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explorer

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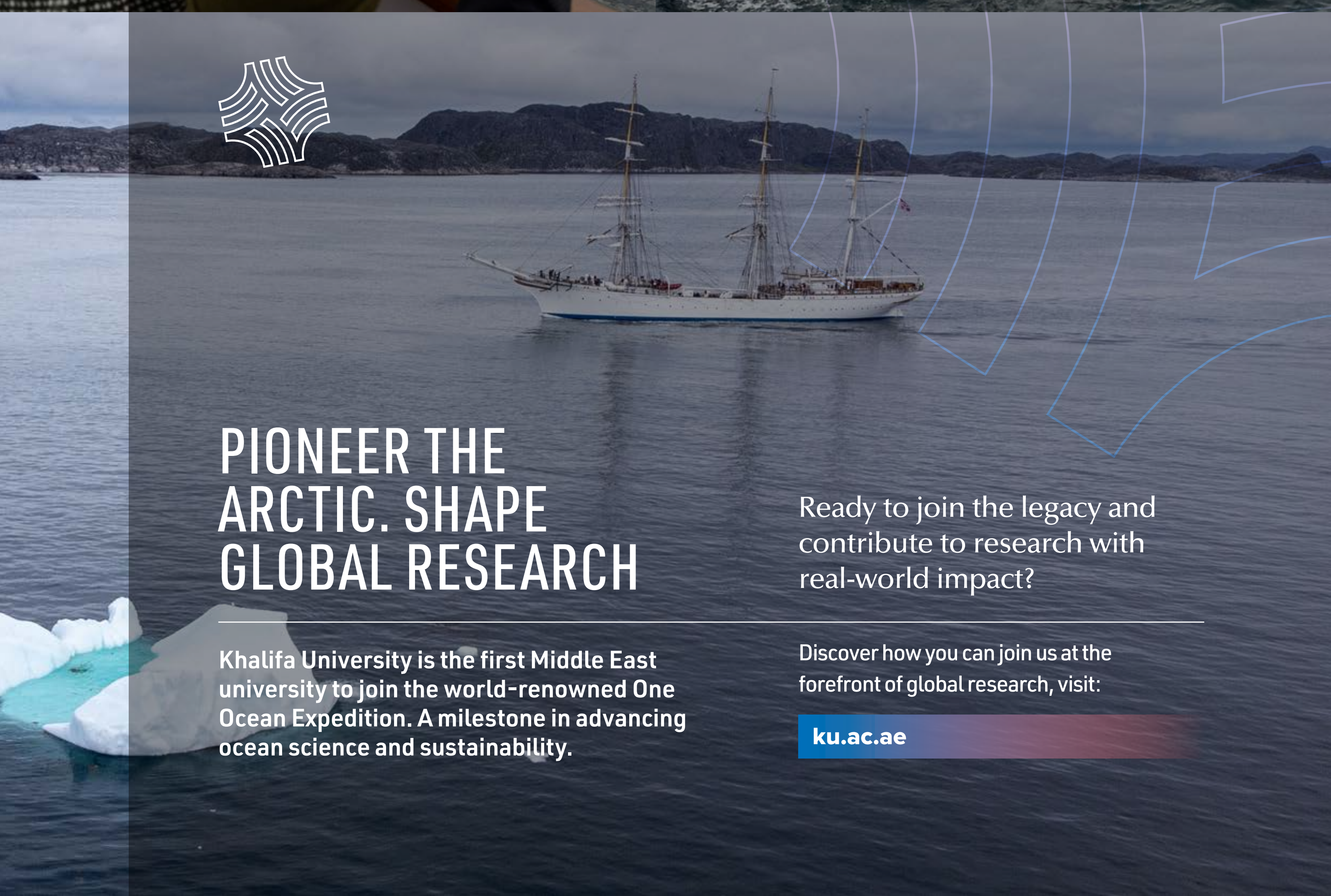
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ABOUT THE COVER

Seen through an AI lens, this issue's cover visualizes a hyperconnected future shaped by AI-powered infrastructures and represents the seamless integration of cybersecurity, communication, transport, and energy—the systems rewriting how we live, work, and connect.

COVER IMAGE: PETER CROWTHER

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ABOUT KHALIFA UNIVERSITY

The internationally top-ranked Khalifa University of Science and Technology is the one university in the UAE with the research and academic programs that address the entire range of strategic, scientific and industrial challenges facing the UAE's knowledge economy transformation and our rapidly evolving world.

Its world-class faculty and state-of-the-art research facilities provide an unparalleled learning experience to students from the UAE and around the world. The university brings together the best in science, engineering and medicine in the UAE, to offer specialized degrees that can take promising high school graduates all the way to top-rated doctorate degree holders.

ABOUT KU EXPLORER

KU Explorer covers the scientific achievements of the internationally top-ranked Khalifa University of Science and Technology. The website is updated weekly with new stories on a range of topics.

Whether you're a student, academic, industry professional or simply interested in learning more about the latest scientific advancements from Khalifa University of Science and Technology, KU Explorer has something for everyone.

We invite you to join us on this journey of discovery and exploration. You can stay up to date with our latest research news by following us on social media or subscribing to our newsletter.

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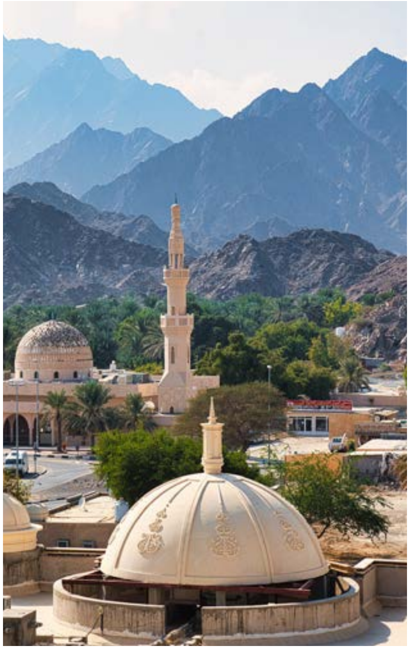

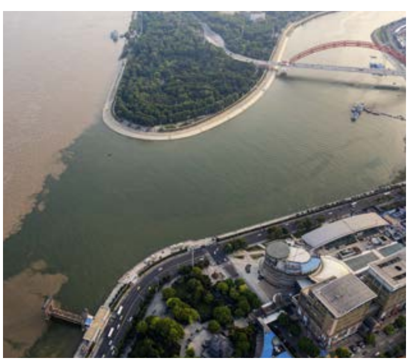

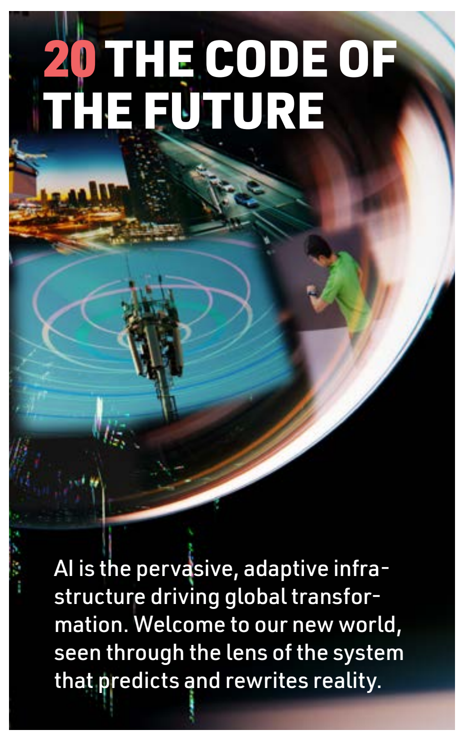

20 THE CODE OF THE FUTURE
AI is the pervasive, adaptive infrastructure driving global transformation. Welcome to our new world, seen through the lens of the system that predicts and rewrites reality.

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Join us at this year's KU Innovation & Research Exhibition from February 11–13, 2026.

EDITOR'S LETTER

"Our innovations show what happens when technology, ambition, and strategic investment meet real-world needs."

Today's world is defined by rapid technological change, and the challenge to digitize the future is far too complex for any single institution to tackle alone. It requires a collaborative ecosystem—where academia, industry, and government converge to turn ideas into impact. At Khalifa University, collaboration is the engine that drives our mission to transform research into real-world, scalable solutions, contribute to the UAE's knowledge economy and inform policy.

That spirit of partnership comes alive in fields as diverse as agriculture and advanced communication. In agriculture and food security, our joint Center of Excellence in Agri-Robotics and Automation with Silal is a model for how academia and industry can provide solutions with tangible economic and societal value. Together, our researchers and Silal's agricultural experts are testing how robotic pollinators, AI-driven crop diagnostics, and autonomous monitoring can support food production in extreme climates—a challenge that will soon extend far beyond the UAE. From wearable devices to AI-powered drones and plant disease detection apps, our innovations show what happens when technology, ambition, and strategic investment meet real-world needs.

The same collaborative energy is shaping the future of connectivity. At our 6G Research Center, researchers are working closely with strategic entities including the Telecommunications and Digital Government Regulatory Authority and the IEEE GenAINet Initiative to set the regional and global standards for next-generation connected systems. These collaborations are laying the foundation for intelligent, adaptable networks—systems that combine AI, sensing, and computing to support autonomous vehicles, secure communication, and seamless human–machine interaction. Whether through tools like TelecomGPT or breakthrough research in interference management for "smart" wireless environments, our shared mission is clear: to build network technologies that think, learn, and deliver.

Across the water, energy, and sustainability landscape, partnerships are also driving transformation. From the Advanced Power and Energy Center to the Research and Innovation Center on CO_2 and Hydrogen, our teams are collaborating with international and regional stakeholders to expand the boundaries of clean power generation, grid integration, and future-ready energy storage. AI-driven microgrid design, algorithms for interconnected power systems, and optimization frameworks for hydrogen fueling and industrial decarbonization are just a glimpse of how these alliances are finding solutions that are not only technically groundbreaking, but deeply aligned with national sustainability priorities.

And as mobility takes to the skies, our aerospace partnerships with industry leaders like Manta Aircraft and UASystems are accelerating the shift from research outcomes to operational capabilities. Today, our robotics and aviation researchers are taking trajectory prediction algorithms, collision-avoidance systems, and autonomous flight control out of the realm of simulation and into real-world testing.

Partnership is also playing a key role in advancing our work in materials, manufacturing, and healthcare. At our Advanced Digital & Additive Manufacturing (ADAM) Center, we work closely with industrial partners to pioneer next-generation materials and innovative 3D printing techniques, accelerating the adoption of smart production for strategic sectors like aerospace.

Similarly, in the critical area of health, our collaborations are translating biomedical research into clinical practice, focusing on AI-driven diagnostics, personalized medicine, and advanced regenerative therapies to improve patient outcomes across the region.These efforts are powered by key alliances with major healthcare providers, ensuring our innovations move swiftly from lab to patient.

This issue of Explorer showcases Khalifa University as a nexus, where progressive scientific research, government strategy partner and industrial capability come together to deliver breakthroughs that matter.

Fear rewired: using VR to treat phobias

An innovative virtual reality therapy platform combines cutting-edge technologies and secure data to help patients face their deepest anxieties, and take control of their lives.

For most people, stepping into an elevator is nothing more than a quick ride to another floor. But for someone with claustrophobia, an intense fear of enclosed spaces can trigger overwhelming anxiety and panic. Recreating that level of psychological distress in a safe and controlled setting is a challenge that traditional therapy often struggles to meet.

Claustrophobia affects millions worldwide. Whether it's set off by elevators, airplanes, crowded rooms or narrow stairwells, the condition can severely limit a person's daily life. To address this, a research team at Khalifa University is developing an innovative exposure therapy that blends three cutting-edge technologies: the metaverse, blockchain and NFTs.

Facing fears in the metaverse

KU's therapy is built around a "claustrophobia metaverse," an immersive world where patients can safely confront their fears. Wearing a VR headset, they can choose from different triggers, such as the experience of lying in a virtual MRI scanner. "Our goal was to create an experience that is immersive, secure, and uniquely tailored to each patient," explains Ahmad Musamih, the project's lead researcher. "Claustrophobia is often triggered by very specific settings. The metaverse lets us recreate those environments with precision."

But creating realistic virtual experience is only part of the challenge. Keeping patients' records and therapy progress safe is just as important, especially when it comes to mental health. To protect such sensitive information, the team uses blockchain technology, a tamper-proof digital ledger which acts like an ultra-secure notebook that no one can erase or alter.

To guarantee this information is completely safe from manipulation, it's uploaded to a secure network that splits the data into pieces and stores it across computers all over the world. This makes it much harder for hackers to find or delete. The team also strengthened the platform's security by using a specialist code-analysis tool that detects vulnerabilities and fixes any digital loophole hackers could exploit.

"One of the biggest challenges in mental health is maintaining con-

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fidentiality without losing the ability to track progress," says Khaled Salah, a member of the research team. "Blockchain solves this by recording milestones in an encrypted, permanent format. Personal details remain hidden, but patients, clinicians, and regulators can still verify the records."

Digital rewards for real-world victories

Building on the secure foundation of blockchain, the therapy uses NFTs, unique digital keys, to create a personalized experience. Each patient receives a private "entry pass" that unlocks their personal therapy session in the metaverse.

As patients progress through their treatment, they earn a digital reward that serves as a meaningful record of their achievements in overcoming fear. "Patients feel a real sense of ownership and accomplishment, which encourages them to stay committed to their treatment," explains Mohamed Seghier, a researcher on the team.

While advanced technologies power the therapy, the team stresses that its success depends on keeping patients' needs at the heart of their work. "Beyond the technology, our focus is always on the patient," notes team member Hamdan Hamdan. "By making therapy both engaging and secure, we aim to reduce stigma and make treatment more approachable for people who might otherwise avoid seeking help."

Predicting effective and personalized treatment

The team plans to gather feedback from patients and mental health professionals to continuously refine and improve the therapy experience. Future enhancements may include AI-driven personalization and machine learning algorithms that predict which exercises will be most effective for each patient, as well as assess the risk of relapse.

Thanks to its flexible design, the therapy isn't limited to claustrophobia alone. Virtual environments can be easily adapted to simulate a wide range of scenarios—open spaces for agoraphobia, tall buildings for acrophobia or crowded social settings for anxiety disorders.

This research supports the UAE's vision to lead in technology and personalized healthcare while contributing to the growing conversation around mental wellness. By combining advanced healthcare techniques with blockchain technology, the platform caters to a clientele accustomed to premium services and could become a major draw for high-end medical tourism.

"This research exemplifies the UAE's commitment to technological leadership," says researcher Mohammed Omar. "Applying blockchain and NFTs in mental health therapy is a game-changer, delivering unprecedented transparency, security and patient empowerment."

Musamih, A., Salah, K., Jayaraman, R., Seghier, M., Hamdan, H., Ellaham, S., & Omar, M., Enhancing claustrophobia exposure therapy: A blockchain and NFT-enabled metaverse approach. *Comput. Hum. Behav,* **160**, 108364, 2024.

On-demand shopping just got smarter

Aerial drones and a new bidding system for delivery jobs promise faster gratification.

Online, on-demand shopping from the comfort of your couch promises convenience and instant gratification. But getting that package to your doorstep is not always as fast and affordable as it could be. The real headache lies in the final stretch of its journey, known as last-mile delivery (LMD). Urban congestion, limited parking and fewer deliveries per route all add up, making this the most expensive and complicated part of the process. As e-commerce continues to grow, so does the pressure to solve this bottleneck.

Most attempts to optimize LMD simply focus on the distance travelled on the last leg but that doesn't always guarantee the shortest delivery time or provide the most cost-effective solution. Now, researchers from the Department of Computer Science at Khalifa University have formulated an LMD framework that harnesses crowdsourced auctions and multiple delivery systems, including drones, to help solve the problem.

"The primary goal is to address the growing demand for efficient, cost-effective, and time-sensitive LMD solutions; particularly in urban environments where traditional logistics often struggle," explains Rabeb Mizouni, who led the team. "Drawing from real-world auction mechanisms and collaborative resource allocation models, we developed a framework that merges economic principles with smart mobility technologies."

The framework kicks off with a bidding race. When a new delivery request appears, nearby delivery agents with ground vehicles or drones can place a real-time bid to handle the job. But it's not just about offering the lowest price. The system also considers ratings of previous performance and how close the bidder is to the delivery route.

In simulations, the team's approach completed 24% more LMDs, while halving the average delay time, compared with two other modelling strategies designed to deal with the LMD problem. Simulated profit on jobs rose almost sixfold.

The drones were especially useful because they could avoid ground-level traffic congestion in urban areas or more easily reach remote locations. Meanwhile, the crowdsourced auctions optimized real-time, dynamic task assignment.

"The framework has strong potential for real-world applications, particularly by on-demand service platforms such as Uber, Careem, Talabat and Deliveroo," Mizouni says. “These platforms already operate with dynamic, crowdsourced fleets and could benefit significantly from integrating an auction-based, hybrid delivery mechanism to enhance efficiency, reduce costs and better meet time-critical customer demands.”

The team is exploring ways to deploy its framework in the real world, through collaborations and prototyping, including using the framework on blockchain to strengthen the system’s security and robustness. The researchers also plan to further improve LMD efficiency by enhancing coordination between drones and delivery couriers.

“We developed a delivery framework that merges economic principles with smart mobility technologies.”

Odeh, E., Singh, S., Mizouni, R. & Otrok, H. Crowdsourced auction-based framework for time-critical and budget-constrained last mile delivery. *Inf. Process. Manage.* **62** 103888 (2025).

DIYUN ZHU/ MOMENT/ GETTY IMAGES

Drones can bypass city traffic to deliver packages.

Microgrids promise decentralized power and a greener future

High costs are limiting the widespread adoption of small-scale energy generation, but getting AI involved could revolutionize our energy future.

WITTHAYA PRASONGSIN/ MOMENT/ GETTY IMAGES

When the lights go out, with our dependence on a steady flow of electricity becomes all too clear. From keeping hospital equipment running to powering the devices we use every day; reliable energy is a necessity. That's where microgrids come in.

For decades, these small-scale electricity networks, able to operate independently of larger urban grids, have delivered reliable power to remote and underserved areas. They can also provide backup energy systems for urban facilities including hospitals, industrial parks, and even entire neighborhoods. Many cities rely on a combination of renewable sources and fossil fuels for self-sufficiency and to balance fluctuations in energy generation and demand.

But as the world moves towards a sustainable energy future, microgrids are emerging as key enablers of change, says Prof. Ahmed Al-Durra, Associate Provost for Research at Khalifa University. "[Microgrids] provide reliable, resilient local power and integrate renewable sources. They also stabilize the grid, improve energy security, and offer efficiency benefits," explains Al-Durra, who is developing systems to encourage more communities to adopt the technology.

Sustainable and decentralized

Microgrids play a pivotal role in the global energy transition, by accelerating renewable energy generation and use at the local level. In the Gulf region, they allow countries to leverage abundant solar energy, ultimately reducing dependence on fossil fuels and improving resilience against extreme climate conditions.

By connecting to other grids, including larger main networks, they can bring greater energy security during periods of low production, natural disasters or equipment failures. "Microgrids provide flexible, reliable energy for communities and industries. This bridges the gap between large-scale renewable deployment and on-demand electricity access," Al-Durra explains.

For all their promise, however, microgrids are rare. Initial costs are high and without reliable insights into cost savings and performance, communities are reluctant to implement them. So how do we convince communities that the investment is worth it?

Al-Durra and colleagues are AI models to address this challenge. Their goal is to transform smaller, local power lines that take energy from the main grid to smaller communities into self-reliant microgrids running on renewables and stored energy.

Their model helps communities determine the best design their microgrid. It creates a blueprint based on the number of solar panels, battery size, the combination of such components and daily weather variations. This keeps costs low while generating enough electricity. "AI models are important because they enable intelligent, data-driven planning and operation, optimizing energy flows, enhancing reliability and facilitating renewable integration," says Al-Durra.

When the researchers simulated a real-life scenario using data from a remote Australian community, they found that an AI-powered, intelligent microgrid could save communities 65% of their costs and cut 98% of carbon emissions.

AI-powered, intelligent microgrids could save communities 65% of their costs and cut 98% of carbon emissions.

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Fair trade for electricity

In a future where more communities implement renewable energy microgrids, more small-scale electricity producers will become capable of peer-to-peer trading instead of relying on centralized grids. Al Durra and colleagues say that this could revolutionize the electricity market, making energy systems consumer centric.

To maximize the benefits, the team is developing frameworks that ensure fairness during energy exchange. A major challenge is accounting for the physical constraints of the network, such as energy losses. The framework incorporates fair loss-sharing, splitting economic gains so that losses are fairly divided between trade participants. It also ensures that each microgrid, regardless of size or location, receives the same profit per unit of energy it trades.

In a computer simulation, the team found that trading using their model to trade directly with other microgrids would reduce operating costs by 13% compared with trading exclusively with a larger main grid. "A new model for transactive energy trading among multiple microgrids is crucial to coordinate decentralized resources efficiently, maximize economic benefits, and ensure stable, scalable, and sustainable energy exchange across interconnected systems," says Al-Durra.

From niche to mainstream

Looking ahead, Al-Durra expects microgrids to become more decentralized and interconnected. "They will not only be capable of connecting multiple energy systems, but also of bringing together diverse renewable sources. They will also integrate advanced storage and have AI-driven control so that the entire system operates optimally," he says.

For microgrids to join the mainstream, they need to become more reliable and cost-effective. Achieving this, he suggests, includes standardized design, adopting AI-driven management and improving energy storage. Policymakers must also attract investment by offering incentives, creating grid-integration standards and developing financing mechanisms.

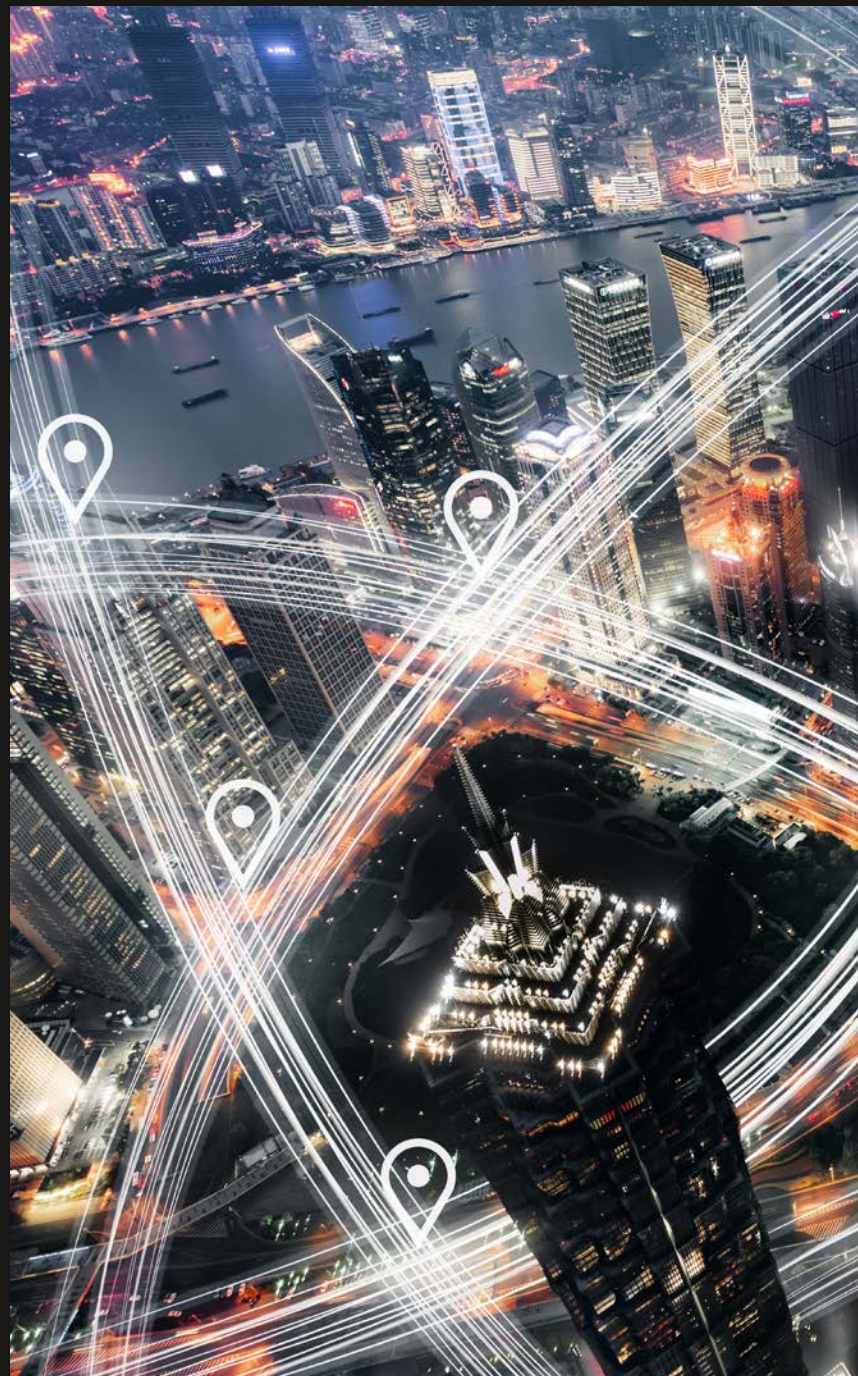
Al-Durra believes early adoption of the technology will be focused on remote areas, critical infrastructure and industrial clusters. Integration into existing urban grids and the emergence of multiple, interconnected smaller grids would follow. While widespread adoption will likely be gradual, the pace could be fast in regions such as the Gulf, where solar resources are abundant and government investment is strong. "Overall, significant penetration could be achieved within the next 10 to 15 years, with coordinated efforts."

1. Elimam, M.; El Moursi, M; El-Fouly, T.H.M; Al-Durra, A.; and Al Hosani, K.H. Transactive energy trading among multi-microgrids in a distribution network with fair loss sharing. *Applied Energy* **381**, 2025.

2. Alam, M.M.; Hossain, M.J.; Zamee, M.A.; and Al-Durra, A. Design and operation of future low-voltage community microgrids: An AI-based approach with real case study. *Applied Energy* **377**, 2025.

Trust issues: How AI picks its teammates

In a world where AI increasingly learns from our devices, a dynamic, trust-driven framework promises security, scale and reliability without risking privacy.



What if your phone could help train a global AI system, perhaps contributing to a smarter healthcare app or improving voice recognition, all without you lifting a finger. Now imagine this happening across millions of devices, all learning together while keeping your private data exactly where it belongs: with you.

This is the promise of federated learning, a technique that allows AI to get smarter by tapping into multiple devices without ever accessing personal data directly. Instead of uploading your information to a central server, your phone trains the AI locally and shares only a summary of what it knows.

But how do we know which devices can be trusted?

"If you allow unverified devices into the training process, one bad actor can poison the model for everyone," explains project leader Hadi Otrok from the Department of Computer Science at Khalifa University. "We needed a system that could tell the difference between a reliable contributor and a malicious one, automatically."

AERIALPERSPECTIVE IMAGES/ MOMENT/ GETTY IMAGES

"Trust isn't just a nice-to-have. It's the backbone of making federated learning work in the real world."

Mario Chahoud from the Artificial Intelligence & Cyber Systems Research Center at Lebanese American University worked with Khalifa University researchers Jamal Bentahar and Azzam Mourad to develop a trust-driven system designed for complex, unpredictable environments such as smart cities and mobile edge networks. "It's like choosing teammates for a group project," says Bentahar. "You only want the ones who'll do solid, consistent work, not those who might sabotage the outcome."

Their system continuously scores each device based on its past behavior, consistency and alignment with others. Smart algorithms then use the scores to select the best combination of reliable, diverse and well-placed contributors. To manage the computations at scale, the team uses containerization to create secure, lightweight virtual workspaces that can be quickly launched and shut down on any infrastructure.

"Think of it as setting up clean, disposable workstations that devices can use only when needed," says Mourad. "Our orchestration process ensures untrusted environments don't compromise the learning. It's practical, and it's deployable today."

But getting it right wasn't easy. "One of our simulations collapsed because all the clients 'moved away'. Our location-based dataset had every device suddenly disappear," Otrok recalls. The biggest challenge was balancing robustness and efficiency. "We had to make sure our trust mechanism could catch deception without overwhelming the system," he says.

Through it all, the Khalifa University team kept sight of one goal: helping AI grow not only smarter, but also wiser about who it learns from. As Bentahar puts it, "Trust isn't just a nice-to-have. it's the backbone of making federated learning work in the real world."

Chahoud, M.; Mourad, A.; Otrok, H.; Bentahar, J.; Guizani, M., Trust driven On-Demand scheme for client deployment in Federated Learning. *Inf. Process. Manag.*, **62** (2025), 103991.

ANDRIY ONUFRIYENKO/ MOMENT/ GETTY IMAGES

A 6G bottleneck breakthrough

As wireless systems grow crowded, one clever design may hold the key to faster, smarter communication.

Imagine gaming with next-to-zero lag, transferring massive files in a blink or joining lifelike holographic-style meetings from the comfort of your couch. These offer just a glimpse of the promise of the ultra-high data speeds of sixth generation (6G) wireless networks. But realizing this vision depends on solving a stubborn challenge: signal interference.

Shimaa Naser, Sami Muhaidat and Zhiguo Ding, from the KU 6G Research Center and the Department of Computer and Information Engineering, are focusing on two particularly disruptive forms of interference that limit performance, including for the Internet of Things (IoT) and Vehicle-to-Everything (V2X) networks, where cars communicate with other vehicles, pedestrians and road infrastructure.

One of the challenges the team is tackling is intersymbol interference (ISI) which happens when units of data, or symbols, overlap, making it hard for receivers in cell phones or cars to distinguish them accurately. This is a particular problem at high data rates, when symbols are very close in time. The second major challenge is inter-user interference (IUI), which is common in dense networks, where multiple users or devices transmit data simultaneously on overlapping frequencies, causing signals to collide, degrading the receiver's performance.

To counter these challenges, the team developed a receiver that combines two advanced techniques. The first is time-reversal (TR) waveforms, which focus energy in space and time. The second is non-orthogonal multiple access (NOMA), which allows multiple users to share the same channel by encoding each user's data at a different power level. The combination significantly enhances spectral efficiency, a key indicator of how effectively a network uses its bandwidth.

"Integrating TR with NOMA enables higher spectral efficiency and more reliable connectivity by leveraging TR's spatial-temporal focusing and NOMA's power-domain multiplexing," Muhaidat explains.

What sets the approach apart is its simplicity and efficiency. Unlike conventional methods, it does not require the transmitter to do complex processing, called precoding, and it would work with low cost, less sophisticated receivers.

"It achieves up to 98.13% average error rate improvement and is a scalable solution suitable for 6G applications," Naser says. The system would also enable more energy-efficient communication, critical for sustainability and battery life.

Following the team's numerical simulations of the TR-NOMA scheme, the next step is experimental testing at the 6G Research Center. "Our research has potential for practical implementation, and real-world relevance for IoT and V2X communications," Muhaidat says.

Meanwhile, the team plans to investigate the use of adaptive TR techniques that can dynamically adjust, to manage changing interference levels and overcome the challenges of implementing the system in real-world high-mobility and high-density V2X and IoT networks.

Naser, S., S. Muhaidat S. & Ding, Z., Receiver architecture design and analysis for NOMA-based multi-user communication systems. *IEEE Trans. Wirel. Commun.* **24**, 7, 5738-5751 (2025).

Cleared for takeoff: The algorithm behind safer air traffic

An algorithm that predicts trajectories of air taxis and other small aircraft could help avoid collisions and get air travel off the ground.

Flying cars have captured the public imagination since the 1960s, when the American TV show *The Jetsons* followed the adventures of the futuristic—and often airborne—Jetson family. Now, that sci-fi vision is starting to come true: air taxis, cargo drones and other aero-cars are poised to begin crisscrossing city skies within the next few years.

But with a swarm of small vehicles sharing the same airspace, managing air traffic to prevent collisions and ensure an orderly flow of traffic becomes a critical challenge. At Khalifa University aerospace engineers Roberto Sabatini and Alessandro Gardi are devising new ways to accurately predict the trajectories of these aircraft of the future—a key step toward safe and scalable air travel.

Conventional air traffic management algorithms lack the accuracy and precision needed to handle so many small aircraft flying at low altitudes over a city. To address this, the team, which also includes researchers from universities in Australia and France, developed a more effective algorithm tailored to future air travel. The KU authors lead the Falcon program, a pioneering initiative bringing together researchers, educators, and industry leaders to tackle critical challenges in sustainable aviation, advanced air mobility, and commercial spaceflight.

Rather than replacing human controllers and pilots, the algorithm is designed to support them, by predicting aircraft trajectories and using that information to balance capacity and demand, Sabatini explains.

"We need advanced AI algorithms that continuously observe the environment and make an online situation assessment; and then modulate the level of automation in such a way that we meet safety requirements while maximizing efficiency and sustainability," the researcher says. Efficient management is key to reducing greenhouse gas emissions, he adds.

The team found that the algorithm improved accuracy by 50% compared to using raw data alone. It also slashed computation time in half compared to conventional methods. "It's quite dynamic in nature compared to anything that has been invented yet," Sabatini says.

The next step is to test the technology in a real-world setting. Working with industry partners such as Manta Aircraft and UASystems, which aim to bring air taxis to the Emirates' skies in the next few years, the team will soon trial the prediction algorithm using real transport aircraft in a designated flight area.

For urban air transport to become a reality, the entire industry needs to innovate together, says Sabatini, who adds that new government regulations will also need to be developed.

"We're transforming the airspace so that it can be safely managed," he says. "And in parallel, we are redesigning flight vehicles and trajectories."

Xi, Y.; Liang, M.; Gardi, A.; Sabatini, R.; Delahaye, D., Accurate and fast-converging trajectory prediction based on Long Short-Term Memory neural networks. *Journal of Air Transport Management*, **125**, 2025.

KINWUN/ ISTOCK / GETTY IMAGES PLUS

Precision control comes to bendy, twisty robots

Modelling the motion of robots with soft and rigid components opens the door to applications in dynamic and unstructured environments.

"Efficient simulation is essential for real-time control, planning and design of advanced robots."

Robots made from rigid materials boast impressive strength, whereas robots made from soft materials excel in flexibility. But what if we could merge the best of both worlds? A hybrid robot that's both strong and flexible would have the edge in many applications, such as picking fruit or surgery.

Predicting the motion of these dual-material robots, however, is not straightforward. While existing computer algorithms expertly control the limited movements of rigid robots, extending these rules to robots with soft components that can bend and twist in countless ways presents a challenge.

Now, a team led by Anup Teejo Mathew and Federico Renda, mechanical engineers at Khalifa University, has reported a model that can simulate and precisely control rigid-soft hybrid robots. "Efficient simulation is essential for real-time control, planning, and design of advanced robots," says Mathew. "Fast and accurate robotic simulation is also critical for training and data generation to support machine learning and AI in the future."

Extending existing models for rigid-body robots, the two engineers derived mathematical formulations for the static and dynamic behavior of hybrids. Building on this, they developed algorithms capable of quickly and efficiently computing their motion. The approach was then tested on a range of hybrid robots, including an octopus arm reaching out and an underwater soft-rigid robot with flagella that deform in a spiral manner to propel it forward.

Critically, the new model uses the minimum degrees of freedom; the smallest number of independent parameters needed to accurately represent an action. This allows faster and more accurate analysis than traditional ways of simulating hybrid robot movement.

The model could one day be used in clinical settings for applications that require safe and adaptive interactions between robots and humans, or in search and rescue when a robot might need to squeeze through tight gaps.

The wider goal of the researchers is to build robots that can carry out precision tasks at high speed and learn at the same time. "Our model helps bridge these needs, driving the development of adaptive and intelligent machines that are ready to operate in dynamic and unstructured environments," says Mathew. "We are excited about the broad possibilities that this approach opens across robotics, healthcare, AI and beyond."

Mathew, A.T.; Feliu-Talegon, D.; Alkayas, A.Y.; Boyer, F. and Renda, F. Reduced order modeling of hybrid soft-rigid robots using global, local, and state-dependent strain parameterization. *Int. J. Robot. Res*., **44** (1), 129–154, 2025.

PIRANKA/ E+/ GETTY IMAGES

A rigid robot picks fruit—an everyday task where flexible robots would excel.

AI learns the language of code to outsmart cyber threats

A software vulnerability checker with the potential to become a repair shop could keep critical computer systems one step ahead.

British retailer Marks & Spencer suffered a cyberattack that compromised its customer data in April 2025.

CHRIS RATCLIFFE/BLOOMBERG VIA GETTY IMAGES

High-profile cyberattacks, such as the one that compromised British retailer Marks & Spencer's customer data in April 2025, highlight the need for better ways to detect software vulnerabilities in the computer systems that increasingly control everything, from oil pipelines to hospital records.

To help, an international research team including Khalifa University's Merouane Debbah, has developed SecureQwen, a smart software checker that automatically detects and flags vulnerabilities for repair. Powered by an artificial intelligence model trained in the language of computer code, SecureQwen could even identify weaknesses that it had not explicitly been taught or come upon before.

"The scale of the problem is overwhelming the conventional approach of detecting vulnerabilities by using human experts to find flaws in the code," says computer scientist Debbah, director of the 6G Research Center at Khalifa University that focuses on sixth generation wireless technologies.

Previous AI-powered software checkers only detected security flaws that they had explicitly been trained to recognize, leaving them one step behind in the cybersecurity arms race. To overcome that limitation, Debbah's team investigated large language models (LLMs) that are trained on vast amounts of text to power tools such as ChatGPT.

"One big advantage of LLMs is their capacity for generalization," Debbah says. When faced with situations that they have never met before, LLMs can extrapolate from their training to successfully respond.

The team finetuned an LLM called Qwen, which is like ChatGPT but 'speaks' English, Mandarin and Python. "Python has become the most common computer language because it is tailored to machine learning applications, which all software developers are now incorporating," Debbah says. Programmers also share large amounts of Python code in open access depositories, including to flag code containing known vulnerabilities.

Drawing on these Python depositories, the team curated a collection of known vulnerabilities, and then finetuned Qwen LLM on this dataset. The resulting AI software vulnerability detection model—SecureQwen—could find vulnerabilities in Python code with 95% accuracy, according to Debbah.

Beyond detection, the tool also categorizes each vulnerability, enabling coders to find and patch the most critical security risks. "SecureQwen works as an efficient software audit tool," Debbah says.

The team is aiming to develop the software into an autonomous cybersecurity reasoning system (CRS) that not only detects vulnerabilities but automatically repairs them. "CRS is the big target for the entire cybersecurity community, and that's the next step for us" Debbah says.

Mechri, A., Ferrag, M.A., Debbah, M. SecureQwen: Leveraging LLMs for vulnerability detection in python codebases. *Comput. Secur.* **148**, 104151, 2025.

Strategic AI predicts cyberattacks long before the strike

Accurate forecasts of future cyberthreats enable the tactical development of defensive countermeasures.

In an era when digital infrastructure is as vulnerable as medieval castles once were, cybersecurity has become a question of prediction and strategy. With geopolitical tensions rising, anticipating the nature of future cyberattacks and strategically developing defensive capabilities in response is a prudent tactic.

"During the age of castles, it was impossible to perfectly fortify against all enemies in all directions," says Ernesto Damiani from the Center for Cyber-Physical Systems at Khalifa University. So, it was imperative to prioritize defenses according to your predictions about the besieging army's approach. "Today, the same tensions play out in cybersecurity," Damiani says.

Modern cyberattack strategies are evolving; ranging from brute-force attacks that overwhelm critical online systems to stealth attacks that quietly infiltrate and compromise a system from the inside. Each requires a different kind of defense.

If we could accurately forecast the types of cyberattack that we are most likely to face several years from now, this would be a powerful tool, Damiani says, because we could gain a head start on developing the right defensive tools to counter the threats.

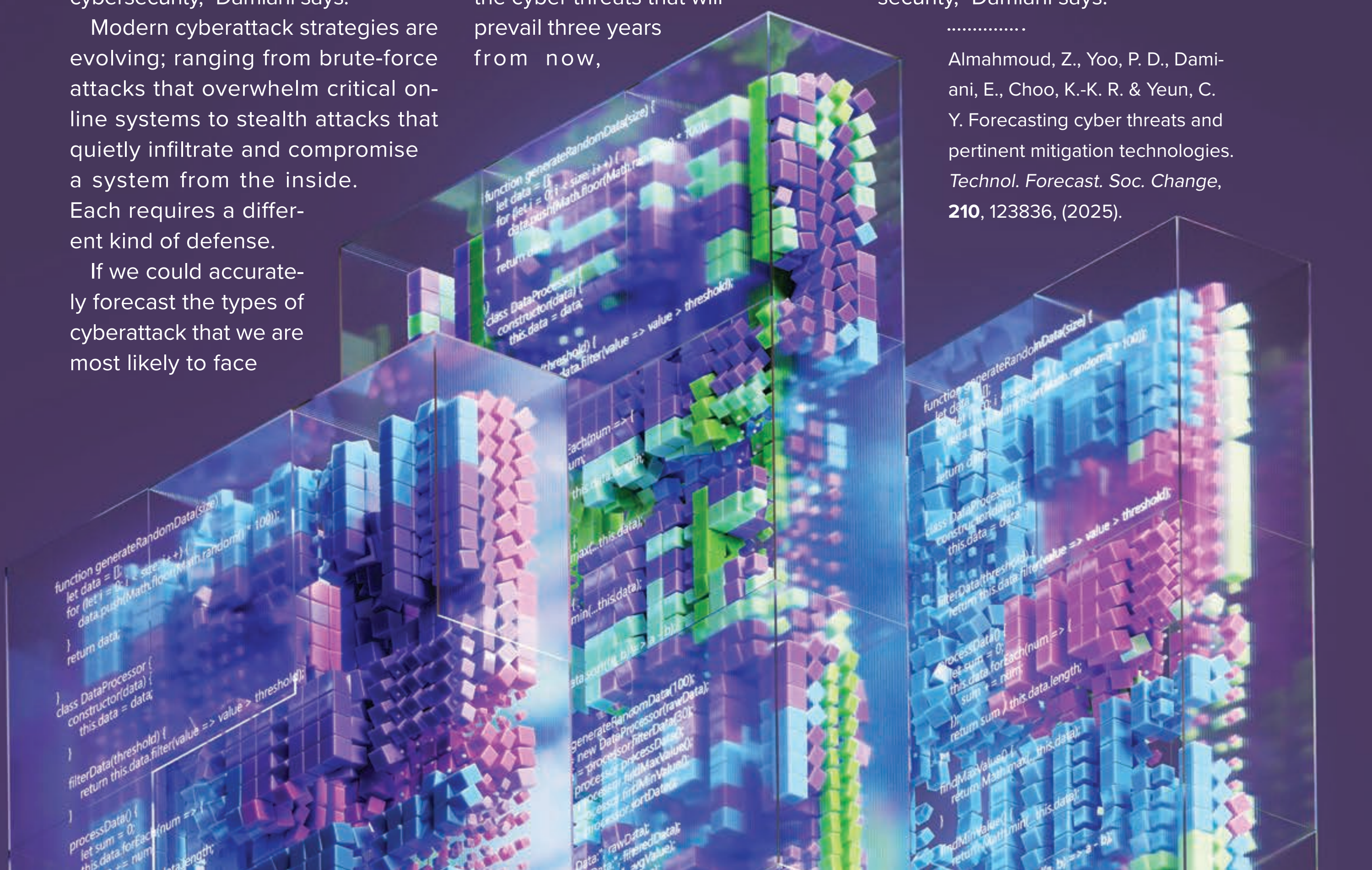
Subject matter expert forecasts are a good starting point, but they are prone to human subjectivity and bias. "We wanted to develop an AI capable of providing impartial, accurate strategic cybersecurity advice," Damiani says. "But this challenge is very difficult to solve with vanilla AI."

AI's use in cybersecurity today is limited to immediate operational activities such as detecting attacks and guiding the response. "To develop a tactical AI to predict the cyber threats that will prevail three years from now, we had to develop specialized training," says Damiani, who co-led the work. The team had to teach the AI to understand the temporal context of its training data, thereby enabling it to project forward and predict the future cyberattack landscape.

The resulting AI strategic assistant was tested on part of the past that it had not encountered during its training. "We took the model five years back in time, asked it to predict cyberattack trends in the following three years. We then compared that with what actually happened," Damiani says. The model's predictions for the volume of different cyberattack types were highly accurate, within 10% of what really happened.

Several cybersecurity companies have already expressed interest in the AI tool, Damiani says, but the immediate focus is on refining the model's memory-encoding to further sharpen its predictive capabilities. The utility of an AI with medium-term strategic capability could be far-reaching. "I see potential applications for our specially trained strategic AI far beyond cybersecurity," Damiani says.

Almahmoud, Z., Yoo, P. D., Damiani, E., Choo, K.-K. R. & Yeun, C. Y. Forecasting cyber threats and pertinent mitigation technologies. *Technol. Forecast. Soc. Change*, **210**, 123836, (2025).



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INSIDE VIEWS

BEYOND THE NETWORK: HOW 6G WILL TRANSFORM OUR DAILY LIVES

Merouane Debbah, Professor at Khalifa University's Department of Computer and Information Engineering, Director of the 6G Research Center, and Ambassador for KU's Digital Future strategy.

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For more than two decades, Merouane Debbah has been at the forefront of wireless communications, mathematics and artificial intelligence. He has built top-tier teams at major industry players including Motorola, his first job after gaining his PhD at École Normale Supérieure Paris-Saclay in 2002, and later Huawei. He joined Khalifa University in 2023 to establish the 6G Research Center, a new hub dedicated to shaping the future of wireless technology.

Tell us about your role as Khalifa University's ambassador for Digital Future strategy.

I focus on bridging advanced research with the digital transformation goals of the UAE. I engage with stakeholders across academia, government and industry to align our efforts with these goals. I also promote awareness of how AI and 6G can be responsibly deployed to serve communities, industries and public services.

What makes the 6G initiative at Khalifa University a unique opportunity for innovation?

I've always been drawn to high-impact foundational problems, and 6G is a rare opportunity to redefine networks and the way intelligence and connectivity co-evolve. Leading the 6G initiative at KU allows me to channel theoretical work into strategic innovation with regional and global resonance.

How are you connecting cutting-edge research to the UAE's digital future?

Our research focuses on enabling 'intelligent connectivity' by grounding AI in reality, literally. We're exploring how AI systems, such as large language models (LLMs) and agents, can be integrated into wireless networks, making them self-aware and self-optimizing. We're also designing architectures that combine sensing, communication and computing; these are essential for immersive experiences and real-time virtual representations called digital twins. Our goal is to create faster networks that are also smarter, adaptive and more sustainable.

What are the team's most exciting research findings, and how might they affect future developments?

We are building intelligent systems that understand context, learn from historical patterns and act. In 2024, we introduced TelecomGPT, the first telecom-specific LLM. It allows telecom operators to optimize, diagnose and automate complex networks using natural language interfaces that facilitate human-computer interaction through voice or text. We've now launched TelecomGPT-Arabic to support regional models and broaden accessibility.

Our most forward-looking endeavor addresses large perceptive models. The models go beyond text and integrate signals from various data types, real-time optimization, and user intent to drive automation. Imagine an environment where a user simply says, "Optimize my home's energy use while I'm away," and the system autonomously reconfigures connected devices, manages charging schedules and balances loads in real time.

How important are collaborations in shaping your research priorities and turning ideas into real-world impact?

Collaboration is crucial. We see ourselves as a scientific hub and a strategic integrator; working across academia, industry and policy to shape the future of intelligent networks. Partnerships amplify our impact and ensure that research outcomes translate to real-world systems that benefit operators, users and society.

We worked with the GSM Association, which represents mobile network operators worldwide, to initiate the first open benchmarking platform for telecom LLMs. The platform, which defines performance standards, is a key step toward responsible AI adoption.

Together with the Telecommunications and Digital Government Regulatory Authority, we developed the UAE's 6G Strategic Vision. We also contribute to IEEE [Institute of Electrical and Electronics Engineers] initiatives, including chairing the IEEE GenAINet [Large Generative AI Models in Telecom Emerging Technology] Initiative that drives generative AI integration into telecom architectures.

AGRICULTURE
Drones and sensors help maximize yield while achieving zero water waste.

TRANSPORTATION
Drones are used to drop off parcels. Delivery vehicles are optimized by AI-powered delivery route prediction.

THE CODE OF THE FUTURE

AI is the pervasive, adaptive infrastructure driving global transformation. Welcome to our new world, seen through the lens of the system that predicts and rewrites reality.

COMMUNICATION
Data flows seamlessly via 6G, enabling uninterrupted, real-time merging of physical and virtual space.

HEALTH
Systems monitor biometric data to identify risk factors, slashing illness occurence rates.

INFRASTRUCTURE & ENERGY
AI anticipates surges and deficits, and instantly reroutes power, ensuring grid stability with near-perfect efficiency.

CYBERSECURITY
Systems detect, isolate and fight off breaches by predicting attacks and addressing weaknesses in real-time.

Farming the future

At Khalifa University's Center for Autonomous Robot Systems, an ambitious partnership with agri-giant Silal is revolutionizing farming, using smart machines to tackle climate change and grow food in the desert.

An AI-powered drone soaring over farmland, scanning fields to assess crop readiness. Below, a robotic pollinator mimics a bee's dance with perfect precision, ensuring every plant is fertilized. As the fruits grow, a wearable smart device helps farmers check for perfect ripeness, while a smartphone app acts as an early warning system, instantly detecting diseases before they can spread.

This isn't science fiction. It's happening now in the United Arab Emirates, where researchers are building the world's first fully autonomous, robotic greenhouse, designed to test whether robots can entirely replace human intervention in food production.

The UAE imports approximately 80% of its food[1], making it one of the world's most food-import-dependent nations. But at Khalifa University's Center for Autonomous Robot Systems (KUCARS), a team of researchers is working to flip that narrative.

Backed by Silal, a leading food hub in the UAE, the team is developing technologies that could revolutionize farming in extreme environments and potentially reshape the country's food production.

The Center of Excellence in Agri Robotics and Automation, which represents a joint investment of approximately 15 million dirhams between Khalifa University and Silal, serves as a proof-of-concept for technologies that address challenges extending far beyond the UAE's borders as climate change makes extreme farming conditions more common globally.

"We are living at the forefront of climate change challenges. Our soil is terrible. There is no fresh water, there is no rain. There are 165 days of sunshine, and the temperature right now is probably 45°C," says Shamal Mohammed, Head of AgriTech at Silal. "But we are not only developing solutions for our own food production, our innovation is going to be relevant to the rest of the world in the next decades."

The 2,000m^2 greenhouse will include real-world farming setups and a digital twin. This virtual environment mirrors the physical greenhouse in real-time, allowing researchers to test scenarios and optimize operations without disrupting actual crop production.

Irfan Hussain, associate professor at Khalifa University and agri-robotics team lead at KUCARS, and four specialized researchers are developing cutting-edge technologies to automate how crops are pollinated, monitored, and harvested. "We are building a facility that can provide a semi-realistic controlled environment during the process of translating our technologies from our KU agri-robotics lab to commercial greenhouses," he says.

"We are living at the forefront of climate change challenges."

Overcoming the GPS challenge

One of the biggest challenges Hussain's team faces is teaching robots to navigate without GPS. Traditional outdoor farming robots rely on GPS for positioning, but greenhouse indoor environments can block or weaken satellite signals.[2] Hussain's team has developed alternative methods that use cameras and sensors to help robots see and navigate, much like a person would.

"In underwater robotics, there is also no GPS," Hussain notes. Various techniques can be used to tell robots where they are in a lab, where

KU researchers are building the world's first fully autonomous greenhouse, designed to test whether robots can entirely replace human intervention in food production.

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there are no crops, no obstacles, he explains. But it is more difficult in a commercial greenhouse.

The team uses motion-capture systems to test these localization techniques first in the lab and then again in the visually rich environment of a real greenhouse, with crops, plants and obstacles.

Four technologies to change farming

Beyond the autonomous greenhouse, the KU-Silal partnership has yielded four specific technologies that are being developed for commercial use. Silal has committed four million dirhams to bring these innovations from lab prototypes to market-ready solutions. These include a robot that pollinates every plant with precision, a smart thumb device that accurately checks fruit ripeness, an AI-powered drone which monitors fields, and a phone app that can instantly detect plant diseases.

This robotic revolution goes beyond mere automation. Team member Rajmeet Bhourji's pollination technology represents a complete reimagining of how pollination works. "The bee might skip flowers," he explains, but when a robot pollinates, "it scans the whole plant, identifies where the flowers are, goes there and does the pollination." This is a fundamental improvement over biological pollinators. The robots work continuously with superior performance and precision.

The choice of target crops for testing is also strategic. "If we start with blueberries and later move to tomato or capsicum, it will take only 10-20% of the development effort of other crops. But if we start with tomatoes and customize that technology for blueberries, it's very challenging," says research associate Mashood Mohsan, who has developed a wearable thumb device that measures fruit ripeness without harming produce.

Meanwhile, Muhammad Owais, a postdoctoral researcher on the team, is developing an AI-powered smart agri-tech drone that fuses computer vision and agricultural expertise for similar purposes. The fourth startup centers around a smartphone application that provides real-time plant disease detection.

From lab to market

Industry leaders and government officials are already showing interest—drawn by the potential to cut labor costs and solve harvesting bottlenecks.

The team follows a systems-thinking approach that allows them to rapidly adapt technologies across disciplines—for example, techniques for underwater navigation now inform greenhouse robot localization.

The timing of KU's work proves particularly relevant as global food security concerns intensify. "After COVID, you saw every country having to depend on other countries for food security," Bhourji notes. "But after implementing robot-based solutions in greenhouses and vertical farming, everyone can easily grow their own food and sustain their own population."

Silal's Mohammed believes this allows UAE researchers to develop solutions for conditions other regions will face in the coming decades. The protected environment in agriculture that's necessary in the UAE today may become standard practice worldwide as temperatures rise and weather patterns become more unpredictable. "Some of these solutions might be relevant to local farms right now, but they might have a much bigger market somewhere else," he explains.

Owais envisions rapid expansion across crop types while Mohsan sees global market potential for standardized fruit assessment. "Our goal is to export the technology. The first step will be to develop and deploy it in local farms, and the next step will be to start exporting once we go for commercialization."

Bhourji also emphasizes the broader implications for food security and

international development. "We want to reduce technology costs so everyone can easily afford it; not only Western or European countries, but for every farmer around the world."

Challenges and the human touch

Despite promising developments, challenges remain. "Our AI-based method is still far from human accuracy, but we want to make it more accurate," Owais says.

The improvement process relies heavily on data collection and iterative training. "AI-based methods are data dependent. If we can get more accurate, more diverse data for any par-

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KU's digital and AI systems are designed to augment and enhance human capabilities rather than simply replace agricultural workers.

> **"After COVID, you saw every country having to depend on other countries for food security."**

ticular field or crop, then we can train our AI model to improve its accuracy," Owais explains. "This process involves collecting images and videos from real fields that capture different weather conditions and different ripeness levels, and all the other complexities that actually exist in real fields."

Partnerships with companies such as Silal are important because they provide real-world validation, according to Mohsan. "With Silal, we plan to test under diverse conditions to ensure reliability, allowing both the product and the AI to mature. Our goal is to launch commercial products by next year, validated through trials with local farmers."

Despite the focus on autonomous systems, Hussein and his team believe human expertise remains crucial to robotics application. Their robots and AI systems are designed to augment and enhance human capabilities rather than simply replace workers.

"When you work with end users, you understand what the requirements of the system are, how it will actually work. There's a lot of iterative process, but you come up with solutions that work," says Hussein.

1. https://www.foodexport.org/export-insights/market-country-profiles/united-arab-emirates/

2. Huang, Z., Shiigi, T., Tsay, L., Nakanishi, H., Suzuki, T., Ogawa, Y. and Naoshi, K. A sound-based positioning system with centimeter accuracy for mobile robots in a greenhouse using frequency shift compensation. *Computers and Electronics in Agriculture*, **187**, 2021

Fly, touch, monitor and detect: **How machines could change farming**

In the heart of the United Arab Emirates, a farming revolution is unfolding inside the greenhouses led by researchers from the Center for Autonomous Robotic Systems (KUCARS) at Khalifa University. There, a team of researchers is reimagining agriculture through robotics and smart technologies. Instead of farmers in fields, robots are doing the planting, tending and monitoring. From robotic bees and wearable ripeness detectors to disease-spotting apps and intelligent drones, these innovations are defining ways to tackle the world's toughest agricultural challenges made worse by climate change.

PollenMatic: Reimagining greenhouse pollination

Greenhouses come with their own set of challenges, especially when it comes to pollination. "It is a very controlled environment [with] lots of humidity and moisture you have to maintain compared with open farms," says Rajmeet Singh Bhourji, a postdoctoral researcher at KUCARS. To tackle this, Bhourji developed "PollenMatic," a robotic pollination system that mimics the natural behavior of bees through precise vibration technology.

The system has evolved through multiple versions: a handheld device that farmers can use, a mobile robotic pollinator, a gantry robot-based system for large-scale operations, and an ambitious small drone-based pollinator.

Why go robotic? "Bees used for pollination in indoor, controlled environments have short life spans. Robotic pollinators show superior performance with around 80% productivity compared with the 60% typical of bees," Bhourji says.

And unlike bees, robots can work around the clock without the need to sleep.

TouchRIPE: AI with a human touch

One of farming's trickiest activities is gauging fruit ripeness. For some produce, color gives a clear clue. But in fruits, such as avocado or kiwi,

The TouchRIPE wearable device can perform non-destructive fruit firmness testing using AI-based tactile sensing.

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determining ripeness can be challenging. "Visually, you cannot tell if they're ripe," says Mashood Mohsan, a research associate who joined the KUCARS team in 2023. "Humans can know the hardness of fruit, how firm the fruit is, just by pressing. This is known as human palpation."

Mohsan came up with "TouchRIPE," a wearable thumb device for measuring fruit firmness that reduces human errors in judgment while keeping produce intact. "It works by mimicking the way humans press fruit to judge ripeness, but instead of relying on subjective feeling, it uses vision based tactile sensing and AI to provide consistent and accurate results. The goal is to turn the intuition farmers use into a standardized, digital form."

Smart crop monitoring: A bird's eye view

Postdoctoral researcher Muhammad Owais is developing a smart AI-powered agri-tech drone. Designed to scan entire greenhouse areas without physical contact, the drone fuses computer vision and agricultural expertise to solve multiple problems simultaneously. It can provide quantitative data that surpasses subjective human assessment, and work with crops where traditional methods fail.

"Methods based on AI are data dependent. If we can get more accurate, more diverse data for any particular field or crop, then we can train our AI model to improve its accuracy," Owais says.

The team started with blueberries, a very expensive crop that is costly and weather-sensitive with a short harvest lifespan. To tackle the challenge, the system uses multiple imaging modalities, including infrared cameras that work regardless of lighting conditions, combined with RGB cameras for color analysis. The AI algorithms are trained on local data from across the UAE.

Initial testing has shown promising results, according to Owais. "We achieved around 60-65% accuracy in terms of ripeness, and 70% for yield information, but our goal is to achieve 80-90%."

Detecting plant disease: In real time

Existing agricultural AI solutions rely on generic datasets typically collected in controlled lab environments to identify plant diseases. That's where computer vision engineer Muhammad Fahad Nasir steps in. His prototype smartphone application uses AI models trained specifically for the UAE's challenging agricultural ecosystem, which is characterized by high heat, humidity and soil salinity.

The technology targets crops including tomatoes, strawberries and bell peppers using a multimodal approach that combines image-based disease detection with contextual farm data.

"Undetected diseases can devastate entire harvests within weeks, leading to significant financial and food security issues," says Nasir.

The app goes beyond simple diagnostics to early disease detection, helping to prevent outbreaks.

"By empowering farmers with an easy-to-use, AI-driven mobile application, we reduce their dependence on delayed lab testing or guesswork, and instead provide them with immediate, data-driven insights," Nasir explains.

Looking ahead, he envisions the system evolving into a comprehensive smart-farming platform that integrates disease detection with predictive analytics, crop health monitoring, and precision treatment recommendations.

Climbing date palms? There's a drone for that . . .

The versatility of robotic agricultural systems can extend far beyond greenhouse operations. Rajmeet Bhourji has already begun exploring applications for outdoor farming, including pollination in the UAE's crucial date palm crop.

Date palm pollination presents unique challenges that robotic systems are ideally suited to address. "The date plant is very tall. People have to climb up there and do the pollination, because dates have separate male and female flowers." His solution involves drone-based technology that can easily reach the height of date palms while carrying pollination materials.

The adaptability of these technologies across different crops represents a key commercial advantage. "You can use this pollination technology for tomatoes, strawberries, cucumbers and watermelon," Bhourji says. This versatility means "this is a commercial, generalized product," he adds.

From desert to table: saving fresh food from going to waste

A data-driven initiative aims to cut postharvest food loss through smart farming, cooling innovation, and farmer training.

In a region where every drop of water is precious, a crop revolution is taking place. Farmers in Abu Dhabi are turning to smart, low-cost technology to save tons of fresh food from going to waste. Think juicy tomatoes, fragrant strawberry, cucumber, fig and even crops you'd never imagine could grow in the desert, like avocados and passion fruit, thriving in a place where abundance seemed impossible. This is the story of how Khalifa University scientists are developing cutting-edge tools to secure the UAE's food future, one small farm at a time.

But these farms aren't just growing food—they're growing solutions. As part of a bold effort led by KU and the Abu Dhabi Agriculture and Food Safety Authority (ADAFSA), they serve as living labs tackling one of agriculture's most persistent challenges: postharvest food waste. Each year, a staggering portion of fresh produce is lost between the farm and the table—damaged in transit, spoiled during storage, or simply wasted due to inefficient systems. In the UAE, where water is scarce and cooling is costly, the stakes are even higher. Here, every cucumber counts.

"The environment here limits what you can grow, but not what you can achieve," says Dr. Nawaf Almoosa, Director of the Emirates ICT Innovation Centre (EBTIC) at Khalifa University. "Our job is to help farmers—especially small-scale, non-commercial farmers—make the most of what they produce."

Scattered across Abu Dhabi, from the fringes of Al Ain to the capital's outskirts, these farms are often modest family-run plots, but they hold great potential. Some are granted as agricultural land, tended by hobbyists; others sell produce in small quantities. Either way, they typically lack access to cutting-edge farming tools that could help them thrive in the harsh desert climate.

Farms of the future

To bridge this technology gap, the Modern Agricultural Technologies program was launched—an initiative funded by ADAFSA and executed in collaboration with international experts. From pre-harvest precision farming to smarter handling after crops are picked, the program covers every stage of farming cycle, promoting environmentally conscious farming practices that reduce water and energy use.

Collaborators include researchers from Wageningen University, in the Netherlands, and a consortium of U.S. universities—University of Georgia, UC Davis, and Kansas State University.

When the team first visited local farms, they were struck by both the potential and the problems. "We saw greenhouses sitting idle," recalls Sara Alshamsi, a research associate at EBTIC and the technical project manager for the Agriculture 4.0 project. "Expensive fertigation systems had been installed, but were

Abu Dhabi is embracing organic farms to save tons of fresh food from going to waste.

"Our goal is to make farmers see the benefit for themselves."

14%
drop in overall energy consumption was recorded.

The technologies are being trialed in
27
farms across Abu Dhabi.

ALISONTEALE24/ ISTOCK / GETTY IMAGES PLUS abandoned after a few weeks." But the team was also amazed by what was growing—avocados, strawberries, figs, mangos, even papayas—all thriving in a landscape many assume to be barren. As Almoosa reflects, "You'd be surprised what you can grow in the desert."

Cool solutions, affordable prices

Growing crops is only half the challenge. Keeping them fresh, especially through the UAE's sweltering summers, is an entirely different struggle. Cooling alone consumes vast amounts of energy, and traditional systems are not always practical for small-scale farmers.

That's where the project's research into low-cost, smart technology comes in. The team began developing systems based on environmental sensors that could monitor temperature, humidity, soil moisture and other vital conditions in real-time. These tools help farmers fine-tune their operations, reduce spoilage, and ultimately increase yields.

But industrial-grade sensors were prohibitively expensive, so, researchers turned to readily available cost-effective sensors, testing them to build reliable, affordable systems suitable for widespread use.

The next hurdle was interoperability. Different sensors came from different vendors and operated on different platforms—some using Wi-Fi, others using Zigbee, LoRa, or wired connections. Kumar Padmanabh, a senior researcher on the project, and his colleagues, tackled this by designing a unified platform capable of integrating all of them. This allowed farms to collect and analyze data from a wide range of devices in one place, making the system more user-friendly and efficient.

One of the most practical solutions came through understanding sunlight. Rather than installing expensive soil sensors throughout an entire farm to guide irrigation, the team used sensors that measure sunlight to predict how quickly water would evaporate. By linking irrigation to sunlight intensity, they were able to control water use more intelligently, reducing both waste and cost.

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"The environment here limits what you can grow, but not what you can achieve."

So far, these technologies are being trialed in 27 farms across Abu Dhabi. Early results are promising. In one experiment, the team compared a manual watering and fertilization system with an automated system inside the same greenhouse. The automated side produced healthier, greener plants and yielded crops significantly earlier than its manually managed counterpart.

They also recorded a 14% drop in overall energy consumption, particularly from cooling, in greenhouses equipped with their systems. Additional features like leakage detection are helping save water—critical in a region where every drop matters.

But the project isn't just about numbers. It's about making the tools usable and the changes sustainable. "Our goal is to make farmers see the benefit for themselves," says Almoosa. "If the technology improves yield, reduces effort, and cuts costs—they'll adopt it."

To make this happen, the team is producing custom training manuals, conducting in-field workshops, and working closely with ADAFSA to offer farmers not just the tools, but the know-how to keep using them effectively.

From Abu Dhabi to the rest of the world

With climate change already making extreme weather more common in many parts of the world, what works in Abu Dhabi's deserts could potentially be adapted to other regions facing heat, salinity, or water scarcity.

That's why the team's work includes updating Abu Dhabi's official postharvest handling manuals for every crop that can be grown and traded in the Emirate. With guidance from international experts, these manuals are paired with a targeted series of farmer trainings that aim to reduce losses and make the entire agricultural system more efficient.

The program runs through 2026, but the researchers are already looking beyond the lab. Their hope is to move from pilot trials to full-scale commercialization, making these smart, desert-tested technologies available to farmers everywhere.

THE MANY FACES OF ROBOTICS

Irfan Hussain, Associate Professor at Khalifa University's Center for Autonomous Robot Systems.

At the forefront of research into embodied intelligence, Irfan Hussain's work spans a remarkable breadth of real-life applications as he fuses physical and cognitive intelligence into wearable and field-based robotic systems,

Why did you choose to work on AI and robotics at Khalifa University?
When I first arrived at KU, I thought that I'd stay for one year and explore the opportunities. My perspective totally changed. Robotics and AI are emerging in the Middle East, and the level of interest and needs in this area is striking.

At the end of day, all robotic systems have different applications, but the fundamental components are the same. Humans rely on senses such as eyes and muscles to interact with the world. In robotics these are called actuators and if you have the ability to design them in the first place, then it's very easy to develop them across different fields.

What's the most fascinating aspect of your research?
Real-world applications. A lot of the research or technology that I have developed has some kind of real-world use that goes beyond the lab. These include a stroke rehabilitation device, advancing underwater robotics for coral reef conservation and creating lifelike robots for wildlife monitoring.

> "Robotics and AI are emerging in the Middle East, and the level of interest and needs in this area is striking."

How can robots help with wildlife monitoring?
We're building a robot that looks and acts like the Houbara bird, an important yet vulnerable species in the UAE. Our goal is for this robot to interact with natural birds, monitor their behavior, and help with conservation.

To make the robot look just like a real Houbara, we first scan different versions of the bird to create a 3D model. Then we use 3D printers to build the body, adding a lifelike skin on top, making sure its texture is a perfect match. Inside, we fit the robot with sensors, cameras, and microphones. Finally, we train the AI to see and understand the real birds, so that our robot can interact with them in a completely natural way.

Tell us about your marine robotics work.
At KU we have a unique underwater pool, one of only a few in the world that can simulate realistic ocean conditions. We use wave generators to create waves with different strengths and directions, and we have tracking systems to measure them, allowing us to test our underwater robots under real-world conditions.

This facility is crucial for performing various underwater activities. For example, we use our robots for aquaculture monitoring in extreme environments that are too dangerous for human divers. We also have projects focused on coral reef inspections. Because of environmental changes, corals are in danger of extinction, and we're using our underwater robots and AI solutions to monitor their health.

Which application really inspires you?
There is a very simple device that I developed to help stroke patients who have lost the ability to use one side of their body, making everyday tasks such as picking something up nearly impossible. The device is a soft robotic finger that compensates the patient for what they lost and enables them to grasp objects. After using the device, one patient who had had a stroke 10 years before said it was the first time that he had used his impaired hand, and that basically, he started to feel that it belonged to his body again.

Making a splash in the water industry

Faisal Al Marzooqi is unlocking hidden riches in the UAE's desalination waste.

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Dr. Marzooqi shaking hands with Sheikh Mohammed ibn Rashid Al Maktoum.

Helping the next generation of scientists flourish, while supporting the UAE's national goal of transforming wastewater into valuable, reusable products, are the aims of Faisal Al Marzooqi, deputy director of the Center for Membranes & Advanced Water Technology (CMAT) at Khalifa University.

"People call the water industry the 'absent present' sector," says Al Marzooqi, "It's 'absent' because we take it for granted, since we have easy access to water and it is always readily available. Then it's suddenly very 'present' when something goes wrong and we lose access to it."

Al Marzooqi has focused his career on developing innovative technologies for the water and energy industry. "His Highness Sheikh Mohamed Bin Zayed said water was more valuable than oil for the UAE, and this really inspired me," says Al Marzooqi who works mainly on specialized membranes for filtering and retrieving valuable elements from water sources, with applications across multiple disciplines.

"My earliest research experience showed me how chemical engineering touches all areas of humanity, and has numerous applications from oil and gas to medicine and therapeutics," says Al Marzooqi whose PhD was a combined project between Masdar Institute and the Massachusetts Institute of Technology, focusing on the application of nanotechnology in the water industry. Following his PhD, he spent several years at MIT as a visiting Assistant Professor working on solar-powered water treatment technologies in collaboration with Professor Evelyn Wang, who is now vice president of MIT.

Waste to health and wealth

Al Marzooqi is currently working on several projects with different collaborators and colleagues at KU. "Khalifa University is one of the top UAE institutes for researching energy and water," he says.

One project focuses on recovering minerals from the brine generated by desalination plants.

"Harvesting minerals will help ensure that we can cater for global technological advances in the future," says Al Marzooqi. "After all, they say you can recreate the periodical table from all the elements that are found in seawater."

One of the UAE's key national goals is to 'change waste to health and wealth,' and Al Marzooqi is playing a leading role in bridging the gap between basic science and real-world applications in this area.

He and his team identified the conditions for improving the recovery of valuable minerals like magnesium, helping the research community to enhance extraction technologies. "We've also published several papers on lithium recovery, and we're involved in refining sustainable ways to produce hydrogen from water and ammonia."

Al Marzooqi also leads a project focused on the recovery of minerals from water emerging during the process of oil extraction. Another project involves converting waste into valuable materials for the water industry, contributing to the UAE's move toward a circular economy. Additionally, he serves as co-principal investigator on a project led by KU's Ahmed Al Hajaj to develop nanomaterials for heat recovery.

A team built on trust

Despite leading multiple projects, Al Marzooqi finds deep fulfilment in teaching and mentoring the next generation of scientists. "I love teaching, and working closely with both undergraduate and graduate students," he says. "There are great researchers and great students here, and you need both to flourish in an academic environment."

One of Al Marzooqi's research associates, Alaa Shaheen, recalls feeling immediately welcome when she joined his team.

"Al-Marzooqi's lab is built on trust, curiosity, and mutual respect, a place where mistakes are seen as part of the learning journey."

"What truly distinguishes Dr. Faisal is his integrity, kindness, and the genuine care for those he works with. He leads by example, always treating others respectfully and encouraging a balanced work-life.

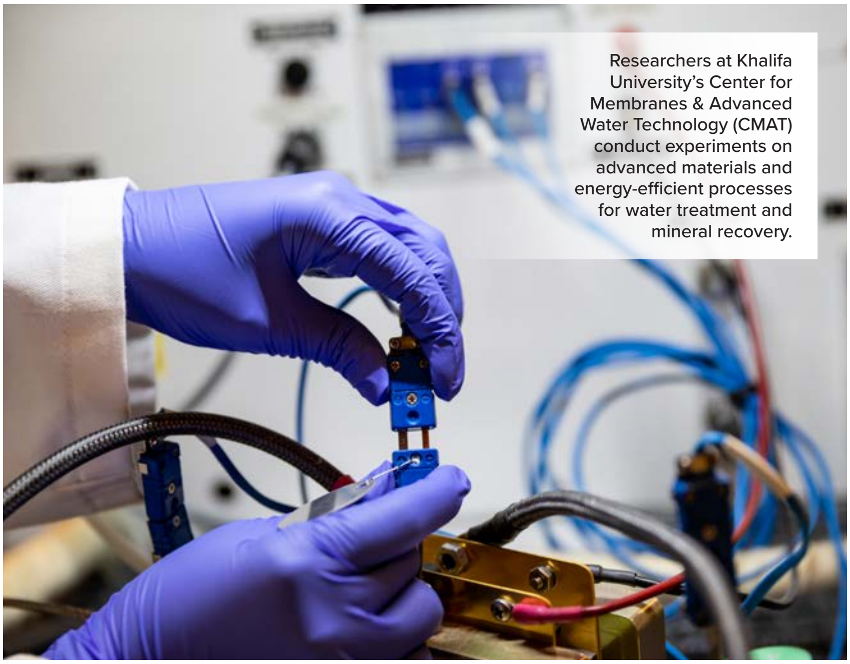
I'll always be grateful for the trust he placed in me. Dr. Faisal was more than a supervisor—he believed in people's potential. Working under his supervision wasn't just a milestone; it shaped who I am, and his character has left a lasting impression on me."

Alaa Shaheen
PhD student at Khalifa University

"It all started with a LinkedIn message, when Dr. Al Marzooqi reached out and offered me a research associate position in the chemical engineering department. At the time, my background was in simulation, and I told him that I was interested, but had no experimental experience'. He immediately reassured me, saying, "No issue. We're one team here, and we learn together to grow." That line captured exactly how he leads," Shaheen says.

Shaheen describes Al Marzooqi's lab as a space built on trust, curiosity, and mutual respect, where mistakes are seen as part of the learning journey. "Dr. Faisal doesn't just assign tasks; he explains the 'why' behind each experiment and encourages critical thinking. He often says, 'Don't hesitate to contact me if you have any questions, comments, or concerns.' He truly means it and that mindset creates a space where I felt safe to learn and ask for help."

Despite having no lab experience when she first joined, Shaheen says Al Marzooqi's leadership and mentoring gave her and fellow students the confidence to take initiative, develop new skills, and build a strong foundation in experimental research.



Researchers at Khalifa University's Center for Membranes & Advanced Water Technology (CMAT) conduct experiments on advanced materials and energy-efficient processes for water treatment and mineral recovery.

Science and heritage secure the UAE's food future

From camel milk to dates, Khalifa University's Food Security and Technology Center is redefining how the UAE transforms its local resources into global food solutions.

MUSTAPHA GUNNOUNI/ ISTOCK / GETTY IMAGES PLUS

With potential to help manage diabetes, camel milk is at the center of a nutrition revolution.

For centuries, camels have sustained desert communities, valued not just for transport and endurance, but for their milk, which was traditionally drunk fresh and rarely processed. Today, that same milk is being rediscovered as a nutritional powerhouse, particularly in the Gulf region, with potential to help manage diabetes, a condition affecting millions. Some regular consumers have reported reducing their medication use by as much as 30%.

Now, at Khalifa University's Food Security and Technology Center (FSTC), camels are at the center of a nutrition revolution. Led by Professor Fawzi Banat, the center is taking this rich heritage and using science to secure the nation's food future.

Banat and his team are producing cheeses, yogurts—even mozzarella. With production growing by around 6% annually, the FSTC's immediate focus is meeting regional demand, but its ambitions extend much further. "We want these products on supermarket shelves globally," says Mustapha Mbye a postdoctoral fellow leading the dairy product research. "The short-term goal is the UAE and the Gulf; the long-term vision is export."

Banat, a chemical engineering professor, has long devoted his career to two scarce resources—water and food. "I grew up in a region where both are limited, so I've always aimed to support sustainable growth in these fields," he says. In the United Arab Emirates, food security is a national priority, elevated by an ambitious goal: to make the nation the top country in the world on the Food Security Index by 2051.

Khalifa University recently established the FSTC as a leading hub of excellence in food research and innovation. Its work spans sustainable agriculture, functional foods, waste utilization, and new processing technologies. But Banat frames them as threads in a single fabric. "Food technology is highly interdisciplinary," he explains. "It brings together microbiology, biotechnology, engineering, and more. Our challenge is to create a culture where these disciplines collaborate seamlessly."

A researcher uses a texture analyzer.

"Food security is a human issue."

From heritage to innovation

For Adiba Akram, a research associate in dairy science, innovation must go beyond functionality—it has to be enjoyable. Her proudest achievement so far has been the near-complete development of camel-milk mozzarella. "Camel milk is difficult to coagulate," she explains. "But we've reached about 85% similarity in stretch and texture compared with bovine mozzarella, and we're getting closer." Using textural and sensory evaluations, her team ensures the products are ready not just for patents, but for palates.

Beyond dairy innovation, Banat's group is turning to the UAE's resilient desert herbs surviving in harsh desert conditions. One standout is *Heliotropium bacciferum, Ramr,* which has anti-diabetic, anti-cancer, and even antivenom properties. Another, *Herm* (*Zygophyllum fontanesii*), shows strong anti-inflammatory effects.

Building on this knowledge, the researchers are developing wound-healing dressings infused with these herbal extracts. "We are proud of our heritage," Banat emphasizes. "We want to align it with modern science to deliver something valuable for future generations."

Cultivating tomorrow

Beyond the labs, a vertical farm rises—an indoor experiment in agriculture designed to withstand the desert's searing heat. By controlling light, nutrients, and irrigation, researchers are helping local farmers grow vegetables under unimaginable conditions in open fields. "It's sustainable and scalable," Banat says. "We collaborate directly with farmers so they can apply our findings in their own operations."

But perhaps the center's most remarkable asset may not be its facilities or growing portfolio of patents—it's the people behind the science. With more than 20 nationalities represented among faculty and students, FSTC embodies diversity.

"Our biggest task is aligning people from so many disciplines and cultures," Banat acknowledges. "But it is also our strength. Innovation happens at the intersections. Food security is a human issue. What we do here in the UAE can resonate across the world."

IRYNA DENYSOVA/ SHUTTERSTOCK.COM

WASTE INTO WEALTH

If camels and herbs represent heritage, dates represent abundance. With around 40 million date palms, the UAE produces about 1 million tons of date seeds every year. From sustainable extraction to application in cosmetic and biomedical product formulations, the Food Security and Technology Center is turning what used to be waste into valuable medical and nutritional resource.

1

Rich in **antioxidants**, oil extracted from date seeds closely resembles high-value oils such as olive oil and is used in foods and wound-healing products. Foods like cheese and cookies are fortified with oil extracts which are also used to preserve seafood. They add value and reduce reliance on synthetic additives.

2

Date **byproducts** are fueling entirely new forms of dairy. Essentially creating synthetic milk without cows, KU researchers are using date waste as feedstock. This dramatically reduces production costs.

3

Antioxidants from date seed phytochemicals are being turned into bio-films to give food its own "shield." The films slowly release bioactive compounds, extending shelf life while being safer for the environment.

4

Fermented date seeds combined with pomace and herbs and mixed into animal feed have been shown to kill off fungal contamination often found in commercial feed.

5

Biodegradable packaging can be produced in the form of a highly functional, ultralight thin film made using friendly bacteria that thrive on high-volume date waste. This creative microbial upcycling process doesn't just manage waste; it is a great alternative to plastic packaging.

INSIDE VIEWS

INNOVATION MEETS FOOD SECURITY

Fawzi Banat, Professor of Chemical Engineering and Director of the Food Security and Technology Center, Khalifa University.

Aligning heritage with science, Prof. Fawzi Banat aims to foster multidisciplinary collaboration and ensure his team's research contributes directly to the UAE's National Food Security Strategy 2051.

What inspired the creation of the Food Security and Technology Center?

The UAE has set an ambitious goal of ranking among the world's most food-secure nations by 2051. To support this national priority, we launched the center to address challenges unique to our region: harsh climate, limited arable land, and heavy reliance on food imports. Our research program is designed around four core themes—sustainable agriculture, bio-functional foods, food waste reduction, and innovative food processing.

Today, around 20 faculty members and their teams bring together expertise ranging from microbiology to chemical engineering.

What role does commercialization play in your strategy?

Commercialization is essential. Filing patents is just the first step; our real goal is to ensure that our technologies reach the market. Rather than launching start-ups ourselves, we work closely with local industries to license our patents. This model accelerates scaling while our researchers remain focused on discovery.

"By 2030, we aim to be recognized as a leading hub for food security research in the Gulf region. "

One example: we're currently working with UAE producers to bring our camel milk cheese to supermarket shelves. As camel milk production in the region continues to grow, currently at about 6% annually, the commercial opportunities will only expand further.

What's the biggest challenge you've faced in leading such a multidisciplinary center?

The cultural and academic diversity. Our researchers come from many countries and disciplines, and aligning them under a single vision requires patience and leadership. Building infrastructure is another challenge; food security is not a field where one lab or one discipline can make an impact alone. It requires microbiologists, chemists, engineers, and industry partners working together.

Still, I believe these challenges are what make the work rewarding. I often remind the team that our aim is not only to create patents but to ensure those patents translate into real products on supermarket shelves. This shared purpose keeps us united.

What's your vision for the center?

By 2030, we aim to be recognized as a leading hub for food security research in the Gulf region. Our first responsibility is local, and we want to deliver real solutions for the UAE and its neighbors.

But our ambition extends globally. With our work on camel milk, date palm waste, and functional foods, we believe we can contribute internationally to healthier diets and more sustainable food systems.

Ultimately, our mission is about people: nurturing the next generation of researchers, respecting our heritage, and aligning it with science. That's how we will help the UAE meet its 2051 food security goal.

KHALIFA UNIVERSITY; TOLIKOFF PHOTOGRAPHY/ SHUTTERSTOCK.COM

Sustainability autopilot optimizes home comforts

A mathematical model that balances a household's need for water and energy could become one of the building blocks of sustainable cities.

Future cities designed for climate resilience need energy- and water-efficient infrastructure seamlessly integrated with clean technologies. But liveability goes beyond environmental performance, demanding affordability and comfort.

To help achieve those goals, Ahmed Elshamy and Ameena Al-Sumaiti, of the Department of Electrical Engineering and Computer Science at Khalifa University, have developed a mathematical model that acts as a sustainability autopilot. This model optimizes household water and energy usage by automatically integrating their management, while helping ensure affordability and comfort.

That integration is necessary because a community's energy and water use are interwoven. Water is needed to cool electric power generators, while electricity is needed to power water treatment facilities. This is particularly important in countries such as the UAE where much of the drinking water comes from desalinated seawater. The energy–water nexus will be crucial in optimizing the efficiency of future smart, sustainable cities.

"By smartly coordinating energy use, water recycling, and cooling in buildings, it's possible to cut costs and reduce reliance on utilities," says Elshamy. "Better management—not just better technology—can make buildings much more efficient and sustainable." The two electrical engineers have tested their model using data from a neighborhood in Masdar City, a purpose-built eco-city just outside of Abu Dhabi, that aims to be a global model for sustainable urban living.

Elshamy and Al-Sumaiti's model paves the way for more resilient buildings by integrating the control of

"This research is on track to make waves in the world of sustainable living, with the potential to reshape the way we think about resource efficiency in our homes."

Masdar City was the testing site for a sustainability autopilot that optimizes household water and energy use, balancing comfort and cost.

CHRISTOPHER PIKE/BLOOMBERG VIA GETTY IMAGES

several energy, water, and cooling subsystems. "The system adjusts to real-time utility pricing, so it knows when to use more and when to use less water and energy to save money," explains Al-Sumaiti, an alumnus of UAE's National Experts Program, which focuses on sustainable development and economic diversification. "It also stores excess energy and even sends it back to the grid. The result: lower bills, reduced water consumption, and a home that's both comfortable and sustainable," she says.

The mathematical model considers a building-wide microgrid, seamlessly connecting key subsystems. The first of these subsystems focuses on the collection and treatment of wastewater from bathing, laundry, and dishwashing known as gray water. A second subsystem manages temperature control using air-conditioning, ventilation, and heating units. The third subsystem enables energy generation using solar cells, with surplus energy stored in batteries for later use. All are managed by a predictive central controller that uses current energy and water pricing to optimise operation of the building in accordance with the homeowners' changing needs for water, temperature control and so on.

Critically, the central controller also considers how the whole system will behave over the next few hours, further optimizing outcomes.

The team ran simulations to test their model based on data from three weekdays and one weekend day from a site in Masdar City. They found an 8.3% reduction in overall operational cost, while the consumption of potable water fell by 21.5% compared with a system that didn't use the sustainability autopilot.

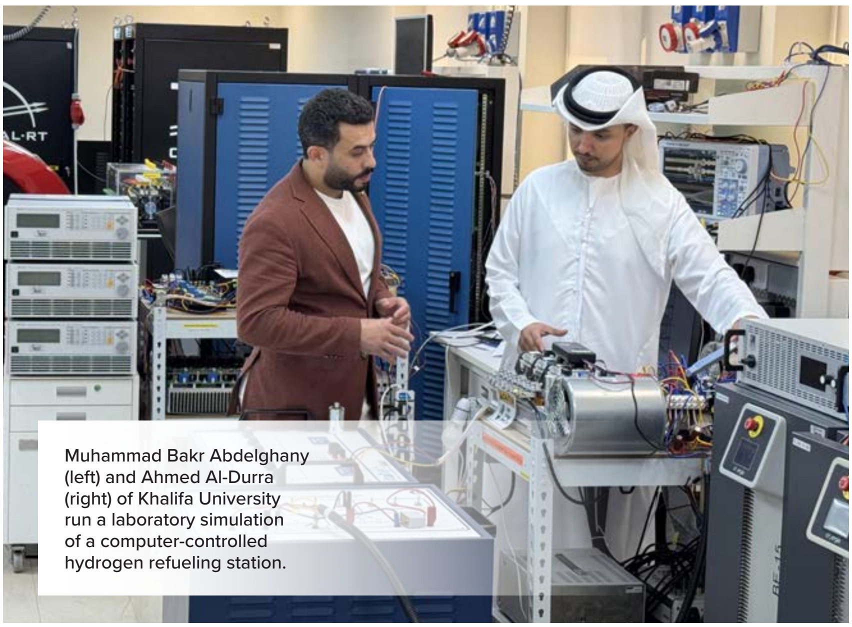
Collaboration between technology developers, utility companies and construction firms will be central to making these ideas a reality. "The next step is to collaborate with utility providers to make the solution practical and scalable, while also engaging with communities to raise awareness of the benefits," says Elshamy. "Hopefully, we can start pilot implementations in selected buildings or neighborhoods to demonstrate real-world impact."

Once proven, the sustainability autopilot could be scaled up and become a standard feature in energy-efficient, future-ready homes, especially in areas with high energy and water demand. "We are on track to make waves in the world of sustainable living, with the potential to reshape the way we think about resource efficiency in our homes," says Al-Sumaiti.

El Shamy, A.R. & Al-Sumaiti, A.S. Optimal cost predictive BMS considering greywater recycling, responsive HVAC, and energy storage. *Applied Energy* **377**, 124589, 2025.

Making hydrogen a viable auto fuel

Hydrogen refuelling stations could become financially viable if fitted with multiple tanks and control systems that enable hydrogen trading.



Muhammad Bakr Abdelghany (left) and Ahmed Al-Durra (right) of Khalifa University run a laboratory simulation of a computer-controlled hydrogen refueling station.

KHALIFA UNIVERSITY

Hydrogen-powered electric vehicles promise clean energy on the go—zero emissions, greater range, and faster refuelling compared to their battery-powered counterparts. Yet, despite these benefits, high costs and an unpredictable supply chain mean refuelling stations remain scarce. With only a few thousand hydrogen refuelling stations worldwide, the dream of hydrogen-powered transport still faces significant hurdles

One way to drive the development of this infrastructure is to improve the cost-effectiveness and reliability of hydrogen refuelling stations. A team led by Khalifa University Associate Provost for Research, Ahmed Al-Durra, has designed a computer-controlled station that generates revenue while providing a reliable, affordable hydrogen supply amid fluctuating demand and supply, and rapid price changes.

“Our findings pave the way for an economically viable, flexible hydrogen infrastructure—key to decarbonizing transportation—and to improve the reliability of hydrogen supply, boosting operational efficiency and supporting national and global sustainability agendas,” says Al-Durra.

The team’s proposed station is powered by solar and wind, and fitted with multiple storage and supply tanks. These tanks enable simultaneous fueling of multiple electric vehicles, and hydrogen trading on the open market or its conversion to electricity for resale.

The station can operate either connected or not connected to the hydrogen market. “In off-connected mode, the system relies solely on renewable energy sources and local storage, enhancing autonomy,” explains Al-Durra. “On-connected mode introduces flexibility by enabling hydrogen trading—purchasing when supply is low and selling surplus to maximize revenue.”

The selection “involves the consideration of various factors, such as forecasted data, economic circumstances, environmental objectives, resilience needs and user preferences,” says postdoc fellow in electrical engineering, Muhammad Bakr Abdelghany. To intelligently switch between refuelling cars, trading hydrogen or selling electricity, the control strategy uses two mathematical techniques designed to deal with complexity and uncertainty—Boolean relaxation and Model Predictive Control. This combination reduces computation time.

Through computer simulation, the team has shown that their flexible design not only cuts operational costs but boosts hydrogen supply reliability. This makes it a superior solution compared to other mathematical models previously proposed for optimizing hydrogen fuelling station performance.

“Simulation results show that the waiting time of the average vehicle is also reduced by around 30%, resulting in less downtime for hydrogen-fueled electric vehicles,” says Al-Durra.

As a next step, the team plan to test their control strategy in a real hydrogen filling station and is also considering incorporating AI for greater responsiveness to changing conditions.

“Additional developments include exploring different hydrogen refuelling station configurations, such as integration of other energy-storage systems, the inclusion of additional renewable energy sources, and interactions with multiple energy markets,” says Al-Durra.

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Abdelghany, M.B.; Al-Durra, A.; Zeineldin, H.; El Moursi, M.S.; Hu, J. and Gao, F. Optimizing resilient parallel refueling operations: relaxed stochastic economic mobility scheduling for fuel cell vehicles with multiple hydrogen storage systems. *eTransportation*, **23**, 100393, 2025.

EZRA BAILEY/ STONE/ GETTY IMAGES

Integrated windows help power, heat and cool buildings

Two energy-harvesting technologies in one window triple the impact on energy performance, promising more affordable comfort.

Sunlight pouring through windows on a bright summer morning can deliver unwelcome heat. Despite the widespread adoption of double glazing, windows remain very porous to heat, adding significantly to the energy needed to keep buildings comfortable.

Globally, buildings consume more than one-third of total energy production, much of it for cooling—especially in hot regions. A smart window developed by researchers at Khalifa University promises to flip this situation, turning windows from energy sinks into significant energy sources by synergistically combining two energy-harvesting technologies.

"Our multifunctional window provides multiple benefits from one integrated design," says engineer Mohamed Hassan Ali, who led the work.

The first benefit is electricity generation. Encapsulated between two panes of glass is a thin layer of a semi-transparent photovoltaic (STPV) material that absorbs most of the visible light passing through the window. The STPV layer provides some shading while generating electricity to help power the building's cooling system.

Although power-generating solar PV windows have been trialed before, they had a major drawback. The STPV materials unavoidably generate some heat as they turn light into electricity. In previous designs, that heat radiated directly into the room, exacerbating the building's cooling demand even as the window trapped incoming solar energy.

To overcome this limitation and bring a second benefit, Ali and his team incorporated a second technology called selective liquid filter (SLF) into their windows. The SLF consists of two glass sheets that sandwich a transparent film of flowing water. The SLF harnesses water's natural capacity to absorb ultraviolet and infrared radiation, intercepting heat flowing into the room and generating a useful stream of warmed water, while letting visible light pass through.

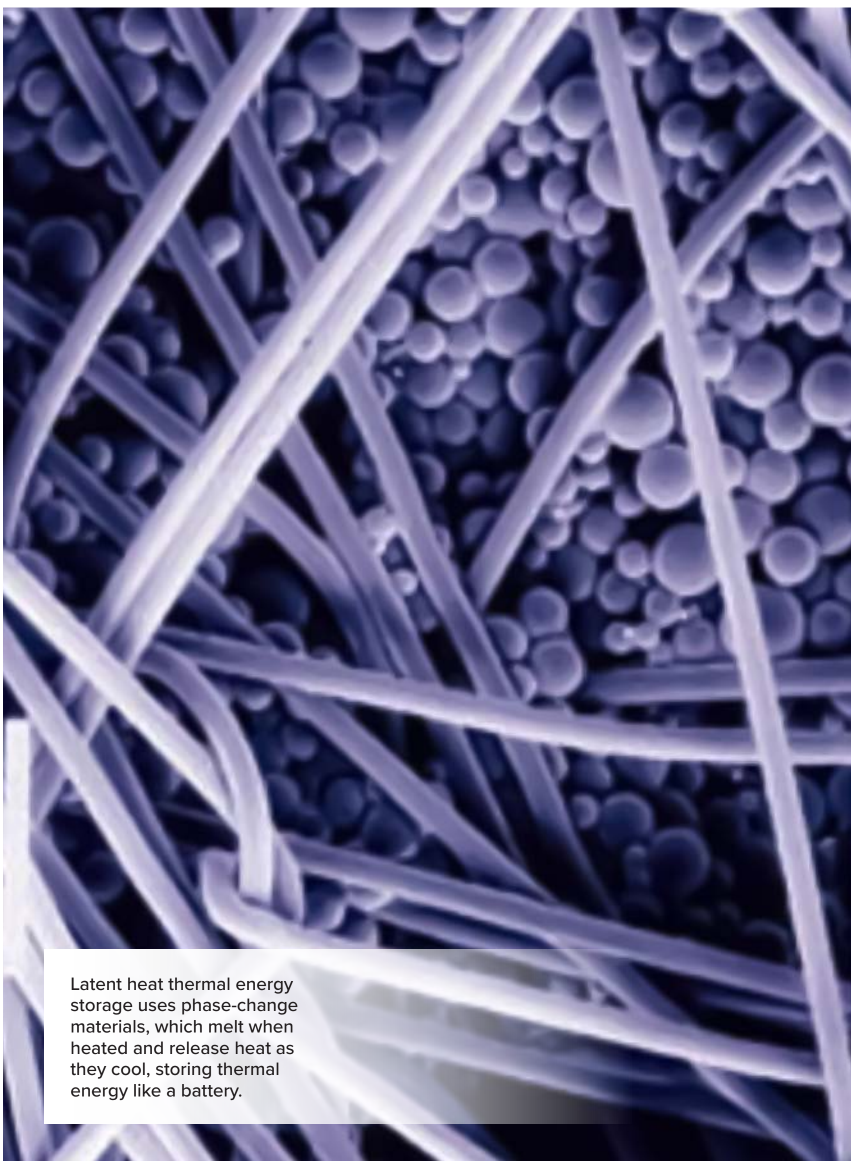
The KU window prototype combines the SLF and STPV technologies in a multilayer assembly. "In our design, as well as [the solar panel] filtering out the undesired solar radiation, the water cools the solar panel," Ali says. "The heat that the water absorbs could help to meet the building's hot water needs."

The multifunction window prototype generated 350 watts of electrical power—comparable to a typical solar panel—and 700 watts in hot water. Once incorporated into a computer model of a building, the windows also lowered the need for cooling, providing an overall net electricity benefit 80% higher than seen in a building that only incorporated STPV windows.

Abdelsamie, M.M., Ali, K. & Hassan Ali, M.I. Enhancing building efficiency: Multifunctional glazing windows with integrated semitransparent PV and selective liquid-filters. *Appl. Energy,* **377**, 124723, 2025.

Smart materials supercharge nuclear power

Computer modeling and artificial intelligence enable nuclear power plants to store and release energy more efficiently, paving the way for a more reliable and greener grid.



Latent heat thermal energy storage uses phase-change materials, which melt when heated and release heat as they cool, storing thermal energy like a battery.

OUTLAST TECHNOLOGIES / SCIENCE PHOTO LIBRARY

Imagine a power plant that can't slow down. Nuclear reactors are designed to run full throttle, but the electricity we use goes up and down throughout the day. This creates a big problem: when demand is low, the plant is still churning out power that goes to waste. It's like a high-performance engine stuck in traffic—inefficient and costly.

But what if a nuclear plant could store all that excess power for later? Researchers at Khalifa University have found a way to do just that, using clever new materials and computer modeling to turn a nuclear reactor into a powerful thermal battery. Their groundbreaking work is making nuclear energy not only more profitable but also a better partner for a greener, more flexible power grid.

"Frequently changing the output of a nuclear power plant is technically complex and economically costly," explains Deepak Ramachandran from the Emirates Nuclear Technology Center. "This mismatch between generation and demand reduces the overall economic efficiency."

Boosting nuclear power plant efficiency

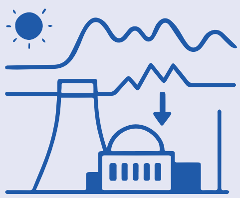
Ramachandran and his colleagues, Abdulrahman Mohammad and Ahmed Alkaabi, in collaboration with researchers from the University of Birmingham, have introduced a way to boost adaptability and profitability by thermally storing energy that is not immediately required.

"Our study shows that by storing heat during low-demand hours and using it to generate extra electricity during peak demand, we can improve how a nuclear power plant works, without changing how the reactor itself operates," says Ramachandran.

The team considered latent heat thermal energy storage (LHTES), which uses a phase-change material that melts when heated and releases heat as it cools, storing thermal energy like a battery. A simple way to picture this is with a reusable hand warmer.

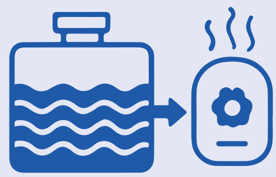
Turning nuclear heat into flexible power

Inflexible Nuclear Output



Nuclear reactors run full throttle, but electricity demand fluctuates-leading to inefficiency and waste.

Thermal Energy Storage



Using phase-change materials, excess heat is stored like a battery—melted when heated, released when cooled.

Smart Modeling & Profitability

Khalifa University's integrated modeling proves the system is profitable and grid-friendly—tailored for APR 1400 reactors.

"Storing this magnitude of energy in electrical batteries, however, would be physically impractical due to size and cost constraints," explains Ramachandran. "LHTES offers a more feasible solution for large-scale energy storage."

Modeling a profitable future

What sets KU's research apart is its reactor-specific focus, as it's tailored to APR1400 nuclear reactors such as the one used in the Barakah Nuclear Power Plant in the United Arab Emirates. The researchers validated their findings using two distinct but complementary approaches.

Ramachandran's team used detailed technical computations and a financial analysis to test their system's viability over a 25-year lifespan. The results showed a 99.75% likelihood of profitability under peak tariff conditions. "While LHTES integration with nuclear power plants is of growing global interest, much of the existing literature remains conceptual or preliminary," says Ramachandran.

Meanwhile, colleagues Muhammad Faizan and Imran Afgan at the Department of Mechanical and Nuclear Engineering used a different approach, employing sophisticated computer modeling known as computational fluid dynamics (CFD) to simulate how heat flows within the system. This physical data was then fed into machine learning algorithms to predict and optimize key performance parameters.

Unlike previous studies, KU's approach integrates CFD, machine learning, and techno-economic analysis into a unified framework, specifically designed to accommodate real-time demand fluctuations. "Integrating thermal-energy storage systems into nuclear power plants allows excess heat during nuclear off-peak operation to be stored and later used during high-demand periods, enhancing flexibility and reducing waste," explains Afgan. "It enables nuclear plants to complement the variable output of renewable energy sources and in this way stabilize the grid."

Paving the way for practical adoption

The findings of both teams pave the way for practical adoption in the region.

"Eventually, we aim to collaborate with nuclear operators and energy planners in the UAE and beyond to explore pilot projects," says Alkaabi. "Our long-term vision is to make thermal storage a standard feature in future nuclear power plants."

To implement this strategy, the researchers emphasize the need to move from concept to action, starting with pilot-scale deployment, policy alignment, and technical collaboration with energy authorities.

"Implementing this optimized TES system can help the UAE enhance grid flexibility, reduce peak load stress, and utilize surplus nuclear heat effectively," says Afgan. "This integration supports the nation's commitment to sustainability and carbon-free energy by minimizing fossil fuel dependence and improving nuclear efficiency."

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1. Ramachandran, D.S.; Mohammad, A.H.; Dai, S.; Ding, Y. and Alkaabi, A.K., Economic feasibility analysis of LHTES integration with a nuclear power plant. *Applied Energy* **392**, 126026, 2025.
2. Faizan, M. and Afgan, I., Dynamic assessment and optimization of thermal energy storage integration with nuclear power plants using machine learning and computational fluid dynamics. *Applied Energy,* **391**, 125939, 2025.
3. Afgan, I. Dynamics assessment and optimization of thermal energy storage integration in nuclear power plants using machine learning and computational fluid dynamics. *32nd International Conference on Nuclear Engineering (ICONE 32)*, Panel talk 6, Weihai, Shandong, China, June 22-26, 2025.

Can we curb global warming without shutting down factories?

Heavy industry can be part of a low-carbon future, but only if the right technologies and policies are embraced.

To meet climate goals, carbon capture technologies are essential for ensuring heavy industry can operate in a low-carbon future.

WITTHAYA PRASONGSIN/ MOMENT/ GETTY IMAGES

How can we curb global warming without sacrificing our quality of life? It's one of the most complex questions facing scientists—and heavy industry is at the heart of it. Cement and steel factories are essential for building modern society, yet they remain deeply reliant on fossil fuels.

At Khalifa University's RICH Center, a team led by Pedro Rochedo has created a powerful computer model to show how these industries could still thrive in a future where global warming is kept under 2°C.

They used a sophisticated computer software called COFFEE (Computable Framework for Energy and the Environment), originally developed by Rochedo. Think of it as a super-smart simulator that maps the complex interplay between a country's economy, its people, and the environment. This gives leaders and policymakers a clear picture of what's possible for a sustainable future.

"COFFEE is the only global model where all the sectors, including land, energy, food and materials, are combined in a single mathematical framework," says Rochedo. "It tries to find the optimal pathways toward decarbonization for all these systems simultaneously, across 18 world regions, up to the end of this century."

Using the COFFEE model, Rochedo's PhD student, Marianne Zanon-Zotin, explored future emission pathways for the cement, steel and chemical subsectors industries, often seen as hard to abate because they emit large amounts of CO_2 from core chemical reactions and require high temperatures, difficult to achieve with current low-carbon technologies, while being important for global economies1. The simulations showed that, while these industries produced some emissions, they could still operate at scale within well-below 2°C climate scenarios, especially if there is sufficient ambition in developing technologies such as biomass energy and carbon capture.

"Some carbon capture technologies like chemical absorption are already used in refineries, but not at the scale required, and they remain expensive,"

"It's really important to have smart policy designs that avoid unfairness and ensure a just transition."

says Rochedo. "The main challenge is the speed at which this technology, and others, like electrification, hydrogen efficiency and circular economy practices, must increase. This requires public acceptance, regulatory changes, and investment."

The COFFEE model is designed to balance the system. It can offset emissions from heavy industry by modeling more aggressive mitigation efforts in other sectors—like renewable energy. It can also suggest that countries with more resources should take on a bigger share of the effort.

"None of our scenarios actually reach zero fossil fuel production, not a single one," says Rochedo. "It's really important to have smart policy designs that ensure a just transition. If, for example, cement is irreplaceable, we must be willing to make up for it somewhere else in the system. Also, we must allow developing countries to use their own fossil fuel resources for economic growth."

He points to the UAE as a great example. "While the economy is still quite dependent on oil, it has redesigned itself to be a hub for tourism, aviation, finance and AI," he says. Rochedo's team is similarly responsive to global changes, and will continue to update COFFEE to improve its accuracy and predictive power.

"I always say to my students, the model itself is never complete, it's a continuous work of improvement. We're always looking ahead."

Zanon-Zotin, M., Baptista, L.B., Rochedo, P.R.R., Szklo, A., & Schaeffer, R. Industrial sector pathways to a well-below 2 °C world: A global integrated assessment perspective. *Applied Energy* **381**, 125173 (2025)

Smart power for remote communities

An algorithm that optimizes the integration of renewables and diesel generators could help provide cleaner, more reliable power to rural communities.

In rural, remote communities, using reliable fridges, phone chargers, computers and lights can be life changing. These utilities open doors to education, healthcare and economic growth. Yet almost 770 million people across the world still live without a dependable energy supply. Many are not connected to a grid, instead relying on diesel generators to power local microgrids: an expensive, high-emissions system that needs to have fuel trucked in.

Renewable energy sources like solar and wind offer a cleaner alternative, but their intermittent nature means diesel generators are still needed as a backup.

To reduce the costs and emissions of these hybrid renewable-diesel microgrids, and improve their reliability, researchers at Khalifa University, and Saint Mary's University in Halifax, Canada, have developed a computer model to optimize performance. "Remote communities in the UAE's mountainous or desert regions, such as Hatta or Liwa, could particularly benefit from this approach," says Ehab El-Saadany of KU's Advanced Power and Energy Center, who led the study.

"With growing global urgency to integrate renewable energy sources, it is essential to develop an off-grid system that reduces both costs and emissions while maintaining energy reliability," he says.

The model—called the Lévy Arithmetic Algorithm (LAA)—forecasts, hour by hour, how much energy a community will need as well as energy production from all available sources—solar, wind, and diesel.

"The system factors in current weather conditions, generator efficiencies, and emission penalties to determine the lowest-cost, least-polluting energy mix at each hour of the day," says El-Saadany. "In tests, LAA outperformed other optimization algorithms in minimizing costs and emissions for hybrid microgrids."

In simulations, LAA-controlled hybrid microgrids gave a 5% cost savings per day and a lower overall carbon output when compared with a hybrid microgrid controlled using other optimization algorithms and a diesel-only system.

Future LAA systems will be improved by adding battery storage, load shifting and electric vehicle integration.

"For now, this work primarily benefits energy planners, rural electrification agencies, and microgrid developers, but in future we hope that millions of people will benefit from a more secure power supply," says El-Saadany. "Plans are underway to test this system in pilot microgrids in the Middle East and North Africa."

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Barua, S., Merabet, A., Al-Durra, A., El-Fouly, T. & El-Sadaany, E.F. Lévy arithmetic optimization for energy management of solar wind microgrid with multiple diesel generators for off-grid communities. *Applied Energy* **371**, 123736 (2024)

@STEFAN TOMIC/ ISTOCK / GETTY IMAGES PLUS

Hatta, in the mountains of Dubai in the United Arab Emirates, and other remote towns benefit from a dependable energy supply to support economic growth.

INSIDE VIEWS

A ROCK SOLID PLAN FOR A GREENER FUTURE

Emad Walid Al Shalabi, Associate Professor in the Department of Chemical & Petroleum Engineering and a member of the Research and Innovation Center on CO2 and Hydrogen at Khalifa University.

Can the same rocks that once fuelled the oil age now help us fight climate change? Khalifa University's Emad Al Shalabi believes the answer lies beneath our feet. Working to get more from our planet's energy reserves, he's exploring new ways to improve oil extraction and gas storage in underground rock formations. His work could be key to addressing some of the world's most pressing energy and environmental issues.

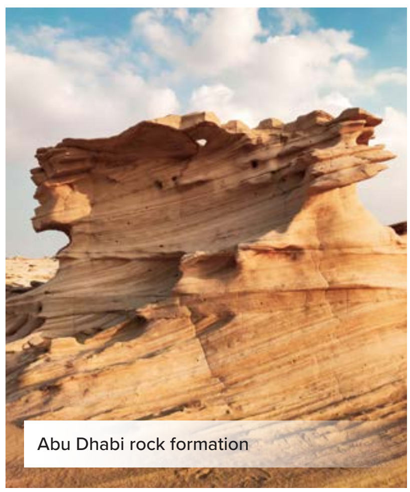
What inspired you to work in oil recovery and gas storage?

My interest in oil recovery stems from the ever-increasing demand for global energy which is driven by a growing population and industrial development, especially in Asia and Africa.

Later in my career, increasing concerns over climate change made me realize that carbon capture, utilization, and storage are the most effective technologies to combat global warming.

What's the ultimate goal of your research?

My research focuses on finding new ways get maximum energy with minimum emissions. At its core, it's about understanding how rocks and fluids interact in geological formations and their role in enhancing hydrocarbon production while maximizing gas storage.



Abu Dhabi rock formation

My team turn the challenges faced by energy companies into opportunities through systematic experimental and numerical approaches. This helps us understand the underlying mechanisms and controlling factors in the lab, then we upscale the findings to the field level, where we can optimize the process.

We also use AI and machine learning to drive accurate, economic, and efficient solutions that help decision-makers deliver low-carbon energy to the market.

What projects are you working on now?

For decades, the industry has injected CO2 into oil reservoirs to boost output by maximizing contact between gas and oil. Now, we're taking it a step further, studying how CO2 interacts with other components in the formation, such as water and rock. This helps trap more gas underground and improves oil recovery at the same time.

How does Khalifa University support this line of research?

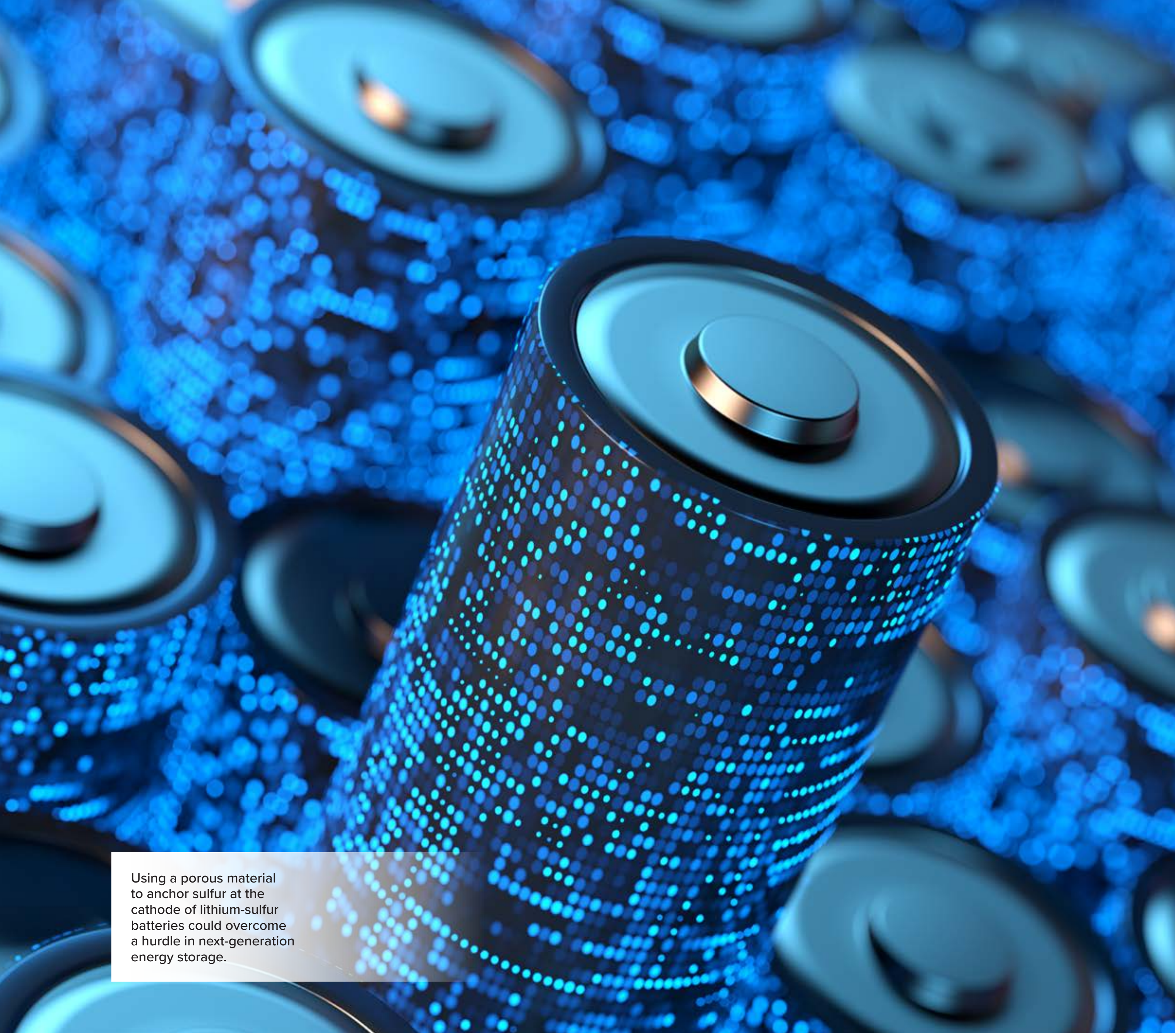
Khalifa University is one of the leading universities and the Petroleum Engineering program is highly recognized globally by achieving the 7th position worldwide in the 2025 QS ranking. We have state-of-the-art technology, well-rounded faculty and researchers with decades of experience in petroleum engineering. This knowledge can be easily applied to other fields, including geological gas storage and geothermal energy, which are current areas of focus at the Research and Innovation Center on CO2 and Hydrogen (RICH) supported by Khalifa University.

What breakthroughs do you expect to see in the future?

I hope to see more advances in making hydrocarbon production more sustainable to help us achieve net-zero targets.

We are currently developing technologies that use advanced CO2 foam systems for enhanced oil recovery and gas storage. These are supported with machine-learning models that hopefully will mature to support the economy of the UAE and beyond.

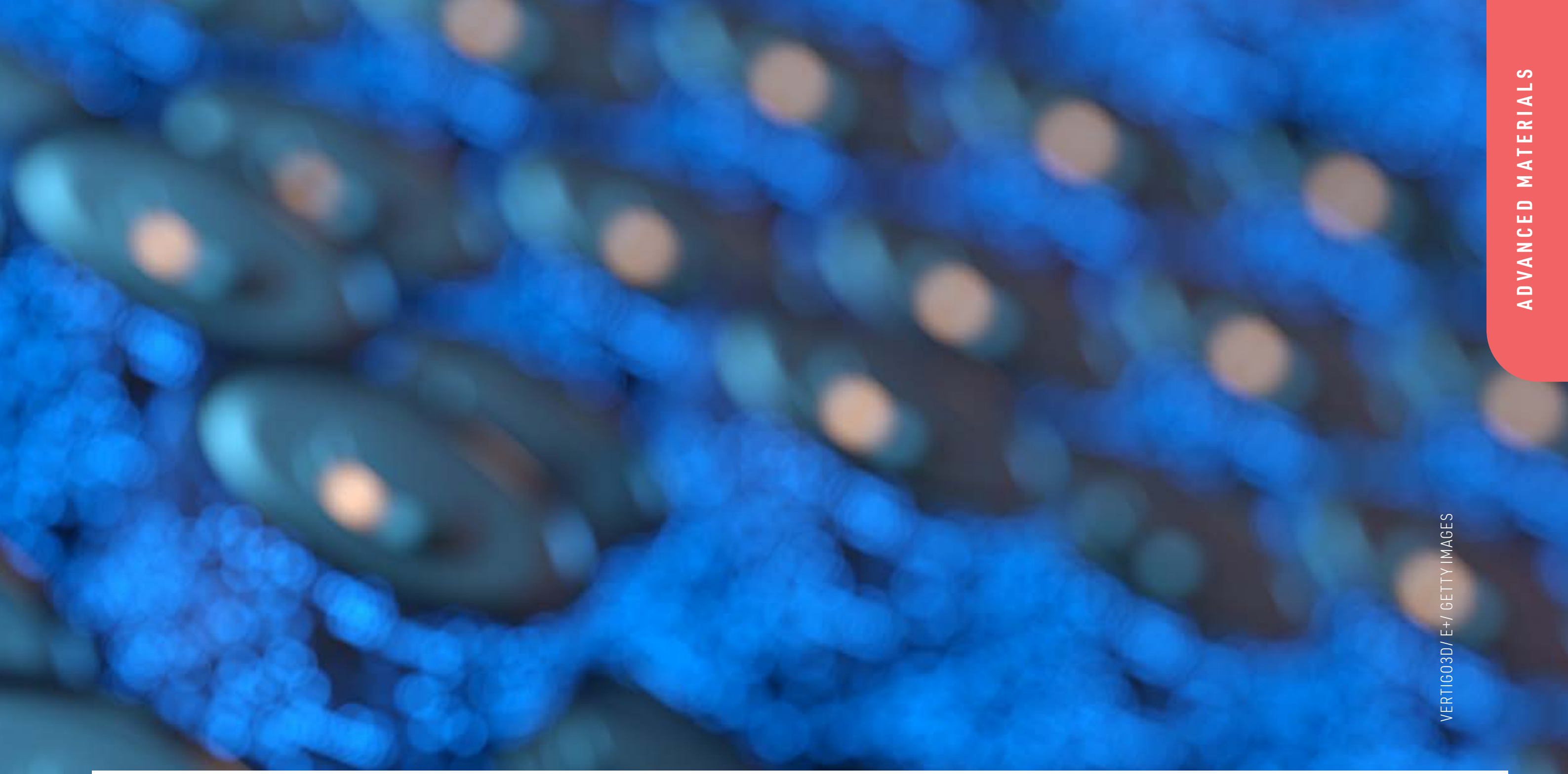
KHALIFA UNIVERSITY;STEFAN TOMIC/ ISTOCK / GETTY IMAGES PLUS



Using a porous material to anchor sulfur at the cathode of lithium-sulfur batteries could overcome a hurdle in next-generation energy storage.

Stopping the sulfur shuttle helps batteries go the distance

Porous materials may unlock longer life for lithium-sulfur batteries.



VERTIGO3D/ E+/ GETTY IMAGES

A lithium–sulfur battery is like a racehorse: bursting with energy but destined for a short running life. Its early demise is due to compounds called polysulfides, which form when the battery charges or discharges and move back and forth between its electrodes. This constant shuttling breaks down the battery's internal parts, so that it can't keep up its superior performance.

Solving the shuttling problem in lithium-sulfur batteries is a priority for energy transition because, at least in theory, they offer higher density storage, larger capacity and faster charging compared with conventional lithium-ion batteries. Exotic materials are not required for manufacture, making this type of battery potentially cheaper than others.

A lithium–sulfur battery architecture that achieves a prolonged performance by reducing shuttling has been developed by Dinesh Shetty from the Department of Chemistry at Khalifa University, together with co-workers from India, Germany and Slovenia.

Shuttling starts during the discharge of a lithium–sulfur battery, when elemental sulfur at the cathode reacts with lithium ions in the electrolyte to form long-chain polysulfides. These polysulfides diffuse from the cathode to the lithium anode, where they react to create soluble shorter-chain polysulfides and insoluble lithium sulfide. When the battery is charged, while the shorter-chain polysulfides diffuse back to the cathode, the lithium sulfide remains irreversibly deposited on the anode.

With each cycle, more sulfur is lost from the cathode and trapped on the anode, degrading the battery components and performance. "This cyclic migration of polysulfides, or shuttle effect, ultimately suppresses the achievable capacity of the sulfur electrode, undermines long-term stability, and poses a major barrier to the technology's commercial viability," explains Shetty.

> **"Our molecular-level design strategy holds strong promise for the commercialization of efficient and durable lithium–sulfur battery technologies."**

Shetty and the team were able to block the worst effects of shuttling by introducing a lightweight porous framework at the cathode. This provided anchor points for the sulfur, preventing it from reacting with the lithium ions.

"Unlike the commonly used approach of simple physical confinement, our covalent organic frameworks enabled encapsulation through two mechanisms: physical confinement in the micropores and chemical bonding to the anchoring sites," says Shetty. Batteries with the porous framework retained up to 80% of their capacity after 500 cycles.

The next step will be to scale up synthesis using cost-effective, industrially compatible methods. "Our molecular-level design strategy holds strong promise for the commercialization of efficient and durable lithium–sulfur battery technologies," says Shetty. "Collaboration with industry partners will be essential to validate performance in real-use conditions and accelerate the path from lab to market."

Ranjeesh, K.C. et. al. Heteroatom-synergistic effect on anchoring polysulfides in chalcone-linked nanographene covalent organic frameworks for high-performance Li–S batteries. *Adv. Sci.,* **12**, 2415897, 2025.

From brine to batteries

A single atom of nitrogen leads a research team to mine lithium from brine, turning desert waste to wealth.

In the shimmering heat of the Arabian Peninsula, a quiet revolution is underway; not in the depths of the Earth, but in the invisible waste streams flowing from desalination plants. In the discarded brine, a precious element hides in plain sight: lithium, the lifeblood of the electric age.

Traditionally lithium is extracted from hard rock and salt flats, both involving processes that guzzle water and scar ecosystems. Now researchers have found a new source of lithium in the desert's own waste stream.

At Khalifa University, Dinesh Shetty, theme Leader at the Center for Catalysis and Separation leads a research group to unlock this potential. He and his team are using a new class of designer materials known as covalent organic frameworks (COFs). These are porous structures engineered with atomic precision to selectively trap lithium ions.

"These aren't just powders," Shetty explains. "They're precision materials. We design them at the atomic level, positioning nitrogen atoms as active centers to selectively capture lithium."

Working alongside Shetty is Rajesh Dhanushkotti, a postdoctoral researcher specializing in electrochemical processes. "Just apply a specific voltage and lithium sticks to the electrode. Then we reverse the voltage and recover it. No mess, no waste," Dhanushkotti explains.

With just 1.4 volts, barely more than the potential from an AA battery, the process extracts lithium from brine without any toxic footprints. It's a radical shift from conventional methods that rely on harsh, chemical solvents and guzzle large amounts of energy.

"It's a contradiction," Shetty notes. "We use immense amounts of water to mine lithium, while we waste lithium-rich water in the form of brine. That's the irony we're solving."

PhD researcher and team member Najat Aldaqqa focuses her work on resource recovery. She turned to nitrogen atoms. "Nitrogen atoms are like magnets," she explains. "They increase lithium selectivity and boost adsorption capacity," she says. "Our data shows the more nitrogen we embed, the better our performance."

Their study marks the first time COFs have been successfully used in this type of lithium recovery and the results are impressive even at this early stage. The team's material was able to recover 15.7 milligrams of lithium for every gram of material used, pulling out more than 80% of the lithium from the test solution.

The researchers are now creating a larger test system to use on real saltwater from desalination plants, which generate an estimated 124.5 million cubic meters of brine daily. "We're scaling up and it's just the beginning," Dhanushkotti says. "Our goal is a stacked system using real brine."

For a region built on desalination, this could be game-changing. Instead of just producing clean water, desalination plants could offer energy independence. "Why not make the UAE a source of lithium too?" Shetty says. "It's a chance to lead in circular economy thinking."

Dhanushkotti, R.; Bin Omer, M.; Alabsi, A.; Najat, N.; Almutairi, A.; Shetty, D., Inherited Nitrogen Distribution Control in Covalent Organic Framework Cathodes for Efficient Lithium Recovery. *Adv. Sci.*, **12** (25), 2308213, 2025.

Researchers at Khalifa University fine-tune their experiment, aiming to turn desalination waste into a valuable battery resource.

ABSTRACT AERIAL ART/ DIGITALVISION/ GETTY IMAGES

Sea squirts, such as these Clavelina lepadiformis, could be a source of nanocellulose for applications ranging from strengthening composites to biomedical implants.

ALEXIS ROSENFELD/GETTY IMAGES NEWS

Could sea squirts be the next big thing in nanotech?

High-quality nanocellulose networks can be extracted from sea squirts by a simple method.

When it comes to a sustainable blue economy and advancing nanotechnology, one marine creature offers promise on both fronts: the sea squirt. This humble invertebrate may unlock ways to produce high-quality nanocellulose—a material made from networks of nanofibers with one dimension in the nanoscale or a billionth of a metre.

Besides being an integral part of healthy coastal ecosystems, sea squirts or ascidians are a culinary delicacy in parts of Asia. They can become a hazardous invasive species, travelling the seas attached to the bottom of ships or on marine infrastructure.

Uniquely for an animal, their outer layer or tunic contains nanocellulose. The material is strong, biodegradable and biocompatible meaning it is less likely to be rejected by, or toxic to, the human body.

"[Sea squirts] both native and invasive, are a renewable, readily available source of high-quality nanocellulose, with properties unmatched by other sources," says Blaise Tardy, a bioproduct engineer at Khalifa University.

Sea squirt nanocellulose may be suitable for applications ranging from strengthening composites to biomedical implants. "The main application we are studying now is associated with microfluidics," explains Tardy, whose team has developed a simple way to extract the nanocellulose.

Microfluidics is the manipulation of tiny amounts of fluids in microchannels—for example, to carry out lab tests such as the rapid antigen tests used at home to detect Covid-19. Nanocellulose has properties, including a surface chemistry that can be tuned to control fluid flow and reactions, that make it a potential alternative to plastics for microfluidics.

Creating the microchannels for microfluidic applications is difficult in nanocellulose extracted from plants or grown in bacterial cultures. That's where sea squirts can step in. Their outer nanocellulose-containing layer has inbuilt channels, ranging from 50 to 500 micrometres in diameter, that make up part of the animal's circulatory system, Tardy explains.

"We have developed a very simple process using alkali and bleach to remove protein and fatty acids," says Tardy. The process preserves the channels embedded in the nanocellulose fibres.

The preserved circulatory channels offer an opportunity to assign functions to different regions, for example injecting magnetic particles in one area to induce a magnetic response and conductive particles to increase electrical conductivity in another area, Tardy says.

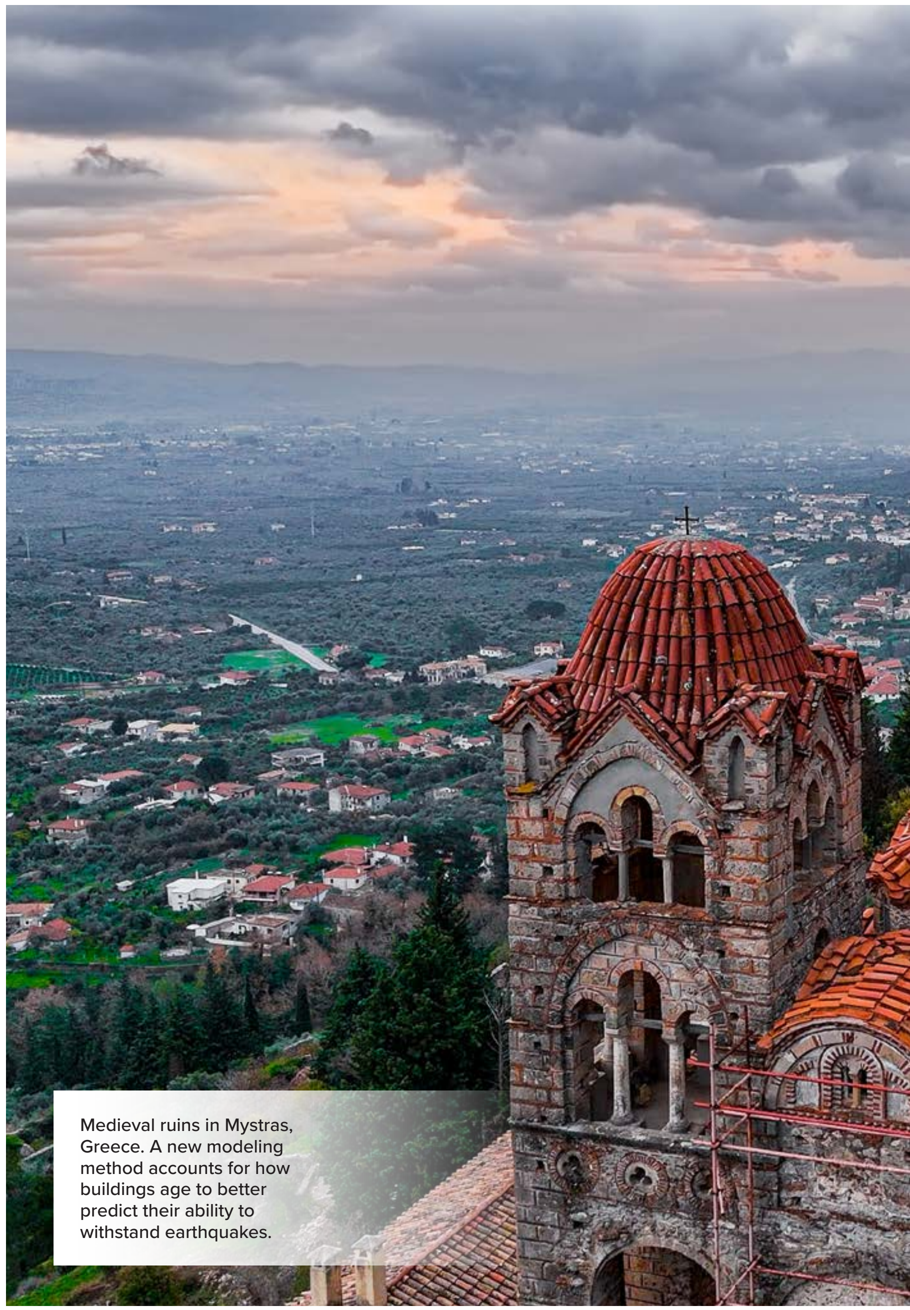
"As the only animal that makes cellulose, ascidians are an unexploited source of nanocellulose," says Tardy, noting that on a dry weight basis, 1 kg of sea squirts yields 232 g of nanocellulose. He proposes two possible ways to efficiently scale up production. One would be by farming native sea squirts in the shallow waters along UAE's long coastline. The other, by removing invasive sea squirts from marine infrastructure, which would also offer an environmentally friendly alternative to the antifouling coatings that are currently used to control the creatures.

Next steps include further development of multifunctional networks and microfluidics, particularly in the biomedical field; and investigation of the mechanical properties of these networks, particularly when wet.

Govindharaj, M., Salim, M., Dali, M-H., Kaniyamparambil, S., Arya, S., Hathi, Z., Mettu, S., Lizundia, E., Pappa, A., Pitsalidis, C., & Tardy, L. Multi-scaled cellulosic nanonetworks from tunicates. *Adv. Funct. Mater.,* ,2422595, 2025.

Age matters: model predicts how ancient walls will withstand earthquakes

Accounting for how masonry ages could sharpen seismic risk models and guide smarter preservation of historical buildings.


Medieval ruins in Mystras, Greece. A new modeling method accounts for how buildings age to better predict their ability to withstand earthquakes.

Historic buildings, constructed from bricks and mortar long before modern engineering, have been worn by centuries of weather extremes, stress and decay. These aging processes alter a building's structure in complex ways, making it difficult to predict how it will respond to an earthquake.

Now, researchers at Khalifa University and Aristotle University of Thessaloniki, Greece, have addressed this challenge by developing a modeling method that doesn't just look at how a historic building was built—but how it has aged. Their method factors in how the physical properties of masonry change over time to better predict what might happen in an earthquake. Their pilot study could help improve future seismic risk assessments and protect both lives, and buildings of historical and cultural importance.

"Securing the resilience of our heritage buildings is a huge challenge, particularly in seismically active regions such as Greece,"

"There is always the hope that heritage buildings will survive in perpetuity. Policymakers therefore need robust evidence and predictions to guide decision-making."

GUVEN OZDEMIR/ E+/ GETTY IMAGES

says Andreas Kappos, the structural engineer at Khalifa, who led the study. "The mechanical and physical properties of older, stone-built buildings shift over time as the stone and mortar deteriorate."

The physical properties that determine how modern buildings change over time, such as the corrosion of steel, are wellstudied. Scientists' understanding of how masonry changes over time, however, is limited.

"It's difficult to study the deterioration of stone over decades in an experimental setup, so this is where computer modeling can help," says Kappos.

"There is [always] the hope that heritage buildings will survive in perpetuity, and the resulting maintenance and retrofitting costs often come down to governments. Policymakers, need robust evidence and predictions to guide decision-making," he adds.

Kappos and his team applied a fragility analysis framework, originally developed by their own research group, specifically to masonry buildings. They incorporated data on how the mechanical properties of masonry, such as its ability to withstand compression, tensile and shear forces, change over time in response to environmental conditions such as heat and moisture. These factors influence how much damage an earthquake would cause.

The researchers used their approach to generate sets of 'fragility curves' for a typical Greek masonry building: a two-story, stone building, built in Athens in the 1830s.

"A fragility curve describes the likely amount of damage expected given a certain strength of earthquake," says Kappos. "These curves allow us to predict damage severity under multiple earthquake scenarios. Such outputs can help engineers decide which buildings to retrofit and when."

A scaled-up, refined version of their method could help guide building inspections and strategies to limit building damage in earthquake zones around the world, says Kappos. Future models could be expanded to include heritage bridges and other ancient structures.

Kafetzi, P.P., Papanikolaou, V.K., & Kappos, A.J. Fragility analysis of heritage masonry buildings accounting for ageing effects. *J. Build. Eng.* **104**, 112267 (2025).

A tiny molecule could clean the world's most polluted waters

Researchers are using cutting-edge catalysts to destroy persistent toxins in our waterways.

The Yangtze River in China is one of the most polluted waterways in the world.

Our rivers and waterways are at increasing risk from a cocktail of harmful industrial chemicals, solvents and urban waste. These pollutants don't just linger in the environment, they can seep into the food chain, posing a threat to both ecosystems and human health. Traditional wastewater treatment methods often struggle to get rid of these stubborn pollutants.

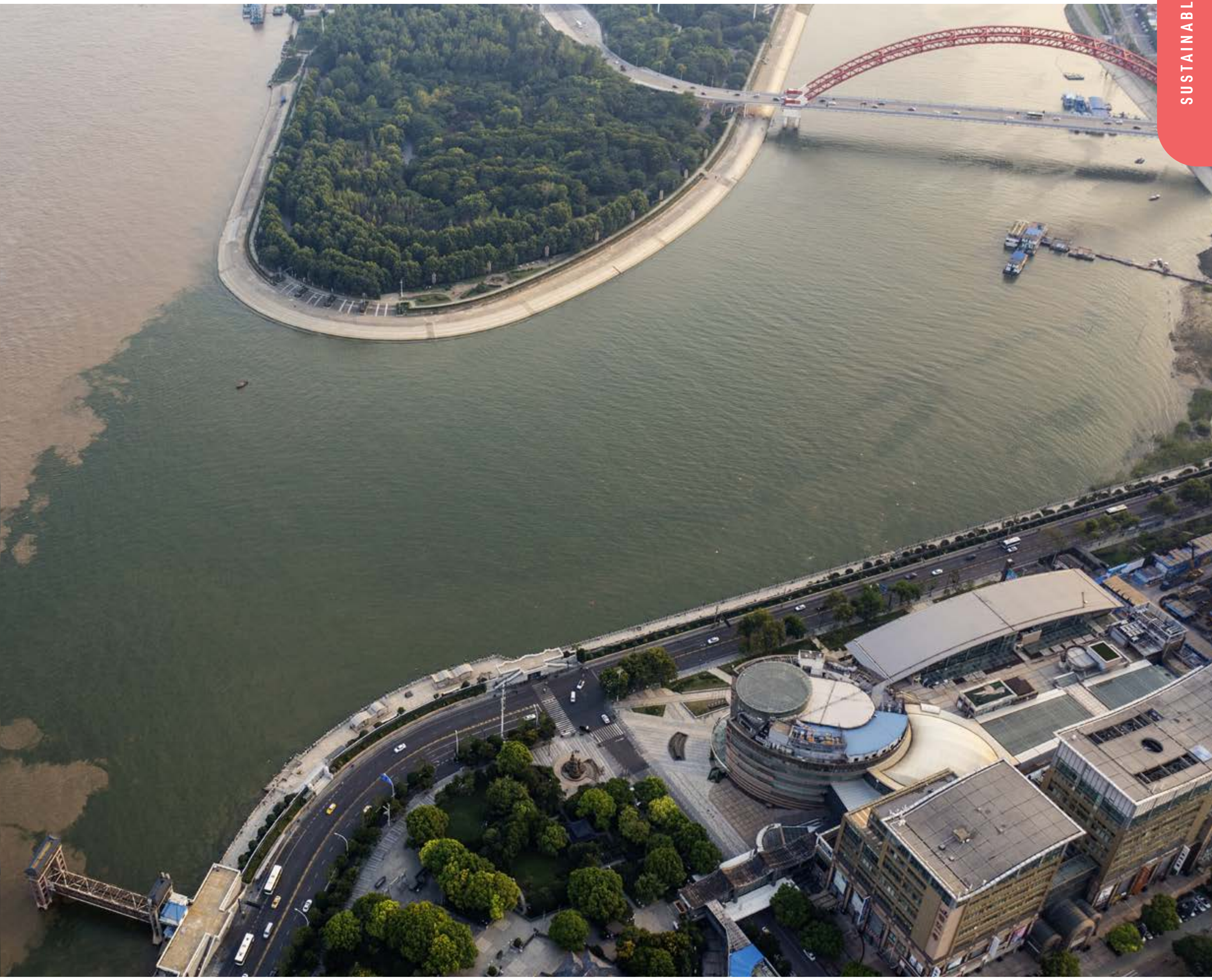
Researchers at Khalifa University are developing more powerful ways to treat water contaminated by these persistent and toxic wastes. The work "represents a major step forward in clean water technologies, offering an efficient, scalable, and environmentally friendly solution for treating wastewater and protecting public health," says Nagy Torad, a KU chemist who works on the project.

"The work represents a major step forward in clean water technologies, offering an efficient, scalable, and environmentally friendly solution."

The team looked at metal-free carbon-based catalysts—materials used to degrade organic molecules in wastewater. By adding nitrogen atoms, they discovered the catalysts created tiny, enclosed spaces. The design dramatically improved their performance and increased the amounts of contaminants they could remove.

Still one mystery remained: they didn't fully understand why the approach seemed to work effectively, or how to optimize these systems for more efficient pollution treatment.

Their latest research revealed the answer, finding that the nitrogen and confined spaces boosted the production of singlet oxygen—a powerful chemical that acts like a targeted cleaning agent, selectively breaking down pollutants. "This innovative



JACKAL PAN/ MOMENT/ GETTY IMAGES

approach not only boosts pollutant removal efficiency but also sheds light on the underlying chemical processes that drive this performance," Torad explains.

Based on this discovery, the team built a new type of catalyst and tested it on water samples drawn from the Yangtze River in China—one of the most polluted waterways in the world.

The results were incredible. The catalyst removed over 99% of the micropollutants. And tests showed it could achieve an impressive 99.4% removal efficiency of bisphenol A, an organic chemical commonly found in plastics and resins, frequently detected in water bodies near industrial and consumer activities and is associated with reproductive problems, metabolic disorders, and certain cancers. This is a huge improvement over similar existing catalysts, which only managed a 14.8% removal rate.

"While these results are promising, further work is needed to advance the technology toward commercialization," Torad says. The researchers are now investigating how to fine-tune the process, and studying how pollutants move through the catalyst at a microscopic level to make it even more efficient.

Li, J., Lyu, W., Mi, X., Yu, J., Liu, Y., Torad, N., Ayad, M., Feng, J., and Liao, Y. Carbonized nitrogen-containing conjugated microporous polymers: Versatile platforms for high-performance carbon catalytic membranes and their angstrom-confined activation mechanism on peroxymonosulfate. *Journal of Hazardous Materials*, **491**, 2025.

How smarter behavior could slash greenhouse emissions

Analysis of energy demand and use highlights the need for tailored location-based strategies.

Every time we flip a switch, hop into a car or crank up the AC, we are using energy. Our homes and offices, and transport account for 19% and 7% of energy-related greenhouse gas emissions respectively. To reduce emissions, research focusing on demand-related approaches seeks to influence how we use energy, not just how we produce it.

Developed with key contributions from Khalifa University and shaped by insights from policymakers and experts to ensure real-world relevance, researchers at Khalifa University used multi-model analysis to reveal that by employing a combination of strategies, global emissions from both construction and transport could be slashed by as much as 90% by 2050.

Using advanced mathematical models that bring together information about energy systems, the economy and the environment, the researchers examined the potential outcomes of behavioral change, technological improvement, and electrification strategies.

While difficult to model due to social and cultural variation, behavioral change is predicted to contribute to significant emissions reductions. Changes highlighted include flying less, using public transport and living in smaller or shared spaces.

Technological improvements, such as better insulation, efficient heating and cooling systems, and more efficient mobility, will also lead to substantial benefits. These measures not only reduce emissions but also help lower overall energy demand, easing the pressure on electricity systems as countries decarbonize.

Electrification, particularly the shift to electric vehicles and heat pumps, offers the largest potential for emissions reduction. However, it requires clean electricity and can significantly increase demand for power, which may strain energy infrastructures.

"To truly cut emissions in buildings and transport, we need a mix of solutions," says Pedro Rochedo from Khalifa University's Research and Innovation Center on CO2 and Hydrogen (RICH). The study found that when all three strategies were combined, emissions from buildings could be slashed by 51-85%, and from transport by 37-91% by 2050.

Not all regions, however, are the same, Rochedo explains. The wide range of estimates reflects differences in model assumptions and underlying socio-economic projections, such as economic growth, urbanization and population size. Improvements in energy efficiency can sometimes lead to increased energy use. For instance, OECD countries may see flat or declining energy demand with strong policies, while rapidly growing economies, such as India and Southeast Asia, could still experience rising energy use, despite technology efficiency improvements, unintentionally offsetting any environmental gains.

"This study highlights the importance of integrated strategies that combine electrification, efficiency and behavior change while ensuring public support and equitable access," says Rochedo. The study also underscores the need for region-specific approaches and policies that consider social systems, consumer behavior and the rebound effect, he says. By understanding these differences, we can design more effective and sustainable pathways toward a greener future for our cities and transport, he concludes.

van Heerden, R. et al. Demand-side strategies enable rapid and deep cuts in buildings and transport emissions to 2050. *Nat. Energy,* 1-15, 2025

By switching to transport methods like the Dubai Metro, nations can slash as much as 90% of global emissions from construction and transport by 2050.

YONGYUAN DAI/ STONE/ GETTY IMAGES

Resilient nations start with sustainable choices

New insights show that a country's ability to withstand crises hinges on its commitment to the UN Sustainable Development Goals.

Building better healthcare systems and investing in innovation and more robust infrastructure can counter global threats like the COVID-19 pandemic.

DUSAN STANKOVIC/ E+/ GETTY IMAGES

Natural disasters and health crises can significantly affect sustainable development by undermining economic growth and social progress. They are often addressed as separate challenges needing unique resilience strategies, but a team of researchers from Khalifa University, the American University of Sharjah and Teesside University in the UK took a more unusual approach. They studied the relationship between achievement of the various United Nations' Sustainable Development Goals (SDGs) and resilience to disasters and pandemics.

The researchers used complex computer models to measure how SDGs influence each other and which ones need to be prioritized. They introduced the concept of "SDG-related risks"—the probability of failing to achieve a specific SDG—and analyzed how these risks affected a country's ability to deal with natural disasters and health crises. But instead of looking at each of the 17 SDGs individually, the team took a broader approach.

"The COVID-19 pandemic triggered the worst global economic downturn since the Second World War and showed just how closely connected all the SDGs are," says Mecit Simsekler from Khalifa University. "It became harder to meet many SDGs—especially those related to hunger, clean water and energy—highlighting the urgent need to think more holistically."

The study found that coordinated efforts that tackle several challenges together would be beneficial, highlighting the need for integrated resilience strategies. In particular, weaknesses in areas such as quality education, sustainable urban development, poverty reduction and access to clean energy were strongly associated with increased risk of both natural disasters and health crises. Conversely, countries that performed well in goals related to environmental protection and strong institutions were better equipped to withstand shocks.

Strengthening governance, building better healthcare systems and investing in innovation and more robust infrastructure can offer solutions to a range of global threats. Disaster-prone countries typically struggled with good governance, urban planning and healthcare. These interconnected weaknesses were seen to limit a nation's ability to respond effectively to emergencies. In contrast, countries with low disaster risk often perform well in energy access, education and poverty alleviation. Countries with limited access to reliable energy are more likely to experience widespread disruptions during health crises.

While the initial analysis is based on national data, the researchers suggest that the same approach could be applied at the city or regional level, enabling more targeted strategies.

"As the world faces escalating risks from climate change, pandemics, and economic shocks, understanding how sustainability gaps affect countries' vulnerability is more critical than ever. This study provides a strategy to inform resilience planning, offering both a warning and a way forward," concludes Simsekler.

Qazi, A.; Angell, L.C.; Simsekler, M.C.E.; Daghfous, A.; & Al-Mhdawi, M.K.S. (2025). Assessing the impact of sustainability risks on disaster and pandemic vulnerabilities: A global perspective. *Global Transitions,* **7**, 159-174, 2025.

The future is now: Inside Khalifa University's 2025 Innovation Day

From drones to desalination, a celebration of ideas reveals how innovation is shaping the UAE's sustainable future.

Morning light spills through the glass atrium, glinting off rows of prototypes and display screens. Researchers and students make final checks as visitors continue to gather. When His Highness Sheikh Hamed bin Zayed Al Nahyan, Chairman of the Board of Trustees of Khalifa University, steps inside to applause, the university's Research and Innovation Exhibition 2025—a showcase of ideas where science meets enterprise and innovation takes center stage—has begun.

Building on the success of its first Innovation Day in 2024, February's exhibition featured projects exploring new frontiers in science, engineering, technology, and healthcare.

Exhibits were organized into three themed zones called Research, Industry Applications, and Start-ups. This offered glimpses into a broader national vision, where discovery fuels diversification, and innovation shapes the future of the United Arab Emirates.

The pulse of discovery

Walking through the exhibition was like stepping into a living laboratory. Drones hovered above the growing crowd, holographic projections displayed data from lunar rovers and gene-sequencing arrays, and robotic arms moved with precision.

"This exhibition brings together more than a hundred research and innovation projects," says Khadija Binsumaida, Marketing Specialist and the event's coordinator. "Innovation Day showcases how our researchers are contributing to national priorities, from healthy longevity and digitalization to energy transition and sustainability."

Across the floor Khalifa University's spin-offs and start-ups were in action. DroneLeaf demonstrated its flight software that allows drones to learn and adapt mid-air, while Kumrah AI revealed the neuromorphic vision technology that mimics human perception for ultra-fast inspection. Both innovations echo the UAE's Vision 2030—melding robotics, AI, and sustainability into the architecture of future cities.

> **"Innovation Day showcases how our researchers are contributing to national priorities—from healthy longevity and digitalization to energy transition and sustainability."**

Innovation Day 2025 featured projects exploring new frontiers in science, engineering, tech and healthcare.

In the Healthy Longevity zone, Golde, a hydrogel-based wearable electrode, flexed like skin, transmitting data with comfort and precision beyond traditional sensors. Nearby, Mashyah analyzed gait and motion to help clinicians decode the rhythms of recovery.

Other displays stretched imagination even further: a mangrove-inspired solar desalination device capturing nature's efficiency; the Cancer Multi-Omics Atlas mapping genetic landscapes for precision oncology; and the compact 6U CubeSat, demonstrating the UAE's expanding reach into space for continuum of innovation, from the molecular to the planetary.

From laboratory to marketplace

Behind the scenes, the Khalifa University Enterprises Company (KUEC), the university's business and investment arm, bridges and catalyzes discoveries from conception to commercialization. "KUEC drives innovation commercialization and helps our start-ups grow beyond campus," Binsumaida explains.

In the Start-up Zone, founders mingled with investors and policymakers, their prototypes gleaming under spotlights. ProScreeniX, specializing in crystallization reagents for structural biology, showed how niche research can seed global enterprise. Around it, posters on 3D-printed solar absorbers, pregnancy-risk monitoring systems, and AI-based utility analytics hinted at the next-generation tech ready to leave the lab.

Across every aisle, the exhibition's themes intertwined, proving that innovation here is not confined to disciplines but woven into the fabric of national ambition. Khalifa University remains central to that vision: not merely a seat of learning, but a compass for the UAE's innovation journey, aligning education, enterprise, and exploration. Its annual exhibition distills that spirit into something tangible, where curiosity meets courage and ideas take shape.

AI THAT SEES AND SPEAKS

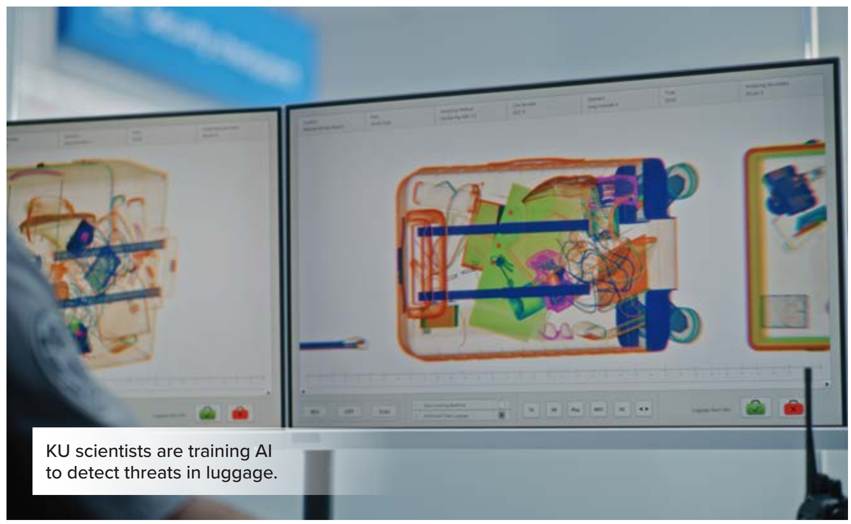
Naoufel Werghi, Professor of Computer Science at the Centre for Cyber-Physical Systems, Khalifa University.

Naoufel Werghi aims not only to replicate the human visual system, but to extend its capabilities so that machines can perceive patterns invisible to the eye and process information at scales beyond human capacity.

Tell us about your journey.
I started my PhD working on robots that can 'see'—machines capable of sensing the environment, analyzing images and making decisions. As I delved deeper, I realized that I was grappling with the same fundamental problems that once preoccupied David Marr, a visionary neuroscientist and the founder of modern computer vision. He believed that for robots to see, we first needed computers to analyze images and understand the context.

When I joined Khalifa University in 2010, just three years after it was established, I saw in it the potential for a great academic career and professional growth, and I wasn't wrong.

What the themes are driving your research right now?
There are three main areas. First, we're training AI to detect threats in luggage—teaching our algorithms to spot contraband in X-ray images. Second, we're working on medical imaging, with a focus on spotting small, subtle patterns of disease in its early stages. Finally, we have partnered with the Abu Dhabi National Oil Company to monitor flaring at oil and chemical



KU scientists are training AI to detect threats in luggage.

KHALIFA UNIVERSITY; EVGENIYSHKOLENKO/ ISTOCK / GETTY IMAGES PLUS

plants, by tracking incomplete combustion to detect harmful pollutants, such as toxic gases and methane.

How are you taking your research into the real world?
I recently launched a startup called IBSAR Technologies, born out of our work in luggage detection. In our lab, we have the same scanners found in airports, so we can run very realistic simulations. We've designed a system that can recognize up to five different threat items with 95% accuracy. To do this, we had to think like smugglers to see how they might hide illegal items. We've also built a data set comprising more than 45,000 X-ray images covering 22 items.

The Khalifa Innovation Centre has offered tremendous support in launching the startup from the very beginning. They did a fantastic job.

What are the most exciting advances in your field?
The emergence of vision-language models stands out. These are trained on both images and text, and combine the different types of information in their analysis. For example, you could give them a medical image and ask them to describe what's going on. Being able to associate image and text also means machines are better at explaining their thinking. That's a groundbreaking shift that moves us closer to true semantic understanding, and a significant step toward explainable AI.

Interestingly, the way these models associate image and text were also inspired by the brain, just like Marr's first model was. Maybe now we're only discovering a percent or two of the many things that the brain will inspire us to create in the future.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