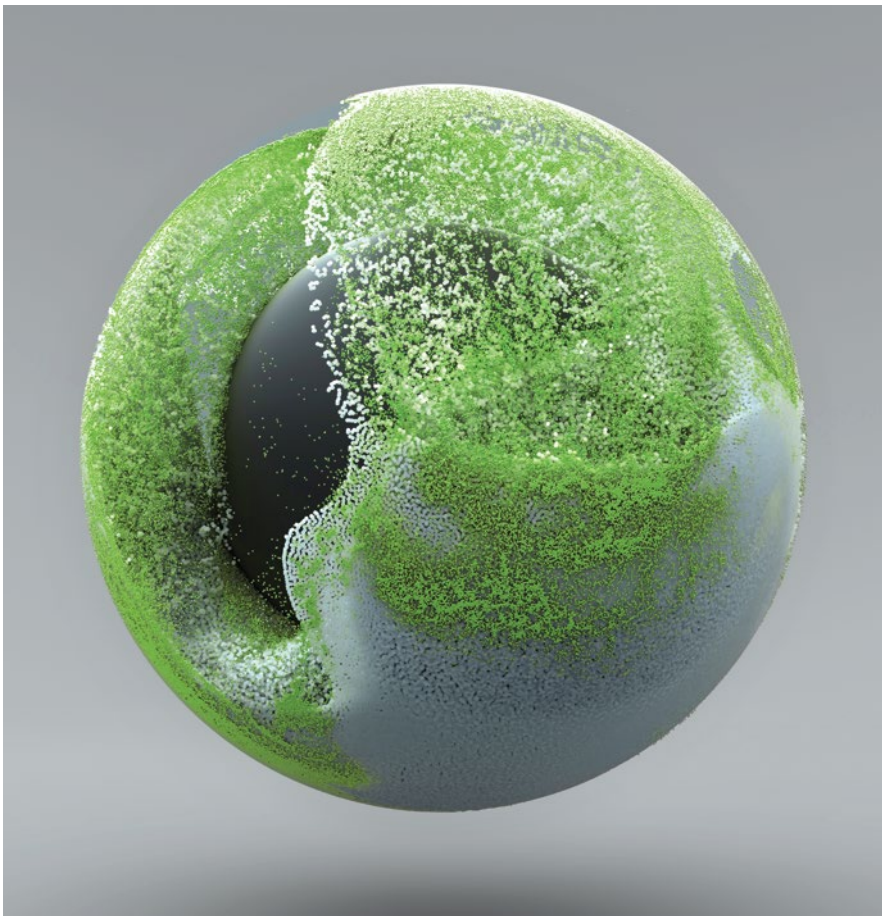
Most importantly, implementing this initiative will significantly reduce the cost of CCS technologies, increase their reliability and global acceptance and ensure a continued robust role for oil and gas well into the second half of this century, while providing clean energy sources (electricity and fuel) to the world's poor.

Recently, the Gulf countries have taken encouraging steps in this direction. The Kingdom of Saudi Arabia (KSA) and the United Arab Emirates (UAE) have adopted clear and well-considered energy-transition strategies.

As part of its Vision 2030, the KSA implemented major environmental initiatives and emission-reduction programs such as the "Green Saudi Arabia" and announced its commitment to becoming carbon neutral by 2060 and producing 50 percent of its electricity from renewable-energy sources by 2030.

On a similar path, the UAE nearly 15 years ago launched pioneering initiatives and implemented the construction of Masdar Clean Energy City, four nuclear power plants and several large solar power plants with total capacities of more than 2 GW.

But more investments and innovations are needed to make CCS and clean fossil fuel an important component of the future global clean-energy mix. The GCC countries and other low-cost oil producers have the most to gain if they do and the most to lose if they don't. ●



⊙ **LEFT:** Individual countries have their own views on how to go green in a post-carbon future.

PHOTOS: Shutterstock

Saving lives
WHILE HONORING RELIGIOUS BELIEFS

Habiba Al Safar is a winner of the International L'Oréal-UNESCO Fellowship for Women in Science.

Habiba Al Safar is an Emirati geneticist, biomedical engineer and academic at Khalifa University. For her, consent and patient privacy are paramount. Also vital is respecting cultures.

She gives the example of the age when a patient can give consent. In the U.S., it's 18. But in the UAE, where children frequently depend on their families longer, it's 21. "Always we talk to the guardians," she says.

> **I need to make sure everything complies with ethics.** - Habiba Al Safar

Katrina Bramstedt is a bioethicist specializing in organ donation, transplant and medical devices.

She's the former chief executive of the Luxembourg Agency for Research Integrity, and prior worked for the FDA, as well as Philips and the Cleveland Clinic.

An author of several books and over 100 peer-reviewed journal articles, Bramstedt is an international speaker and researcher.

DILEMMA: What would you say to the following? A biotechnology venture has created a life-saving "skin" for patients with severe burns. Cells used for this are derived from porcine sources. Patients and doctors from some communities might not want to use the product because of this, but assuming the product can't be changed, how could the company balance saving lives with honoring religious beliefs?

THE ETHICIST: In this situation there are two delicate matters in tension. Respecting culture and religious values is extremely important. Saving lives is another important value.

In some religions and cultures, pork consumption is prohibited. However, life-threatening situations change the context, and blanket prohibition is not the reality.

Consider the following: Skin is a vital organ serving as a protective barrier for the body, with a special immune function that helps fight infection.

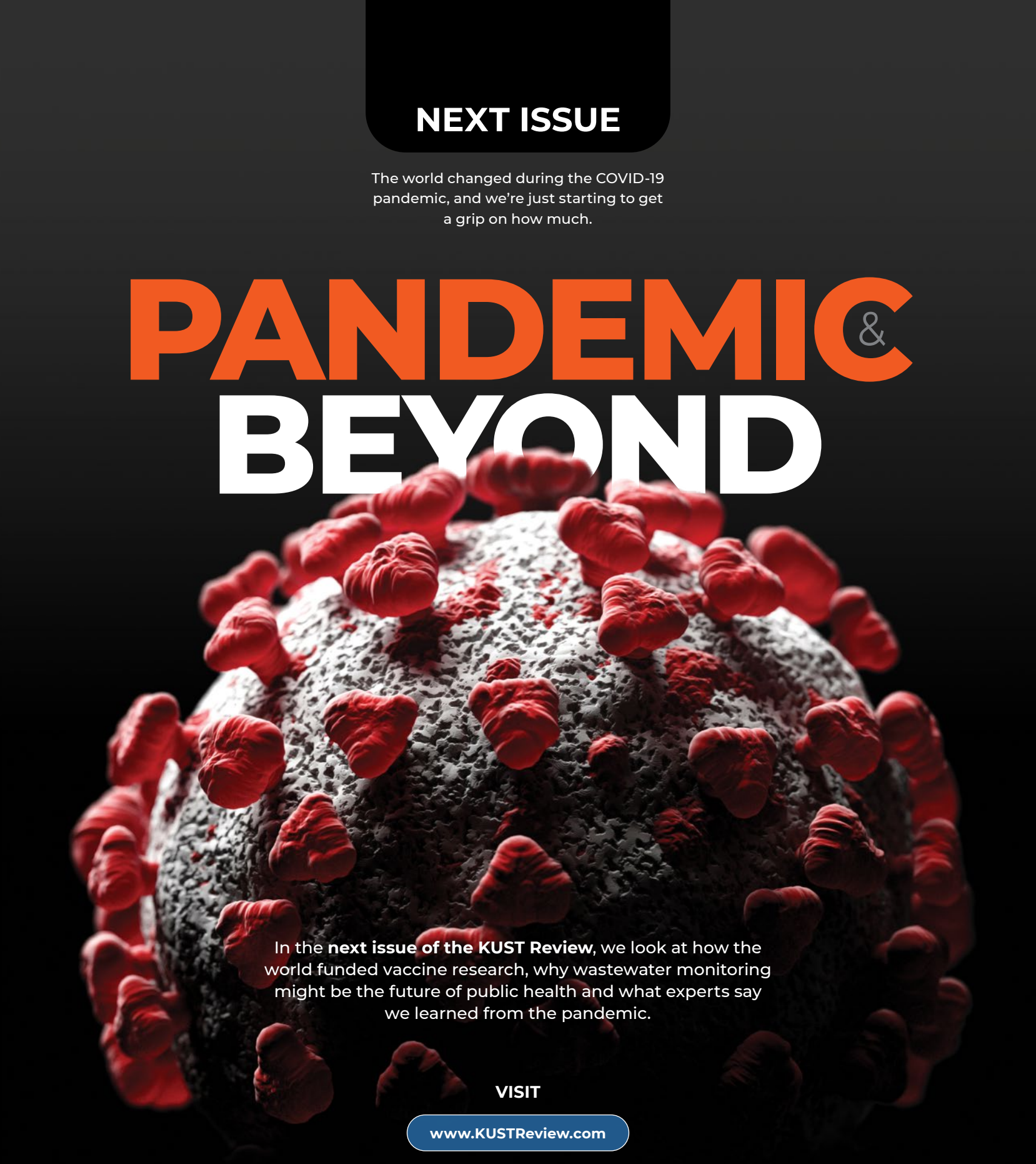
Loss of large amounts of skin is critical and patients are at risk of infection, dehydration and death. Often, there is a shortage of human donor skin, and other options are needed such bioengineered-skin technologies. Considering all of these facts, there may be religiously acceptable exceptions to the general rules against pork products.

Companies developing products with ethical sensitivity should consult with consumers as well as a bioethics expert. Additionally, they should create education materials to address ethical concerns, giving patients, families and physicians honest, detailed information about product use and alternatives.

NEXT ISSUE

The world changed during the COVID-19 pandemic, and we're just starting to get a grip on how much.

PANDEMIC & BEYOND



In the **next issue of the KUST Review**, we look at how the world funded vaccine research, why wastewater monitoring might be the future of public health and what experts say we learned from the pandemic.

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HOW MUCH WATER DOES IT TAKE TO PRODUCE THESE ITEMS?

Your water footprint is more than just the water you use to bathe and drink. It's also the amount of water consumed in the objects you use every day. **But how many 1-liter bottles would it take to produce these consumer goods?**

5.3 L
To produce a typical plastic single-use **water or soda bottle** [1]

132 L
To make a **cup of coffee**. **Tea**, however, requires just 27 liters [2]

140 L
To grow one **peach** [2]

155 L
To make a **300g French baguette**, 80% of which goes to wheat [2]

196 L
To produce one **60g egg** [2]

1,259 L
To make one **pizza margherita** [2]

1,900 L
To manufacture a **pair of jeans**, including water used to grow cotton [3]

4,325 L
To produce 1 kg of **chicken meat** [2]

15,415 L
To produce 1 kg of **beef meat** [2]

17,730 L
To build **a car**, over 50% of which goes for the tires alone [4]

PHOTO: Envato Elements, **SOURCES:** [1] foodprint.org [2] Waterfootprint.org [3] WSJ.com [4] USGS.gov