KAUST INSIGHT

THE STORY
BEHIND THE DISCOVERY

ISSUE 01

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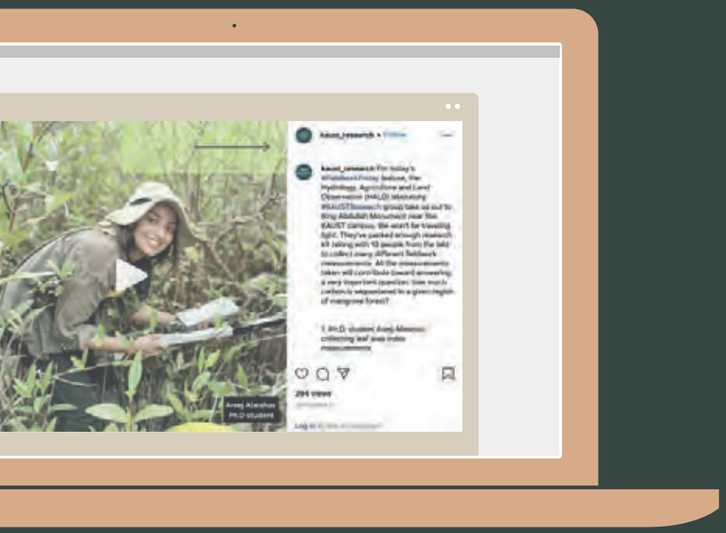
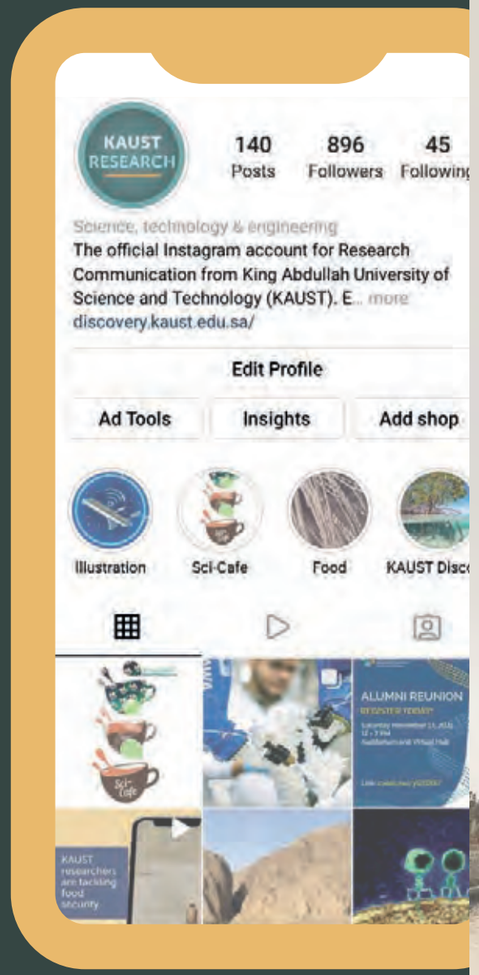
KAUST INSIGHT





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Dear Reader,

Welcome to the first issue of *KAUST Insight*, our new publication dedicated to revealing the stories behind KAUST's research discoveries. In this issue, we recount stories of unexpected collaborations, the inspiring pursuit of answers to global challenges and the, sometimes tortuous, paths to tackling difficult questions in fundamental research. These stories speak to the high quality of the education and research experience at KAUST by highlighting student successes and academic accomplishments, and the key role played by KAUST's world-class laboratory facilities.

While we support a wide diversity of research interests at KAUST, seven research focus areas — Smart Health, Climate Change and Livability, AI and Advanced Computing, Semiconductors, Sustainable Energy, The Red Sea and Nonmetallic Materials — have been chosen to guide our story selection. Where our stories directly address U.N. Sustainable Development Goals, in line with KAUST's sustainability initiative, we have also flagged them accordingly.

I hope you enjoy your journey through this first issue of *KAUST Insight* magazine and that it invigorates you with the same passion and motivation that inspires our researchers every day. Please visit insight.kaust.edu.sa to sign up for our bi-weekly email notification and to read our weekly stories.

Sincerely,
Professor Donal Bradley
Vice President for Research

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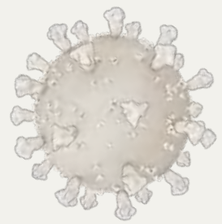

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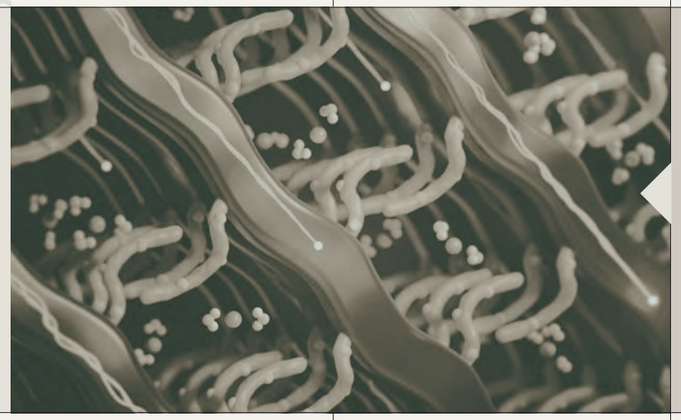

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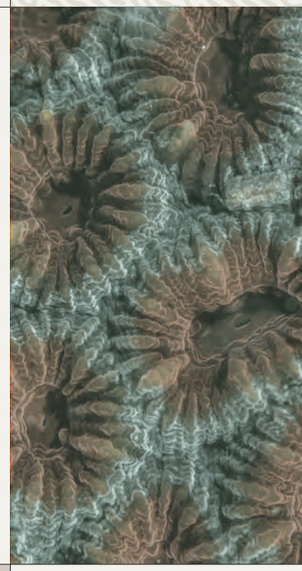

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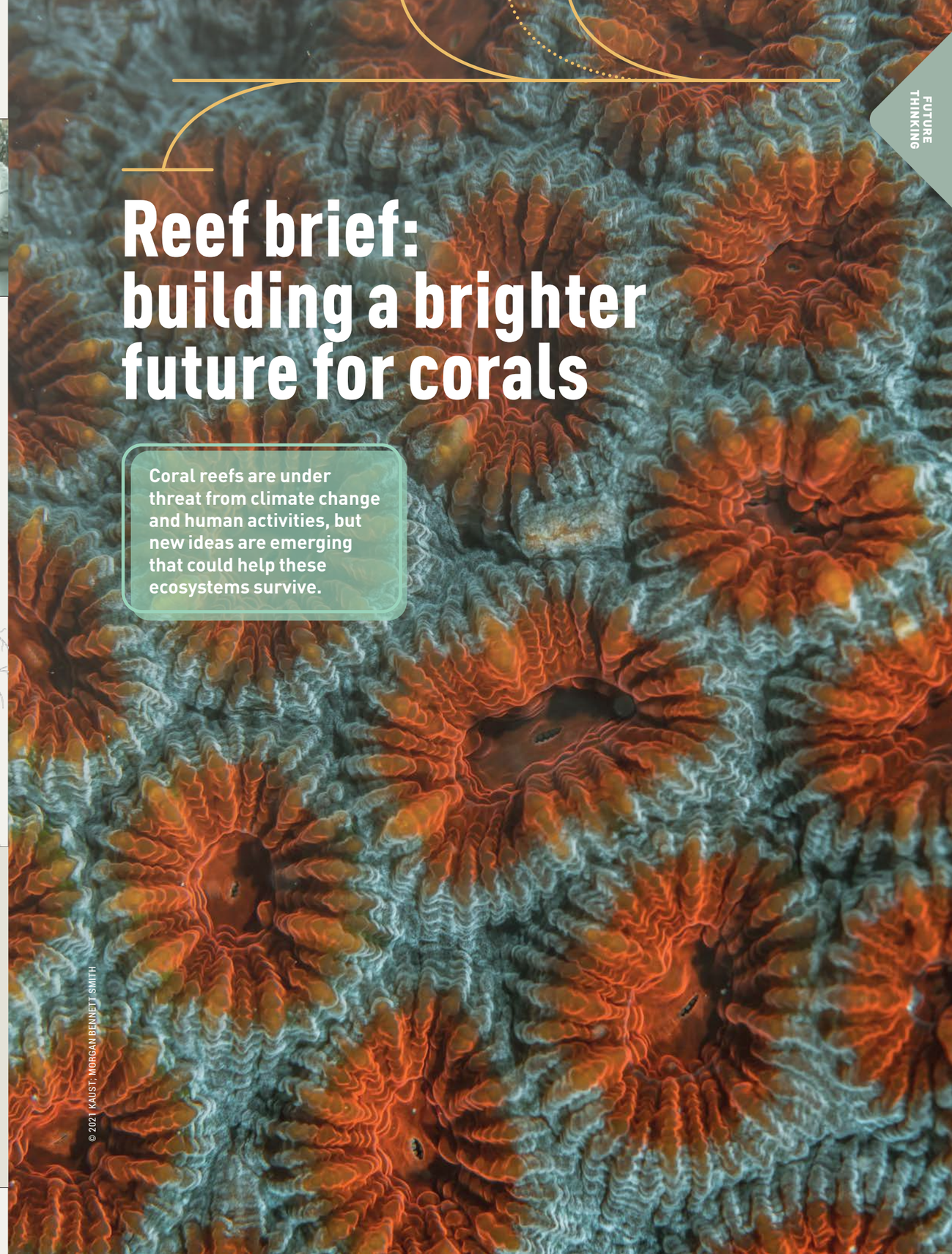


FUTURE THINKING

Reef brief: building a brighter future for corals

Coral reefs are under threat from climate change and human activities, but new ideas are emerging that could help these ecosystems survive.

Coral reefs exist in only a fraction of the world's oceans, and yet they are home to more than 25 percent of all marine organisms, making them rich biodiversity hotspots. They also support almost one billion people by providing services such as tourism, fisheries and coastal protection.

Despite their importance to both humans and biodiversity, coral reefs are rapidly disappearing as global temperatures rise due to climate change. The coral bleaching events of 2015-2018 alone affected 74 percent of global coral reefs.

"The window of opportunity to secure a future for coral reefs is rapidly closing, and no single nation has the capacity to reverse the situation," says Carlos Duarte, executive director of the new G20 Global Coral Reef R&D Accelerator Platform, a global program that aims to develop next-generation restoration solutions for the world's coral reefs. "We need to produce the next generation of science and technology to secure a future for them. That will require a program that brings the best minds together from different fields."

In August 2021, KAUST was appointed as the Platform Central Node (PCN) of the G20 Global Coral Reef R&D Accelerator Platform. The KAUST PCN will manage the program's funding, facilitate local and international collaborations, and identify research priorities to restore and protect the world's coral reefs.

In a race against time, KAUST researchers are drawing on their broad expertise to develop fresh approaches to help corals adapt to a fast-changing world and survive a warmer future.

"The window of opportunity to secure a future for coral reefs is rapidly closing, and no single nation has the capacity to reverse the situation."

"It's about producing offspring that have everything they need to be successful in the local environment while also increasing their resilience to be able to cope with what is coming."

Breeding resilience

Although corals have been adapting to environmental change for millions of years, they are struggling to keep pace with rapidly rising sea temperatures, says Manuel Aranda, a KAUST professor of marine science. "The temperature is increasing so fast that corals might not be able to naturally adapt," Aranda explains.

The solution to this problem lies in the coral genome. Aranda and his colleagues are identifying the genes that make certain coral colonies more heat tolerant than others. Through selective breeding, these resilient traits can be introduced to populations of less tolerant coral colonies to give them a better chance of survival under warmer temperatures.

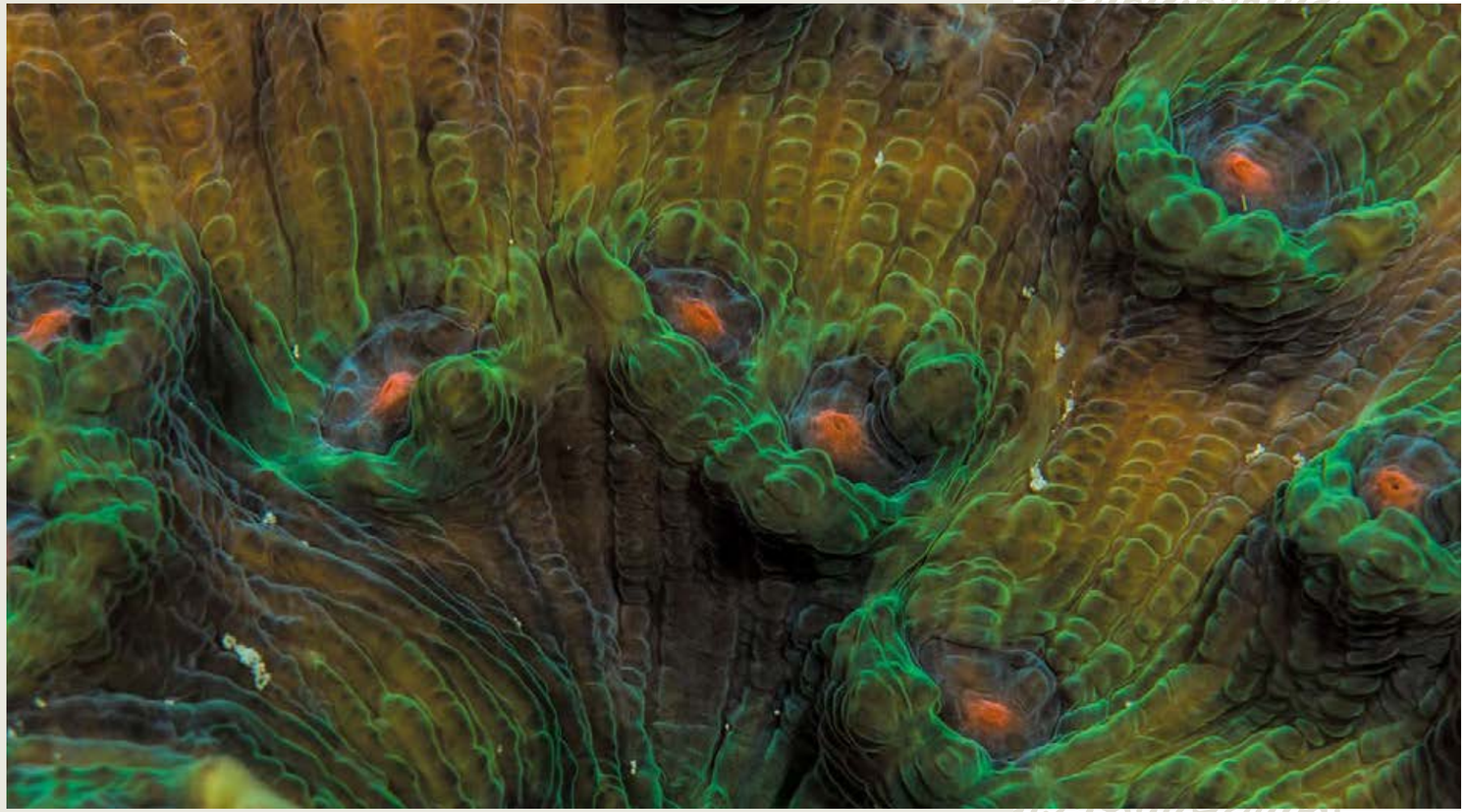
"It's about producing offspring that have everything they need to be successful in the local environment while also increasing their resilience to be able to cope with what is coming," says Aranda.

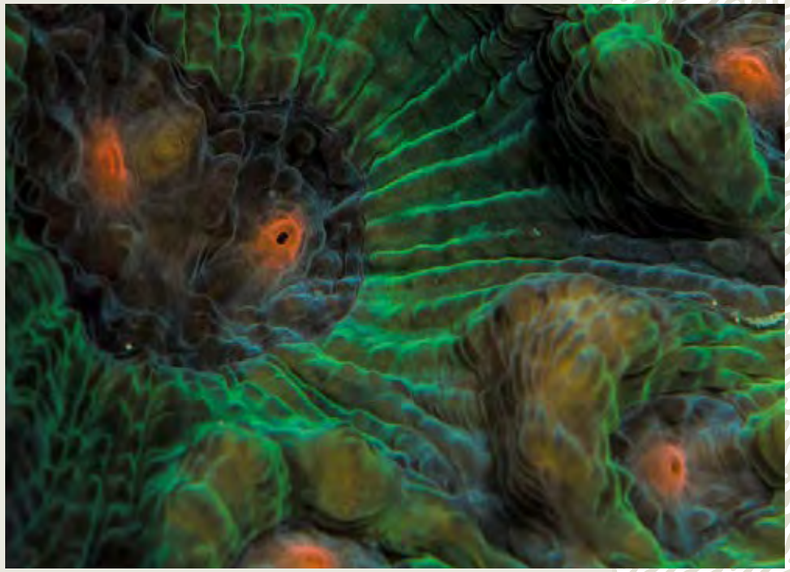
To explore this idea further, Aranda is co-leading a collaboration with KAUST and NEOM (a new planned sustainable city being developed in Saudi Arabia) to create the world's largest coral garden at Shushah Island in the Red Sea. The 100-hectare reef is set to be completed in 2025 and will provide a natural laboratory for testing and discovering the best restoration techniques.

The coral garden will be built and populated using KAUST Maritechture, a suite of restoration technologies designed by Aranda and Duarte with their colleagues. The process involves implanting corals onto 3D-printed skeletons coated with a material that accelerates their growth. The approach will make it possible to include slow-growing corals in restoration projects, which could lead to more diverse and balanced restored reefs down the track.

For Aranda's research on coral genetics, the coral garden will provide an environment where assisted evolution can be witnessed in action. Heat-tolerant corals will be planted alongside other types so that they can interbreed and produce offspring that can better withstand warming temperatures.

"By doing this over time, we can start increasing the number of resilient colonies in the natural population," says Aranda.





A microbial boost

Tapping into corals' natural adaptation ability to help them survive stress is also a key goal for Raquel Peixoto, a KAUST professor of marine science.

Peixoto and her team are developing probiotics that can help corals bounce back from heat stress and bleaching, an idea that was sparked by Peixoto's previous work that used probiotics to clean up oil spills in mangroves in Brazil.

In addition to symbiotic algae, corals have a beneficial relationship with other microbes, such as bacteria. When corals bleach under heat stress, they dispel their photosynthetic algae, causing their microbiome to be thrown out of balance.

Lab experiments led by Peixoto have shown that bleached corals bounce back to their original state quicker when treated with a potent cocktail of beneficial bacteria. Exposing corals to these microbes can also boost their immune system and guard them against pathogens and other negative impacts, such as pollution, Peixoto says. "It's about making these corals stronger and healthier so they can resist virtually any kind of impact."

In August 2021, Peixoto's team started testing out their probiotics on a selection of living *Pocillopora* corals in the Red Sea to find out how they can benefit the entire ecosystem and if they result in improvements that can be passed on to the next generation of corals.

While conserving the coral reefs of today underpins Peixoto's work, ensuring that they survive for future generations is the driving force behind her research.

"I really want my children to live in a world with coral reefs," says Peixoto. "If we are to expose coral reefs to huge impacts and challenges, let's help accelerate their natural adaptation."

A blend of disciplines

"These outstanding researchers and their innovative approaches exemplify the core values of the Red Sea Research Center," says Michael Berumen, professor of marine science and engineering and director of KAUST's Red Sea Research Center (RSRC). Berumen explains that cross-disciplinary methods are required to address the many challenges facing the marine environment around the world. "The RSRC has dedicated substantial effort to understanding and enhancing resilience of coral reefs. The value of maintaining healthy marine environments has never been more obvious, especially as a key pillar for many of Saudi Arabia's ambitious goals under Vision 2030."

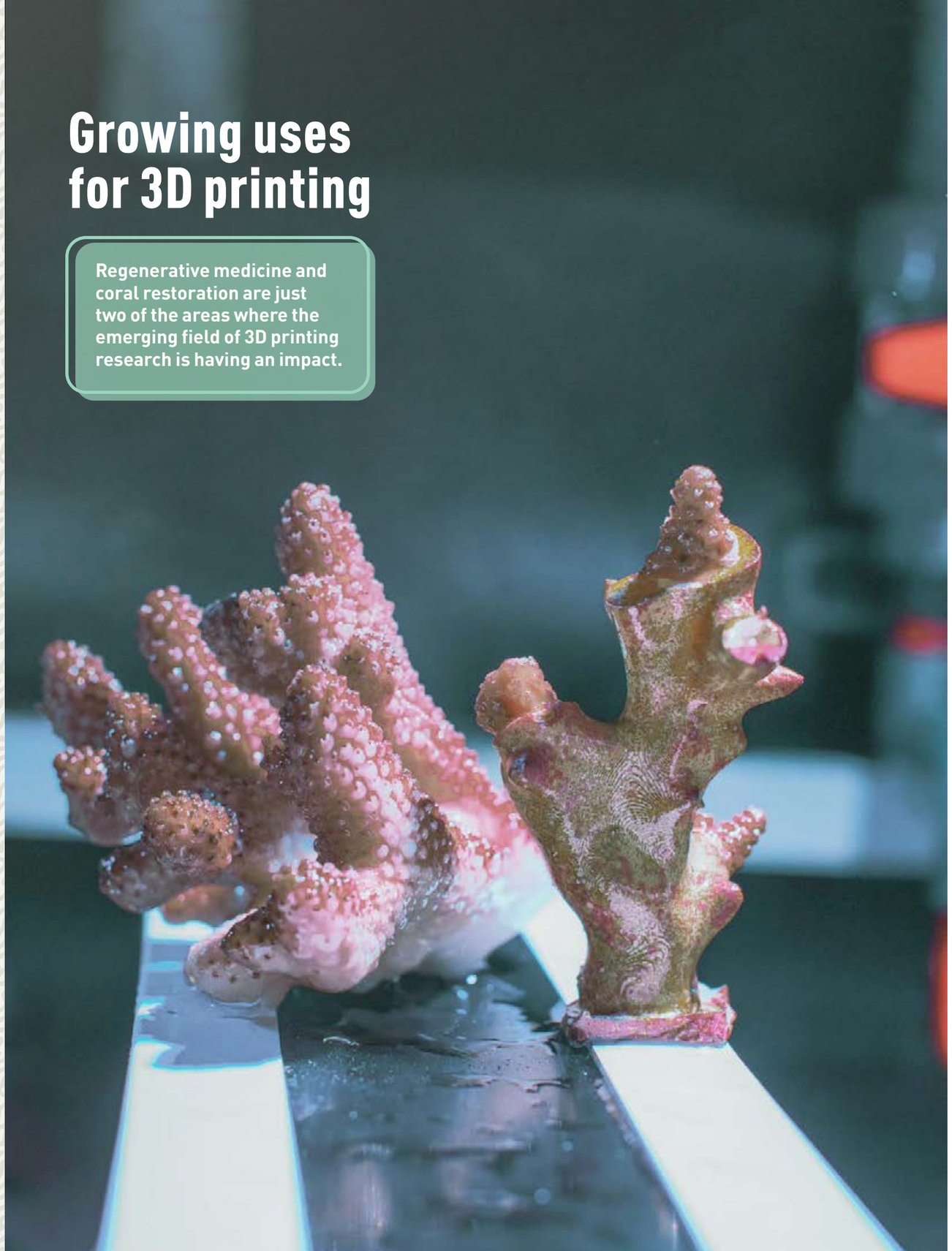
The researchers from the RSRC play key roles as knowledge partners and advisors to Saudi Arabia's giga projects, including NEOM and The Red Sea Development Company.

Berumen adds that Saudi Arabia is home to a major portion of the coral reefs in the Red Sea. "There are exciting opportunities for KAUST research to have regional and global impact in conservation of this critical natural resource."

"It's about making these corals stronger and healthier so they can resist virtually any kind of impact."

Growing uses for 3D printing

Regenerative medicine and coral restoration are just two of the areas where the emerging field of 3D printing research is having an impact.



Imagine going for an operation to replace your diseased trachea — the surgeons have a small printer in the operating theater and, using your own previously harvested cells, they print you a new windpipe and transplant it directly into your body.

Such a scenario could be realized within the next 5-10 years, according to KAUST bioengineer Charlotte Hauser, who works at the forefront of 3D bioprinting research.

"With all my materials, I'm trying to ensure that they are decomposable, sustainable and ecofriendly for a more biocompatible world."

The most innovative aspects of her research are the material she uses for the scaffold — the interlocking structure of the body part — and the robotic printer developed in her lab, which ensures extremely accurate and consistent results.

Bioprinting is used to create tissue, organs or other body structures in the presence of cells. The process requires a scaffold to mimic the structure of the target body part and a gel that contains the human cells or proteins to promote their growth. Unlike many groups who use nonnatural polymers that have no resemblance to natural fibers, Hauser has developed a biomimetic collagen that closely resembles human collagen, the body's connective tissue, to use as a scaffold for all kinds of grafting with tissues. She describes it as a natural synthetic material.

As well as the tracheal replacement project, Hauser and her team work closely with hospitals in Saudi Arabia for drug screening using models for certain diseases, such as colon cancer and leukemia.

By recreating a 3D structure of a tumor in the lab, they can screen to determine what drug or cocktail of drugs is most effective to reduce or even destroy the tumor.

Coral regeneration

3D printing also has environmental applications. Hauser and her team are collaborating on coral reef restoration with Carlos Duarte and other colleagues in KAUST's Red Sea Research Center. She is also involved in Saudi Arabia's NEOM coral restoration project, which will include the world's largest coral nursery.

Coral skeletons are made of calcium carbonate. Hauser's team has developed a calcium carbonate photo-initiated ink, which is a mixture of resin and calcium carbonate.

"The problem with other materials used as substrates, such as concrete and metals or even ceramic tiles, is that the substrate itself becomes waste," she explains. "With all my materials, I'm trying to ensure that they are decomposable, sustainable and ecofriendly for a more biocompatible world."

Her team is currently performing proof-of-concept studies with this material in seawater tanks. However, for large-scale reef restoration projects, they are printing silicone molds that are much quicker to print and will enable them to scale up the project.

Hauser says the main challenges lie in the technology itself and sourcing the materials, such as the customized bio inks and scaffold material, for example. For her, the goal is always to come as close to nature as possible in tissue engineering, in terms of devising the best biomaterials to use in scaffolds and learning how to grow organ-specific cells outside the body while keeping them alive.

She believes that the future lies with in-vivo printing, such as a printer in an operating theater that uses the patient's own cells and that is easy enough to use by surgeons. "The translation is already happening."

Protecting the date palm for future prosperity

Modern research and technology are being used at KAUST to protect this very ancient crop.

(From left) Vinicius Lube, Gwendolyn Kirschner, Yasha Zhang, Ting Ting Xiao, Abrar Deek and Ikram Blilou.

At least 8,000 years old, the date palm is so culturally and economically important to Saudi Arabia that it takes center stage on its national flag, representing growth, vitality and prosperity. Saudi Arabia is also one of the world's largest producers of date palms. Now, researchers at KAUST are working on preserving Saudi Arabia's coveted cultivars, improving their breeding protocols, understanding their biology and protecting them from disease and climate change.

"Saudi Arabia's vision for 2030 is a more sustainable country with more sustainable agriculture."

"Saudi Arabia's vision for 2030 is a more sustainable country with more sustainable agriculture," says plant scientist Rod Wing. "This involves reducing water uptake by crops, for example, and that requires learning their biology so we can select plants that can grow in extreme environments while using less resources. Another part involves education and outreach, and so KAUST is involved in training the next generation of plant scientists who will be stewards of the country's agriculture and environmental protection."

This is where the KAUST's Fast Fit Palms project comes in. Led by root developmental biologist Ikram Blilou, the project aims to establish a molecular toolbox that can be used for improving date palm growth and preserving elite local varieties. The Fast Fit Palms project is also establishing a breeding program that aims to find ways to improve date palm crop resilience in the face of challenging conditions. This work will establish a foundation of knowledge that can be carried forward by the next generation of researchers.

Boon Ooi (second from right) and his team created a sensor to filter out the munching noises made by weevil larvae in several trees at once.

It's a date!

Blilou's interest in date palms was ignited while eating a date in the Netherlands. At the time, she was an associate professor at the University of Utrecht. "I thought: I love dates, so why don't I study them? I tried to germinate the seeds; they germinated and, well, voila! The journey began."

What began as a weekend hobby in her university lab has since developed into award-winning research. In 2020, Blilou and colleagues won the United Arab Emirates' Khalifa International Award for Date Palm and Agricultural Innovation in the category of Distinguished Innovative Studies and Modern Technology.

The award was for a collaborative study between researchers at KAUST and in Mexico, England and China. Their work revealed a mechanism used by date palms to survive in dry environments whereby they stop growing until surrounding conditions become more favorable.

"Date palms undergo remote germination, which involves the plants making a structure that carries the seedling, and thus the baby plant, deep into the ground," explains Blilou. Embryo development is then paused within a growing and dividing structure called the cotyledonary petiole. When the soil conditions become favorable, development kicks in for the roots and shoots to separate and grow below and above ground.

"Date palms are also interesting because their roots don't only grow downwards, but also sideways and sometimes even upwards, maximizing water uptake from their surroundings," says Blilou. These research findings could help KAUST and breeders develop crops that are more adaptable to desert conditions.

"Dates will have great potential for future food security," adds Blilou. The precious fruit is rich in slowly digested sugar, and vitamins and minerals. The plant also offers many other uses. The trunks and leaves can be used as a building material and in textiles, and the seeds can be used to extract date palm oil and to produce cosmetics. Date palm milk can even be found in some supermarkets.

Battle of the beetle

For these productive trees to continue growing, they need to be protected from one of their most deadly enemies: the red palm weevil. These flying beetles feed on and lay their eggs inside date palms, and they have destroyed palm farms all over the world. Detecting the pests is expensive and tedious, and it is not always reliable. Past solutions have involved the use of sniffer dogs, inserting sensor probes into individual trees or even screening trees with computer-based tomography.

Boon Ooi, professor of photonics, brought to light a solution. He and his team previously developed a hair-thin optic fiber for optimizing oil production. They designed a tiny probe that can be deployed many kilometers underground through oil well downholes, which feeds back data to an algorithm-trained sensor to monitor fluid dynamics inside the piping. After hearing from a colleague about the weevil problem faced by local date palm farmers, Ooi got in touch with KAUST's vice president for research and said, "I think we have a solution to monitor many trees at once."

Ooi and his team then modified and trained their sensor to filter out the munching noises made by 12-day-old weevil larvae from other surrounding sounds. Their final product involves sending a laser pulse through a very long optical fiber that can be wound around many trees at once. The sound of weevil munching distorts the frequency of the light and sends this feedback to the sensor.

The team has tested their technology on Ministry of Water and Agriculture date palm farms dedicated to red palm weevil research in Al-Ahsa in eastern Saudi Arabia. It has also been tested on private farms.

"It's a rewarding project to work on," says Ooi. "A 60-year-old farmer on a private farm hugged us and shook our hands because he was so grateful for the technology. So many of his trees had been destroyed by this beetle."

The technology has grabbed the attention of many people worldwide. Ooi has been contacted by people in the U.S. and the Philippines, for example, about testing the technology for detecting similar pests that infect ash and maple trees, and also coconut palms.

The technology has been patented and a spin-off company is soon to be launched. In the meantime, Ooi and his colleagues are continuing to fine tune their sensor for use in the oil and gas industry, and in agriculture.

"We have to take care of the plant as an individual," says Blilou. KAUST's date palm research and collaborations are playing a vital role in preserving, protecting and breeding this important crop of the future.

"I thought: I love dates, so why don't I study them? I tried to germinate the seeds; they germinated and, well, voila! The journey began."

BRINGING CARBON RESOURCES BACK INTO BALANCE

KAUST's Circular Carbon Initiative (CCI) brings together many disciplines to fill an innovation gap and to support Saudi Arabia in its vision to achieve a circular carbon economy. Through the CCI, KAUST aims to change the carbon narrative to one of reduce, reuse, recycle and remove.

The CCI aims to create a strong and well-informed network of research, from developing clean-burning fuels to optimizing the performance of renewable energy technologies and from maximizing the oceans' storage of blue carbon to minimizing the energy input needed to drive industrial processes.
— Donal Bradley

Why do we need a CCI?

- Pragmatism is needed to address climate change. The CCI offers a framework that allows different countries to reach the objective of zero emissions through different paths and recognizes the value of carbon as a fuel and as a very important raw material.
  – Jorge Gascon
- It's really important for engineers, physical scientists and biologists to speak together about carbon dioxide — how it can be used or stored — because the scales that we work at are often very, very different.
  – Bill Roberts
- Decarbonization of the global economy will only be possible with subsurface solutions; anything else cannot, and will not, remove and store sufficient volumes of CO_2 timely and effectively. Saudi Arabia offers abundant opportunities for subsurface solutions. Clean energy export and CO_2 utilization are feasible, especially for Saudi Arabia, when enhanced by geothermal energy.
  – Thomas Finkbeiner
- The linearity of our current economy models needs to shift to circularity, where the wastes of one process or industry can be feedstocks for the next. The CCI creates an amazing narrative that engages stakeholders in all fields to look at this problem and find design solutions to bring our carbon resources back into balance.
  – Kyle J. Lauersen

What is your research in the CCI?

- We are finding efficient ways to utilize CO_2 (reuse) and develop new catalytic processes that result in lower emissions (reduce).
  – Jorge Gascon

DONAL BRADLEY
Vice President for Research

KYLE J. LAUERSEN
Professor, Bioengineering

- We are looking at what to do with CO_2 and then considering options across the entire value chain. First, we need to see how we can use CO_2 and then determine what the requirements are for a specific use, such as storage options or purity.
– Bill Roberts
- We are looking for geo- and subsurface solutions for the removal and storage of CO_2. Research on geothermal energy and energy storage for renewables is an integral part of this.
– Thomas Finkbeiner
- We use genetic engineering and bioprocess design to bioconvert CO_2 into valuable products (reuse) like medicines, biofuels, materials or clean water. For example, we can engineer microalgae to be light-driven green cell factories that convert waste carbon, such as CO_2, into tailored valuable bioproducts for consumers and industry.
– Kyle J. Lauersen
- My research evaluates and develops clean hydrogen technologies, which can be used to reduce carbon emissions. In addition, we are enabling the use of clean e-fuels, produced from recycled CO_2, in road and marine transportation.
— Mani Sarathy

What difference does the CCI make to your research?

- It gives us a helicopter view to show us that there isn't a single technology to address the whole climate change and emissions issue. It will be through very different technologies and nature-based solutions that we will manage to address this gigantic challenge.
– Jorge Gascon

> **It gives us a helicopter view to show us that there isn't a single technology to address the whole climate change and emissions issue.**
> JORGE GASCON

- It means I speak with a variety of industries that I don't usually talk to so I can really start to put together what I am going to do with the carbon once it is captured. That's really important because what you plan to do with carbon dictates the best way to capture it.
– Bill Roberts
- It brings into sharp focus the utilization aspect of CO_2 and carbon capture, utilization and storage. We have a clear vision for "utilization": it is the generation of zero-emission fuel + CO_2-based geothermal electricity.
– Thomas Finkbeiner
- It has kickstarted our efforts in bioprospecting new photosynthetic microbes from Saudi and the Red Sea. It also provides a valuable funding structure to support our efforts in exploring nature's treasure chest of undiscovered photosynthetic organisms.
– Kyle J. Lauersen
- It creates an environment where I can work with colleagues across KAUST to address challenges related to CCI technologies. The CCI enables interdisciplinary research between application-focused engineers, discovery-driven scientists and technology-enabling digital experts.
— Mani Sarathy

THOMAS FINKBEINER
Professor, Energy Resources and Petroleum Engineering

WILLIAM ROBERTS
Professor, Mechanical Engineering

MANI SARATHY
Professor, Chemical Engineering

JORGE GASCON
Professor, Chemical Engineering

SHAPING A NEW FUTURE

As Saudi Arabia charts a new future, one professor is challenging bright young minds to think how that future could be.

Saudi Arabia's plans for the next decade or so are reflected in its Vision 2030 program, which highlights the government's goal to move away from its dependence on oil and petroleum products toward more renewable sources of power. It also comes with a mix of attempts to develop better agriculture and education and more efficient healthcare, among other priorities.

Chemical engineer and physicist Tadeusz Patzek is renowned for his highly sophisticated expertise, such as his research on the complex recovery of oil and gas from geological formations called shales. However, Patzek readily rebuffs such acclaim. "I am a scientist expected to provide technological fixes for problems that can never be solved with technology alone."

Born and raised in Poland, Patzek says his love of nature has never changed. "The only thing that has changed is the painful recognition of the extent of destruction we have inflicted on the planet. Now nature is hitting back with climate change," Patzek adds. His research has shown the Arabian Peninsula is heating up at twice the global rate of temperature increases.

Patzek is working hard — through lectures, papers and a blog — to guide other people to think about environmental problems more seriously. He says the biggest issue is the rapidly growing global population. While he routinely advises on solutions, such as wastewater treatment and the introduction of new building and air-conditioning codes needed for an ever-increasing population, he also has concerns. "Things won't be managed effectively unless people disregard their customs and change mindsets toward 'degrowth,'" he says.

What does give him hope for the future is his current research working with young minds through graduate programs at KAUST. "My biggest contribution here is the introduction of a course on earth, environment, energy and economy. Generations behind me will understand what's going to happen and how they can change the ways that humanity acts."

Reflecting on Patzek's course, Ph.D. student Philip Mitchell suggests an important lesson is to be skeptical of technology. "Sometimes as scientists and engineers, we are easily enamored with the latest technology but fail to take into account the scalability and negative externalities of new technology."

"The course has broadened my view of how scientists can contribute to the common good. With the growth-oriented economic paradigm collapsing, we need generalists well versed in thermodynamics and ecology to help communities and governments design sustainable replacements," Mitchell says.

Cooling houses without heating the planet

Houses on the KAUST campus will trial an air conditioner that uses less energy.

In this new system, the proprietary adsorbent coats the coils of a mechanical vapor compressor, which cools the air that the adsorbent has dehumidified in the manner of a conventional AC system. Airflow through the system is periodically reversed to cyclically regenerate the saturated adsorbent.

A new air-cooling system, which offers a dramatic efficiency increase over existing air conditioning systems, is being piloted at KAUST to see how it behaves under weather conditions in Saudi Arabia.

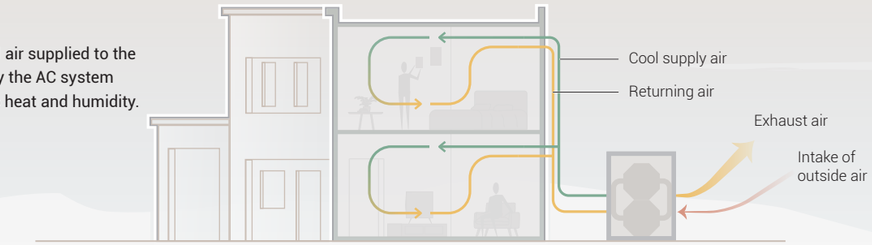
Air conditioning systems in use today typically achieve only 35–40 percent of the cooling possible for the amount of electricity they consume. As well as their principal task of cooling air, they also remove moisture from the air by lowering its temperature to the level at which the water in it condenses. This double step wastes a lot of energy.

A team led by Kim Choon Ng has now devised a way to reduce the amount of energy consumed by decoupling the two processes. Instead of dehumidifying air by cooling it, the system uses a more efficient process called adsorption. This binds the water in the air to the surface of a specially developed nanomaterial. Made of calcium chloride salt embedded in a silica gel lattice, this material can adsorb up to 20 times as much water as conventional silica gel in proportion to its weight.

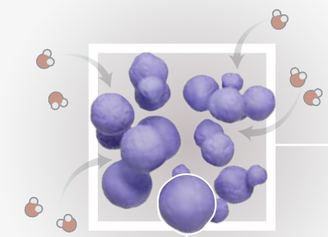
Ng is now testing prototypes, and findings to date show an improvement in efficiency of 30–60 percent over conventional air conditioners. "This new type of air conditioner could offer a much-needed means to slow down the increasing contribution of cooling systems to climate change," says Ng.

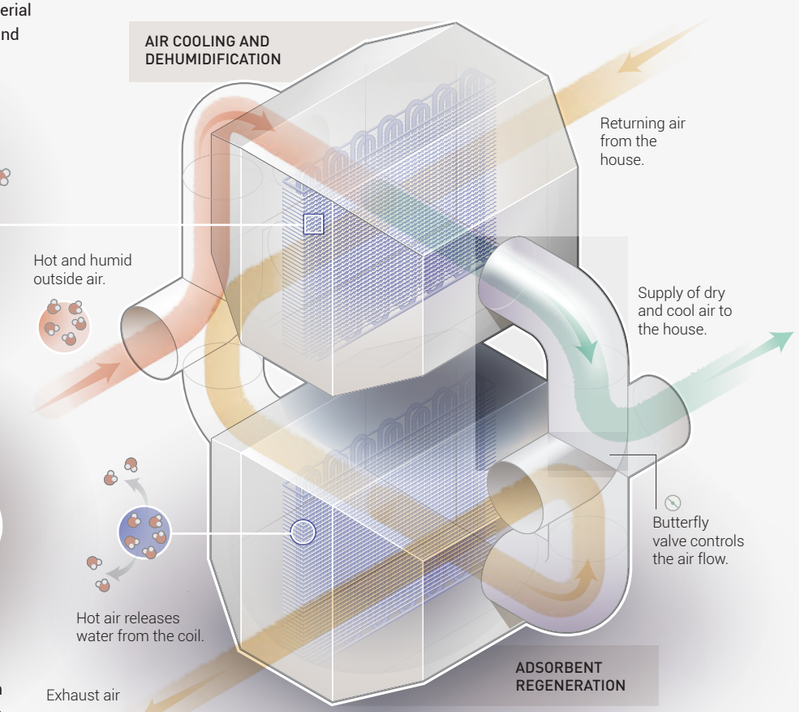
Global consumption of air conditioning electricity, mainly generated from burning fossil fuels, has risen from 600 TWh in 1990 to 2,200 TWh in 2020, and based on current trends, could reach 6,300 TWh by 2050. By then, half of all electricity used by the world's hottest countries, including Saudi Arabia, would be used just for keeping people cool.

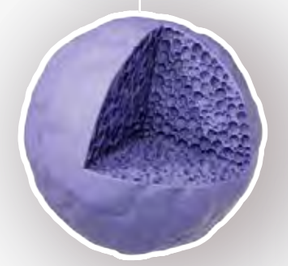
The cool air supplied to the house by the AC system takes up heat and humidity.



Coating the cooling coils with material that adsorbs water dehumidifies and cools the air flow simultaneously.



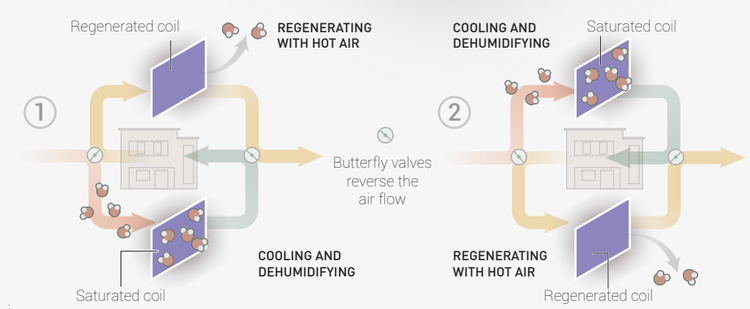




The coating material is made from calcium-chloride-embedded silica gel spheres.

A CYCLICAL TWO-STEP PROCESS

In the cooling and dehumidification stage, when the maximum capacity of the coil to adsorb water is reached, the air is reversed. This pushes hot outdoor air through the saturated coil and regenerates it. Meanwhile, the other regenerated coil takes over and provides cool air to the house.



ART AND DESIGN: XAVIER PITA

Poop culture helps address global challenges

Sampling feces seems an unglamorous way to tackle global challenges, but for one KAUST researcher, it helped to address two very contemporary crises: water security and the COVID-19 pandemic.

Water scarcity is a significant global threat that will be further exacerbated by climate change. One solution, suggests microbiologist Peiying Hong, is the reuse of high-quality treated wastewater, which can have uses from domestic consumption to irrigation for crops or landscaping.

"Desalination has helped Saudi Arabia and many other dry, arid countries in the region to achieve national water security," explains Hong, "but the treatment of our wastewater — which should not really be viewed as "waste" water — can also help our water security."

There are treatment options that can clean wastewater to a level that is even purer than our surface water or groundwater, says Hong. "Technologies like membrane separation processes that use reverse osmosis membranes can basically strip out almost everything in the wastewater except for the water molecules. The treated wastewater can then be reused again, even for drinking water purposes."

Hong's interest in wastewater began during her Ph.D. in Singapore. "Working with fecal samples from animals and humans, I learned the fascinating insights fecal microorganisms provide about host health," says Hong, "Over the years, I worked with a variety of fecal material, which is what most wastewater is basically made up of."

> "I always try to look into wastewater like a detective."

Hong's research team focuses on improving processes for the reuse of wastewater. "We develop technologies that are able to clean wastewater in a very energy efficient manner so that we can achieve high-quality wastewater in a sustainable way," Hong explains. "We also study emerging microbial contaminants that might be present in wastewater and look to technologies to remove those contaminants to ensure the water is safe for reuse."

When the COVID-19 pandemic arose, Hong's research on wastewater pivoted to understand this new health threat. Her team had already been sampling urban wastewater throughout the years to see what microbial lessons emerged. "I always try to look into wastewater like a detective. I try to understand what type of microbial contaminants in terms of bacteria and viruses may be present. Then, potentially, we can help predict the next public health outbreak that might happen within the community," she says.

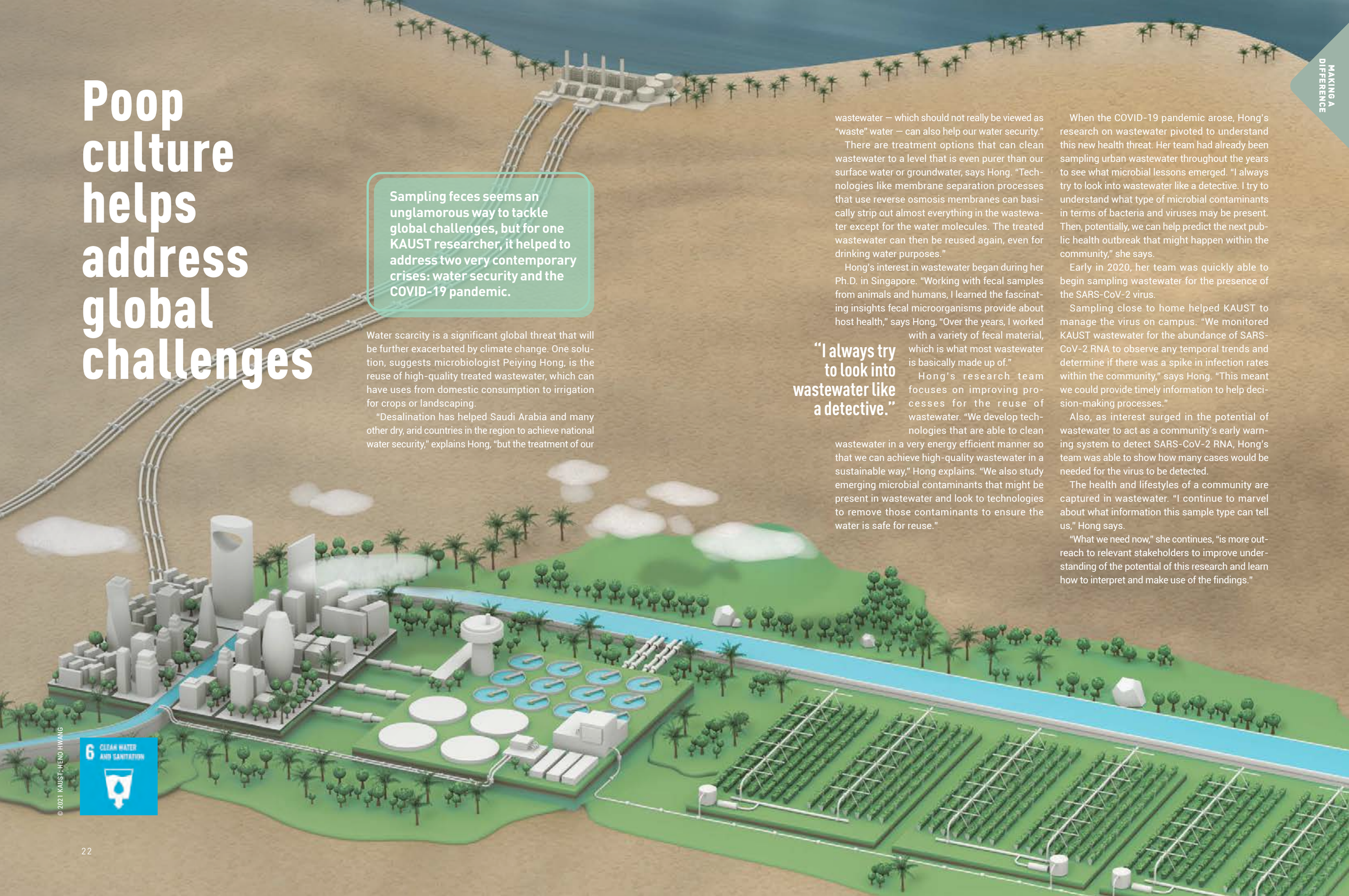
Early in 2020, her team was quickly able to begin sampling wastewater for the presence of the SARS-CoV-2 virus.

Sampling close to home helped KAUST to manage the virus on campus. "We monitored KAUST wastewater for the abundance of SARS-CoV-2 RNA to observe any temporal trends and determine if there was a spike in infection rates within the community," says Hong. "This meant we could provide timely information to help decision-making processes."

Also, as interest surged in the potential of wastewater to act as a community's early warning system to detect SARS-CoV-2 RNA, Hong's team was able to show how many cases would be needed for the virus to be detected.

The health and lifestyles of a community are captured in wastewater. "I continue to marvel about what information this sample type can tell us," Hong says.

"What we need now," she continues, "is more outreach to relevant stakeholders to improve understanding of the potential of this research and learn how to interpret and make use of the findings."



6 CLEAN WATER AND SANITATION

LEARNING FROM A CRISIS

When the SARS-CoV-2 virus began to spread across the globe, researchers from KAUST rapidly mobilized into teams to confront the challenge, often with support from other hospitals and universities in Saudi Arabia. They reflect on their experiences.

What were your significant findings?

Learning about the virus

- We analyzed genome sequences, and their mutations, from virus samples collected across five cities in Saudi Arabia to identify patterns of the virus lineages being imported into the country.
  – Arnab Pain
- Most scientific focus has been on the spike protein of the virus; our team showed that changes in the nucleocapsid protein are also important for determining the outcome of the virus-host interplay.
  – Arnab Pain

Detecting the virus

- Our work was the world's first published fully automatic AI method to extract visual features of chest CT scans of lungs affected by COVID-19. Our method can segment out the infection lesions and quantify their volume. This helps clinicians with treatment and prognosis of the disease.
  — Xin Gao
- We showed that, for tracking SARS-CoV-2 RNA in wastewater, the detection sensitivity is around 250 infected people per 10,000. Therefore, by the time RNA from the virus is detectable in wastewater, there may already be a significant outbreak in the sampled community.
  – Peiying Hong

> **KAUST community members showed great social responsibility to control this pandemic within the community.**
>
> PEIYING HONG

- In collaboration with Prof. Arold's team, we built a tiny electronic chip that can detect the virus in a saliva sample or nasal swab, with a sample-to-result time of about 10 minutes.
  – Sahika Inal
- The next-generation device that we developed with Prof. Inal's team combines the sensitivity of a PCR test with the speed of lateral flow tests.
  – Stefan Arold
- We developed a one-step RT-PCR kit for diagnosing COVID-19 that directly detects the SARS-CoV-2 virus. Our kit, which is on par with the best commercial kits produced in the U.S. and Europe, is unique because it is assembled entirely in-house and is cheap to produce. It will also be much faster to deliver to the regional market because it is produced in the country.
  — Samir Hamdan

> **Collaborators from various hospitals responded to my call to form a consortium of researchers to work together to sequence and analyze the genomes for molecular tracking of the virus.**
>
> ARNAB PAIN

Supporting the health system

- We quickly mobilized to support Saudi Arabia's manufacturing companies with design, engineering, rapid product development and agile manufacturing of compliant ventilators with our main partner the Olayan Group. One of our significant findings was the complex and intricate technical requirements required by a ventilator to support and monitor patient lungs during both the inhalation and expiration stages.
  — Barry Hogan

What helped your success?

Building on existing relationships allowed for a rapid response

- Our team works with a large number of clinicians and scientists from several healthcare institutions nationwide. Collaborators from various hospitals responded to my call to form a consortium of researchers to work together to sequence and analyze the genomes for molecular tracking of the virus.
  – Arnab Pain
- Strict regulations meant getting patient samples to KAUST was a huge challenge in the beginning, but colleagues in King Faisal Specialist Hospital and Research Center in Riyadh came to our aid and invited us to use their laboratories so we could gain access to patient samples.
  – Sahika Inal
- Ironically, a key problem at the time was accessing sufficient samples from COVID-19-infected individuals. Despite great help from KAUST's health clinic, there just weren't enough infected people at KAUST. The only solution was to pack our equipment into a car and have three members of our team drive to King Faisal Specialist Hospital and Research Center in Riyadh to measure the samples they had there.
  – Stefan Arold

Working across disciplines helps enrich understanding

- We have a gap in our toolbox for disease diagnostics, which is a huge obstacle during pandemics. This gap can only be overcome if engineers like myself work with biologists and clinicians.
  – Sahika Inal

Making it real

- Even pre-COVID, our team was surveying wastewater, but often people didn't understand why we studied wastewater. With COVID, it became easier to explain that wastewater can provide a lot more information.
  – Peiying Hong

SAMIR HAMDAN
Professor, Bioscience

STEFAN AROLD
Professor, Bioscience

BARRY HOGAN
Facilities Director of Marine, Fabrication and Maintenance CoreLabs

What did you learn about your team?

Supporting each other in tough times

- Our team is very resilient. Extreme attention to detail was required to ensure the safe environment necessary for carrying out validation studies of our device using real samples of the virus. We worked day and night to make the project work and supported and cared for one another in a way that I have never seen before in any team. The pandemic brought us closer together.
  – Sahika Inal
- To minimize the number of labs open during the COVID lockdown, we hosted Prof. Inal's team in our lab space. We were probably the only researchers working on the entire campus at that time. The resulting isolation, focus and daily informal exchanges between team members were key to successfully combining our technologies and fields of research in such a short time.
  – Stefan Arold

Achieving mission impossible became possible

- Usually, projects of this kind take 4-12 months to develop. We formed a taskforce that included four of my students and myself, and we built the model, optimized the code, conducted the experiments and wrote the paper all in just 12 days. Mission impossible became mission accomplished!
  — Xin Gao

> **Mission impossible became mission accomplished!**
>
> XIN GAO

- We discovered how quickly people can mobilize and bond if the purpose and meaning are strong and well understood. Many people of different backgrounds and disciplines willingly came together, with great passion and energy, once there was a humanitarian benefit as the end goal. We learned a lot of new things about each other, such as the hidden talents we have, and we realized how natural leaders and strong team players emerge when the moment requires it.
  — Barry Hogan

Making an impact was motivating

- Making an impact is an important motivating force. Our team was really committed and motivated, especially when they saw firsthand how the information we generated was helping relevant stakeholders to devise appropriate responses or interventions.
  – Peiying Hong

Persisting paid off

- During the height of the pandemic, getting the reagents, consumables and some equipment delivered on time was challenging. With everyone's perseverance, we overcame the logistical issues as we actively tried to collect our samples, despite the travel restrictions that were imposed on us. We all worked extremely long hours to overcome these challenges.
  – Arnab Pain

Following through to market

- Until now, my translational research activities have been focused mainly at the discovery phase. Developing the one-step RT-PCR kit was my first experience of developing from the discovery phase all the way to a final product. While this experience was very enjoyable, it was also stressful because we had to go beyond the discovery in the lab to generate a product that would work and compete in the market. I learned that translational research activities can be really fulfilling, and I am really looking forward to expanding future research in this direction.
  – Samir Hamdan

What did KAUST do well?

Forming a valued and dedicated team

- Our president, Tony Chan, formed a Rapid Research Response Team (R3T), which contributed greatly to fighting the pandemic. I'm very proud to be a part of it.
  – Xin Gao
- I feel very privileged to have the opportunity to contribute to the fight to combat COVID-19.
  — Samir Hamdan
- The R3T program allowed several laboratories working on COVID-19 to function during the entire pandemic. This initiative helped to support COVID-19 research immensely in the hour of national need.
  – Arnab Pain
- Seeing how KAUST supported researchers from different disciplinary backgrounds and expertise working toward a common goal was very rewarding.
  – Peiying Hong
- The call for our faculty and KAUST's Core Labs to contribute their capabilities through the R3T efforts showed real depth and breadth, and resulted in very quick and impactful solutions. Some of these continue today through novel healthcare innovations adopted by our industry partners for use across the country. It shows we can deliver quickly when we are empowered.
  — Barry Hogan

Making the KAUST campus safe

- Members of the KC3 (KAUST COVID-19 Crisis Center) worked tirelessly throughout this period to formulate the right strategies under the dynamic and unpredictable pandemic situation. KC3 kept us well informed on the developments and shared their strategies to keep the campus under an operational safety net.
  – Arnab Pain
- KAUST acted quickly to keep the pandemic under control across the campus. The restrictions were all necessary, and our leadership communicated the rules to the community in a transparent way.
  – Sahika Inal
- KAUST community members showed great social responsibility to control this pandemic within the community.
  – Peiying Hong

> **The call for our faculty and central labs to contribute capabilities to the R3T team showed real depth and breadth and contributed to very quick and impactful COVID-19 solutions.**
>
> BARRY HOGAN

- We achieved full vaccination on campus at an extremely fast rate — perhaps one of the few university campuses in the world to achieve this goal.
  – Arnab Pain
- KAUST's approach was well balanced, constantly adjusting measures according to the latest scientific knowledge, local situation and nationwide directives. This approach allowed us to open relatively quickly after the lockdown and remain open, thanks to the hard work of all those involved.
  – Stefan Arold

PEIYING HONG
Associate Professor, Environmental Science and Engineering

SAHIKA INAL
Associate Professor, Bioengineering

ARNAB PAIN
Professor, Bioscience

XIN GAO
Professor, Computer Science

Salim Al-Babili and his team are using genetic and hormone-based approaches to control weeds such as purple witchweed from ravishing crops in sub-Saharan Africa.

2 ZERO HUNGER

Improving global food security by controlling a persistent weed

The challenges of food production and global food security require a long-term, multipronged approach.

In efforts to improve local farmers' yields and improve regional food security, a large project in Burkino Faso and Niger is using genetic and hormone-based approaches to control a persistent weed invading cereal crops.

Professor of plant science Salim Al-Babili is leading a project, funded by the Bill and Melinda Gates Foundation and KAUST, to prevent infestations of purple witchweed (*Striga hermonthica*).

Purple witchweed is an invasive parasitic plant that infests cereal crops, particularly in Africa where it causes annual losses exceeding US$7 billion. The weeds survive by siphoning off water and nutrients from host crops, such as pearl millet.

The ambitious project involves collaborations with experts in chemistry, structural biology, bioinformatics, agronomy and weed science, genetics, and pearl millet breeding from KAUST, Japan, the Netherlands, Burkina Faso and Niger, in addition to an industrial partner, UPL.

Along with his collaborators, Al-Babili is using his knowledge of plant hormone biosynthesis to develop strategies to interrupt the interaction between the parasitic plant and its host, and to identify genetic factors that can help increase the resistance of pearl millet to *Striga*.

"We are trying to solve the huge problem of the accumulated seed bank of *Striga* in the soil. One plant can produce up to 200,000 seeds and these seeds can remain viable in the soil for up to 10 years," says Al-Babili.

He says the challenges of leading and coordinating a project of this scale have been magnified during the pandemic.

The project spans the whole R&D process, from discovery work in the lab, to small greenhouse and mini-field experiments, to larger trials in fields of small-holder farmers.

"We have established a pipeline starting with developing and synthesizing hormone-based compounds with our partner at the University of Tokyo, and involving several biological tests at KAUST, and then in farmers' fields in sub-Saharan Africa," says Al-Babili.

"Developing scientific solutions for real-world problems requires intensive research in basic science. Once you have something in your hands that can be translated, you need to take a risk and, of course, you need reliable partners with complementary expertise.

"I'm quite optimistic. The field trials with farmers look promising and now we have an industrial partner to improve the formulation, application protocol, etc."

Al-Babili says major challenges for farmers in the region are the very poor infrastructure and infertile soils. They rely on local varieties, which are adapted to the conditions, but in many cases are not very productive.

On top of this, they face the challenges of climate change, higher temperatures and more frequent drought conditions.

He adds that, like many scientists, his dream is to see that what he is doing in the lab is also beneficial to humanity.

"Addressing huge challenges is what motivates me. It is very satisfying to publish papers and to solve scientific questions, but the satisfaction you gain when you see that your work is helping to solve a major global challenge is quite extraordinary."

LIGHT REFLECTIONS

From the first experiments that shed light on the photovoltaic effect to the most efficient and economic devices now available, KAUST scientists are proud to contribute to this fascinating field of research.

1839

French physicist Edmond Becquerel discovered the photovoltaic effect when he created an electrolyte cell that generated electricity when exposed to light.

1883

American inventor Charles Fritts invented the world's first solar cell with 1% efficiency. His simple design comprised selenium on a thin layer of gold.

1954

The world's first silicon photovoltaic cell was developed at Bell Labs in the U.S. The cell could convert enough of the sun's energy to power everyday electrical appliances. The solar cell had 4% efficiency.

1980s

Widespread adoption of solar cells was limited by semiconductor technology. The standard first-generation cells required large volumes of monocrystalline silicon, which was very expensive, limiting solar technology to niche applications and research only.

1990s

Major breakthroughs in solar technology, mainly in the type of semiconductor, rekindled interest in photovoltaics as a viable renewable energy source. Second-generation photovoltaics replaced the bulky expensive monocrystalline semiconductors. Amorphous semiconductors power small electronic appliances, like calculators. Polycrystalline silicon reduced manufacturing costs and became the benchmark technology for the next 20 years.

1992

The 15% barrier was broken with a 15.9% efficient thin-film photovoltaic cell made of cadmium telluride.

1995

Third-generation solar cells emerged — tandems or multijunctions — that used multiple semiconductors to maximize light absorption. They achieved unprecedented efficiency but remained prohibitively expensive for large-scale manufacture. Their use was limited to novel uses like space exploration technology.

1999

Global capacity of all installed photovoltaic devices reached 1 gigawatt.

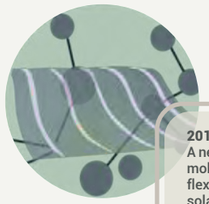
2000s

Organic solar cells. New materials such as semiconducting polymers enabled a new type of flexible and lightweight solar cell. These cells helped to expand the use of solar energy to new applications using carbon-based materials.

2015, BAKR: An easier way to obtain large crystals to fabricate solar cells.

2010s

Manufacturing costs of silicon solar cells began to fall. Public investment and subsidies meant that silicon solar technology took over both the residential and utility market. The conversion efficiency almost doubled through new technologies, materials and processes. Chinese expansion of the manufacture of silicon photovoltaic modules reduced power costs to US$1.25 per watt. New alternative solar technologies emerged — organic photovoltaics and perovskite solar cells.



2016, MCCULLOCH: A new class of molecule to produce flexible polymeric solar cells in a greener and simpler way.

2012

Perovskite solar cells became contenders to standard silicon-based solar cells. Being cheaper and easier to manufacture, they were commercially attractive but still limited by their short- and long-term stability.

2018, BARAN: Irys — a startup focused on semitransparent polymeric solar cells as windows for greenhouses.

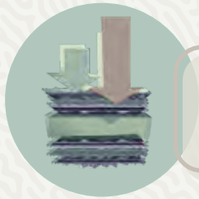
2019

A new world record for solar cell efficiency was set with 47.1% efficiency using a multijunction concentrator silicon solar cell. This type of cell was too expensive for commercial use but indicated the potential of solar cell technology.

2019, ANTHOPOULOS: An inexpensive 2D semiconductor coating to improve performance of polymeric solar cells.

2021

Perovskite and organic solar cell efficiency increased. In 2021, perovskite solar cells achieved efficiencies as high as 25.5%, while organic solar cells achieved >18%. In parallel, tandem solar cell technology reached a power conversion of 29.5%.



2020, DE WOLF: A tandem solar cell that combines the efficiency of silicon and perovskites.

TODAY

Boosting perovskite solar cell stability and long-term reliability while increasing efficiency is still the main research focus. KAUST researchers are developing perovskite/silicon tandem solar cells to combine the benefits of both solar cells and maximize the amount of power generation possible from the sun's energy.

Source: Michele De Bastiani and Daniel Corzo

COLLABORATIONS HELP ALL STARS TO SHINE

In modern science, collaboration is the grist to the mill – but successful collaborations shouldn't feel like a grind! Collaborations tend to work best with dedicated time and resources to develop relational capital, which includes intangible values such as trust, norms, obligations, expectations and identity. KAUST values collaboration highly, which is evidenced by the number of initiatives to get these parties started. Here are some stories of collaboration with in-Kingdom partners.

Deanna Lacoste (right) and Amal Alamri.

Support helps crystallize new ideas

Nanoparticles have a bright future in new ways with light and photonics. Deanna Lacoste, mechanical engineer at KAUST, has had a longstanding interest in nanoparticles and now, with KAUST support, is sharing that interest with Amal Alamri, electrical engineer from King Abdulaziz University (KAU) and KAUST alumna.

The two met in 2020 at a KAUST workshop for Women in Science and Engineering and discovered a shared interest in nanocrystals, explains Lacoste. "On my side, for their production by plasma, and on Amal's side, for their photonic properties," she says.

With support from KAUST's Centre Competitive Funding (CCF), they began a one-year project that aims to produce silicon-carbide (SiC) nanocrystals for photonic applications, such as LEDs or photovoltaic systems used in solar power. "The project aims to produce an accessible and inexpensive method, with little chemical waste, that any small- or medium-sized enterprise could afford," explains Lacoste.

"With my student Roman Zamchii, I am producing different SiC nanoparticles using various plasma techniques," explains Lacoste. "Professor Alamri and her student Wesal Madani are characterizing them and providing feedback about their potential for photonic applications."

The initial idea to use SiC nanocrystals was sparked by Donal Bradley, Vice President of Research, who was seeking a local source of tiny (less than 10 nm) nanocrystals for use in LEDs. "Once we have reached a high selectivity and good yield, we will pass these results to Professor Bradley to determine their potential for LED applications," says Lacoste.

The collaboration is going well. "The group at KAU have really complementary skills as well as different ways of working. They are material scientists, and we are mechanical and electrical engineers," says Lacoste. "It's really interesting to combine our strengths to create a high-tech product for use in a large range of applications. I am also very excited to work with young female scientists from Saudi Arabia and contribute to professional development in the Kingdom," she says.

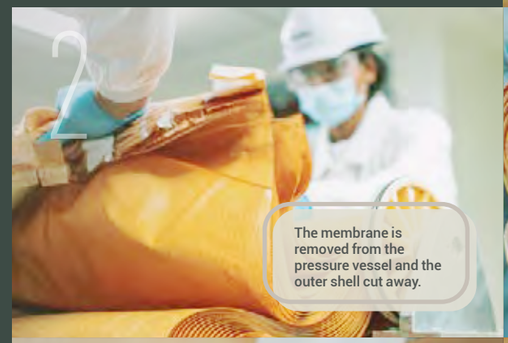
Alamri agrees. "This collaboration with Professor Lacoste highlights for me a sustainable way to engage with KAUST throughout my research career. As an assistant professor at KAU, this collaboration expands the diversity of my networks and supports me to better interact with the international research community.

Membrane autopsy provides clues to efficient desalination

Desalination plants rely on the good performance of reverse osmosis membranes, but over time these membranes become fouled with biofilms and precipitated minerals. A membrane autopsy can be used to determine what is fouling the membrane and thus prescribe the best methods for cleaning, as well as other ways to improve its efficiency.

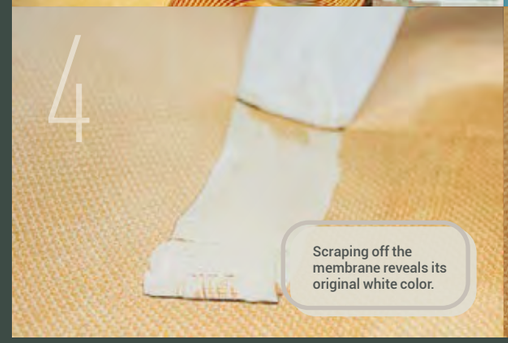
Johannes Vrouwenvelder and his team are partnering with energy company ACWA Power to perform autopsies on membranes that have been used to produce drinking water from seawater. The team will use information from these autopsies to propose improvements to the desalination process. We outline the process they use.

1 Water for desalination is pumped through membranes that are housed in pressure vessels.



2 The membrane is removed from the pressure vessel and the outer shell cut away.

3 The layers of the membrane are rolled out so the researchers can examine the surface.



4 Scraping off the membrane reveals its original white color.

5 Sections are cut for chemical and biological sampling.

Fueling great opportunities

A 10-year industry-academic collaboration is an ambitious endeavor, but a partnership between the Clean Combustion Research Center at KAUST and the Transport Technologies Division at Saudi Aramco's Research and Development Center has exceeded expectations in terms of nurturing talent and achieving outcomes.

The fuel combustion program, known as FUELCOM, aims to develop early-stage technology through improving the science and application of the core ideas that underpin Aramco's current transport R&D program. Specifically, FUELCOM serves as a lever for two of Aramco's research pillars — increasing the efficiency of internal combustion engines and the use of low climate-impact fuels — to support the decarbonization and sustainability of the road and marine transport sectors.

For Aramco, an attraction of the partnership is the KAUST group's flexibility and multidisciplinarity, says engineer Abdullah AlRamadan. "This is the third phase of this project. In the first phase, we began by developing a fundamental understanding and now, by the third phase, it has grown to be more applied. KAUST is one of the few institutions in the region that has the capacity to deliver across all of these stages."

FUELCOM has been an exemplary research collaboration between industry and academia, according to Hong Im, the lead principal investigator of the project. "It has showcased how state-of-the-art experimental and modeling tools are used in the actual engineering design and development process," he explains. "The students and postdocs learn from each other and work as a team toward a common goal."

In addition to its scientific achievements and more than 250 journal articles published, FUELCOM is a great talent incubator. The students and postdocs, supervised by both KAUST and Aramco principal investigators, gain unique exposure to problem-solving pathways in both academia and industry at the same time.

FUELCOM works well as a recruiting pathway, says Bill Roberts, director of KAUST's Clean Combustion Research Center. "Students get to work on relevant and interesting problems, and then they have the possibility of going to Aramco, and many of them want to. It's wins all around."

"I was a student of FUELCOM up until my graduation in 2020," says AlRamadan. "Within the project timeframe, I transitioned from presenting on the project and delivering project outcomes to leading a project theme."

Other KAUST alumni that worked on FUELCOM-related research topics include Jihad Badra and Emre Cenker: both were KAUST postdocs and are now laboratory scientists in Aramco.

17 PARTNERSHIPS FOR THE GOALS

FUELCOM meeting at KAUST in October 2021.

Catalyzing a long and rewarding partnership

A long-running research collaboration between KAUST and the Saudi energy and chemical giant Aramco is driving innovation in industrial catalysis.

What started in 2014 as exploring the possibility of one-step conversion of crude oil to chemicals has bloomed into a major research partnership between KAUST and Aramco, Saudi Arabia's flagship petroleum refiner. Aramco's dedicated state-of-the-art research center was built on the KAUST campus in 2019 and the collaboration has now expanded to numerous research streams supported by a rolling program of Aramco employees studying for a Ph.D. amongst KAUST's vibrant research community.

"We are fortunate to be one of the preferred universities for Aramco employees to undertake their Ph.D.," says Jorge Gascon, director of the KAUST Catalysis Center (KCC). "The KCC collaborates intensively with Aramco on several research topics, including a flagship program that deals with the one-step conversion of crude oil to chemicals. We are in an excellent position to develop the technologies that will shape the chemical industry of the future while contributing to the education of future industrial leaders, like Mohammed Alabdullah (pictured), who finished his Ph.D. on the one-step conversion project in September 2021."

Alabdullah, an Aramco engineer, was attracted to do his Ph.D. at KAUST by the potential of the research and Aramco's high regard for the KAUST collaboration.

"Aramco believes in KCC researchers' capability and knowledge in reaction engineering and catalysis," says Alabdullah. "KCC has world-class synthesis, characterization and catalysis facilities that make it possible to investigate complex reaction pathways."

The goal of the collaboration is to develop a novel reactor design that could eliminate energy-intensive processes, reducing the carbon footprint associated with oil use and using crude oil more efficiently to produce essential chemicals. It is important work, and Alabdullah has already published findings in top-tier journals such as *Nature Catalysis* and *ACS Catalysis*.

"This research project is quite important and interesting as a potentially competitive alternative to conventional refining practices," says Alabdullah. "Working at KAUST is a great opportunity to get involved in the fundamental aspects of research on unique and challenging technologies."

Heading into orbit to improve Earth observation

Small affordable satellites provide more opportunities for enhanced monitoring of the Earth and its ecosystems.

A collaboration between KAUST and global space services company Spire Global will see the launch of a nanosatellite, known as KAUST CubeSat, by the end of 2022. This first-of-its-kind, shoe-box-sized system will collect high-resolution data to improve understanding of the Earth's terrestrial and ocean ecosystems.

"CubeSats provide the capacity to launch a customized platform at a fraction of the cost of traditional satellites," says Matthew McCabe, director of the KAUST Climate and Livability Initiative.

The KAUST satellite will allow researchers to compile and analyze high-resolution hyperspectral imagery that can be used for mapping terrestrial habitats, monitoring vegetation health and condition, exploring coastal ecosystems and coral reefs, and advancing precision agriculture research, for example.

"With on-board processing and machine learning capabilities, it represents a new breed of remote-sensing platforms," says McCabe.

More traditional satellite systems tend to trade off how often you can observe a location on Earth and how finely you can see detail on the ground. Constellations of smaller and cheaper CubeSats avoid this compromise and receive high-resolution information every day.

McCabe has long recognized the value of working with the space industry to maximize research impact, having previously collaborated with Planet to utilize their CubeSat platforms and now working with Spire to launch a multiuse satellite platform.

"Leveraging different capabilities is key," explains McCabe. "To launch a satellite involves many steps, from sensor design to payload integration and, ultimately, in-space operations. It would be impossible to do this without industry partnerships and international collaborations."

"CubeSats provide an opportunity to reimagine how we observe the Earth, merging sophisticated sensors and on-board processing capabilities that provide both real-time monitoring and deep scientific insights into the Earth and its processes."

In the past, the KAUST team has used data from CubeSats and other satellites to help monitor crop health and irrigation rates to build a picture of Saudi Arabia's water use, which will help guide future policies toward improved water security.

While McCabe is excited by the potential of the new high-resolution hyperspectral data to transform the field of precision agriculture, the data will also provide new insights across the broader Earth system sciences.

"We are witnessing an exciting revolution in Earth observation that is changing the way we can sense and interpret our impact on the environment. Through enhanced observations, we can move toward a more sustainable interaction with our natural world," McCabe says.

"We are witnessing an exciting revolution in Earth observation that is changing the way we can sense and interpret our impact on the environment."

ART IMITATES LIFE WITH HELP FROM AI

Artificial intelligence (AI) is shaking up the art world. A new style of art event shows how machine learning can be applied across artistic fields.

What would emotions look like if an algorithm had brushes and paint to draw them? An online prototype gallery, SentiMo — artwork from a global art-AI hackathon — can turn social media complaints into a mosaic picture, and pandemic suffering into a symphony.

The potential of AI in art led KAUST to take a prominent role in the first contemporary art-based AI hackathon, the Super Artistic AI (SAAI) factory, held during August-September, 2021. "The hackathon brings together AI artists/designers and researchers to accelerate production of quality art," says Mohamed Elhoseiny, computer scientist at KAUST and co-chair of SAAI with Christoph Faulhaber, film producer and director.

With more than 600 participants worldwide, the hackathon included a three-day online symposium and a panel discussion with participants from Google Brain, Facebook AI and Veesual AI. It also involved collaboration in local hubs across cities including Thuwal, Riyadh, Berlin, Hamburg, Zurich, Lagos, Dubai, Mumbai, Bangalore and San Francisco.

Projects included experimenting with text, writing, music, sound, image, pictures, movement and motion. It included hackers, artists, coders, designers and developers. Elhoseiny says he was delighted with "the quality and diversity of the submissions and with the level of female participation." Sixteen projects are shortlisted for awards in November 2021, including three projects from Saudi Arabia of which two are from KAUST: SentiMo and AI Eclipse of diversity.

SAAI is a global collaboration including KAUST, the Goethe Institute and ETH in Zurich. "KAUST encourages this collaboration hoping it will inspire more AI researchers and artists to engage in this vital area," says Elhoseiny. Projects and other details are available at https://saai.devpost.com/

Created by KAUST students Sakhaa Alsaedi and Sara Althubaiti, SentiMo captures public sentiment about controversial or popular topics and, using AI algorithms, expresses it in a mosaic form.

EGO4D, DO YOU SEE WHAT I SEE?

What if artificial intelligence could look at the world and understand it just like we do?

Scientists are teaching AI to use a first-person perspective to perceive the environment through our eyes, which will make AI even more useful, especially when combined with wearable cameras. Currently, most computer vision systems employ imagery from a third-person perspective, but we humans experience the world as the center of the action. This "egocentric" perception is fundamentally different, and computer vision systems struggle to understand it.

KAUST researchers are part of a collaboration among 13 universities and labs in nine countries to form Ego4D, a Facebook-funded project aimed at solving research challenges in egocentric perception. The project has five benchmarks: helping with tasks related to memory, forecasting, hand and object manipulation, audiovisual records and social interaction.

The KAUST team contributed roughly 450 hours of first-person video, part of more than 3,000 hours of anonymized video created by over than 700 participants who used wearable cameras to record what they saw in their everyday lives. The result is a publicly available dataset that is more than 20 times larger than the biggest resource of similar imagery.

"Given our expertise in human-activity understanding in long-form video, my team specifically targeted the episodic memory benchmark, which focuses on finding moments, objects or answers to language queries occurring in the past," says Bernard Ghanem, lead researcher in visual computing at KAUST. "In other words, we developed and evaluated baseline methods to take an egocentric video and find the moment or language query you are interested in."

Just as speech recognition made virtual assistants much more useful, teaching AI to use egocentric video will yield more powerful assistive tools.

"Ego4D enables AI to gain knowledge rooted in the physical and social world, gleaned through the first-person perspective of the people who live in it," says Kristen Grauman, lead research scientist at Facebook. "Not only will AI start to understand the world around it better, it could one day be personalized at an individual level — it could know your favorite coffee mug or guide your itinerary for your next family trip. And we're actively working on assistant-inspired research prototypes that could do just that."

(From left) Bernard Ghanem, Mengmeng Xu, Chen Zhao and Merey Ramazanova.

PARTNERS IN GOOD HEALTH

Patients, clinicians and researchers all benefit from KAUST's collaborations with Saudi hospitals. Patients with difficult genetic conditions can access the latest diagnostics. Researchers and students interact with clinicians and hear real-world stories from patients, which helps them understand societal impacts of their work and motivates them even more to pursue excellence in research.

Machine learning, but researchers and clinicians learn too

Machine learning algorithms can churn through realms of data, but productive collaborations between researchers and clinicians are also an important part of the health equation.

Computer scientist Robert Hoehndorf and his team's collaborations begin with researchers and clinicians developing joint research questions about what they all want to know. Current collaborations include work on diagnosing rare metabolic disorders with King Khalid University Hospital and King Abdullah International Medical Research Center. Cancer-related projects investigate risk factors of ovarian cancer in the Saudi population with King Abdulaziz University and on hepatocellular carcinoma and retinoblastoma with King Fahd Medical City.

The collaborations provide mutual benefits. "As researchers, we get to test our AI methods for diagnosis, prognosis or determining risk while gaining insight into clinical practice; the clinicians generally want to improve the life of their patients and their clinical workflows," Hoehndorf says. He also notes the satisfaction of improving lives: "there are Saudi individuals and families who would not have received a diagnosis without our work."

One collaboration also highlights the importance of communicating research. "Researchers from King Saud University contacted us after reading a *KAUST Discovery* article and seeing a video about a paper related to AI and metabolic disease," says Hoehndorf. "We have collaborated ever since."

(From left) Azza Althagafi, Robert Hoehndorf and Sumyyah Toonsi.

Addressing the most difficult genetic problems

Peregrine Genomics, a KAUST startup, is collaborating with three medical facilities to investigate complicated genetic disorders. Computer scientist Xin Gao and bioscientist Mo Li from KAUST apply the latest sequencing technologies, artificial intelligence and machine learning to cases referred by clinicians.

These are intractable cases that remain undiagnosed after conventional genetic tests, explains Li. "Some of these genetic disorders reoccur in local family groups. Without a clear genetic diagnosis, it is impossible to screen for carriers of the disease, making it difficult to prevent the disease or plan for a healthy baby," Li says. "The clinicians send us patient samples and we develop nanopore sequencing technologies to investigate these cases."

"Our pipeline helps clinicians and leads to better understanding of the disease, preventative services and potentially better therapy," Gao says. "It provides relief to individuals and families."

Strategic insights also emerge. "Our long-read sequencing technologies have found many mutations often overlooked by conventional sequencing. We can solve many of these to understand the mechanism of such mutations in genetic diseases," Li says.

Peregrine Genomics came from the 2019 TAQADAM Startup Accelerator Program and began collaborating with Saudi hospitals following discussions at a 2020 KAUST research conference.

Current clinical collaborators are from King Faisal Specialist Hospital and Research Center, King Abdullah International Medical Research Center and the National Guard Hospital, but may include other medical facilities in the future.

SPARKING CONVERSATIONS

What has happened on social media since the launch of the KAUST Research Twitter, Instagram and Facebook channels?
The simple answer is, a lot. Here you'll see a snapshot of some memorable moments on social media. But the truth is, it was too hard to choose just a few, so please head to our social profiles and follow along with the **#KAUSTResearch** stories.

We hope to engage with you there!

Collaborative research with industry is one way KAUST Research teams can test and deploy their discoveries.

Engaging with collaborators via social media is a great way to re-enforce those collaborations so they last beyond a paper published or patent filed.

KAUST Research

The **@HALOLaboratory** did #fieldwork in the heat & humidity to collect lots of #mangrove habitat data.
They will calculate carbon sequestration & storage of mangrove environments.

MicaSense

Please share the results of this study with us! We are very excited and so much looking forward to learning more about your findings :)

Fuentk

#KAUST researchers have visualized stem cell rolling to understand what happens during homing at the molecular level.

KAUST Research serves Saudi Arabia and the world. We give a cheer when our social media posts are liked and re-shared by entities within the country as well as worldwide.

KSA Mission UNESCO

#SaudiArabia has continued to rise in global rankings, topping the @NatureIndex Annual Tables in the Middle East in several disciplines last year.
(Photographed: Inkjet-printed #solar cells by a **@KAUSTResearch** student that illustrate the printing process' possibilities.)

Saudi Green Initiative

A new plant probe mold by **@KAUSTResearch** could help improve 'precision farming', improving agricultural output without a need for more arable land, for more sustainable food supply.

KAUST_Research

A KAUST research team is studying marine predators. The team is made up of @KAUST_Alumni Ashlie McIvor (@findingamcivor) and current student Collin Williams (@capn.collin). Both researchers are connected to the Reef Ecology Lab led by Prof. Michael Beruman @rsrc_kaust.

The KAUST Research social media feeds are visual. Through scrollytelling, infographics, gifs, videos, photography and illustration, our social media posts are made up of accurate research-focused visuals that represent real #KAUSTResearch teams and their stories.

KAUST Research

Dr. @ErikaPSantoro works @RSRC_KAUST w/ Prof. Raquel Peixoto (@peixotors). She studies the potential of Red Sea coral reef #probiotic microbes to help coral ecosystems survive bleaching events.

The KAUST Research team is made up of artists, engineers, scientists and designers - all are science curious. So it is natural that the audience of our social channels also has a mixture of interests and professions.

Engaging with research communicators from other universities and from scientific journals has been a highlight of launching the #KAUSTResearch channels.

Iain McCulloch

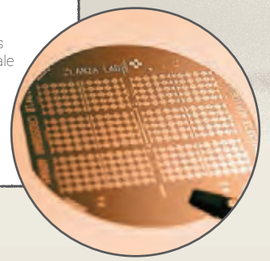
Really love the animation below. I will be using it in presentations for the next ten years! Well done.
@XavierPita_
@rhallani
@CostantiniGroup
@CarolynUnck

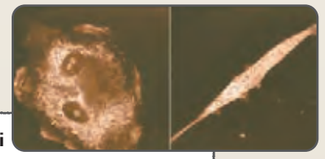
Medical Xpress

Better reporting, measurement and control of the environmental conditions of cell cultures is needed.
@lanzalab
@KAUST_News

Advanced Sci News

Using 2D films, researchers have developed a nano-scale random number generator with enhanced long-term stability and reduced power consumption.
@KAUST_News





Mo Li

My students suggested that I tweet about cool images of iPSC-derived macrophages doing their thing in cell culture. Captured completely label-free using a new toy-NANOLIVE 3D cell explorer.
@KAUSTResearch
@NanoLiveLtd

Naadiya Carrim

I loved doing this episode of SciCafe KAUST; it truly opened my eyes to the world beyond oil, to alternative fuels and understanding how science at **@KAUST_News** is contributing to the storage, transport and production of #hydrogen.

Is there a new piece of laboratory equipment being unboxed, or are you prone to sharing your excitement for the next Sci-Cafe at KAUST? Let us know by tagging our social media profiles.

And don't forget to use **#KAUSTResearch** to engage in the conversation!

KAUSTResearch

CONCEPT AND DESIGN: CARMEN DENMAN AND XAVIER PITA

Mastering the zigzags: working together as women in STEM

A chance conversation at a coffee break leads two women into a fruitful collaboration that will continue long into the future.

Sometimes something as simple as sharing a cup of coffee with a colleague can lead to breakthroughs. This was the case with two of KAUST's renowned chemists, Suzana Nunes and Niveen Khashab, whose chance conversation ultimately resulted in an extraordinary working relationship and led to high-performance selective separation membranes.

"Our offices are next door to each other at KAUST, and although I had looked up to Suzana for many years as a role model, a founding faculty member, and as a friend, we had never worked together," says Khashab. "We met up at coffee break one morning and started to chat about our respective projects: I develop highly specialized, designer molecules for diverse applications, while Suzana specializes in membrane technology."

"Our decision to work together was completely spontaneous," says Nunes. "We had a lightbulb moment when I realized that membranes could really benefit from specifically designed molecular building blocks like the ones Niveen designs. A task such as filtering organic solvents on the nanoscale is a tough challenge that scientists have been wrestling with for many years. Suddenly, a potential solution was right in front of me!"

"Respect for one another is vital. If you don't see each other as equals then you'll never grow and learn together, which is really the best part of the process."

A unique collaboration followed, with the two women working together on a new strategy for building bespoke ultrathin membranes for high-performance selective separations in organic solvents. Their results were published in *Nature Communications* in 2020.

"We are both incredibly proud that this is one of the first *Nature Communications* papers ever published by KAUST where both corresponding authors are women," says Khashab. "I hope that younger women see this and believe they can achieve equal success."

Both women are encouraging women to enter into STEM careers, and they regularly work with school-age girls and women at undergraduate and postgraduate levels across Saudi Arabia. They are on the board of WISER — Women in Science, Engineering and Research — a KAUST initiative that organizes events for young women through school outreach and conferences. The events celebrate female achievements across science and engineering. The next conference will be on International Women's Day in March 2022.

Suzana Nunes
Professor, Environmental Science and Engineering.

"You have to catch girls at a young age to engage their curiosity and determination to enter STEM," says Nunes. "I was given a chemistry set on my seventh birthday, and from that initial step, I went on to a specialist technology school for chemistry in Brazil."

"From this early fascination, I grew passionate about making specialized materials that would improve people's health."

Similarly, Khashab was drawn to chemistry from a young age. She was fascinated by medicines, and was desperate to understand how they worked. "I watched people taking tablets and suddenly they would feel better; it was like magic," she recalls. "From this early fascination, I grew passionate about making specialized materials that would improve people's health."

Both women agree that working together must be a relaxed, completely transparent process. All goals should be clear from the start — a mantra that Nunes has always followed — and tasks should be divided up to make the best of each individual's skillset.

"Respect for one another is vital. If you don't see each other as equals then you'll never grow and learn together, which is really the best part of the process," says Nunes. "It is worth pointing out that these tips for successful collaboration are not gender specific. It is perfectly possible to have strong collaborative partnerships with male colleagues too."

Khashab agrees wholeheartedly, although both feel that certain dots are linked more intuitively between women.

"Whatever you do, never feel forced into working with someone," says Khashab. "Bright ideas come from human interaction — from the sparks that fly between people with open minds. You have to find people with whom you can be honest, and there must be complete acceptance of each other's ideas, opinions, processes and procedures. Otherwise, you'll fall at the first hurdle."

Retaining women in STEM subjects beyond their initial early-stage career is a considerable hurdle that academia, and indeed industry, has yet to overcome. Whether pressure comes from society, cultural backgrounds or within family is unclear, but many women either choose or are forced to step away from their STEM careers.

"We have to stop thinking of careers as linear and straightforward," says Nunes. "The careers of women pass through different stages to those of men — that's a fact — and it doesn't have to be because of marriage or children. Women may face additional hurdles that slow down their path. They may have to find alternative routes, reinvent themselves and then rise once more; this must be taken into account. We should be facilitating their growth in these nonlinear steps of their careers."

"This is a key theme in our work with WISER," says Khashab. "We explain to young women about all the different ways in which STEM careers can pan out. We show them that they can work in different ways and demonstrate the wide variety of jobs available with STEM links, not just industry and academia, but in law and government, for example."

And their advice to young women hoping to make their way in STEM? Be flexible but stand your ground, don't give up, and find a perfect blend of being stubborn but enthusiastic.

"I'm with former German Chancellor Angela Merkel," says Khashab. "She once famously said 'I might bend but I will never break.' This is the best advice I can give to young women in work, no matter what field they are in."

"I read from the astronaut Buzz Aldrin the phrase; 'You have to be a master of zigzag,'" adds Nunes. "So true for women, in every area of life."

Niveen Khashab
Professor, Chemical Science.

Learning to raise a glass

Science and art are fused through the ancient craft of glass blowing.

Glass equipment is vital to most areas of science at KAUST, and now a new generation of glassblowers will be trained through the university's central lab glassblower apprenticeship program, the first of its kind in Saudi Arabia.

Fasil Nour and Mohammed Al-Amri, the first two apprentices in the program, began training in 2020, virtually in June and then on campus in October, with master glassblowers Ernest Neil Davison and Emilio Harina.

Both from Saudi Arabia, the pair will learn their delicate yet challenging craft — along with a lot of patience — over about 7,000 hours or five years of training and mentoring before they will graduate as glass journeymen. It will take them a further five years to become master glassblowers.

As well as learning about the many types of glass and the different techniques for working and manipulating it, the pair will develop a diverse range of skills for designing, fabricating and repairing bespoke scientific glassware for KAUST researchers and their research and industry partners.

The glassware they will make could range from giant distillation apparatus to something tiny, even nanoscale.

The program, developed by Davison with LaVon Bennet, will bring in a new cohort of apprentices every two years and aims to produce graduates that will help build a niche industry for Saudi Arabia in providing scientific glassware for national universities and industries.

New lab manager Jason Serin has plans to expand the facility and introduce a new basic glassblowing class for students to enable them to undertake simple glassblowing tasks in their own labs.

LITTLE RESISTANCE TO INCREASING IMPACT

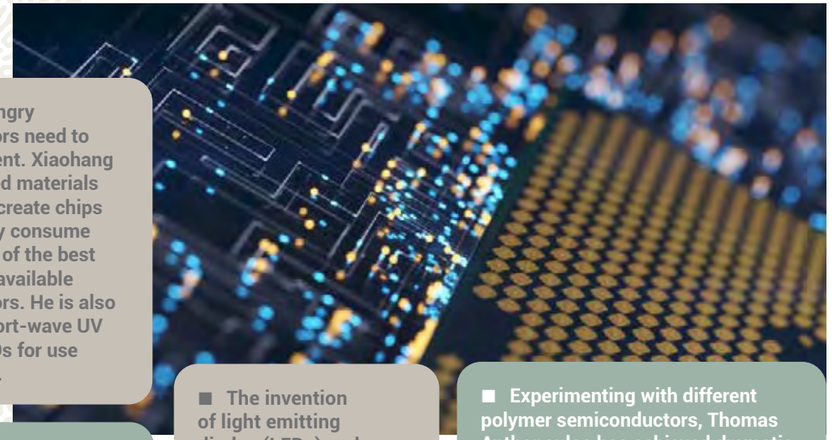
The inventors of the first semiconductor and the transistor effect won the Nobel Prize for Physics in 1956. Today, this technology permeates most aspects of modern life and much of KAUST's research focus.

As devices that amplify and switch current, semiconductors have extensive uses in electronic circuits and therefore limitless applications. Semiconductors play a central role in KAUST's research agenda, and key to this research is KAUST's world-class Core Labs, a system of centrally governed, multidisciplinary laboratories equipped with state-of-the-art technologies and supported by expertly skilled staff.

The Nano Fabrication Core Lab has a very large (2000m^2) "clean room" — a lab with very tightly controlled levels of temperature, humidity and particulate matter — used for the manufacture of semiconductors.

The Imaging and Characterization Core Lab is used for determining the structure and properties of prototypes and samples. It houses a full suite of the most advanced instruments including six super-advanced Titan Transmission Electron Microscopes that help studying the finer details of the semiconductors.

The Core Labs have been instrumental in advancing semiconductor research.



■ Energy-hungry microprocessors need to be more efficient. Xiaohang Li has improved materials and design to create chips that potentially consume half the power of the best commercially available microprocessors. He is also developing short-wave UV lasers and LEDs for use in disinfecting.

■ 2D materials, in sheets just one-atom thick, exhibit remarkable properties of strength, chemical and mechanical stability, and conduction or insulation of light, heat and electricity. Mario Lanza is looking at ways to incorporate these materials into semiconductors, along with their remarkable properties, to improve their efficiency.

■ The invention of light emitting diodes (LEDs) and semiconductor lasers helped semiconductors to expand into lighting and communications technology. Boon Ooi has developed laser-powered lightbulbs that are much more energy efficient than existing LEDs and can also transmit internet data at ultrahigh speeds of up to 10 Gbps.

■ Experimenting with different polymer semiconductors, Thomas Anthopoulos has achieved dramatic improvements in the performance of printed solar panels, which can be produced with less energy and cost than today's silicon equivalents.

■ Khaled Salama has developed a low-cost, robust, miniature, self-powering air monitoring station that can measure levels of different pollutants, as well as temperature and humidity, and transmit its data wirelessly.

Working together to get more from oil

A collaboration between two disparate research groups provides insights into a challenging problem in the field of enhanced oil recovery.

Maintaining the production rate of oil while reducing its environmental footprint is a global challenge and particularly important in Saudi Arabia, where a serendipitous collaboration between two unlikely disciplines is helping to solve a decades-old problem in the area of enhanced oil recovery.

Professor of energy resources and petroleum Hussein Hoteit and professor of bioscience Satoshi Habuchi are bringing together their expertise to use polymers to optimize hydrocarbon extraction from subsurface reservoirs.

Hoteit aims to enhance oil recovery using polymer-based solutions.

"When mixed with water, polymers form a viscous fluid that helps to extract oil more efficiently," he explains.

The method, known as polymer flooding, can reduce operational costs and environmental footprint by using less water. However, polymers are very large molecules that may cause operational problems related to their interaction with rocks at the microscale.

This is where Habuchi's team comes in. They are developing new molecular imaging tools, including single-molecule imaging of polymer molecules.

In 2019, KAUST's research magazine *KAUST Discovery* featured a story on the single-molecule polymer imaging carried out by Habuchi and his team. While paging through the magazine, Hoteit came across the story and contacted Habuchi with an idea for collaboration.

"Although I did not have any previous knowledge about petroleum engineering, after our first meeting, I clearly saw an opportunity to utilize the tool we had developed," says Habuchi.

"Our imaging method provides an excellent tool for the characterization of polymer flow in a microscopic space at the molecular level and could provide valuable insights into enhanced oil recovery," he explains.

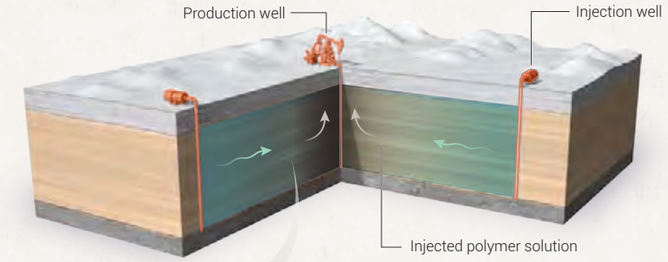
The researchers are now looking at other areas where they could work together.

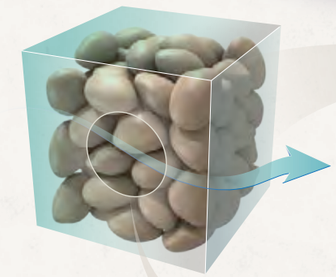
"When we started this collaboration, we had no idea where it could lead," says Hoteit. "With the successful technical outcomes and, most importantly, the synergy between our teams and the interest in exchanging knowledge and expertise, we see opportunities to work together on other problems," he says.

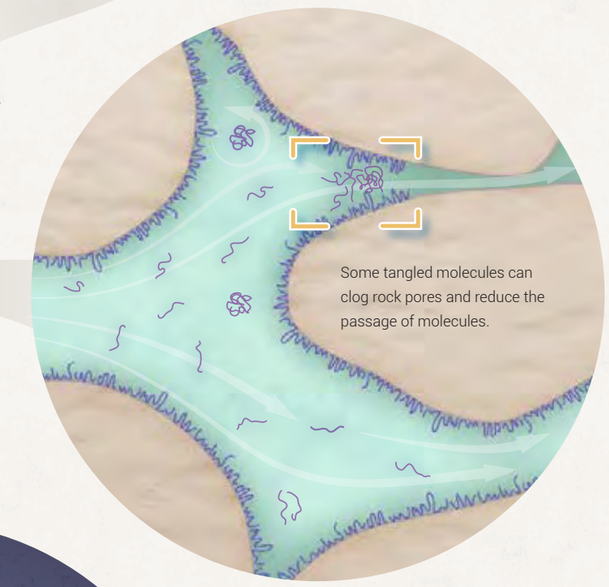
"With the successful technical outcomes and the synergy between our teams we see opportunities to work together on other problems."

They will focus on issues in energy and the environment, where the problems are complex and require nontraditional approaches. The pair agree that important factors for the success of this work were the extraordinary facilities and support provided by the central laboratories at KAUST.

Polymer flooding involves injecting a polymer solution (water mixed with polymers) into an oil reservoir to enhance the recovery of oil.

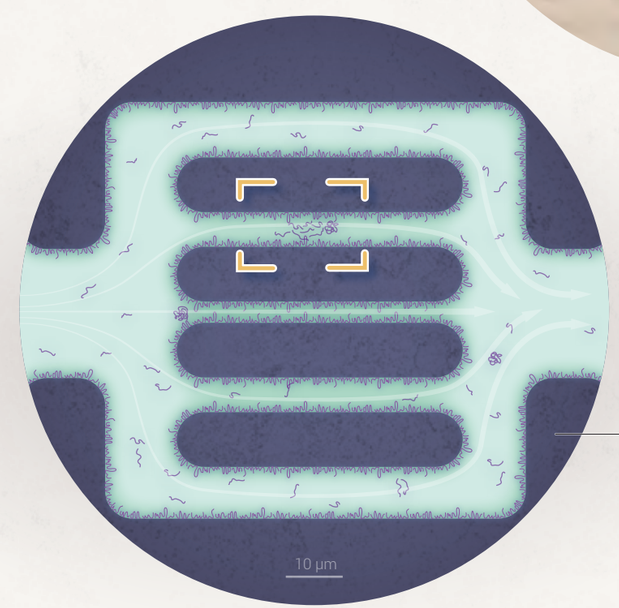






It is well established that the mixing of polymers in the water contributes to a greater efficiency of oil recovery.

However, polymers are large molecules that can interact with the rock and can become entrapped, which impacts the extraction process.

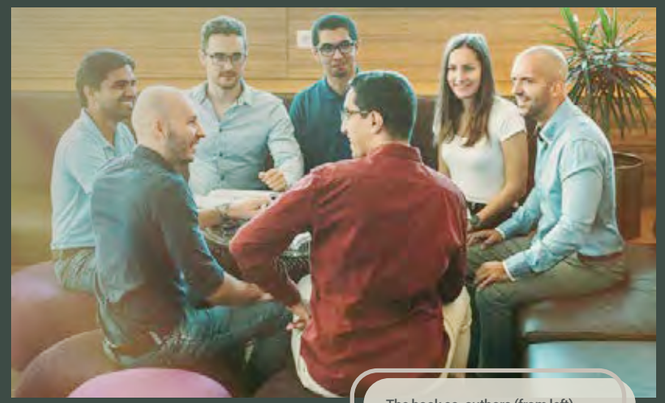


The use of single-molecule imaging methods to study the polymer solution flow allows the direct observation of this phenomenon and opens a new avenue to gain insights on how to achieve more efficient oil extraction.

The designed 2D micromodel mimics key features of the heterogeneous nature of rock pores and the flow behavior of polymers.

RIGHT PLACE, RIGHT TIME FOR TALENTED STUDENTS

Graduate students who come to study and learn at KAUST from across Saudi Arabia and the globe are encouraged to engage in "excellence, curiosity, integrity and a passion for doing things that matter." During their time on campus, these students often have opportunities to undertake novel tasks that can make a difference to their field and careers. Here are some examples of the real-world contributions they are making in addition to their individual research endeavors.



The book co-authors (from left) Sushil Kumar, Martin Gede, Gergo Ignacz, Edwing Grajales, Abdulhadi Alhaji, Diana Gulyas Oldal, Gyorgy Szekely. Absent are Nawaf Alghamdi and Fabiyan Angikath.

Students write the book they want to read

Noble laureate Toni Morrison once said, "If there's a book that you want to read, but it hasn't been written yet, then you must write it." So, when Gyorgy Szekely was preparing a new course unit on sustainable chemical engineering for use in the graduate program, he found he needed a new text — one that would bring together the principles of green chemistry and green engineering to help promote chemical processes that are more sustainable.

To produce the book, Szekely looked to engage his graduate students as a way to provide them with a unique opportunity. "I thought by involving the students," he says, "the knowledge they would gain during the process will be retained much better than by simply attending lectures or reading the book."

"The students participated in all aspects of the creation of the textbook, from the conceptualization and gathering information, through to writing the text and crafting the illustrations, till the final formatting and proofreading," says Szekely. "I found it really refreshing to work on the textbook with the students, and it made the entire process of writing a textbook much more enjoyable."

The student co-authors most involved were Diana Gulyas Oldal (Masters) and Gergo Ignacz (Ph.D.). Support was also provided by Ph.D students Martin Gede, Nawaf Alghamdi, Abdulhadi Alhaji, Edwing Grajales, Fabiyan Angikath and post-doc Sushil Kumar.

Szekely was right about the value of this experience to the students: "I learned an immense amount about the topic of sustainability," says Gulyas. While for Ignacz, the significant lesson "was how the whole concept of sustainability intertwines with every other engineering field."

Szekely was pleased with how much he learned too. "Working with the students was really beneficial for me as a faculty member. I learned a lot from them through their questions and the different perspectives they brought to the table during the process," he says.

The students also described the other aspects they found eye-opening, including the duration and complexity involved in writing a book. "I gained more advanced science communication skills and realized the importance of scientific illustrations," says Gulyas.

In the future, says Ignacz, "I would gain a more holistic perspective of my chapters before writing anything, then it would be easier to be on the topic and not get lost in the details. And definitely, I'd avoid 'rookie' omissions," he jokes, "by making sure right from the beginning to agree with the authors which citation tool to use!"

Alghamdi described how this was his first time contributing to written material such as a book, and it was a whole different game to his other teaching experiences. "In a written format, we deliver the material to students to learn without the opportunity to discuss it. And so, for this book, we needed to be precise, accurate and to phrase the writing in a way that's constructive for all types of students. So in addition to learning a lot about the scientific material itself, learning the skill of putting together a book chapter was an enriching experience," he says. "I would urge my fellow Ph.D. students to get involved in writing a book chapter. It's different from writing papers, and it's a skill that should prove useful in the future, almost regardless of career direction."

Overall, the value and quality of the collaboration is reflected in the textbook. "Writing the textbook with the students actually helped the contents of the book, as well as the depth of each topic, to be tailored to the needs of graduate students: as co-authors, the students could provide instant feedback," says Szekely. "This has ensured the final result is a textbook that graduate students can understand, that provides all the relevant information and, importantly, is engaging."

Sustainable Process Engineering was published in 2021 by German academic publisher De Gruyter. "It was a lot of effort to produce this textbook," says Szekely, "and considering both the content and the presentation of the book, I am very happy with the end result."

Graduate program attracts boy next door

It's not unusual for students from Saudi Arabia to come to KAUST for graduate studies – Saudi students comprise about a third of the student population. What is unusual, however, is for a student to come from the same town as the KAUST campus.

Samhan Alsolami, a Ph.D. student working in the laboratory of Mo Li, originally hails from Thuwal, "where my family and relatives have always lived," he says. "I've always been interested in the process of science and discovery because it is the basis of modern society."

After graduating from a local high school, Alsolami joined the King Abdullah scholarship program to travel abroad to undertake undergraduate studies in California, U.S. "While I was studying for my undergraduate degree, I was one of a few candidates who was awarded an internship funded by the California Institute for Regenerative Medicine (CIRM)," explains Alsolami, "So I was at UC-Irvine where I participated in exploring how stem cells can be used to treat neurological disorders."

While at UC-Irvine, Alsolami met his current mentor Mo Li, who was just setting up his bioscience lab at KAUST. "I was also funded by a CIRM fellowship as a postdoc, and this connection between us and Samhan's enthusiasm for stem cell research convinced me to bring him halfway around the world back to Thuwal and KAUST. He is one of the most diligent students in my group and his passion for research is infectious." says Prof. Mo Li. "Meeting Professor Li strongly influenced my decision to come to KAUST because his research interest is at the heart of regenerative medicine," says Samhan.

Alsolami's Ph.D. studies aim to advance the field of regenerative medicine through optimization of stem cell cultures and generation of 3D models of human embryogenesis. He has recently published the first two papers of his Ph.D., "one of which is at the forefront of the stem cell field where we created one of the first human embryo models," he says.

He also has lofty ambitions for the future. "I'd like be able to continue conducting high-quality research working with the best minds from around the world," he says, "and I aim one day to have my own lab that focuses on realizing the promise of the field of regenerative medicine."

Ph.D. student Samhan Alsolami traveled the world to end up back in Thuwal, where he grew up.

A fruitful lockdown spent playing with marbles

Lockdown observation and analysis conducted at home have led to a pioneering intellectual framework for predicting the fate of evaporating liquid marbles.

When the 2020 COVID-19 lockdown closed laboratories across the world, KAUST Ph.D. student Adair Gallo Jr. followed the advice of his supervisor, Himanshu Mishra, and took some marbles home to play with. Not just any marbles, but liquid marbles — tiny, specially designed structures made from water droplets coated in water-repellent silica particles.

Liquid marbles were first discovered by scientists investigating the behavior of insects called aphids, which live inside galls, abnormal growths on plants. Aphids create liquid marbles by covering their excreta in a waxy substance so they don't drown in it.

"Liquid marbles are unique structures with various engineering applications," says Gallo. "But no one had studied how the different coatings, particle sizes and friction characteristics influence how they evaporate. I was inspired by patterns in data collected by my colleague Fernanda Tavares to take the equipment home to study."

The different particles for the coatings were prepared in the lab by KAUST's Ratul Das. "I couldn't have done this at home because it is surprisingly complicated," notes Gallo. "But I could create the marbles at my apartment."

Gallo arranged a simple setup with a time-lapse camera on his desk at home to monitor the ways the different marbles evaporated. He had to be careful not to overheat the marbles with excessive light. When one set of marbles coated in sticky nanoparticles began to yield fascinating results, he became very excited.

"The marble coating got thicker as the liquid inside evaporated, possibly because the particles were being pushed outward from the water surface to form a multilayered coating. This left behind hollow shells after the water had gone," says Gallo. "I was so excited I couldn't wait to run the time-lapse observations, so I slept with the lights on for several nights to gather the data!"

Gallo combined his lockdown data with those previously collected and developed a comprehensive framework to predict the fate of any evaporating liquid marble.

SEA CLASSES

With its location on the shores of the Red Sea and an international reputation for marine science, KAUST needs teams of skilled research divers with expertise in identifying key marine species. Now, marine researchers and partners from industry and other institutions can receive internationally accepted dive training on site, while others further develop their expertise in identifying corals.

Diver safety training delivers for marine research

KAUST can now offer an American Academy of Underwater Sciences (AAUS) scientific diving course that provides 100 hours of intense, advanced training over a flexible period.

As an organizational member of the Academy, KAUST's central lab is now able to provide scientific diver training and certification, the only entity in Saudi Arabia with such a license. Through the university's AAUS membership, KAUST-trained divers are eligible to dive at other member institutes, facilitating research collaborations and ensuring that best practices are shared around the world.

In 2021, KAUST signed a memorandum of understanding with the Saudi Water Sports & Diving Federation (SWSDF) to develop scientific diving regulations by sharing knowledge and experience. The aim is to encourage the appropriate and safe use of the Red Sea's resources.

KAUST is now able to offer expertise and collaborate with SWSDF to implement policies, regulations and procedures for scientific diving in Saudi Arabia.

After completing the course, divers are qualified to help others in emergencies, perform advanced oxygen administration and CPR, and carry out emergency first response for diver accidents and incidents.

Divers also gain practise carrying out activities in extreme marine environments, including seabed scientific research, recovering scientific instrumentation, commandeering and assisting remotely operated underwater vehicles, and helping to recover an aircraft black box.

After the first course in 2020, the university now has 92 registered scientific divers and scientific divers in training. For KAUST and the country, the course meets a real need for Saudi citizens to lead in their fields of expertise in marine sciences.

"Looking to the future, KAUST has the opportunity to build on the course's success, expand access to it and certify more Saudi nationals," says lab director Edward Lloyd Smith.

"Students from across the country and further afield may now realize their ambitions in underwater research, placing Saudi Arabia on the map for scientific diving for the first time in history."

Fostering coral culture in the Red Sea

A coral identification workshop has been organized by KAUST with colleagues from Saudi Arabia's giga projects to increase regional knowledge about corals, which are so important for the conservation of the Red Sea marine environment.

The Red Sea is home to a rich diversity of marine life still being discovered and described, including more than 360 different hard coral species, with a high rate of endemic species from shallow and deep reefs not found anywhere else in the world.

Marine biologists Francesca Benzoni and Tullia Terraneo from KAUST recently organized a coral identification workshop for marine researchers working on national giga projects and in other Saudi universities.

The 14 participants represented The Red Sea Development Company, NEOM, Imam Abdulrahman Bin Faisal University and KAUST's Red Sea Research Center. The participants work in diverse areas such as fish ecology, invertebrate biology, coastal biodiversity and marine conservation.

The workshop helped participants to identify corals and explained which corals can be identified from images, thus avoiding destructive sampling, and which ones require further sampling for identification.

Even more importantly, says Benzoni, "it opened their eyes to coral. The end game for me is not just to have everybody going home and being able to place a name on a species, but also to have them more interested in the resource.

"To see people who are not necessarily working with coral every day become interested in them, want to find out more about them and maybe look at them with a different eye was the most rewarding aspect of the workshop," she says.

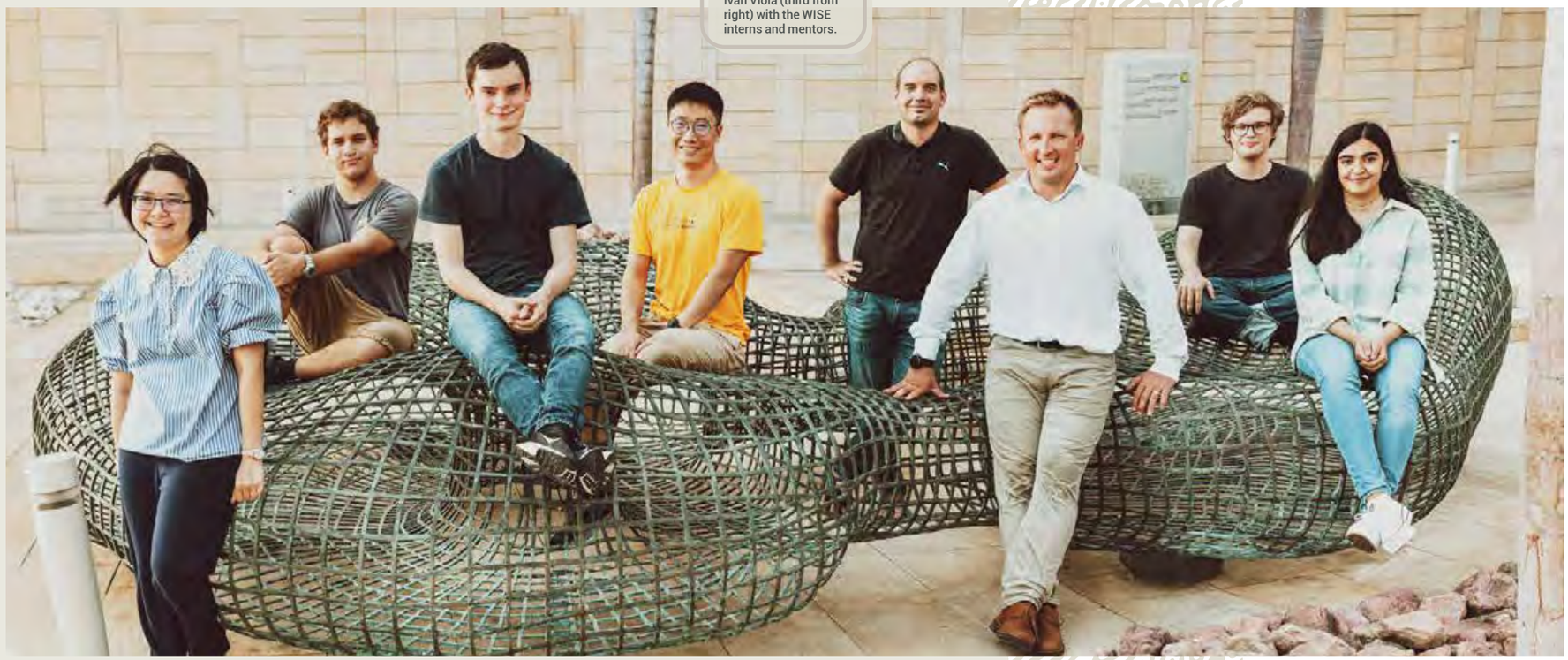
During lockdown, Benzoni and colleagues met over Zoom to discuss features of different corals from Benzoni's extensive collection of images.

The interactions and the workshop have helped strengthen the collaboration between researchers from the giga projects and local universities.

"They know what the challenges are to identify corals, and now they know that they can come back to us at KAUST or collaborate with each other to find solutions to various challenges," adds Benzoni.

Benzoni and her team are developing a comprehensive identification guide to the corals of the Red Sea, which will be published in 2022.

Model students get to write the rules



Ivan Viola (third from right) with the WISE interns and mentors.

High school students had the opportunity to work with a KAUST research team to create a new model of a bacteriophage, a virus that attacks bacteria, while also road testing the team's new prototype software.

Computer graphics scientist Ivan Viola is fascinated by life at the nanoscale. In September 2021, he used the summer internship program for high school children of KAUST residents (known as WISE) to develop an exciting opportunity that he hoped "was not only fun, but provided an experience where the students could gain new knowledge and a new skill — an intellectually enriching entertainment experience, or 'edutainment.'"

The research focus of Viola's Nanovisualization Research Group is designing very tiny nanoscale computer graphics and 3D visualization algorithms and techniques. Their research outcomes include research software prototypes, one of which is MesoCraft, a tool for rapid modeling of molecular assemblies.

The idea of running a student internship program began with a discussion with the high school's head of Life Sciences, Emma Nason, who was already familiar with Viola's research. The researchers wondered if some of the students who love biology or 3D modeling would be keen to work with them. Following an oversubscribed application process, the researchers described how they "had four great young minds to help us define the spatial rules for assembling the complex bacteriophage model." While Viola oversaw the internship, the organization fell to Deng Luo with the help of Ngan Nguyen, both Ph.D. students in the group.

The internship gave the students a chance to create a challenging mesoscale structure to showcase the type of bio-assemblies that can be modeled using the team's software prototype. But the benefits flowed both ways: the internship also gave the research team a group of real users that could test MesoCraft and help the researchers learn about the utility of the tool, raising questions like: Is it stable enough? When does it crash? Is it easy and intuitive to use? How much support does a user need to become proficient?

The program began with briefing the students on the digital data used to represent structural biology on a nanoscale level. They were then trained by research scientist Ondrej Strnad in modeling and specifically in the use of the KAUST MesoCraft software prototype. Once they had mastered this, Luo described the T4 model, including a literature review of current knowledge of T4 bacteriophages and their ultrastructure. Luo had worked up this suite of information with collaborator David Goodsell, renowned computational biologist and artist from Scripps Research Institute.

Then came the modeling that was at the crux of the internship. The students were given basic structural building blocks (proteins) and then tasked with figuring out the rules that led to the assembly of the desired structural part.

"I was quite impressed by the students' 3D modeling skills and knowledge of biology from high school classes, and their artistic minds and ability to rapidly master MesoCraft," says Luo.

Viola expressed how impressed he was that the internship produced such a meaningful outcome. "The students, along with Deng and Ngan, actually managed to model T4 within the four-week timeframe of the internship," he says. "It is a very complex structure to model, plus rule-based modeling requires a lot of quite logical thinking. Nevertheless, during the internship we got the entire structure modeled. That really surprised me."

While the students learned a lot, so did the researchers. "Through this, we acquired new knowledge, new skills, test reports for our software prototype performance, and last but not least, the first scientifically accurate model of T4 that is publicly accessible and available for everyone to use or analyze," says Viola.

Luo describes how now, "with the model on hand, we can visualize it in a color scheme, print it out, or even animate it," and this animation will be the next step of his research. "Developing the first scientifically accurate model of the well-studied but little communicated bacteriophage T4 will better guide us, and others. Being able to visualize it means we can communicate better and disseminate knowledge faster, and thus educate deeper and more broadly."

"By visualizing this, we can communicate better, disseminate knowledge faster, and thus educate broader and deeper."

"Also gratifying was that all of the students really liked the internship and were genuinely excited and proud of the outcome of their hard work," Viola says. "We made an offer to the students that when they have a school break and would like to model another biological entity, we will be happy to work with them again."

4 QUALITY EDUCATION

Exploring underground from the sky

Satellite data delivered directly to a computer can tell a geophysicist much of what they need to know, but fieldwork still adds value to their work.

(From left) Rémi Matrau, Nicolas Castro-Perdomo and Mohammad Youssof carry out fieldwork in the Gulf of Aqaba.

"The only way to learn is … to go and see," declares Von Hardwigg, hero of the 1864 seminal subterranean science fiction novel *Journey to the Centre of the Earth*, as he prepares for a bold expedition into a volcano to investigate the Earth's depths.

Some places on Earth are hard to get to because reaching them may be difficult, expensive or dangerous. However, advances in scientific tools mean that studying the Earth's depths doesn't always require scientists to physically "go and see" the study site. Modern satellite radar methods enable even tiny changes to be noted, quite quickly, from afar.

"Now we can observe the entire globe without traveling into the area, which is very important for improving our observation capability," says geophysicist Sigurjón Jónsson. "For example, at the moment we are studying Syria," which is currently too dangerous to visit.

Jónsson researches big hazards such as earthquakes and volcanoes, which involves studying precise changes in geological structures. For volcanos, he explains, this includes monitoring deformation, or how the ground "inflates," which is often the first sign of a volcano entering an active phase. Or for earthquakes, where the plate boundary has "jumped."

The satellite data is collected as radar scans, collected by several space agencies and licensed for download as large data sets. Jónsson's work uses data from many satellites but relies mostly on data from the European Space Agency's Sentinel-1A and Sentinel-1B satellites. "When we study an area, we typically collect all the data we can get. Then, we can process these big data sets and produce colorful images that are like contours of deformation," Jónsson says. "From these, we can sometimes infer exactly where an earthquake happened."

To complement the satellite data, Jónsson's team does get to "go and see" in the field. "Fieldwork inspires our work in the office," Jónsson explains. So, for a few weeks each year the scientists visit far-flung places — including Iceland, northern Saudi Arabia and sometimes Eritrea — where the students are exposed to the elements and the challenges of collecting field data.

An important field site for Jónsson's team is the Gulf of Aqaba, which he describes as having spectacular scenery with beautiful mountain ranges that rise vertically out of the sea. These also provide a clue that there is something geologically interesting going on. The dramatic 4-kilometer relief — from a 2000-meter-deep sea trench to 2000-meter-high mountains — is a sign of very active tectonics, he says.

"The Gulf of Aqaba is really a boundary between two plates," he explains. "It's between the Arabian plate that is moving northward with respect to the Sinai plate to the west. Because it's moving about 5 millimeters per year, from time to time the normally stuck boundary jumps, and we experience a big earthquake."

This field research helps refine the methodology for the earthquake hazard discipline, but it also provides compelling findings for the region, and for the nation. Bold development giga projects for Saudi Arabia include construction of the futuristic city NEOM near the Gulf. "While more work is needed to fully understand the earthquake hazards for this new city, our current work in this area shows the hazard may be somewhat lower than previously thought, but it is still significant and needs to be considered in infrastructure designs," Jónsson says.

"Now we can observe the entire globe without traveling into the area, which is very important for improving our observation capability."

Also planned for the region is a new crossing from the Gulf of Aqaba to Egypt, near the city of Sharm El-Sheikh. "This is a tricky project because you go right across this plate boundary fault, which can generate large earthquakes, and that would need to be considered when engineering such a crossing."

Although this area of the Middle East has limited historical information about past earthquake activity, there was a large earthquake in 1995 of magnitude 7.2, known as the Gulf of Aqaba or Nuweiba Earthquake. This occurred in a sparsely populated area, but there were still 11 deaths, around 50 injuries and significant damage to infrastructure.

Coincidentally, just a few months later in 1996, young Jónsson traveled through the area on a holiday with some friends — oblivious to the recent earthquake, and unaware that during his future career he would be studying the movement of those plates beneath his feet.

School of rocks: lessons from Al Wahbah crater

Al Wahbah crater, a popular tourist attraction, is the largest and best-preserved crater of its kind in Saudi Arabia. The origin of the crater is not fully understood. Local folklore suggests that a nearby mountain was shot by a jealous cousin and fell to the ground, creating the crater. The crater was also believed to have been formed as a result of a meteorite crashing into the desert. We now know that the crater was formed by a volcanic explosion during the last million years, but there is still much to learn from this natural wonder.

KAUST scientists are studying the crater to better understand volcanic activity in the area. Petrologist Froukje van der Zwan and her research group study the minerals and chemistry of the volcanic rocks of the lava fields, known as harrats. This includes the rocks that were formed by the lava itself, as well as deep mantle and crustal rocks that were entrained by the lava. "We try to understand the harrat volcanic systems to learn about the origin of the melts, the depth and processes of magma chambers, how different rock types are formed and how that affects their explosivity," explains Van der Zwan. "This is important to assess their hazard potential, as well as to understand why we have harrat volcanism in Saudi Arabia at all!"

Historical volcanic eruptions

Vesuvius, Italy 79 AD · Hopango, El Salvador 450 AD · Laki, Iceland 1783 · Mt. Tambora, Indonesia 1815 · Krakatoa, Indonesia 1883 · Santa Maria, Guatemala 1902 · La Palma, Spain 2021

Harrat Kishb

Saudi Arabia has several volcanic formations and lava fields, mainly located in the Arabian Shield in the western Hejaz region. These harrats are made of basalt (solidified lava) from eruptions 30 million years ago, as well as more recent eruptions. The Al Wahbah crater is located on the western edge of Harrat Kishb, a lava field that covers about 5900 km² and sits 1000 m above sea level. The last documented volcanic eruption in Saudi Arabia was in the northern part of Harrat Rahat in 1256 (or 641 Hijri). Witness accounts reported the lava flow nearly reached the holy city of Al Madinah. The most recent earthquake activity in Harrat Lunayyir occurred in April-June 2009.

1 Magma rises to come into contact with a layer of underground water. The water vaporizes instantly to trigger a sudden violent explosion.

2 Subsequent eruptions contributed to the formation of the landscape.

The Al Wahbah crater

Located 250 km northeast of Jeddah, the Al Wahbah crater is 2.2 km wide and 250 m deep. The crater was formed by a volcanic explosion that blasted through 500-million-year-old Precambrian basement rocks and two 30-million-year-old Quaternary lava flows. The massive explosion also blasted in half an older volcanic cone to the northwest of the crater. Scientists have used the layers of rock exposed by the blast to estimate the time of the crater's formation to be younger than 1.1 million years old.

Saudi Harrats

1. Shamah
2. Uwayrid
3. Ithnayn
4. Hutaymah
5. Lunayyir
6. Khaybar
7. Rahat
8. Kishb
9. Hadan
10. Nawasif al Buqum
11. Al Birk
12. Sirat

Geological timeline

Source: Froukje van der Zwan and Ivana Zivadinovic
Art and Design: Ivan Gromicho

Shaheen II still soars high to support world-class research

Supercomputers can work with vast amounts of data by performing computationally intensive tasks rapidly, saving time and money.

If supercomputers had a motto, it would be "live fast and die young" as rapid advances mean supercomputing technology becomes outdated within just a few years.

KAUST's supercomputer, Shaheen II, has powered diverse research from climate forecasting to molecular modeling, but is now approaching the end of its cycle. Shaheen means falcon in Arabic. Shaheen II is due for replacement in 2023. Shaheen II is due for replacement in 2023 but meanwhile, the machine continues to punch above its weight in terms of the world-class research it powers across different disciplines and diverse projects.

Climate research

Like the very first supercomputers, Shaheen II is used to simulate weather. Researchers led by mathematician Ibrahim Hoteit use the capacity of Shaheen II to simulate, understand and predict atmospheric and oceanic circulations over and around the Arabian Peninsula.

Engineers planning KAUST's neighboring King Abdullah Economic City's coastal development originally foresaw potential future storm surges up to 4 meters high. Exploiting Shaheen's capacity, Hoteit's models, however, showed that a nearby coral reef would dissipate waves from the Red Sea to reduce the storm-surge risk. This meant the elevation of the project's foundations could be reduced by 2 meters, saving around US$600 million.

Risk levels were also clarified for the coastal megacity NEOM, being constructed on the northeastern shores of the Red Sea. Hoteit's simulations predict freak wind episodes, now factored into the new plans.

Hoteit claims his research group's biggest achievement is the discovery and modeling of the Red Sea's natural circulatory flow. This helped direct plans for oil spill cleanup and explain patterns of seasonal circulation cycles driven by the Indian monsoon and the impact of these cycles on the biological productivity of the Sea's deep-water basin. This natural circulation occurs when surface waters are blown northwards during winter, where it becomes saltier and cooler and sinks at the northern reaches of the Red Sea, before returning southwards as a deep current. This cycle reverses during the summer.

Sporadic events were also examined. Faraway volcanic eruptions in 1982 and 1991 produced unusually cold winters over the Sinai Peninsula. During these events, the water in the northern Red Sea sank deeper, with knock-on benefits across the ecosystem. "The colder water went deep down, taking oxygen with it. It sped up the cycle, which mixed the water column and ventilated the basin sea," says Hoteit.

Fluid dynamics

In 2014, NASA called for a revolution in computational fluid dynamics, predicting that by 2030, there would be new algorithms running on supercomputers to simulate more comprehensively and accurately the flow of air around spacecraft and high-performance aircraft.

However, KAUST researchers beat NASA's prediction. Aerospace engineer and computational scientist Matteo Parsani developed the first prototype of a next-generation fluid dynamic solver and tested it on Shaheen II in early 2021. Parsani's team is now collaborating with scientists from NASA and other aerospace heavyweights Boeing and Airbus.

"We developed the world's first fully discrete entropy-stable adaptive solver for complex geometry," says Rasha Al Jahdali, applied mathematician on this forward-looking project. "The aerospace industry knows that we have this unique capability. They want us to run simulations to see how it performs."

Developing a new aircraft model is expensive. "Engineers select one option from several designs and then go through the costly process of building a prototype to test it in a wind tunnel," says Al Jahdali. Parsani's system enables this to be done virtually, simulating many designs and tweaking them during the process. It allows developers to look at airflow at every point of their design, and under conditions impossible to replicate in a wind tunnel.

The science can also help build faster cars; Formula 1 developer McLaren already licenses Parsani's software. KAUST's research puts Saudi Arabia at the vanguard of fundamental upstream contributions to the software infrastructure of computational fluid dynamics. As part of Saudi's plans to diversify its economy, this know-how will support indigenously developed aircraft by the mid-2030s. In line with Vision 2030, Saudi Arabia plans to localize aerospace industries. KAUST will be able to support these translation opportunities.

Machine learning

Computational scientist Peter Richtarik and his team develop algorithms that train machine learning applications. The team, including several graduate students, has also demonstrated their own successful learning. In the past three years, they have contributed five papers to the prestigious International Conference on Machine Learning.

The team's machine learning applications perform tasks such as recognizing faces or translating text into another language. Currently, algorithms learn by looking and learning from millions of examples. However, this process is inefficient. Richtarik has developed "arbitrary sampling," which uses more efficient methods so fewer examples are needed to train machine learning applications.

Richtarik's original papers on the machine learning subfield have been followed and cited by thousands. Now, the biggest tech companies, including Google, Apple, Meta, Samsung, Huawei and Tencent, have established dedicated federated learning research teams.

Desert plants hold the key to crop survival

A fascination with desert plants and their survival mechanisms has led to a game-changing discovery for improving crop productivity under stress conditions.

KAUST researchers believe that desert bacteria could hold the key to improving both plant and human health. They are examining the beneficial role of these microbes and how to extend their benefits to crop plants.

Heribert Hirt and his team study the survival mechanism of plants living under extreme conditions, such as drought, excessive salt or heat. They then apply this knowledge to crop plants to re-establish agriculture in arid regions or under difficult environmental conditions.

Hirt has identified how microbes interact with plants to assist their survival and, over the past eight years, his team at KAUST has collected several thousand strains of such microbes from deserts all over the Middle East.

Their groundbreaking achievement was to show that many of the microbes living in the roots of desert plants are not host specific. They then went on to successfully transfer these microbes to other plant species.

Senior research scientist Maged Saad says one of the challenges was how to make the beneficial microbes available to small-scale desert farmers.

To solve this challenge, they developed a seed-coating technology for selected microbes. With funding from KAUST, the team provided small quantities of bacteria-coated seeds to smallholder farmers in Saudi Arabia to test on crops, including cucumbers, tomatoes and alfalfa.

Hirt believes these beneficial soil microbes could be the "magic bullet" for agriculture this century, helping plants to grow under drought conditions, salt stress and extreme temperatures.

"Desert microbes are well adapted to extreme environmental conditions, such as heat and high salinity. They help desert plants thrive in these conditions, providing nutrients and enhancing plant tolerance to high temperatures and scarce water," he explains.

For example, Hirt's team has identified one strain of bacteria that makes plants more resistant to drought by enhancing water-use efficiency. "We can reduce water irrigation by 30-40 percent, while still maintaining yields," says Hirt.

"The Food and Agriculture Organization estimates that farmers will need to produce 70 percent more food by 2050 to meet the needs of the world's growing population. If you can enhance crop productivity without the use of synthetic fertilizers or pesticides, it's a game changer," he says.

"We need fast and low-cost solutions that are affordable and accessible to subsistence farmers who eat what they grow."

Saad says their research is helping to address global challenges such as climate change, food security and sustainability, and it could lead to applications in human health through potential new antibiotics and genetic tools, for example.

Microorganisms help plants cope with arid conditions

Another team, led by Daniele Daffonchio, is also exploiting microbial diversity to promote plant growth in arid soils. The team is investigating the ecology of microorganisms in desert ecosystems, particularly microorganisms associated with desert plants.

"The microorganisms, together with the soil, rhizosphere and root endosphere, function as interactive communities of diverse microbial types that also interact with the plant host, soil matrix and surrounding environmental factors in a complex interactome network," says Daffonchio.

His team investigates how this interactome influences plant root colonization and plant growth. Researchers are examining environmental factors like temperature, humidity, drought, salinity and the chemical landscape at the soil-root interface, as well as the type of plant species and their associations.

Microbiologist Ramona Marasco studies assemblages of microbial communities in wild desert plants and in cultivated species, such as date palms, under different climatic conditions and soil types. Her work shows that date palms, like other desert plants, always recruit very similar microbial communities made of selected plant growth promoters that alleviate drought stress, despite the diverse pool of microorganisms available.

"This type of conserved selection is dictated by the extreme conditions of the desert soil and of the desert environments, which restricts the choice available to the plants," Daffonchio says.

In considering the complex soil microbial community and extreme conditions of the desert ecosystem, it is important to assess and understand the ecology of the root system at the microbial community scale. "This is where the action lies in terms of plant-growth-promoting microorganisms, either natural or added as inoculants, exerting their beneficial effects," Daffonchio says.

Lessons from extremophiles

Bioscientist Alexandre Rosado has also developed an interest in microbes from several Saudi ecosystems, including deserts and volcanoes, through his research on organisms that thrive in extreme environments, known as extremophiles.

His research has identified one family of desert bacteria that can thrive with only trace amounts of carbon dioxide and can assimilate nitrogen with high efficiency.

He says these novel mechanisms of nitrogen and carbon fixation could lead to new biotechnological products for sustainable agriculture and bioenergy.

"Possible biotechnological applications may include further development of genetically modified plants capable of using nitrogen with little or no chemical fertilizer."

Rosado is also interested in how microbes that are successful in extreme environments could have applications for space colonization.

Plants recruit a pool of microorganisms from the soil to colonize different compartments of their root systems, the rhizosphere and the endosphere. Specific soil subsets of microorganisms first colonize the rhizosphere, which is the few millimeters of soil attached to the roots where microorganisms are enriched by organic compounds. They also act as signal compounds to activate the metabolism that promotes plant growth and colonize the interior tissues of the roots.