

# ingenia

SEPTEMBER 2025 ISSUE 104

**CLOTHES THAT ARE SMART**  
**NEW TECH FOR THEME PARKS**  
**EXPLORING THE UK'S GEOTHERMAL ENERGY**  
**THE BENEFITS OF LAB-GROWN DIAMONDS**



Royal Academy  
of Engineering



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**Front cover**

Diamonds have several potential uses, from helping to diagnose diseases to quantum sensing and mapping  
© Benjamin Leon

# WELCOME



Along with solving problems, engineers also redefine what's possible. In this issue, we explore the lab-grown diamonds that are revolutionising quantum sensing, healthcare, and electronics (page 19). We also dive into the magic behind theme parks, where engineers bring fantastical worlds and creatures to life through cutting-edge immersive experiences (page 10). And if you've ever dreamed of wearing tech straight out of a sci-fi film, turn to page 24 to discover how textiles and electronics are merging to create the clothes of tomorrow.

Engineering isn't just about what's visible, it's also about what lies beneath. Academy Fellow Professor Susan Gourvenec FREng is leading pioneering research to pinpoint the best locations on the seabed for offshore wind farms, accelerating the shift to renewable energy. Across the UK, other teams are drilling deep into the Earth to tap into geothermal energy, an underused resource that could one day heat our homes sustainably.

This issue also marks a personal milestone: my final edition as Editor-in-Chief of *Ingenia*. It's been an incredible journey working with a brilliant editorial board and team, all committed to celebrating the ingenuity and impact of engineers. And during this time, *Ingenia* has expanded its digital footprint with a redesigned website, exclusive online content, and a fast-growing monthly newsletter (which you can sign up for at [ingenia.org.uk/subscribe](http://ingenia.org.uk/subscribe)).

As I step away from *Ingenia*, I do so with immense pride in what we've built together – a platform that celebrates the brilliance and boldness of engineering. It's been a privilege to help tell these stories, and I leave knowing that *Ingenia* will continue to shine a light on the people shaping our world in extraordinary ways.

*Faith Wainwright*

**Faith Wainwright CBE FREng**  
Editor-in-Chief

# CONTENTS

## UP FRONT

### 02 IN BRIEF

- Italy approves world's longest suspension bridge to Sicily
- Data-driven designs could transform how prosthetics are fitted
- Space solar panels could cut battery storage needs and costs
- Get involved in engineering

### 06 HOW I GOT HERE

Masters student Delia Stemate is exploring how shark skin could inspire lessened aircraft drag.



### 08 OPINION

AI can boost our creativity, rather than replace it, say Nick Jennings FREng and Lise Jaillant.



## FEATURES

### 10 TAKING A RIDE ON THE DARK SIDE

'Thrill engineers' are exploring so-called dark rides that get their kicks from robotics, AI and immersive experiences.



### 14 DIG DEEP FOR RENEWABLE ENERGY

Deep under the UK is a potential energy source that could provide a not-insignificant chunk of our energy needs. Can we tap into it?



### 19 DIAMONDS: NOT JUST A PRETTY FACE

So much more than jewellery, diamond is a wonder material with myriad applications, including in the quantum world.

### 24 THE ROAD TO SCALING ELECTRONIC CLOTHES

Making wearable electronic textiles that are comfortable, washable and stylish is no easy feat, but engineers are on it.



### 29 PROFILE

Susan Gourvenec FREng began her career as an 'accidental engineer'. She's now a leading authority in ocean infrastructure.

### 34 INNOVATION WATCH

Retrofitting buildings promises energy savings: now, drones could speed up the process by spotting where heat is lost.

### 36 HOW DOES THAT WORK?

If you've ever wondered how aluminium drinks cans are made, now's your chance to find out.

## IN BRIEF

# ITALY APPROVES WORLD'S LONGEST **SUSPENSION BRIDGE** TO SICILY



**Italy's Strait of Messina connects Sicily to the mainland, and is expected to be home to the longest suspension bridge in the world by the mid-2030s** © Shutterstock

In August, Italy greenlit construction of the longest suspension bridge in the world, which will connect the island of Sicily to the mainland across the Strait of Messina.

The bridge, known as the Strait of Messina Bridge, will feature a central suspended span of 3,300 metres, surpassing the current record held by Turkey's Çanakkale Bridge ('Bridging the Eurasian gap', *Ingenia* 96) by a kilometre. Once completed, the full deck will stretch 3,666 metres and carry both road and rail traffic, dramatically improving connectivity to mainland Italy for Sicily's five million residents.

The structure will be built to accommodate three lanes of vehicle traffic in each direction, two railway tracks, and two service lanes. It is expected to handle up to 6,000 vehicles per hour and 200 trains per day, operating around the clock throughout the year. The bridge's steel towers will rise to 399 metres, supported by cables measuring 1.26 metres in diameter and extending over 5,300 metres – an engineering first.

Designed to withstand seismic activity and extreme winds, the bridge will also be equipped with

an intelligent monitoring system to ensure safety and enable predictive maintenance. The project is being led by COWI, a Danish engineering firm known for designing major suspension bridges, including the Great Belt Bridge in Denmark and the Çanakkale Bridge in Turkey.

Officials say the bridge will act as a catalyst for economic growth, tourism, and cultural exchange in Southern Italy, marking a new chapter in the region's development. Italy's transport minister has said that the aim is to complete the bridge by between 2032 and 2033.

# DATA-DRIVEN DESIGNS COULD TRANSFORM HOW PROSTHETICS ARE FITTED



**The data-driven approach could save prosthetists time and allow them to focus on perfecting personalised designs for patients**  
© Shutterstock

A new approach to designing prosthetic limbs using patient data and digital modelling has shown promising results in an NHS trial, which could lead to prosthetics that fit people better, are less expensive and take less time to make.

Developed by Ralii Devices, a University of Southampton spinout, in collaboration with researchers from the university, the technology uses data from over 160 previous prosthetic designs to generate personalised socket recommendations based on a 3D scan of a patient's residual limb. The results of the trial were published in *JMIR Rehabilitation and Assistive Technology*.

The socket is the critical interface between a person and their prosthesis. Traditionally, sockets are crafted by skilled prosthetists using plaster casts

and trial fittings, or more recently, computer-aided design (CAD) software. While effective, the process can be time-consuming and require multiple appointments to achieve a comfortable fit.

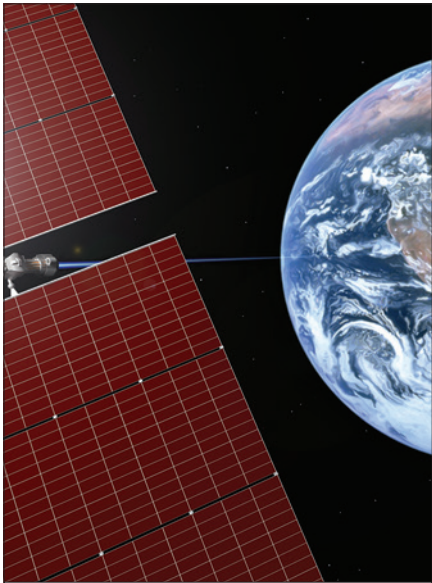
In the NHS trial, patients from three rehabilitation centres were fitted with two sockets – one designed by a prosthetist and one using the data-driven method. Comfort scores were similar across both designs, but the data-driven sockets showed slightly more consistent results. Several participants preferred the fit of the data-driven socket and chose it for their final prosthetic.

Alex Dickinson, Professor of Biomechanical Engineering at the University of Southampton, emphasised that while 3D scans can

tell us a lot about the residual limb's external shape, only experienced prosthetists can identify internal issues like bone spurs or neuromas. "We developed the data-driven socket design approach to save prosthetists' time by giving them a solid base to work from," he said. "As an engineer, I wouldn't dream of suggesting I could do a better job than a prosthetist. Instead, the method we have developed effectively helps prosthetists to learn from each other."

The final phase of the project is now underway, focusing on developing an effective software interface for clinicians. The project received funding from Innovate UK, with earlier support from the University of Southampton, Orthopaedic Research UK, and the Royal Academy of Engineering.

# SPACE SOLAR PANELS **COULD CUT BATTERY STORAGE NEEDS AND COSTS**



Could beaming solar power to Earth cut the cost of renewable energy in Europe? © Shutterstock

Solar panels placed in space could reduce Europe's reliance on energy storage in batteries and cut the cost of its renewable energy system by billions of euros, according to new research from King's College London.

In a study published in the journal *Joule*, researchers analysed a NASA design for a space-based solar power system, planned to be operational by 2050. Unlike solar panels on Earth, those in space can collect sunlight continuously, unaffected by weather or the day–night cycle. The energy would be transmitted wirelessly to receiving stations on Earth, then converted into electricity and fed into the grid.

The findings suggest that space-based solar power could reduce the need for battery storage by over 70% and lower the overall cost of Europe's

energy system by up to 15%, an estimated saving of €35.9 billion every year.

Professor Wei He, lead author and Senior Lecturer in Engineering at King's College London, said the research shows the potential of this emerging technology. "Although the feasibility of this technology is still under review, our research highlights its vast economic and environmental potential if adopted," he said. "Reaching net zero emissions by 2050 is going to require a significant shift to renewable energy, and this emerging technology could play a pivotal role in that transition."

The study is the first to assess how this technology could be integrated into European energy systems and to estimate its cost-effectiveness in that context.

## REMEMBERING MICHAEL KENWARD OBE, SCIENCE WRITER AND EDITOR



Michael Kenward OBE, a former member of *Ingenia's* editorial board and a longstanding contributor to the magazine, sadly passed away in August 2025.

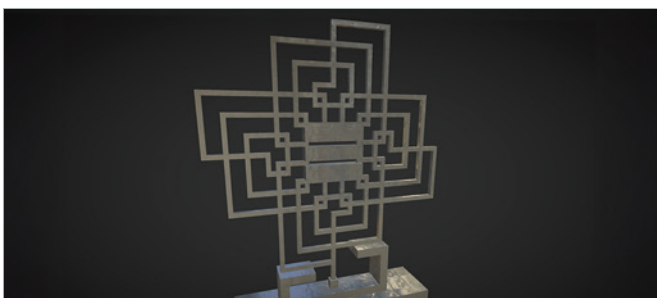
Michael began his career as a research scientist, working on nuclear fusion at Culham Laboratory. He went on to spend over a decade as editor of *New Scientist*, before becoming a freelance writer, editor, and editorial consultant. Throughout his career, Michael was driven by a passion for making complex scientific and engineering ideas accessible and engaging to wider audiences. His writing consistently bridged the gap between research and public understanding, bringing innovation to life for readers beyond the expert community.

For more than 20 years, Michael was a valued member of *Ingenia's* editorial board and a regular contributor. He played a pivotal role in shaping the magazine, most notably through his work profiling Academy Fellows in each issue. His thoughtful interviews and skilful storytelling captured their engineering journeys and achievements, helping to inspire and inform readers with clarity and warmth.

Michael's legacy lives on in the pages of *Ingenia*, and he will be missed by all who had the pleasure of working with him.

"Mike was such a huge supporter of the Academy and the magazine, and I learned so much from his style and support for editing all my editorials. His skill at editing what I thought was a well-written piece was remarkable. He always improved everything he touched." Dr Scott Steedman CBE FREng, *Ingenia* Editor-in-Chief, 2004 to 2021.

# GET INVOLVED **IN ENGINEERING**



## CREATE **THE TROPHY**

**Ends 28 November**

The Queen Elizabeth Prize for Engineering (QEPrize) Create the Trophy competition is now open to young people all around the world, aged 14 to 24. Using the free QEPrize 3D Design Studio app, entrants can design a trophy that will be presented to the winner of the 2026 Queen Elizabeth Prize for Engineering. The winner of the competition will receive a high-end laptop and see their design displayed at the Science Museum. For more information and to download the app, visit [qeprize.org/trophy](https://qeprize.org/trophy)

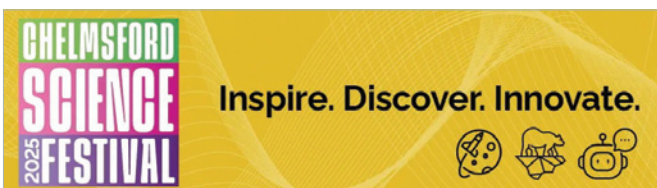


## NEW SCIENTIST **LIVE**

**Excel, London**

**18 to 20 October**

Across the weekend visitors can hear talks, get hands-on at interactive exhibitions and explore more about STEM. Explore assistive robotics, programme a quantum computer and learn more about innovations in aviation. Monday's session is exclusively for schools groups and features an Academy-sponsored session on discovering the A to Z of engineering. Book tickets at [live.newscientist.com](https://live.newscientist.com)



## CHELMSFORD **SCIENCE FESTIVAL**

**Various locations, Chelmsford, Essex**  
**21 to 28 October**

Hosted by Anglia Ruskin University, this year's Chelmsford Science Festival explores the theme 'Our AI World – Power and Perils', diving into the fascinating and fast-evolving world of AI, from its transformative potential to the ethical dilemmas it poses and how it is reshaping our lives. Family Science Days take place on Saturday 25 and Sunday 26 October. For more details and to book onto panel talks, workshops and shows, visit [aru.ac.uk/events/Chelmsford-science-festival](https://aru.ac.uk/events/Chelmsford-science-festival)

## INNOVATION INCOMING: **ADVENTURES IN ORGAN PRESERVATION**

**Royal Academy of Engineering, London, and online**  
**8 October**

Join MacRobert Award winner OrganOx and an expert panel to explore the impact and significance of its innovative technology, which is supporting more organ transplants and helping to cut waiting lists. It's free to attend but please register online at [www.raeng.org.uk/events](https://www.raeng.org.uk/events)



## NATIONAL ENGINEERING **DAY**

**5 November**

The countdown to National Engineering Day has begun! This year will see the launch of the AI-Z of Engineering: a modern, future-focused guide to the world of engineering careers, from today's roles to the possible jobs of tomorrow. An Innovation Late: National Engineering Day special will also take place in Liverpool on 4 November. Keep an eye on the Academy website for further information.

# HOW I GOT HERE

## Q&A

### DELIA STEMATE AEROSPACE ENGINEERING STUDENT

After carrying out a placement at Airbus Defence and Space, aerospace engineering student Delia Stemate is exploring how patterns similar to those found on sharks' skin can reduce the noise generated by airflow over aircraft wings during flight.

#### WHY DID YOU FIRST BECOME INTERESTED IN SCIENCE/ENGINEERING/STEM?

My interest in STEM began at a very young age during primary school, largely thanks to a teacher who placed great emphasis on mathematics. Throughout my education, I was fortunate to have at least one teacher in each stage who nurtured my passion for mathematics and physics. Teachers are often our first real exposure to academic subjects, and I was lucky to have mentors who supported and encouraged me – starting as early as age seven, when I was selected to participate in maths competitions.

#### HOW DID YOU GET WHERE YOU ARE NOW?

I knew quite early that I wanted to study abroad and I committed myself fully to that goal. As an international student, I understood that strong academic results alone wouldn't be enough and that I needed to stand out. During my final two years of high school, I worked intensively: preparing for final exams, obtaining my English language certification, staying active in volleyball, and navigating the university application process. However, I owe much of my success to the constant support of my family and teachers, who believed in me and motivated me to achieve my best.



Delia sits inside a plane's cockpit at the Farnborough International Airshow

#### WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

My biggest achievement to date has been completing my placement year. If someone had told my 16-year-old self that I would one day spend a year working at one of the world's leading space and defence companies, I would have thought it impossible. But that's exactly what I did at Airbus Defence and Space, and it was an experience that still feels surreal at times.

During my internship, I worked in the procurement team, helping to find new technologies and potential suppliers for some of the equipment used in satellite ground systems. I carried out market research on a wide range of products, from modems and antennas to satellite communication devices and power units, looking into what options were available, how well they matched the technical requirements, and which companies could supply them. I even helped organise an innovation event where different suppliers presented their latest technology solutions to our team.

I also visited suppliers to learn more about what they could offer and prepared reports that helped decision-makers understand the market better. On top of that, I was involved in work related to making the supply chain more sustainable, which was a great



**Delia (centre) with her mentor Alexandra Knight, CEO of Stemazing (left), and Dr Roni Savage (right) at the Inspirational Business Women in STEM and Construction Awards at the House of Lords**

opportunity to contribute to something I really care about. The experience gave me the chance to develop both technical and professional skills, while seeing how the space industry works behind the scenes.

### WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

What I love most about engineering is that it never stands still – there is always something new to learn. Technology is constantly evolving and engineering spans so many disciplines that you're never truly done discovering. It's a career where curiosity is continuously rewarded and boredom is never an option.

### WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

This year has been very different from last year, as I returned to university to complete the final year of my aerospace engineering degree. A typical day now includes attending lectures, completing assignments, and dedicating a lot of time to my final-year dissertation. My project explores ways to reduce the noise generated by airflow over aircraft wings during flight. I've been investigating special surface patterns called riblets, which are inspired by the texture of shark skin and can help control the airflow to make it quieter.

To test this, I used a model aircraft wing (called an airfoil) and placed it inside an anechoic wind tunnel – a quiet testing environment designed to measure sound accurately. I used very fine sensors to capture how the air moves over the surface and then analysed the data using software tools to understand how different riblet placements affected airflow and noise. I also faced challenges such as limited lab access and budget restrictions, which meant adapting my original plan, for example by working with a premade model instead of 3D printing a custom one.

Alongside my academic work, I've continued to play volleyball and taken on a leadership role as chair of the volleyball club. This has involved organising matches, events, and helping manage the team, which has added a fun and rewarding leadership element to my year. Balancing all these responsibilities has taught me to manage my time effectively and strengthened both my technical and interpersonal skills.

### WHAT WOULD BE YOUR ADVICE TO YOUNG PEOPLE LOOKING INTO PURSUING A CAREER IN ENGINEERING?

Don't be discouraged if things seem difficult or overwhelming at first. Engineering concepts can be complex,

but there is always a way to make them accessible. What matters most is being willing to put in the effort and trusting that understanding will come with time and persistence.

### WHAT'S NEXT FOR YOU?

Next, I'll be continuing with a master's degree in aerospace engineering, in potentially my final academic year. I'm especially looking forward to exploring more space-oriented topics through my major project and optional modules. I also hope to continue playing volleyball, ideally with a London league team.

#### QUICK-FIRE FACTS

Age: 22

Qualifications: **third-year aerospace engineering student at Brunel University; Commodity Management Intern at Airbus Defence and Space; Chair of Brunel Volleyball**

Biggest engineering inspiration: **Henri Coanda**

Most-used technology: **wind tunnel testing during my major project**

Three words that describe you: **optimistic, hardworking and empathetic**

## OPINION

# INNOVATION MACHINES: CAN AI BOOST HUMAN CREATIVITY?

AI won't replace human creativity – but it can be our partner, say Professor Nick Jennings CB FREng FRS and Professor Lise Jaillant.



Professor Nick Jennings CB FREng FRS



Professor Lise Jaillant

If you think that machines cannot produce art, think again. There is now ample evidence that artificial intelligence (AI) can expand human creativity and produce stunning artwork.

Take the example of *Machine Hallucinations: Unsupervised* by the Turkish American media artist Refik Anadol, exhibited at the Museum of Modern Art (MoMA) in 2022. After training the model on the museum's wide-ranging collection, the artist ceded some creative control to AI, allowing it to 'hallucinate' and generate its own interpretations. The exhibition was so successful that it was extended four times, and eventually, MoMA acquired the seven-by-seven-metre 'data sculpture' for its permanent collection.

Soon after, an AI-generated 'photograph' fooled judges and was awarded the Sony World Photography Award. In 2024, a prize-winning Japanese author admitted part of her book was generated by ChatGPT. While AI-generated artworks and creative writing may divide opinion at times,

when it comes to evaluating artistic quality, research shows that they are often considered at least as good or even better than the average human creation.

## FROM THREAT TO OPPORTUNITY

The AI era comes with extraordinary creative opportunities, but also widespread fears. Some believe AI will exhaust our scope for creativity. In 2023, AI ethics researcher Timnit Gebru and colleagues wrote that with AI, "nothing new is truly created, a stale perpetuation of the past". Last year, researchers at UCL pointed to a risk that, despite the possibility for individual gains, "collectively a narrower scope of novel content is produced". Then, there is the potential economic impact: AI is already disrupting existing jobs and labour models in the creative industries, enabling the production of quality work in a fraction of the time and cost required previously.

Many artists fear that if they share their work online and on social media,

it will be used to train AI systems. To avoid plagiarism and breach of copyright, it may be tempting for artists to withdraw from the online sphere. Withdrawal may also prevent reputational damage – for example, if AI tools are used to create offensive images imitating the style of the artist. But having less visibility reduces artists' ability to find new clients and opportunities, leading to more economic loss. As an alternative, artists can check if their work has been used to train AI without their consent with tools such as "Have I been trained?", and opt out of future AI training by adding images or domains to the Do Not Train Registry.

Do these threats of copyright infringement and economic loss exist? Yes, undoubtedly. Should we get rid of AI and go back to a world of human-only artworks and creative writing? No. It is simply not possible to turn the clock back on these developments. Moreover, we believe this is undesirable because it would prevent artists from harnessing AI to enhance their creativity.

## CROSSING THE ART/SCIENCE DIVIDE

First, no human artist could ever gather a range of sources comparable to the huge datasets on which AI systems are based. Artists and writers do not reinvent the wheel each time they produce a new artwork, book or poem. They are influenced (and not always consciously) by their cultural environment and by other artists, past and present. It is these influences that lead to 'original and unusual ideas', which is at the core of the definition of 'creativity'.

In his book *Range: How Generalists Triumph in a Specialised World*, David Epstein argues that the world's most successful artists, musicians and scientists have developed

broad interests and skills. Their vast knowledge base is key to understanding the way they produce new and imaginative work. The same applies to AI systems: although they cannot feel or use personal experience, they have access to a mass of information much broader than any human could possibly gather.

Second, AI can be used to overcome technical obstacles. For instance, the French-Senegalese photographer Delphine Diallo has used AI as a creative partner for her visual project *Kush*, which transposes an ancient Egyptian civilisation into a utopian future. "I understood that AI would allow me to do what was impossible with photography," Diallo told French language magazine *Azerty* in 2024. She goes on to explain that at first, the technology did not generate satisfactory images of African faces. To move beyond biases and clichés, she prompted the AI to draw on a more diverse range of ethnic groups from different parts of Africa.

Since AI makes it much easier to produce technically advanced artistic work, professional artists will also need to distinguish themselves from amateurs. For a performance on speculative bubbles, for example, the British artist Anna Ridler put together her own database of tulip photos

and created an installation that could generate new tulip shapes, linked to the price of bitcoin. Such distant connections highlight the possibilities for collaborations across the art/science divide.

This human-AI creative collaboration is already pushing the boundaries of what art can be, moving beyond human perception and leading to creative outputs that have not been seen before. Works by Anna Ridler, Refik Anadol and others rely on AI processing and responding to complex data at scale – sometimes in real time. No artist could do this unaided, because the human brain cannot analyse such large datasets instantaneously.

While current AI systems are expanding the frontiers of creativity, we do not believe they will entirely replace humans. When researchers tried to train an AI system to generate Beethoven's unfinished tenth symphony, the result was disappointing at the artistic level, lacking the depth of feeling and originality of the musician's finished works.

Nevertheless, today's artists who use AI to enhance their work have much to gain. Some serious risks need to be negotiated, but human-AI co-creativity has the power to unlock extraordinary new and original work at the crossroads between art and technology.

### BIOGRAPHIES

**Professor Nick Jennings CB FREng FRS** is the Vice-Chancellor and President of Loughborough University and the Vice-President for Fellowship Engagement at the Royal Academy of Engineering. His research is in the broad area of artificial intelligence and has been used to help save lives in the aftermath of disasters, to help monitor the impact of climate change, and to win Olympic medals in sailing. He is particularly focused on using AI for real-world applications and in the study of human-AI partnership.

**Professor Lise Jaillant** is Professor of Digital Cultural Heritage at Loughborough University. She has extensive experience of collaborating with computer scientists, archivists, and government professionals to unlock digital archival data with innovative technologies. Since 2020, she has led several externally-funded projects on archives and artificial intelligence, which aim to make digitised and born-digital archives more accessible to researchers and other users.



Riders sit in a simulator that mirrors the action projected on 180-degree screens that surround it, on Flying Eyes Theatre at Ba Na Hills theme park in Vietnam © Simworx

# TAKING A RIDE ON THE DARK SIDE

Theme parks often look for ways to test the limits of what is possible in their rides, relying on speed, height and numerous inversions to give riders the ultimate thrill. Now, advances in digital technologies are becoming just as essential to their daily operations and existence. Beverley D'Silva speaks to the 'thrill engineers' who are reinventing the theme park.

## Did you know?

- The global theme park market is projected to reach over \$82 billion by 2032, driven largely by digital innovation
- Dark rides, which incorporate trackless vehicles, AI-driven animatronics and other interactive elements, are becoming more widespread
- These rides use special lighting, sound, animatronics, and visual effects to immerse riders in a narrative or fantasy world

Once defined by roller coasters, theme parks are now entering a new era, powered by digital innovation. From AI-driven character interactions to immersive augmented reality experiences and dark rides that blur the line between physical and virtual worlds, the industry is embracing cutting-edge technology. Virtual reality (VR), augmented or mixed reality (AR), AI, animatronics, and technically advanced ride systems are becoming more widespread in both the engineering and design of rides. And these technologies are not just being used for entertainment; they are also becoming a key component in other areas such as queuing logistics, throughput (moving people through an area), and safety.

All theme parks want to make the visitor experience immersive, exciting and memorable, to generate return visits. And guests are demanding deeper engagement and storytelling. Creating illusions and managing thrills is the work of theme park engineers and designers, such as ‘the world’s first thrill engineer’ Brendan Walker, who describes his work as “the process of taking the science and the engineering of thrill and communicating it to an audience”. Walker, professor of creative industries at Middlesex University, has found that theme parks tend to invest in new forms of entertainment about every three years, “to satisfy that hunger for novelty, a necessary component of feeling thrilled”. We are “hardwired to have an emotional response” to movement, which is why ride designers and engineers have previously aimed for attractions

and rides that break records in speed, height and inversions. In this camp is Hyperia – the UK’s newest, tallest and fastest roller coaster – which opened at Thorpe Park in 2024. As Professor Hannah Fry found when she went for a spin on it for her TV series *The Secret Genius of Modern Life*, it’s hard to beat the spine-tingling thrill of being hurtled on 10 tonnes of tubular steel tracks, at speeds of up to 80 miles per hour (130 kilometres per hour), through two stomach-churning inversions, with the power of G-force (and state-of-the-art lap bar restraints) to keep you safely in your seat.

Great – except, says Walker, we have reached the limits of what the body can safely be exposed to. “The scope for developing new forms of thrill and novelty from just moving the body has peaked,” he explains. Michelle Hicks, a fellow thrill engineer and Co-Owner and Executive Producer of theme park consultancy Firefly Creations, agrees. “In the past 10 years, we’ve seen a change from it being about the tallest, fastest ride, for example, to something where the audience can feel really immersed in the experience. It’s all about the thrill or the fear, or laughing together,” she says.

## THE TECH TRANSFORMING THEME PARKS

**Augmented reality (AR):** a technology that overlays real-time 3D-rendered computer graphics onto the real world through a display, such as a smartphone or head-mounted display.

**Virtual reality (VR):** the use of computer modelling and simulation that enables a person to interact with an artificial 3D visual or other sensory environment. Devices such as VR headsets and goggles immerse the user in this digital world.

**Dark ride:** an indoor ride on which passengers board guided vehicles to travel through specially lit scenes that typically contain animation, sound, music, and special effects.

**Simulators:** a type of attraction that replicates real-life experiences with corresponding movement on a screen. This can include motion, sensory and environmental effects, moving seats, and visual projections.

**Audio-animatronics:** a lifelike electromechanical figure of a person or animal that has synchronised movement and sound.

**Projection mapping:** used to turn objects, often irregularly shaped, into display surfaces for video projection. Specialist software spatially maps a 2D or 3D object onto the virtual program, which mimics the real environment it is to be projected on.

**Advanced video projection:** sophisticated techniques that enhance the quality and interactivity of projected images, often using technologies such as laser or LED projectors. This allows for high-resolution visuals and can transform various surfaces into dynamic display areas, creating immersive experiences.

## OFF THE TRACK

One area of theme parks that can deliver this 'new thrill' is dark rides, which have been increasing in popularity as immersive technologies have advanced. An early precursor is the old-fashioned ghost train that trundled around indoor tracks with primitive effects such as hanging slime, screeches and ghoulish apparitions. Today's dark rides are high-tech displays of animation, audio-visuals, sensory elements, and special effects. Dark rides, which often feature AGVs (automated guided vehicles that follow a predetermined route without tracks), can be slower paced and riders are generally not required to meet the physical requirements typical of some attractions, such as minimum height. This means they are more accessible to a wider range of age groups, and to those with a lower tolerance of motion sickness. As they are indoors, in air-conditioned buildings, riders are also not affected by bad weather or excess heat.

AGVs themselves have been a game changer, says Hicks, because they are not constrained by track, and can be programmed to go on multiple routes, making them more interesting. "AGVs also don't require large facility spaces. They're changing our industry hugely."

As dark rides take passengers through themed environments, they have huge potential for interactivity and immersive storytelling, created by techniques such as motion capture and robotics. The most expensive dark ride to date – *Harry Potter: Battle at the Ministry* – uses these to great effect. The new ride is the centrepiece of the Wizarding World of Harry Potter at Epic Universe in Orlando. The magic and illusion starts when riders step into a reconstruction of a Paris Metro station, where the pyrotechnics and special effects begin: fireplaces puffing green flames; auditory effects such as animals screeching, ghostly chatter and eerie music; visual effects such as talking paintings that riders can interact with and uncannily realistic audio-animatronics.

While the ride's technical details remain fiercely guarded, it's likely that projection mapping – which uses high-resolution projectors to project



**An animatronic house elf, which greets visitors on the Harry Potter: Battle at the Ministry ride at Epic Universe © Universal Orlando® Resort**

three-dimensional images onto physical surfaces to create visual effects – was used to create aspects of the ride, such as a ceiling with rapidly changing weather and flocks of virtual birds whizzing through the atrium. High-resolution projectors are cinema-grade RGB laser projectors that produce ultra-bright, colour-rich images built to run continuously, ensuring worlds feel vivid and convincing. "Their advanced optics and warping allow seamless projection across complex surfaces, turning bare walls into landscapes that feed a rider's sense of wonder and awe," says Walker.

The dark ride itself – or 'Ministry lift' – combines advanced robotics and simulation. Created by Simtech Systems, a leading flying theatre and simulator ride supplier, the 14-person AGV is mounted on robotic arms and can be lifted in every direction. As the story unfolds, it tilts forward and backward and creates sudden drops and high-speed motions that are synchronised with physical sets and audio-visual effects, lighting and darkness, which are projected on a vast screen in front of the lift, so no 3D glasses or VR headsets are required.

Walker points out that the motion that riders experience needs to be precision engineered to match what's happening around them, to maintain the illusion. "The core challenge is synchronising physical motion with visual cues, because even tiny mismatches can break immersion and cause discomfort," he says. "Engineers design vehicles and motion bases to deliver movements that are not only

precise and safe but also tuned to evoke moments of intense delight and surprise in riders."

## CREATING THE FANTASTIC

Ride designers and engineers are mindful of giving the visitor what they want, and Hicks says what's driving the industry are "attractions that think": rides that leverage AI to use input from guests' visits to develop the ride itself. "So, if a ride features snakes, the computer can monitor the audience reaction and say: 'That person in row four screamed when they saw snakes'. We can take that and make it more terrifying – if it's that kind of experience. It's personalised and it can be rewritable, every ride can be a bit different based on guest response, meaning they can go on it multiple times." AI-powered animatronics and chatbots are also enhancing visitor interactions, making characters on the rides more lifelike and responsive. Outside of the rides themselves, AI is being used to analyse visitor behaviour and deliver personalised experiences, from tailored ride recommendations to dynamic pricing models.

Another way of transporting visitors to fantastical worlds without needing massive physical infrastructure is through VR and AR, which designers and engineers integrate into attractions and apps to create layered, interactive environments. However, the challenge with VR, says Hicks, is that headsets can limit sharing emotions with friends and family. "As soon as you put on a

VR headset, you're cut off from the real world." It's a view shared by Bob Iger, CEO of Disney, who has said AR not VR is the way of the future for Disney's parks. Headsets can also slow up the ride process, as simply getting them on and off can take time. With AR, a headset and screens can be set up that still allow the rider to see worlds on the other side and also share reactions of friends and family, "because that's where those memories are made," says Hicks. Such a ride is Mario Kart: Bowser's Challenge at Universal, a hugely successful and popular AR dark ride based on the Mario Kart 8 video game. "If you're on a ride as the superhero chasing a villain, we can show the villain through AR, and you can see those around you reacting," Hicks adds. "You're interacting in the game too."

## MAKING MEMORIES

Considering what happens next, Walker says: "Dark rides are evolving into hybrid physical-digital worlds where technology deepens emotional immersion as much as visceral thrills. The next decade will see AI and AR create attractions that respond to riders in real time, turning passive journeys into personal, story-driven adventures."

Hicks agrees: "We are still in the early days of development of AI and its continued development will unlock further opportunities to enhance the experience." With at-home technology, such as Yaw VR motion simulators and VR treadmills, now increasingly affordable, the onus will be on theme parks to "embrace technology to entice guests to experiences they cannot do at home".

While Walker and Hicks are deeply invested in how technologies such as AR and AI are shaping theme parks now, and in the future, it's evident that their deepest interest and concern comes down to what people feel when experiencing them, to basic human emotions. "When we start an attraction design, the first thing we look at is: what do we want audiences to feel? Scared, or excited, or calm... it may be awe or wonder," says Hicks. "Whether it's thrill or fear or laughter, it comes down to the special moments you have and memories you make with others."



Besides the ride systems themselves, Hicks works with audio, lighting and sensory input, which can include touch and smells: smellscaping is about using fragrances to enhance the ride's ambience. This was at the fore when she worked on Room on the Broom – A Magical Journey (above) and The Gruffalo River Ride Adventure, at Chessington World Adventures, where Gruffalo Crumble smells somewhat similar to apple pie

## QUEUES

Queuing for rides at theme parks can often somewhat dampen the experience, with waiting times for some of the most popular rides often reaching the two-hour mark. Queues cause the most complaints for theme parks, says Nick Varney, CEO of Merlin Entertainments, which owns Thorpe Park, Chessington World of Adventures and Alton Towers, the UK's biggest theme park, which had almost 7,000 visitors per day in 2023, across the year.

Queue modelling and monitoring help ensure the right number of visitors are in the right place at the right time, and most theme parks use real-time data and technology, including from guests' mobile apps, to monitor and manage queues, provide updates and optimise visitor flow. Parks also use camera tracking, to count numbers going in and out, those waiting and to calculate the ride's throughput.

Parks such as Disney and Universal are leading the charge with mobile apps that handle everything from ticketing to food orders and ride reservations. Virtual line technology at Universal Studios lets guests reserve ride times, reducing waiting times and improving flow. Meanwhile, virtual queuing programmes, such as Disney's Lightning Lane App, allow guests to book a slot and turn up at their allocated time, thus cutting down queues. Mobile phone apps, such as Disney Genie, can send pre-visit information and offers; create a bespoke itinerary based on personal interests; and send reminders and real-time info about queues.

## BIOGRAPHIES

**Michelle Hicks** is a Chartered Civil Engineer and experienced project manager who combines her design expertise with creativity to lead the development of groundbreaking attractions and experiences. She has successfully delivered projects including dark rides, water rides and media-based experiences, always focusing on the identification of innovative solutions to push the boundaries of creativity. As Co-Owner and Executive Producer of creative design studio Firefly Creations, Michelle leads teams of creative designers, architects and engineers, integrating technical and creative solutions to create award-winning experiences.

**Professor Brendan Walker** leads Studio Go Go, creating VR swing and fairground ride adventures. With a background spanning aeronautical engineering and experience design, he has advised global entertainment leaders including Merlin Entertainments and Disneyland. Brendan's work combines cutting-edge technology with visionary storytelling to deliver next-generation thrilling experiences for future audiences.

# DIG DEEP FOR RENEWABLE ENERGY



The Eden Project in Cornwall heats its biomes with geothermal energy, thanks to its spinout company Eden Geothermal  
© Hufton + Crow

### Did you know?

- Geothermal energy is the heat stored within the Earth, which is harnessed to provide heat or electricity
- Geothermal energy is currently used to generate electricity in 26 countries and heating in 70 countries
- The UK has deep geothermal resources in locations including Cornwall, Scotland, and central and northern England, which could theoretically supply the country's heating needs for the next 100 years



In the UK, geothermal energy is not recognised as a natural resource, such as water or gas is. But this might all be about to change thanks to several pioneering projects and innovative technologies allowing us to tap into the heat locked deep within the ground beneath our feet. Lee Williams takes a look at the projects that are already paving the way.

The UK is not known for its hot springs, geysers or volcanoes. This has traditionally made it an unlikely candidate for geothermal energy – the use of the Earth's natural heat to provide power and heating.

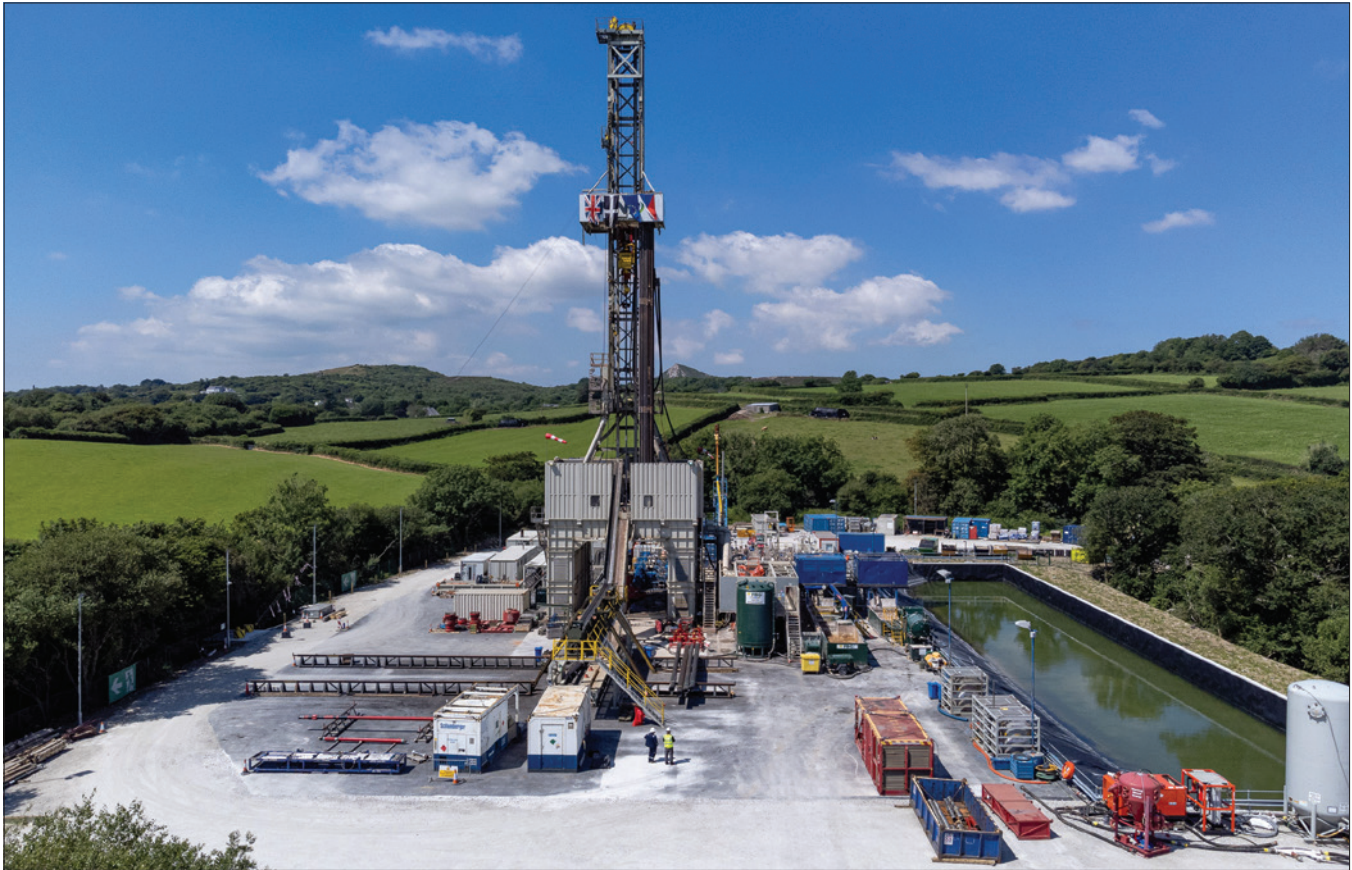
However, according to a 2018 report, if you dig deep enough, the UK has enough geothermal energy potential to heat all our homes for 100 years, and to provide a fifth of our electricity needs. These figures are still early-stage estimates, but they make it clear that, given the right technologies, deep geothermal could be an important resource. It is also a renewable form of energy, meaning it could play a vital role in tackling climate change. And unlike other renewables such as wind and solar, it is constantly available. "It is the missing piece of the jigsaw," says Augusta Grand, CEO of the Eden Project's Eden Geothermal Ltd. "It is a renewable energy source on a very small piece of land that does base load, clean power and heat... and it's just waiting for us."

Heating alone accounts for more than 40% of the UK's energy usage

and is responsible for a third of our greenhouse gas emissions, so a renewable energy source that could cover all our heating requirements is obviously not to be sniffed at.

### GETTING DEEPER

The problem traditionally has been that the UK's geothermal potential is buried too deep to be economically viable. Geothermal heat increases proportionately with depth. The Earth's core is as hot as the surface of the sun, and temperatures rise the deeper you dig, at an average rate of 27°C per kilometre in the UK. There are currently over 55,000 ground source heat pumps in the UK. These use small amounts of energy that are obtained by drilling tens of metres into the ground to supply heat to individual buildings. But for bigger projects, deep geothermal energy is required, which is defined in the UK as energy stored at depths greater than 500 metres. For projects that will heat thousands of homes you need to dig at least 2 kilometres down, and that costs money.



Eden Geothermal Limited drilling the heat well in Cornwall © Toby Smith

"This is the hairy thing about drilling," says Dr Ryan Law, a geologist and CEO of GEL Energy, a UK-based geothermal energy company. "You're paying a daily rate for all that equipment, including the drilling rig... Every day, you're probably burning through £55,000. You really need to get that right. A 10-day mistake is half a million pounds."

It is these high costs that have discouraged investment in deep geothermal energy in the UK. But things are changing. Several pioneering new projects are showing how the UK's geothermal potential can be tapped. And a raft of new technologies are paving the way for what could be a deep geothermal revolution.

One of these pioneers is Cornwall's Eden Project. The vast geodesic domes housing its rainforest and Mediterranean biomes and plant nurseries are heated by geothermal energy, thanks to a 5.3-kilometre-long well drilled into Cornwall's granite bedrock by Eden Project spinout company, Eden Geothermal. At this depth it can access hot water trapped in fractures in the rock. The water, which reaches temperatures of 190°C, is pumped to the surface where it is run through a

heat exchanger that delivers heat at 76°C to the biomes. The water is then returned underground to be naturally reheated by the Earth. This circulating system of water using one well is known as a coaxial system. Although it is over 5 kilometres deep, it takes up limited surface ground. The well took 162 days to drill and £22 million to develop and was funded by Cornwall Council, the European Union and an institutional investor.

The Eden Project's well has been heating its biomes since 2023. It was only designed to produce heat, and its output is a modest 800 kilowatts, requiring a gas top-up during peak times. However, the initial well was only intended as a proof of concept. Eden Project has far more ambitious plans for the future, including wells that can produce electricity. "We'll have another 5.2-kilometre well," says Grand. "So that will be the next 5 megawatts, and that will be electricity. And then we'll do another six wells [three double wells at 5 megawatts each], so that will be another 15 megawatts on top." 15 megawatts is enough energy to power 15,000 to 20,000 homes. It will be provided

by double well systems: one well that extracts the hot water and another, shorter, well that returns the used water to the Earth to be naturally reheated.

It's no coincidence that one of the UK's first deep geothermal projects is situated in Cornwall. The UK's most southerly county sits atop a 300-million-year-old granite spine that has some very special geological properties that bring its heat closer to the surface. This extra heat occurs because granite has another, hidden, source of energy stored within it.

Some of this extra heat is produced by radioactive elements in the granite including uranium, potassium, and thorium. "It's not like you take a handful of granite and it's radioactive," says Law, "but across hundreds of kilometres, all these tiny radioactive elements produce heat."

Law's company, GEL, runs the United Downs project just outside Truro, which has tapped into Cornwall's hot granite by digging the deepest well in the country. Technically, the Eden Project's well pips it for length at 5,277 metres, but this takes into account its deviation from vertical.



**Overview of geothermal energy potential for four geothermal technologies in the UK: Closed loop ground source heat pumps (GSHP), open loop ground source heat pumps, hot sedimentary aquifer and deep geothermal, EGS granites.** (Contains OS data © Crown Copyright and database right 2025, data © Department for Energy Security and Net Zero, 2025, data BGS © UKRI 2025.)

When true vertical depth is calculated, United Downs comes in as the deepest at 5,057 metres, compared to the Eden Project's 4,871 metres.

GEL started drilling in 2019. It received the funding to dig two wells, which means it can produce electricity as well as heat. GEL's double well is called a geothermal doublet system. It pumps the 190°C water up from fractures in the rock. The resulting steam is then used to produce electricity in the same way as a conventional power station: spinning turbines attached to generators that transform the mechanical energy into electricity. The water is then pumped back down the second, shorter, injection well, where it percolates down through the granite, being naturally reheated as it goes, until it returns to the aquifer and is ready to be reused.

GEL's well and power plant are now fully completed. It expects to produce its first power output by the end of 2025. The plant will produce 3.15 megawatts of electricity, enough to power 10,000 to 15,000 homes. As with the Eden Project, the first well is to demonstrate the concept and will pave the way for more in the future. "We have other sites in Cornwall that have planning permission for larger power production," says Law.

"Those sites are up to 5 megawatts, and we'll just keep growing it as we prove it more and more."

It's not just Cornwall that has great geothermal potential. Further north, the University of York has discovered that an area of Carboniferous limestone might run directly beneath its campus and hold the potential to supply its power and heat into the future.

Carboniferous limestone is a source of hot underground water occurring in fractured aquifers. A study by the British Geological Survey indicated that the geology under the university could be rich in this type of rock, which can be a great source for deep geothermal energy. The same study estimated that Carboniferous limestone in the UK could provide up to 222 gigawatts of energy. While the study makes it clear that these are "tentative" early estimates, and that the presence of the Carboniferous limestone will only be confirmed by actual drilling, it is still an exciting find. "It's five times more than the complete peak electricity supply of the UK," says Paul Bushnell, Estates Works Manager at the University of York. "So, there's an enormous resource there."

York's geothermal scheme is still in the preparatory stages. The plan was

announced in April this year and has received £35 million funding from the Department for Energy Security and Net Zero. Drilling is expected to start in 2028. The project will come in two stages over a seven-year period; the first producing heat for the majority of the university's 500 buildings, the second providing electricity. The scheme will form part of the university's plans to cut its fossil fuel consumption by 78% by 2030. "It'll be the quickest scheme done, certainly in the UK," says Bushnell, "and possibly Europe."

## DRILLING BREAKTHROUGHS

Despite these three pioneering projects, the UK is behind many other countries when it comes to geothermal energy. The US produces the greatest amount of geothermal energy and yet still only taps into 1% of its total geothermal potential. It is closely followed by Indonesia, the Philippines and Turkey. In Europe, countries are setting ambitious geothermal heating targets, with Germany looking to provide 850 thermal megawatts by 2030, and the Netherlands a full thermal gigawatt in the same time frame. The EU has a goal of heating 25% of its houses with

geothermal energy by 2030. In stark contrast, the UK has no set geothermal targets.

The rush towards geothermal in Europe has been inspired by several breakthroughs in drilling technology and techniques that have made it more economically viable. These include new polycrystalline diamond compact drill bits, which are much harder than traditional steel bits, increasing drilling rates by up to 70%. Other developments have enabled multi-well drilling, allowing for more wells at a single site; horizontal drilling, enabling more precise targeting of aquifers; and multistage perturbation, which enhances access to underground water by creating artificial fractures in the rock (but differs from the fracking technique used in the shale oil industry). As a result of these technologies, the International Geothermal Association expects deep geothermal energy to be competitive with market electricity prices by 2027 in the US.

Horizontal drilling has also enabled the construction of so-called closed loop systems in which circulating fluid is pumped through huge underground systems of pipes. These projects are being pioneered in countries like Germany and Canada by companies such as Eavor. Its Eavor-Loop system uses a proprietary fluid that is pumped through a closed loop of underground pipes to extract heat much in the same way as a car radiator. The Eavor-Loop can reach depths of over 5 kilometres and uses magnetic ranging technology to accurately intersect its wells at the target depth. The benefits of this system are that it avoids extracting water from the ground itself and doesn't require expensive drilling techniques to target fractures in the rock.

Other projects are developing their own proprietary drilling technologies, such as the EU's DeepU, which is testing lasers combined with cryogenic gas to liquify and vitrify the rock, enabling faster drilling speeds. And US company, Quaise, is developing a technology borrowed from nuclear fusion research to blast rock using millimetre-wave radiation. Quaise believes this technology could enable drilling to depths of up to 20 kilometres where rock temperatures reach 500°C.

This could unlock terawatts of energy, enough to power billions of homes.

## NOT A SILVER BULLET

There are still challenges to overcome if deep geothermal is to make a sizeable impact on the energy industry. One of the main issues in the UK is regulation. Drilling sites need access to road and electricity networks, all of which requires planning permission. Law says that the problem also lies with local councils, which are too understaffed to deal with all the documentation and data requests that go with the dozens of new renewable energy projects constantly landing on their desks.

However, despite the blockages there are some signs that the UK government is trying to clear the path towards a geothermal future. The British Geological Survey has just released the new Geothermal Platform, a one-stop digital database for the UK's geothermal data, which should simplify the process of researching whether geothermal energy is a viable resource at any given location in the UK.

With more accessible data, deep geothermal energy could become an important part of the UK's renewable energy solution. Grand points out how geothermal could contribute to our soaring energy demands: "The UK is expecting to need another 62 terawatt-hours of electricity for data centres by 2050. That's about 8 gigawatts

of geothermal [electricity]," explains Grand. Based on the anticipated performance of the new Eden Project wells, that's about 3,200 wells, which with multi-well drilling may mean as few as 160 sites. "It's doable. It's not a big number."

Dr Alison Monaghan, Head of Geothermal at the British Geological Survey is cautiously optimistic. She doesn't believe that geothermal energy is a silver bullet that will solve all the UK's energy needs. She points out that figures that calculate that it could heat all the UK's homes for hundreds of years are more about theoretical potential than actual usable energy. With that caveat, however, she is hopeful that geothermal will be a significant part of the UK's energy landscape far into the future. "I think geothermal energy has a really important role to play in heating and cooling... and a contribution towards electricity generation," says Monaghan. "It is never going to be 100% of the UK's heating requirements, but in many places, and with many heat users and demands, it could form a really important part of the net zero energy mix."

Bushnell is more effusive, pointing out the huge potential of the Carboniferous limestone that the University of York hopes to tap into. "If it's proven," he says, "and this becomes a kind of exemplar then there's a potential for kickstarting a whole industry, which is really exciting."

## BIOGRAPHIES

**Paul Bushnell** is a Chartered Engineer with over 35 years of experience. He has led and managed numerous multidisciplinary engineering and infrastructure projects. He is Project Director for the University of York's Deep Geothermal scheme. His work is central to the university's decarbonisation strategy and the delivery of sustainable, low-carbon infrastructure.

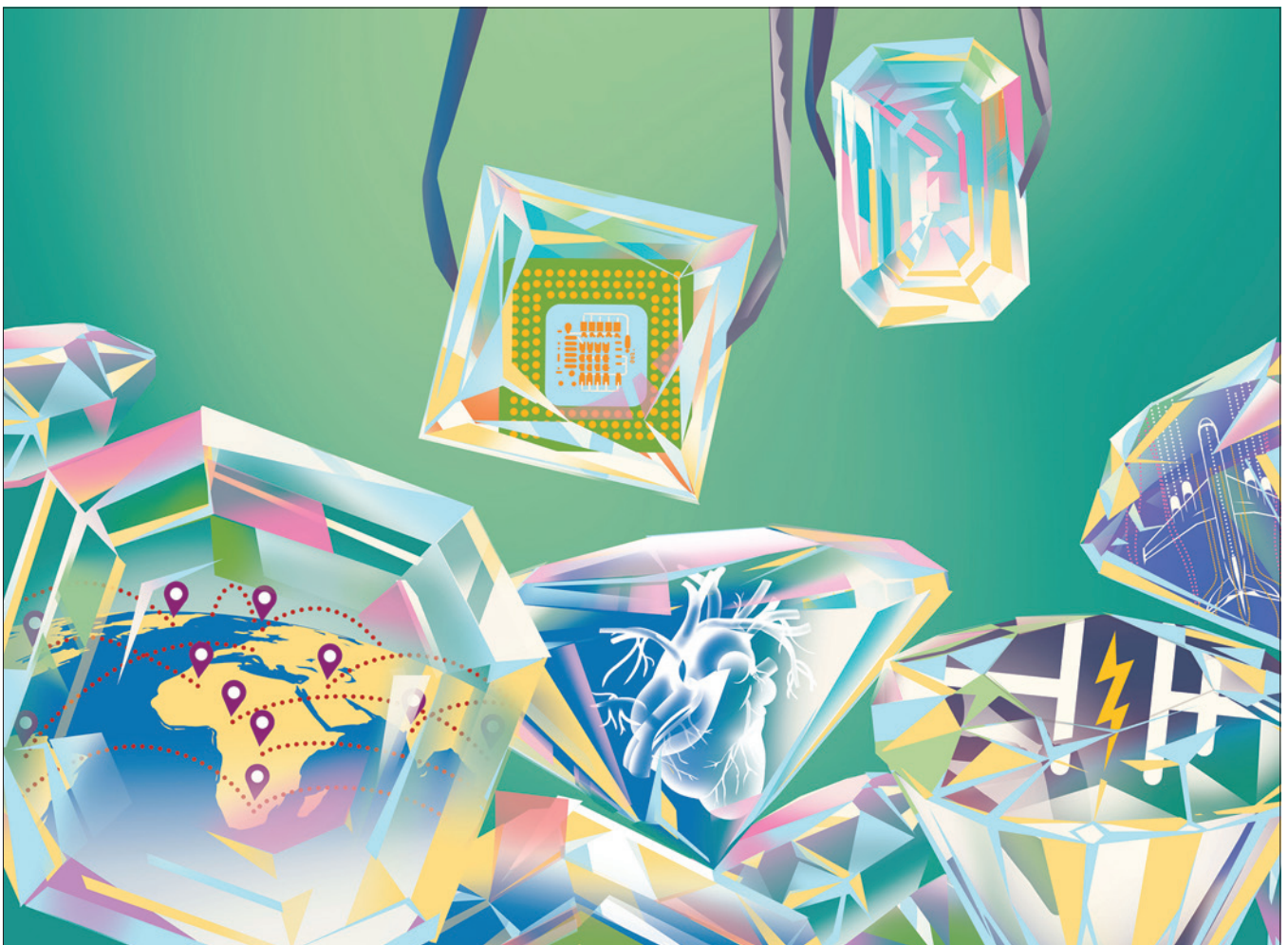
**Augusta Grand** has led Eden Geothermal through funding, procurement, drilling, construction and into operation since 2019. She was previously Head of Policy at Eden Project, developing Eden's sustainability and science programme, having joined when it opened in 2001 and worked on policy, public education and science communication projects across several subjects.

**Dr Ryan Law** is Founder and CEO of GEL. Prior to forming the company, he worked for Arup on a large number of high-profile geothermal heating and cooling projects in London. He has raised over £30 million for GEL to develop deep geothermal projects in the UK.

**Dr Alison Monaghan** is Head of Geothermal at the British Geological Survey. A geologist by background, she leads a portfolio of research projects across all types of geothermal energy with and for government, academia and industry. She recently led delivery of the UK Geothermal Platform mentioned in this article, funded by the Department for Energy Security and Net Zero.

# DIAMONDS: NOT JUST A PRETTY FACE

Far more than a sparkly rock with a hefty price tag, diamond is an incredibly versatile material that can help us solve some of our biggest problems – from diagnosing diseases earlier to making the electronics underpinning data centres more efficient. Leonie Mercedes finds out how.



© Illustration for *Ingenia* by Benjamin Leon

## Did you know?

- Diamonds are made of (almost) pure carbon, and form under extreme heat and pressure
- About 70 years ago, researchers discovered how to replicate the process and create synthetic diamonds in a lab
- Lab-grown diamonds have several benefits, such as lower costs, ethical production and reduced environmental impact

Diamond's abilities are all down to its structure. It is pure carbon, a lattice of carbon atoms in a neat tetrahedral arrangement, where one central atom is joined to four others by strong covalent bonds.

This super-strong structure puts diamond high on the medal table for many properties – it's the hardest material, the stiffest, and has the highest thermal conductivity because of those closely packed atoms. It is such a good conductor of heat that you can easily cut through ice with a blunt, half-millimetre-thick wafer of diamond, as the heat from your fingers would go straight through the diamond and melt the ice.

We've long exploited its unbeatable hardness in engineering, to cut, grind, polish, and drill. But now we know how to build diamonds atom by atom, there's no need to wait millions of years for the Earth to cook them up. Now it's possible to deposit super thin layers of diamond onto other materials, and control their composition in minute detail. This means we can access all manner of tremendous capabilities we simply can't get with regular diamonds.

As we get better at manipulating the material's properties, we're finding new applications for the material in areas as diverse as communication, navigation and public health. By making a profusion of energy-hungry electronic devices run more efficiently, it may also have a big role to play in a net zero world.

So, diamonds have the potential to make us healthier, our devices greener and our world cleaner. The fact that they can do all of these things comes down to how they're made.

## HOW TO MAKE A DIAMOND

Natural diamonds form about 150 kilometres beneath the Earth's surface, at temperatures way over 1,000°C and under extreme pressure. Later, the diamonds are delivered to the surface, to places where we can find them, by volcanic eruptions. For diamonds mined today, these volcanic eruptions would have happened in ancient times.

Once we'd worked out – in the late 18<sup>th</sup> century – that diamond is simply another form of carbon, making our own in the lab was just a case of simulating the pressure and temperature required, although this would be hugely challenging. "The pressure you need to grow a diamond is the equivalent of taking the Eiffel Tower and putting it upside down on a Coke can," says Oliver Williams, chair of the condensed matter and photonics group at Cardiff University. "It's difficult."

Only in the 1950s did we crack it. Teams in Sweden and the US simulated the extreme conditions needed to force carbon atoms into the regular lattice of a diamond, with the appropriately named 'high-pressure

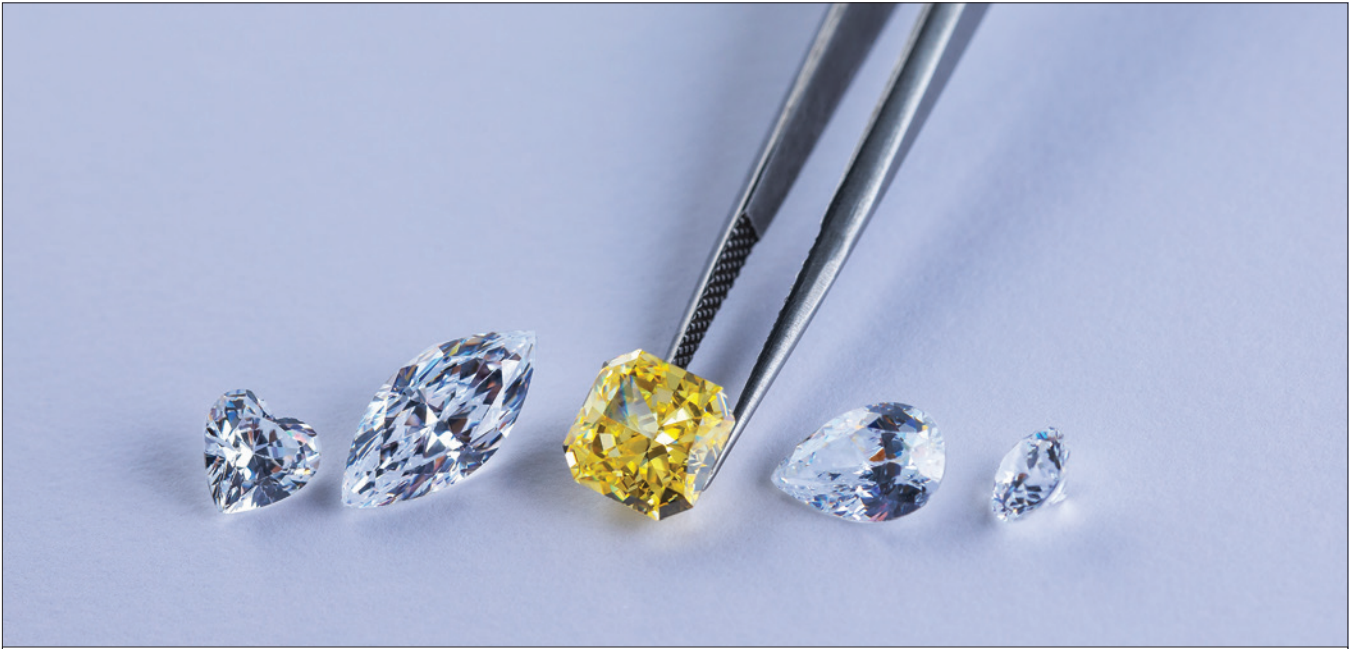
high-temperature' (HPHT) process. Back then, the HPHT process couldn't produce diamonds that were big or pretty enough to be made into jewellery, and so instead, the resulting material was put to work for industrial uses such as cutting and grinding.

By the 1980s, researchers had developed another method called chemical vapour deposition (CVD), which works at lower pressures and produces a material whose properties we can more easily control.

In CVD, hydrogen and methane are heated in a chamber with microwaves up to 10 times more powerful than your microwave oven at home, until they form a plasma. The excess of atomic hydrogen, which "eats everything" but the diamond, Williams says, both prevents the formation of graphite and acts as a catalyst for the formation of diamond.

Under these conditions, the four hydrogen atoms are stripped from the methane, leaving a single carbon atom. The carbon atoms then bond to an existing bit of diamond, called a "seed", layer by layer. Single diamonds can be made this way, which can go on to become jewellery, as can wafers, which can become electronic components. We can also coat electronic components in a thin layer of diamond using this process.

We said before that diamond is pure carbon, and in an ideal world, it would be. But because of how they're formed, all natural diamonds contain



**Impurities in diamond can change its colour. For example, synthetic diamonds with a higher nitrogen content appear yellow, compared to a transparent diamond, which is pure carbon** © Shutterstock

some impurities. These impurities are responsible for a stone's colour – for example, the Hope Diamond's violet hue is due to the odd boron atom in its structure. Early HPHT diamonds often contained nitrogen, boron or transition metals from the catalysts used.

Not so for CVD: because we can better control what's in the CVD chamber, there are fewer impurities. "The advantage of this method is that you can grow diamond that is a million times purer than nature," says Williams. "That's where these new applications come from. We can start to exploit the really extreme properties of diamond."

## TAILORING DIAMOND'S PROPERTIES

With CVD, researchers can also add elements to diamond if they so wish. In its purest form, diamond can't conduct electricity – there are no free electrons in that stiff lattice. But we can change that by adding certain atoms to its structure, a process physicists call 'doping'.

Doping diamond with boron atoms – which can be done by adding a boron-containing gas to the mix in the CVD reactor – makes the diamond a semiconductor. While an emerging area of research, diamond semiconductors won't be replacing silicon ones any time soon, in no small part because the doping process is so difficult to control. However, we can

also use these unique properties in electrochemical electrodes to treat wastewater and clean swimming pool filters, although we've recently found another use for them – destroying PFAS (polyfluoroalkyl substances).

Element Six specialises in making pure synthetic diamond for industry and research. It recently partnered with a company called Lummus Technology to develop devices to eliminate PFAS from water supplies.

The bonds between carbon and fluorine atoms in PFAS are what put the "forever" in these so-called "forever chemicals". They're extremely tough – it would take more than 1,000 years for them to break down – although with boron-doped electrodes, it's possible to break these bonds more easily.

Channelling PFAS-contaminated water between electrodes made of boron-doped diamond splits

the carbon-fluorine bonds in the material, explains Bruce Bolliger, head of business development, North America, at Element Six. "Boron-doped diamond electrodes are more effective than other electrodes," he explains, as they can operate at very high current densities, are inert and thus less prone to fouling, and last "a very long time".

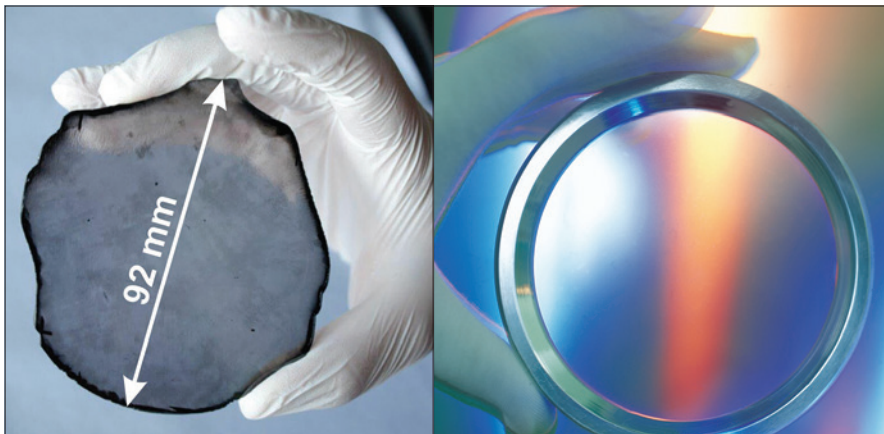
Diamond is also poised to play a role in making silicon-based semiconductors more efficient. Here, it's diamond's unbeatable thermal conductivity – five times greater than copper – that comes into play, particularly for compound semiconductors. Because they can handle more power than pure silicon ones, they're ideal for applications such as solar panels, spacecraft and electric cars. The problem is, they get a lot hotter.

## CREATING DIAMONDS FROM THE AIR

Gloucestershire-based company Skydiamond makes carbon negative diamonds with atmospheric carbon as its raw material. It captures CO<sub>2</sub> from the atmosphere and hydrogen from harvested rainwater, and brings them together with a methanogen, a microbe that takes in CO<sub>2</sub> and hydrogen and produces methane.

This methane goes into CVD reactors that run at about 1000°C, which are powered by solar and wind energy. After a few weeks in the chamber, the diamonds are ready to come out and be cut and polished.

According to an impartial lifecycle analysis conducted by Imperial College London, Skydiamond's greenhouse gas emissions represent a 99.97% reduction on what you'd expect from mined diamonds. In the end, it has negative carbon emissions because of its capture of carbon and use of renewable electricity.



**(Left) A single-crystal disc of diamond grown by continuous vapour deposition (CVD)** © Matthias Schreck, Stefan Gsell, Rosaria Brescia, and Martin Fischer.  
**(Right) A polished diamond optical window made by Element Six, also made by CVD** © Element Six

“There’s a big push to upgrade everything with compound semiconductors, but then you need to thermally manage them. And diamond is the greatest thermal conductor there is,” says Williams. Williams established the Cardiff Diamond Foundry, a part of Cardiff University’s physics department that tries to solve “real problems” with diamond, including making electronic components more efficient.

When we push high currents through electrical components, they heat up, making them less efficient. These inefficiencies add up, meaning a lot of wasted energy.

Coating electrical components with a thin layer of diamond just 50 to 200 micrometres thick means that the heat is rapidly channelled away. This process, known as thermal management, is important for devices that run on high voltages, such as those in cars and planes. Better thermal management of semiconductors can improve performance and reduce costs for applications such as longer distance satellite communication, explains Bolliger.

This ability to cool devices more rapidly will also be important for running the data centres we rely on for 5G and AI more efficiently – especially with US data centres projected to

consume up to 12% of the country’s total electricity by 2028. Bolliger says thermal management could significantly reduce the power required by AI and high-performance computing devices at data centres.

## QUANTUM SENSING – DETECTING THE TINIEST SIGNALS

Sometimes a nitrogen atom and an empty space replace two carbon atoms in a diamond lattice, in what’s called a nitrogen vacancy. Thanks to the properties of the nearby electrons, certain types of nitrogen vacancies have their own quantum spin, and act like tiny bar magnets.

Magnetic fields change the spin state of these little “bar magnets”, which we can detect by shining a light on them. The strength of the light that comes back depends on the spin state, which means we can use it to measure things with devices known as quantum detectors.

The nitrogen vacancies in natural diamonds are distributed in such a way that makes them unviable as quantum detectors – as these little “bar magnets” interfere with each other, they can’t hold their spin state for long enough

to make a measurement. However, researchers can deliberately introduce a smaller number of these vacancies to the structure with CVD, to unlock the material’s quantum properties.

Quantum detectors apply the same principle as MRI (which relies on the inherent spin of hydrogen atoms), but on a smaller scale. They can detect magnetic field changes with thousands of times more sensitivity, and on a cellular scale, opening up a new world of diagnostic science. Such sensors could detect tiny changes in the brain’s magnetic field, letting us spot early indicators of Alzheimer’s disease, for example, before symptoms develop.

Cardiovascular diseases, too, could be diagnosed earlier. “You could pick up very weak signals, magnetic signals from the heart that [classical detectors, such as ECGs] just can’t detect,” says Melissa Mather, professor of diamond quantum sensing and engineering at the University of Nottingham. Researchers in Mather’s lab are exploring quantum sensing for healthcare, food security, defence, green chemistry, and materials science. They’re designing devices that can be used and maintained by nonspecialists, with a view to finding more applications for the technology.

Launched in December 2024, Q-BIOMED is a research hub led by UCL, the University of Cambridge and the University of Oxford, seeking to improve diagnosis and treatment of disease with quantum technology. The hub is developing super-sensitive lateral flow tests (LFTs) that, by integrating nanodiamonds (diamond nanoparticles), can help diagnose cancer and infectious diseases, including COVID-19. In fact, according to a preprint paper by the research team published earlier this year, spin-enhanced LFTs could let us diagnose COVID-19 two days earlier than conventional ones, which could reduce transmissions and infections.

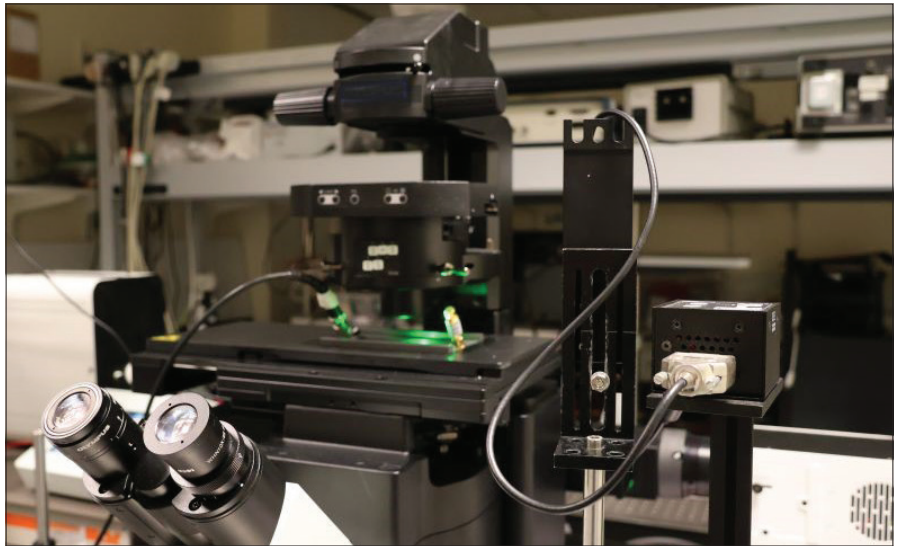
## SHINE ON

What can we expect from diamond science in the near future? The quantum properties that make diamond an excellent detector of magnetic fields make it perfectly suited to mapping the Earth in fine detail by measuring variation in the planet's magnetic field. This means we can navigate accurately without the need for satellites, which can fail or be inaccessible.

Mather is working with biologists to better understand the electron transport chain in cells using diamond quantum sensors. The electron transport chain is a process that happens within mitochondria, the part of the cell that produces energy. Dysfunctional mitochondria have been linked to diseases including Parkinson's, heart disease and cancer. Quantum sensing can help us better understand the electron transport chain, and why things go wrong.

"With quantum sensing, we can start to sense the electrons as they move," she says. "It opens the world to a window onto things that have been right in front of us, but previously unseen." Her team is investigating the impact of too few or too many free radicals on this process, and how to treat problems when they occur. She says this may be able to help us understand the origin of some mitochondrial diseases, which affect about 1 in 5,000 people in the UK, and help us develop new types of treatments for them.

Mather suggests that with diamond quantum sensors, we can start to probe the quantum goings-on in our bodies and other biological systems. "While phenomena like entanglement, electron tunnelling, and coherence are thought to occur in biological building blocks, we need better tools to fully detect and measure them in a living system," she says.



**This microscope lets Mather and her research team detect weak magnetic fields, such as those produced by free radicals in biological systems, using diamonds**  
© University of Nottingham

"We're starting to open a new window on how the quantum world impacts biology, and we need more quantum sensors that can function directly within a biological system to really understand what's happening."

Williams describes the UK as "dominant" in diamond research, and

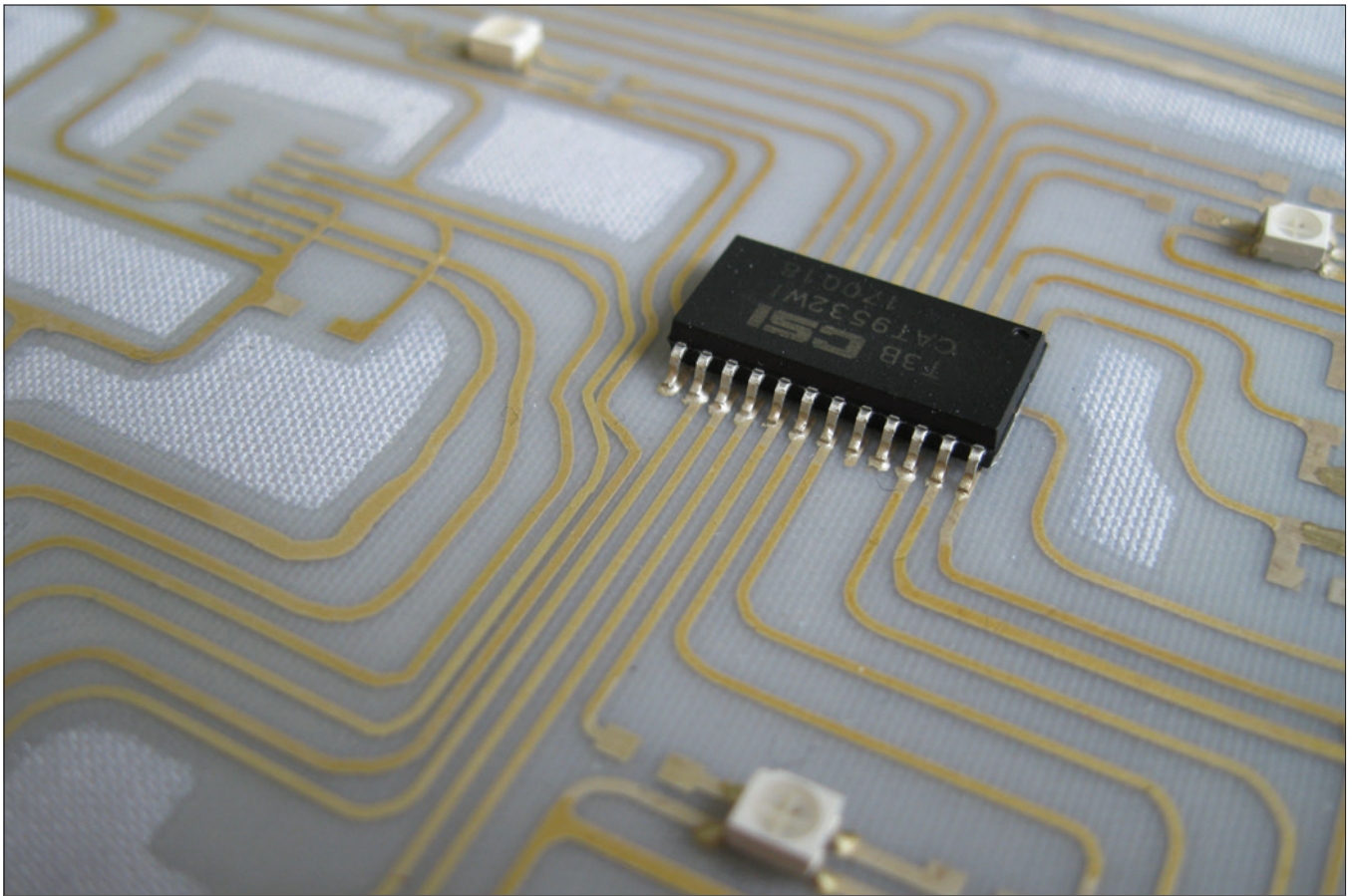
with the UK government committing £2.5 billion to quantum technologies up to 2033, we should see even more exciting innovations coming to fruition in the years to come. It appears that solutions to some of the biggest problems we face as a society will come from the realm of the very small.

### BIOGRAPHIES

**Professor Melissa Mather** is Professor in Quantum Sensing and Engineering at the University of Nottingham's Faculty of Engineering. She develops diamond quantum sensors that use atomic-scale defects to measure extremely subtle phenomena, such as tiny magnetic fields. Her research has broad applications, from studying biological processes in living cells to investigating new materials for quantum technologies. In 2023, she became a Chair in Emerging Technologies at the Royal Academy of Engineering.

**Professor Oliver Williams** is Professor of Experimental Physics at Cardiff University's School of Physics and Astronomy, where he established the Cardiff Diamond Foundry. His work focuses on microelectromechanical systems, devices on a micrometre to millimetre scale that integrate electrical and mechanical components, as well as superconductivity, high frequency filters, thermal management, quantum technologies, and anything that exploits the extreme properties of diamond.

**Bruce Bolliger** is Head of Business Development, North America, at Element Six, which develops industrial application and solutions using a variety of engineered diamond material. He has published papers, and is focused on the thermal applications of diamond, such as heat spreaders for high-power radio frequency semiconductors, and boron-doped diamond applications such as for PFAS destruction.



An electronic circuit printed onto textile

# THE ROAD TO SCALING ELECTRONIC CLOTHES

Electronic clothing could become the next generation of wearable technology but haven't landed in our wardrobes just yet. Florence Downs talks to the engineers weaving electronic components into textiles that are manufacturable, sustainable, and can withstand everyday life.

## Did you know?

- E-textiles integrate electronic components into fabric to create ‘smart’ materials that can sense, display, compute, and communicate
- Such fabrics can be used in healthcare for patient monitoring, in sports for performance tracking, and in the military for security and protection
- Engineers are currently addressing challenges in mass production, washability, durability, and the high cost of developing and integrating these technologies

We may take clothes for granted, but a lot of clever engineering makes them comfortable, aesthetically pleasing and functional, from the drape of a boxy T-shirt to the way raindrops roll off a waterproof jacket. Beyond our everyday wardrobes are even more highly engineered garments, such as bullet-stopping Kevlar® vests or space suits that protect astronauts from cosmic radiation and temperature extremes.

Now engineers want to take our wardrobes further and weave in glowing threads, sensors, and other electronic components. The high-tech electronic textiles under development could expand the ways we interact with technology beyond touchscreens, keyboards and buttons, and promise more accurate, yet less obtrusive ways to monitor our physiologies.

But before such textiles become a feature of everyday life, researchers must shift from handmade prototypes to manufacturable products, with designs that genuinely meet people’s needs. And they must find ways of making ordinarily delicate electronics as robust as a pair of jeans we wear day in, day out, without compounding e-waste and textile waste into an even worse problem. In short, there’s a mountain to climb.

## MAKING MORE WEARABLE WEARABLES

Despite promises from analysts and journalists a decade ago that smart clothes would be everywhere in a year (or even five), wearable technology

remains resolutely dominated by the smartwatch.

In fact, electronic clothing has barely had a look in, apart from a handful of haute couture, light-up garments worn by popstars such as Take That and Katy Perry during the peak of the hype cycle (a trend revived earlier this year by Beyoncé on her *Cowboy Carter* tour).

However, there is at least one wearable electronic textile product that first took off with consumers in the 1990s: the heart rate monitor. For athletes (or just hardcore running nerds), the accuracy that comes from measuring heart rate via a chest strap, rather than solely a smartwatch, makes it worth investing in a separate device.

Like the heart rate monitor, any new wearable electronic textile must capitalise on value added for potential wearers if they are to succeed. This is why health monitoring is a key focus area: sensors embedded in a close-fitting garment can sit next to the skin to pick up clear signals from the body.

“ECG electrodes on a T-shirt capture much more information about your heart than the pulse sensors [on watches] at the moment,” says Steve Beeby, Professor in Electronic Systems and Devices at the University of Southampton. Smartwatches, as they are confined to the wrist, perform “an awful lot of really clever processing” to capture metrics such as heart rate and step count, he adds. Electronic textiles, meanwhile, can be integrated into virtually any item of clothing and worn anywhere on the body – as well as tap

into the sizeable market not served by existing wearables. “A lot of people don’t wear watches, but they all wear clothes,” says Beeby.

But so far, functional electronic clothing remains “very clunky” and expensive, he adds. Professional golfers can invest in a bodysuit that tracks swing to give feedback about their technique, but the sensors are bulky and must be removed to wash it. Gamers can purchase the \$12,999 Teslasuit, which has full-body haptics to give a sense of touch in virtual and augmented reality (and must be professionally or steam cleaned).

## THE COLLIDING WORLDS OF ELECTRONICS AND TEXTILES

In the late 1990s, Beeby was a postdoc printing hybrid electronic circuits onto rigid substrates. Heavy metal fan Beeby looked at his Iron Maiden and Ozzy Osbourne band T-shirts, screen printed with gold and silver patterns, and had an idea. “I was thinking, why can’t you print the silver and gold that we’re printing as part of circuits, onto fabric?” he recalls.

Now a Royal Academy of Engineering Chair in Emerging Technologies at the University of Southampton, Beeby is developing electronic textiles as a platform technology for wearables and other applications.

The main challenge for the field, he explains, is that electronics and textiles are fundamentally different, which

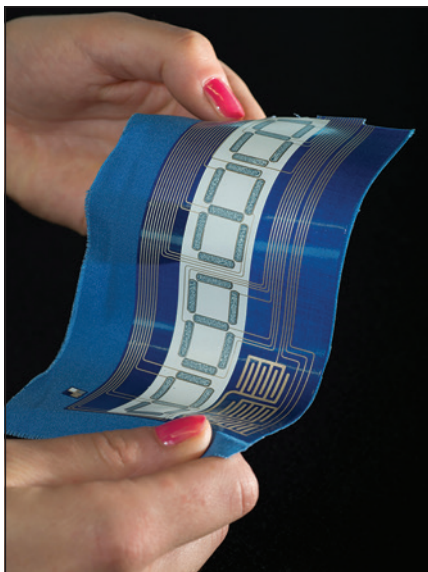
complicates design and manufacturing. For one thing, textiles are tough. Before a pair of jeans arrives in a shop, the denim might have been dyed, bleached and pummelled with pumice stones. After all that mistreatment, we can still usually wear them a hundred times and put them through at least 50 machine washes before they start to fade or thin. Electronics, on the other hand, are normally encased in a protective box, and heaven forbid your AirPods go in the washing machine.

The materials are also worlds apart structurally. Textiles are “a unique class of material,” says Beeby: porous, flexible, stretchable. “It’s the actual structure of the textile, the way it’s made – woven or knitted, for example – that plays a massive part in the way it feels and behaves mechanically.” Whereas crack the box protecting an electronic device open, and its innards are probably anchored onto a rigid substrate, the printed circuit board (PCB).

Bringing the two together means finding ways for the electronics to survive everyday wear and tear, and making them compatible with a woven or knitted structure. Engineers have developed many ways of doing this, but one of the simplest is to take a very small flexible circuit and put it inside a chunky, shoelace-like yarn, explains Beeby.

Another approach involves a technique common in both electronics and textile manufacturing: printing. Beeby’s spinout company, Smart Fabric Inks, sells conductive silver inks, inks that encapsulate and protect electronic components from moisture, electroluminescent inks that emit light, and piezoelectric inks that respond to pressure. With these specialised inks, Beeby explains, engineers can even create supercapacitors and batteries to power circuits, and antennas to communicate with external devices.

To make sure such newly made electronic textiles are tough enough, Beeby has testing rigs in his lab designed to replicate the rigours of



**A textile printed with electroluminescent inks, which can light up**

everyday wear in a standardised way. A bending rig twists and bends a textile over tens of thousands of cycles. Wash testing, meanwhile, subjects the material to repeated cycles in a washing machine until failure.

That’s one key difference between the electronic textiles under development today, and the high-fashion electronic garments worn by popstars and the like. “I haven’t seen Beyoncé’s dress, but I can imagine you certainly wouldn’t put it in a washing machine,” says Beeby.

On the other hand, simple textile circuits made in his lab have lasted for up to 50 washes before failure – also the standard requirement for run-of-the-mill, non-electronic clothes. More complex circuits might make it to 20 washes at the moment, he adds, but the aim is to reach 100. One current line of enquiry is a common failure point at the interface between rigid components and the flexible substrate. His lab is investigating ways to avoid these sharp changes in stiffness, including with tapered stiffeners that spread the stress away from soldered contact pads.

To top it all off, there is very little overlap in skills and expertise between the two fields. Textile engineers and electronics engineers “speak different languages”, says Beeby. “You need to get the right people together to be successful.” He believes this may be one reason why commercial examples of electronic textiles have so far been limited.

## FROM ARTISANAL TO AUTOMATED

Engineers in the field are finding ways to gain both skillsets. When interdisciplinary researcher, designer, and engineer Irmady Wicaksono was a PhD student at MIT, he developed a fabric keyboard that could be rolled up and taken on the road. His first prototype took a month to make. Spanning a single octave, the keyboard was sewn from ‘functional yarns and fabrics’ made from silver-plated and polymerised fibres, working similarly to those made by Beeby’s spinout. He then spent two months at a textile company in Shenzhen, China, learning an industrial 3D knitting technique. The next prototype, spanning five octaves, took just 40 minutes to knit.

The faster manufacturing process also enabled Wicaksono to experiment with different types of sensor and tactility. Thanks to piezoresistive fibres, the knitted keyboard responded not only to proximity and touch, but also to stretch and pressure. Wicaksono also architected and engineered its “squishiness” and stretchiness. By stretching the keys apart while playing a chord, the pianist can bend and alter the base sound, like a built-in wah-wah pedal.

In 2023, he put his industrial knitting machine to work on a much larger scale, with a 6-metre-high knitted pavilion for US desert arts festival Burning Man – a giant, colour-changing theremin. Embedded in the 12 ‘petals’ was a network of antennas, knitted from conductive yarns, that sensed an electric field emitted by the central structure. Revellers entering and moving around the pavilion’s electric field triggered an eerie soundscape and colour-changing, moving lights.

Now director of the Soft Technologies Lab at the National University of Singapore, Wicaksono says the field has been largely “boutique research”. He says researchers and manufacturers need to work together to go beyond one-offs and prototypes



**Irmandy Wicaksono's knitted keyboard can be controlled by touch, pressure, stretch, and even just proximity: a musician can play by hovering their hands over it, similarly to a theremin** © Irmandy Wicaksono



**Wicaksono designed a knitted pavilion, a giant, immersive lighting and theremin system, for the 2023 edition of Burning Man festival in Nevada. Revellers moving inside the pavilion and altering the local electric field triggered light effects and a soundscape** © Irmandy Wicaksono

and translate these emerging materials into everyday products. The manufacturing capabilities and technologies are all there, he says, but manufacturers need to be open to more "alien" materials.

Theo Hughes-Riley from Nottingham Trent University's advanced textiles research group holds a similar view. "If you want to create something that everyone can use, you need to develop the manufacturing techniques so it can be made at scale," they say.

The research group is trying to automate the production of tiny electronic components. In 2022, they created a textile woven with over a thousand solar cells, which generated enough energy to charge a smartwatch. Embedding the solar cells in yarns by

hand is as painstaking as it sounds (and looks): each individual cell, measuring half a centimetre by 1.5 millimetres, had to be soldered on the front and back. "We have a PhD student that's very, very good at it now," says Hughes-Riley.

So far, the research group has developed a semi-automated approach, meaning that it needs minimal human input, for 'simple' components, such as LEDs or thermal sensors. However, more complex components are still largely made by hand. Take an inertial measurement unit, a device used for tracking motion. This involves soldering 11 terminals, each about twice the width of a human hair. "I'm sure I can get a robot to do it," says Hughes-Riley. They are indeed training one for this very purpose, "but we're not there yet."

## DESIGNING FOR SUSTAINABILITY

One day, when electronic textiles are more commonplace, like any other consumer product, we'll inevitably wear them out. What then?

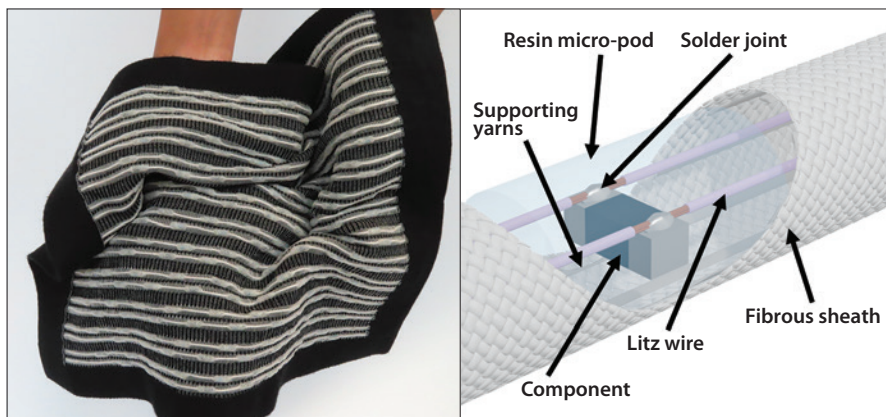
Their fate will be more complex than a garden-variety T-shirt or a power cable, as they compound e-waste and textile waste. "Textile waste is a big issue for the planet and electronic waste is just piling up," says Associate Professor Shaila Afroj, a researcher in sustainable electronic textiles at the University of Exeter. "We can't treat sustainability in e-textiles as an afterthought."

Post-consumer, we should be asking whether it will biodegrade and how long that might take, Afroj says. Another important question is whether we should integrate the electronics into the textiles or choose electronics that can be separated and upcycled.

In a collaboration with several universities, including Southampton, Afroj is developing a biodegradable, washable T-shirt that will monitor atrial fibrillation, a heart condition that causes irregular heart rhythms. These can happen at any time, so the idea is for the T-shirt to be worn all the time and continually capture data. It is designed as an alternative to the bulky devices that people with atrial fibrillation are currently sent home from hospital with, which cannot be worn continuously, so might miss irregular heart rhythms.

To make it biodegradable, Afroj swapped metal wires and sensors for organic and graphene electronics. The fabric base is Tencel, a biodegradable fabric made from wood pulp. It's not just the materials that can be made more sustainable. Instead of screen printing, where waste ink can pollute effluent, Afroj suggests drop-on-demand inkjet printing, which dispenses small amounts of ink directly where it's needed.

The trade-off for sustainability, however, is performance. Silver



The textile containing solar cells developed by Nottingham Trent University's advanced textiles research group (left) and a cut-through diagram of the e-yarn concept (right)

nanoparticles in silver inks are highly conductive but not very environmentally friendly. On the other hand, eco-friendly alternatives aren't as conductive, which Afroj believes is one of the biggest challenges to getting more sustainable electronic textiles to market. "You want it to perform really well so that it captures all your data very safely and accurately," she says. "You cannot really compromise on that part." Still, she is optimistic that advances in graphene and other 2D materials, together with organic electronics, may soon not only close the performance gap, but also unlock new multifunctional capabilities, such as sensing and harvesting energy from the environment, paving the way for truly sustainable smart materials.

## BEYOND THE NICHE

Sensor-laden and haptic body suits are a start for niche audiences, albeit expensive. What might come next?

Along with a wearable successor to his knitted keyboard and theremin-pavilion, Wicaksono is developing a pneumatic space suit, designed to assist with health monitoring and support the heart in pumping blood effectively in microgravity. At Nottingham Trent, Hughes-Riley and their colleagues have developed a bevy of user-focused, wearable

electronic textile prototypes, including a fall-detecting sock for older adults. To ensure the needs of those who will ultimately use the devices are met, the group has conducted workshops with potential wearers. Unsurprisingly, for the fall-detecting sock, comfort and washability were non-negotiables.

Beeby also states that near-term applications are likely to be in specialist

areas such as health monitoring, rather than general consumer uses. His lab, too, has socks in the works, in this case, wirelessly powered and designed to more accurately track physical activity. A pressure-detecting variant, meanwhile, will help prevent foot ulcers for people with diabetes. Also under way is a fully washable, motion-activated LED garment ("so we can all be like Beyoncé on the dancefloor", he adds).

Ultimately, electronic clothes will only become widespread if people find them genuinely useful and want to wear them. And while high costs are a barrier to adoption at the moment, there is reason to be optimistic. "Especially in healthcare and in sports, we're seeing good progress," says Afroj. "Once people feel the value and it's solving an important problem – like early detection of any disease or monitoring patients – that would be a real gamechanger."

## BIOGRAPHIES

**Professor Stephen P Beeby** holds a Royal Academy of Engineering Chair in Emerging Technologies on the topic of e-textile engineering and his research interests include wearables, printed active materials and flexible electronics. He is Director of the University of Southampton's Centre for Flexible Electronics and E-Textiles (C-FLEET), he leads the UK's E-Textiles Network and is Chair of the International Steering Committee for the E-Textiles conference series.

**Professor Shaila Afroj** is Associate Professor of Sustainable Materials at the University of Exeter. She specialises in graphene and 2D-material-based wearable e-textiles for healthcare and sustainable applications. A former researcher at the National Graphene Institute, she co-developed the world's first all-inkjet-printed graphene e-textiles. Her work focuses on scalable, biodegradable, and high-performance smart textiles.

**Dr Theo Hughes-Riley** is an Associate Professor in Electronic Textiles at Nottingham Trent University where their research focuses on the design and development of novel electronic textile (E-textile) devices. Their research has a particular emphasis on sensor technologies and the creation of E-textiles for wellbeing, healthcare, and workwear applications.

**Dr Irmandy Wicaksono** is an Assistant Professor at the National University of Singapore, where he leads the Soft Technologies Lab. He holds a PhD in media arts and sciences from MIT and an MSc in electrical engineering and information technology from ETH Zurich. His research integrates electronics into soft materials and everyday surfaces for applications spanning wearables to architecture.

# BRINGING GEOTECHNICAL ENGINEERING TO THE SURFACE



Professor Susan Gourvenec FEng

Having made her way into engineering by “accident”, Professor Susan Gourvenec FREng is now a leading authority in resilient and intelligent ocean engineering, particularly when it comes to offshore wind farm infrastructure. She also works to ensure that more people from underrepresented backgrounds have a clearer way into the field, and has chaired equality, diversity and inclusion committees in the UK and Australia. So, how did she get here? Leonie Mercedes speaks to her to find out.

Engineering was never on the cards for Professor Susan Gourvenec FREng when she was younger, growing up in a suburb just north of London. “My dad was an accountant, and I wanted to be an accountant,” she says.

But she showed her ingenuity and flair for problem-solving from an early age. “I was always interested in how things worked,” she says. “I liked making things as a kid, especially to make something fit for purpose, if it wasn’t how I wanted it.”

Although she had never considered her childhood tinkering as an interest in science and engineering, “and I don’t think my parents or teachers did”, she found her way to civil engineering. She studied at undergraduate level at Queen Mary University of London, topping her class, before specialising in geotechnical engineering and getting her PhD at her current home of the University of Southampton.

“I was a bit of an accidental engineer, and I’m immensely grateful for that turn of fate,” she says. “This is one reason why I’m passionate about outreach and public engagement.” Indeed, with just a third of young people saying they “know a fair amount about what engineers do”, and only half of teachers saying they feel confident advising students on pathways into engineering, the profession may remain invisible to a countless number of potential engineering stars.

## SHIFTING PERSPECTIVES

After more than a decade working with the oil and gas industry in Australia, developing innovative design methods for foundations and anchors to secure offshore infrastructure in deep waters and challenging seabeds, Gourvenec began to question whether her knowledge and skills would be better applied to advancing renewable energy. “I had genuinely believed we were doing something important, providing energy and energy security, by developing design solutions for safe and reliable infrastructure,” she says.

But as the reality and urgency of climate change became clearer, she started taking a different perspective.

She found herself with a tough decision to make: stay in her exciting and challenging career in oil and gas, where she had built up a great track record, or begin her transition to renewables, which meant a change of continent.



**Gourvenec (centre) with the Intelligent & Resilient Ocean Engineering (IROE) research team (and Gourvenec’s two teenage children – far right) ready for the annual Southampton Science and Engineering Festival public engagement event**

So, when the opportunity to return to Europe and work in renewables arrived in 2017, she took it. “It was a career risk,” she says. “At the time, quite a few people thought I was mad.”

Today, it’s fair to say she made the right decision. In 2019 Gourvenec became a Royal Academy of Engineering Chair in Emerging Technologies, leading the Centre of Excellence for Intelligent and Resilient Ocean Engineering (IROE). Her centre develops responsible and resilient solutions for harnessing energy from offshore windfarms, and her research guides policy on how we should use oceans in the future.

## SECOND WIND

Gourvenec is Professor of Offshore Geotechnical Engineering, and Deputy Director of the multidisciplinary Southampton Marine & Maritime Institute at the University of Southampton. “I’m a geotechnical engineer, so I deal with engineering challenges that involve the ground; soil and rocks,” she says [see ‘What is a geotechnical engineer?’. In her current role she applies her geotechnical engineering expertise to address big renewables problems, including where we should put the wind turbines we need to reach our climate changes, and how can we ensure they last their entire lifecycle?

The UK has an ambitious and urgent renewable energy target. We’re aiming to reaching 50 gigawatts of offshore

*The UK has an ambitious and urgent renewable energy target. We're aiming to reaching 50 gigawatts of offshore wind by 2030, from about 14 gigawatts today, to generate enough renewable energy to supply millions of UK homes and businesses with electricity and reduce our carbon emissions on a pathway to net zero by 2050*

wind by 2030, from about 14 gigawatts today, to generate enough renewable energy to supply millions of UK homes and businesses with green electricity and reduce our carbon emissions on a pathway to net zero by 2050.

The target means we're going to need more wind turbines. A lot more wind turbines. We know that taking them offshore is the way to go – more wind blows out at sea, and we can build the turbines bigger to generate even more electricity. But there are various challenges we need to solve to reach these offshore targets.

One challenge is working out where best to build them. Many sectors use the ocean – “We identified 37 different ocean sectors in a recent piece of research,” Gourvenec says – and it's important to ensure that wind farm sites, along with other ocean activities, are planned to balance environmental and societal needs.

Another key challenge is the seabed itself – it's not an easy place to build. Not only is it highly variable, with soils ranging from fine clays to large boulders, it is a dynamic environment – constantly under the influence of ocean currents. Also, the seabed properties change over time. When you install a foundation or anchor for a wind turbine, the loads imparted on the soil around it alter the engineering properties of the soil, which in turn affects the response of the foundation or anchor to the future loads.

Gourvenec and her research team at the University of Southampton develop theoretical methods to capture this evolution of soil properties through the life of infrastructure. This is so that they can develop foundation and anchoring systems for wind turbines that will stand firm for a generation, but not be wastefully overdesigned. It's also important that these structures can be decommissioned safely, with minimal disruption to marine life and minimal lifecycle use of resources.

Along with her team at Southampton, she's pioneering novel design philosophies and methods, developing solutions that can be rolled out around the world.

## A DAY IN THE LAB

Gourvenec and her team work at the National Infrastructure Laboratory, based at the University of Southampton, a facility with state-of-the art geotechnical and structures



**Gourvenec also extends her work promoting a lifecycle approach to offshore wind as theme lead of the Engineering X Safer End of Engineered Life Programme for Safer Decommissioning of Offshore Infrastructure and Ships, a collaboration between the Academy and Lloyd's Register Foundation. Having held the role since the programme's inception in 2019, Gourvenec has led on workshops and reports on the topic, and spoken at events, including at a panel discussion on the future of wind power at the Akademiet for de Tekniske Videnskaber (the Danish Academy of Technical Sciences) in Copenhagen, alongside Queen Elizabeth Prize for Engineering laureates Andrew Garrad CBE FREng and Henrik Stiesdal, and Science Minister Lord Patrick Vallance KCB HonFREng FRS FMedSci**

## WHAT IS A GEOTECHNICAL ENGINEER?

Geotechnical engineers are responsible for construction involving the ground. Their contribution to projects includes foundations for buildings or bridges; tunnels for transport projects; ground preparation for roads, railways and utilities routing; as well as coastal and offshore structures such as foundations for seawalls and flood defence systems; and monopiles or anchors for wind turbines. By analysing the behaviour of the surrounding soil or rock, geotechnical engineers ensure that designs are feasible to construct and sufficient to withstand a design life of loading from use or the environment.

Geotechnical engineers investigate geohazards, and they test and sample the ground at the project site to build a ground model. They then simulate the planned infrastructure using computer models or geotechnical centrifuge models, to optimise the construction process and ensure long-term integrity of the infrastructure.

labs that was established recently as part of the UKCRIC Collaboratorium, a multidisciplinary network of UK universities connecting research with policy and practice in infrastructure and urban systems.

When we meet (online), Gourvenec has just come out of a meeting with a PhD student to work through some comments on a journal paper, and a research meeting with a postdoc before that. She has a relaxed, but enthusiastic, energy, and seems happiest when discussing her research teams' work.

She tells me about the geomechanics lab and geotechnical centrifuge facility. Researchers test elements of soil and models of soil-structure interaction to work out how different parts of the seabed, or different foundations and anchors – otherwise invisible to us – will behave under a range of stress conditions and over the duration of their operating life.

The facility is fitted with a geotechnical centrifuge six metres in diameter. "Like the one in the Bond movie *Moonraker*, if you know it!" The centrifuge simulates prototype-scale stress levels with small-scale models.

Researchers load the soil samples and scaled-down models of the turbine foundations into a "strong box" about the size



**Gourvenec with the 6-metre diameter geotechnical beam centrifuge at the National Infrastructure Laboratory, which allows geotechnical engineers to scale up stresses to scaled-down models and test a design life of loading in a highly controlled, instrumented environment**

of a small fridge, which represents an area of seabed the size of a football pitch, and a depth of more than 60 metres. When the centrifuge spins into action, the sample is subjected to forces of up to 130G – 130 times Earth's gravity.

"The centrifuge can also 'speed up time', because of the scaling relationships that control the response of soils in centrifuge conditions. This means that a 25-year operating life can be modelled in a day," Gourvenec explains. "You can observe the response of the ground and the structure, whether or not the soil will densify or loosen, and at what point, if ever, the trend will stabilise, and how this affects the response of the system." The method lets engineers simulate the conditions that structures experience over the duration of their life in a controlled and instrumented environment. This provides performance data that is impractical to obtain at full scale and over real operating periods, allowing new design methods to be validated.

Many of the team focus on computational work using numerical models, often in combination with AI approaches, to simulate soil-structure interaction problems. The experimental and computational work complement each other. Gourvenec's team also faces the challenge of characterising those ever-changing conditions of the seabed. "[We use] computational and AI techniques... in conjunction with extant data, to derive reliable geotechnical engineering parameters from seismo-acoustic data," she says. "Such a step-change in offshore site characterisation is essential to achieve the pace and scale of offshore wind deployment needed to meet net zero targets."

Gourvenec and her team work closely with experts in many different disciplines including ship science, robotics, acoustics, geoscience, marine science, computer science, law and policy, and archaeology. "Ocean activities and our impacts on ocean health cross many disciplines," she says. She works with many partners, in both industry and government, to ensure her team's research is "informed by need", and that their solutions can be practically deployed.

## QUICK Q&A

### What inspired you to become an engineer?

The realisation that engineers use maths and science to solve problems.

### What are you most proud of?

That my research is used in practice to make things better or to make things possible.

### What is the best part of your job now?

The diversity of projects I work on, the diversity of people I work with, and making positive change.

### What's your most admired historical example of an engineer?

Can't get it down to one. Mary Jackson and Rachel Mary Parsons – for being extraordinary engineers and extraordinary human beings in the face of societal adversity.

### Which engineering achievement couldn't you do without?

Underground sewer systems! And indeed the entire subterranean network of pipes and cables that bring us clean water, electricity, internet and more, and dispose of our waste. Out of sight but not out of mind.

### Most impressive engineering to look at?

As a geotechnical engineer, the impressive stuff is usually underground and often underwater too! Venice is an astonishingly impressive geotechnical engineering marvel.

## TO TOMORROW'S ENGINEERS

Solving global problems calls for people with a wide range of skillsets and expertise. Just as an insight from one area of research can solve a problem in another, someone with an outside perspective can shake you out of your current ways of thinking and bring a new perspective.

While she was a professor at the University of Western Australia, it took an interviewer conducting an equality, diversity and inclusion (EDI) survey to show Gourvenec things could be different.

"Of these people you started with: one's your boss and one's director of their own centre. Why aren't you in such a role?" the interviewer asked Gourvenec, then in her 10<sup>th</sup> year at the university. "Well, they're probably better than me," Gourvenec answered. That had to be it, right? "No, no, no..."

After this meeting, diving into the EDI literature, and reading up on how decades of unconscious or conscious bias can manifest in inequalities in society, it occurred to her that perhaps it wasn't that her peers were better than her, and that "there was probably more at play".

The meeting set her on a course that would change her career. "Just becoming aware of this made me seek out a deeper understanding, rooted in the evidence in the literature, as well as seeking out an EDI-aware community and allies," she says.

By 2015 she had become the Chair of the inaugural ED&I committee at the University of Western Australia's engineering faculty. "There had never been an EDI committee," she says. After arriving at the University of Southampton in 2017, she became Chair of the engineering faculty's EDI committee.

While EDI has improved since her start in engineering, there is still a lot of work to be done. Gourvenec notes the difference between "highlighting pockets of good practice", and "making meaningful and pervasive cultural change". The former may win an institution brownie points, but doesn't do much in the long run.

"The engineering profession – and society – is still on that journey," she says. "In my own group and network, I champion EDI through building confidence and awareness, ensuring everyone's voice is heard, mentoring and sponsoring individuals, and creating a culture of inclusion."

So, how do we get more diverse voices in the field? "Give under- and unrepresented voices a platform and

opportunity to be heard, and value a diverse range of skills and perspectives" she says. "The Academy does a good job of this – giving people a platform to shine, doing what they are great at."

## A LOOK BACK

Gourvenec's list of achievements is long, although is there anything she's particularly proud of that isn't on her CV? "The achievements of people I have worked with or taught," she says, referring to the undergrads she sees doing well in their grad schemes, and the PhD students and early career researchers developing their careers in academia or industry. "Without taking anything away from what they have achieved themselves, I am very proud to have been part of their experience."

She also describes having a family – Gourvenec lives with her husband and two teenage children – as an achievement she's particularly proud of. "In the 21<sup>st</sup> century, that should not be such an achievement, but having a family and a career is still made too hard for too many people."

To those who are interested in engineering as a career, she advises following your interests: "There are so many types of engineering, there will be something that captures your interest and imagination and that you are good at," she says – and encourages people to take a look at #thisisengineering to reveal the diversity of job opportunities and pathways.



Gourvenec and IROE PhD graduate and Royal Academy of Engineering Enterprise Fellow, Oscar Festa, co-founded spin-out XMOOR, an AI-based surrogate modelling software for design optimisation of offshore renewable energy systems

## CAREER TIMELINE AND DISTINCTIONS

BEng in civil engineering, University of London, **1995**. PhD in geotechnical engineering, University of Southampton, **1998**. Postdoctoral Fellow Geotechnical Research Group, University of Cambridge, **1998–2001**. Postdoctoral Fellow to Professor, University of Western Australia, **2001–2017**. Professor of Offshore Geotechnical Engineering, University of Southampton, **2017–present**. Chair, ISO committee responsible for offshore geotechnical standards, **2017–2020**. Elected Fellow of Institution of Civil Engineers, **2017**. Deputy Director of Southampton Marine & Maritime Institute, **2018–present**. Chair in Emerging Technologies for Intelligent & Resilient Ocean Engineering, **2019–present**. Elected Fellow of the Royal Academy of Engineering **2022**. Co-Founder and Director, XMOOR, **2025**.

# THE DRONES DIAGNOSING HEAT LOSS IN BUILDINGS

Retrofitting the UK's buildings could slash emissions and energy bills – but it can be hard to know where to start. Startup Kestrix aims to accelerate the process with drones equipped with thermal imaging technology and AI.



Insulation is a key part of the retrofitting toolkit © Shutterstock

According to the government's *Heat and Buildings Strategy*, 25% of the UK's greenhouse gas emissions come from heating buildings. One way to cut emissions and energy bills is to retrofit buildings – with the added benefit of reducing fuel poverty and health issues from cold homes.

Retrofitting aims to boost energy efficiency either by improving the 'fabric' of a building – think insulation

or triple glazing; or by improving its energy systems, for example by installing a heat pump. To complicate things, the two are interlinked: heat pumps become more expensive to run if buildings are not well insulated.

The usual starting point for retrofitting is to bring in a specialist energy surveyor to test where heat is leaking. The problem is, there aren't nearly enough of these specialists

for the amount of homes that need surveying.

The scale of this challenge is "really staggering", says Lucy Lyons, co-founder of Kestrix, a startup aiming to become the "Google Maps of heat loss". Of the 29 million homes in UK, "almost all" would benefit from some form of retrofitting, Lyons explains. Kestrix aims to accelerate energy surveying, and thus retrofitting, by flying drones equipped with infrared cameras over buildings and analysing the images with AI. The company was recently named as a finalist for the Manchester Prize, funded by the UK Department for Science, Innovation, and Technology.

## DIAGNOSING HEAT LOSS

Kestrix's story started when Lucy's co-founder Matt Goodridge was renovating his home. He wanted to make his home more energy efficient but couldn't for the life of him figure out where to start, despite growing up with parents who renovated their homes.

At the same time, he'd seen AI being applied to analyse medical images while working in the medical devices industry.

## EYES ON THE INNOVATORS

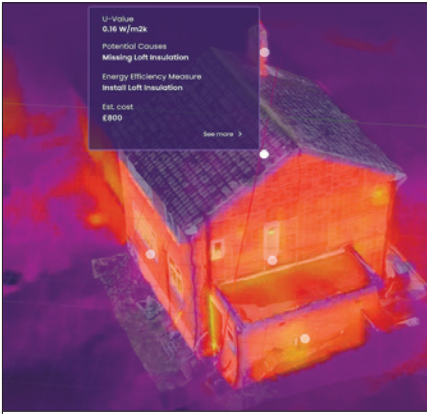
**Ingenia** is keeping a close eye on the engineering breakthroughs making a difference around the world.



2025 MacRobert Award winners, **OrganOx**, which has developed a life-saving organ preservation technology, has been acquired by Terumo for \$1.5 billion



**Loughborough University** study finds one in five homes in the UK are not equipped to handle hot weather



**Kestrix analyses images captured by drones to diagnose where heat is lost in buildings. Darker (purple, black, or blue) areas are cooler, while lighter (orange, yellow, white) areas are hotter. Part of Kestrix’s algorithmic work is “correcting” these temperatures to ensure they accurately represent where heat is being lost © Kestrix**

He thought, if analysing images of people with AI allows us to diagnose diseases, why can’t we diagnose heat loss by analysing images of buildings?

After the two co-founders met at a climate tech venture builder Carbon13, based in Cambridge, they decided to launch Kestrix to solve this problem by applying AI to aerial images, at the moment captured by drones. Drones are a well-established technology in the building sector, for example, to inspect wind turbines and roofs. It wasn’t too much of a stretch to imagine they could be used for energy surveying too.

Kestrix’s approach is to fly off-the-shelf drones fitted with thermal cameras about 30 to 60 metres above buildings. The thermal images are stitched together into a 3D model, which can be toggled on or off over a regular photographic view, to identify anomalies: anywhere heat is leaking will light up red.

While it might sound simple, this belies the complex building physics and thermography underneath, says Lyons. If you think of a terraced house, compared with a new build block from 2021, a bungalow or a 1970s tower block, the way heat is lost from each type of building can differ substantially.

So, Kestrix’s algorithm estimates a U-value, a measure energy surveyors use to calculate how heat travels through materials. Normally, measuring U-values requires attaching heat flux plates to the inside surface of walls, roofs and floors, and recording how much temperatures change over time. “Simply put, leaving a bunch of hardware inside a house and taking measurements,” explains Lyons. (There are other options too, such as thermally imaging the building combined with an internal blower-door test or conducting an Energy Performance Certificate survey, albeit outputs will be mostly assumptions-based rather than based on real performance. But all require a trained, qualified person – which is where the bottleneck lies.)

However, estimating the U-value without internal readings is not a trivial task, says Lyons, and the company is working to validate its accuracy with academic partners, initially for certain housing types. Getting it right is “not a challenge we’re taking lightly,” she adds.

## VERIFYING AND ACCELERATING RETROFIT PROJECTS

Once the test is complete, the client can then make an informed decision. Should they get triple glazing? Are they ready for a heat pump? Have their past retrofitting efforts been successful?

Kestrix is currently testing out its technology in partnership with social housing providers, local authorities, and utilities. The idea is to help them plan, price and verify retrofit projects, ultimately helping people save on their energy bills and reduce carbon emissions.

For example, the company is working with social housing provider Peabody Trust to see how well past retrofitting projects have worked, which can help shine a light onto the carbon intensity of operating homes before and after. “Today, there’s not



**Lucy Lyons, co-founder and CEO of Kestrix**

really a scalable, reliable way to assess how a building performed before retrofit and then after,” says Lyons. “You can look at someone’s bills, but there’s no way to say [a decrease is] because the cavity insulation is performing really well.”

Kestrix is also working on a heat pump siting tool in collaboration with EDF, funded by the Department for Energy Security and Net Zero, and also rolling out a retrofitting roadmap tool for residents with Islington Council. To create the latter, the company has scanned a neighbourhood in Islington. With the data, local people will be able to access free advice on how to make their homes more energy efficient.

Next autumn and winter, Kestrix plans to scan tens of thousands of properties. Longer term, the company has set its sights on helping the government back up decisions on allocating funding in the social housing sector. With a billion pounds’ worth of funding to be distributed over the next few years, Kestrix hopes to verify the success of completed retrofits, and show where funding should be prioritised in future.

The company’s involvement will “hopefully address the not just the 25% of emissions coming from heating buildings in this country, but the plight of fuel poverty and the burgeoning health crisis that cold homes are causing,” says Lyons. “We really hope to be a part of the transition.”



Researchers from the **University of Cambridge** are using AI to speed up detection of landslides after earthquakes



The **University of Strathclyde** has solved a key challenge for manufacturing next-generation optical chips for quantum technologies and telecoms



In a partnership with sports giant Decathlon, **Rheon Labs** will apply its strain-responsive materials to running leggings

# HOW DOES THAT WORK?

# ALUMINIUM CANS

Ever taken a sip of a drink and wondered how the can, with seemingly no joins, is created and keeps your drink fresh? The answer is a finely tuned balance of design, engineering and sustainability.



© Shutterstock

Pick up a can of your favourite drink and you're holding a quiet marvel of mass production. Every year, more than 370 billion aluminium drinks cans are produced worldwide – that's over a million in a minute.

It all starts with flat sheets of aluminium, often made from over 69% recycled material. These sheets are fed into a powerful press that punches out circular blanks and shapes them into shallow cups. From there, a body-making machine stretches and moulds the cups into that familiar cylindrical form, complete with a domed bottom designed to handle the pressure of carbonated drinks. Once the can is formed, any uneven metal at the top is trimmed away to create a clean and levelled edge.

But before the cans can be dressed up and filled, they need a deep clean. Lubricants and oils are used during shaping to help the metal flow smoothly through the machines. These are washed away with hot water and chemicals, prepping the surface for coatings that protect both the inside and outside.

Cans are generally distinguished by their vibrant designs and recognisable logos. A high-speed printer applies these, layering ink and sealing it with a clear varnish to keep everything crisp during transport and handling. The cans are then baked to cure the design into a durable finish. Inside, a food-safe lacquer is sprayed to prevent the drink from reacting with the metal and preserve its flavour. Another quick bake hardens this inner coat.

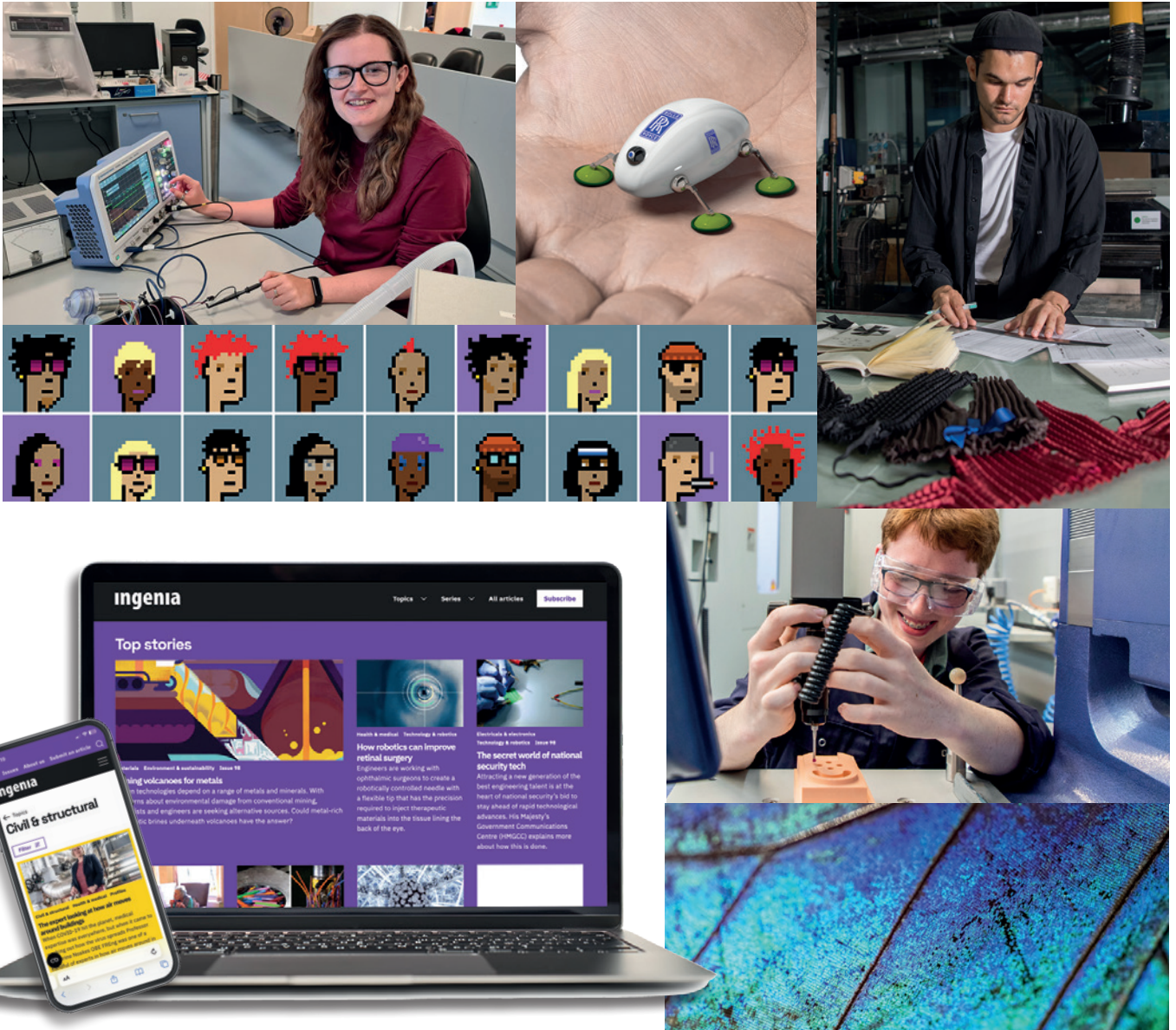
Next, the can gets its signature neck and lip. To achieve this, the can is forced through a set of progressively smaller tools that gently squeeze the top inward, then flare it out to create a protruding rolled edge, where the lid will be securely fitted later. This process is done in multiple small steps as aluminium cans are very thin (less than 0.3 millimetres), so one wrong move could tear or wrinkle the cans.

Before leaving the factory, the cans are tested to confirm strength and quality. Those that pass are shipped to manufacturers, where they'll be filled, lidded and sent to stores.

And what about the lid? This is manufactured separately, and the process begins similarly to can bodies: aluminium sheets are pressed into round shells and curled at the edges. A sealing compound is added inside the curl, then baked to form a soft, rubbery ring that keeps drinks fresh. Next, a groove is scored into the lid, to make the can easy to open, and a separate tab is placed perfectly over the top, locked in place with a rivet to maintain pressure. When you pull the tab, it presses into the groove, breaking the seal and letting the fizz flow. After the drink is filled, the lid is attached using a process called 'double seaming', which ensures an airtight, leak-proof seal.

The result is a can that's strong, light, and endlessly recyclable. Aluminium drinks cans are the most recycled packaging in the world. In fact, your empty can could be back on the shelf as a new one in as little as 60 days.

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