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ROYAL ACADEMY OF ENGINEERING
AWARDS DINNER SPECIAL

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of Engineering

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Front cover
Illustration depicting technology advances at the Wimbledon Championships © Benjamin Leon

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WELCOME

Engineering is everywhere, but nowhere is it the same. This issue reminds us of the great breadth and diversity of engineers working to solve some of the world's greatest challenges – benefiting society and the economy.

In this issue, we celebrate some of the best of UK engineering, featuring individuals and teams of engineers whose excellence and achievements have been recognised with awards from the Royal Academy of Engineering.

STEMAZING Founder Alex Knight, winner of the Rooke Award for her work promoting engineering to the public, discusses on page 8 how important it is for children to be exposed to engineering role models from a young age. We also talk to researcher Dr Mahmoud Wagih, winner of the Sir George Macfarlane Medal, to hear how his interest in engineering was sparked from an early age.

Professor Nilay Shah OBE FREng, who has received the President's Medal for his contribution to Academy activities, details a career that has taken in vaccine manufacturing, green fuels and encouraging a more diverse engineering workforce. You can also read about Scotland's lowest carbon wastewater treatment works, which has won the Major Project Award for Sustainability.

We also have not one but two Innovation Watch articles that highlight the pioneering researchers and entrepreneurs who have received the Princess Royal Silver Medals for their work in AI and nanoelectronics.

As Wimbledon will be captivating many of us shortly, we explore the technology transforming the spectator experience. Other stories include the difference solid-state batteries could make to electric vehicles, and the potential that machine learning offers in addressing the challenge of multi-scale modelling.

Are there engineering achievements or engineers that you would like to recognise? Let us know by contacting us at ingenia@raeng.org.uk.

Faith Wainwright

Faith Wainwright CBE FREng
Editor-in-Chief

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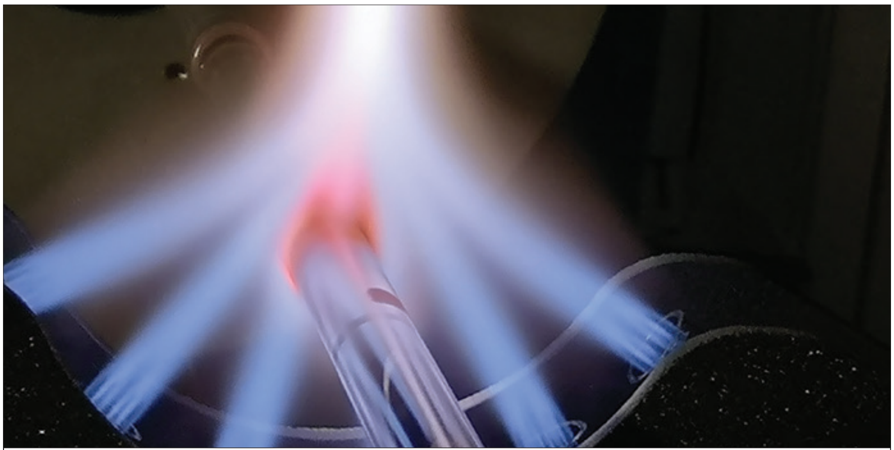
IN BRIEF

FINALISTS ANNOUNCED FOR 2025 MACROBERT AWARD



Microsoft Azure Fibres' hollow core optical fibres could revolutionise the internet by enabling near-instant transfer of data

OrganOx's devices replicate the physiological conditions of an organ within the body, preserving it outside of the body for at least twice as long as cold preservation techniques

Synthesia was the first generative AI company to create a responsible framework for synthetic media, preventing the formation of nonconsensual deepfakes and introducing content moderation at the point of creation

Innovative hollow core optical fibre technology enabling near-instant data transfer, a life-saving device that enables many more organs to be transplanted, and a human-centric AI platform that generates audio and video from text have been announced as finalists for the 2025 MacRobert Award, the UK's leading prize for engineering innovation.

This year's three finalists are all successful engineering innovations connected with UK universities, two of which are spinout companies. The hollow core optical fibre technology was developed by Lumenisity, a University of Southampton spinout later acquired by Microsoft. OrganOx's transportable normothermic organ perfusion device is a world first originating from research at the University of Oxford, and one of the founders of Synthesia's text-to-video generation business is a professor at University College London. They are recognised not just for technical innovation but also for the commercial and societal impact they have demonstrated.

Microsoft Azure Fibre's technology replaces the solid glass core of traditional optical fibres with air and comprises a central light-guiding cavity surrounded by microscopic, nested glass tubes running the length of the fibre. This stable, low-latency innovation improves the speed of transmission and enhances energy efficiency, needing fewer power-hungry electronic components over longer distances. It will enable more flexible datacentre placement and meet the growing demand for high-volume data transfer driven by growth in the use of AI, as well as enabling the development of 6G and edge-computing and other 'tactile' applications where response time is key, such as remote medicine.

OrganOx has developed the world's first transportable normothermic organ perfusion technology. Its two devices maintain livers and kidneys in a functioning state outside the body for at least twice as long as conventional cold preservation techniques, increasing the number of transplants for patients, eradicating night-time operations for clinicians, and reducing overall healthcare costs. Beyond transplantation, a third patient-connected device is under development with the aim of providing 'liver dialysis' using either a human or porcine organ outside the body, to help patients in liver failure recover without the need for a transplant. The technology has enabled over 6,000 transplants across four continents and 12 countries.

Synthesia allows users to create and distribute professional-quality videos directly from a web browser without cameras, lighting, studios, or specialist editing software, using a collection of hyper-realistic digital avatars that look, sound and behave like real people. Its large, generative AI audio and video model interprets text input and vocal intonations, produces natural speech in over 140 languages, and delivers complex body language for nonverbal cues to express emotion. It has more than one million users across 65,000 businesses that use the technology to generate videos for employee training and internal communication, customer support, sales, or product marketing.

This year's winner will join an esteemed group of past recipients who have delivered outstanding innovation, commercial success, and tangible societal benefits. Since the presentation of the first award in 1969, which honoured Rolls-Royce for the Pegasus engine and Freeman, Fox and Partners for the Severn Bridge, the MacRobert Award has recognised transformative contributions, from the world's first bionic hand, developed by Touch Bionics, to innovations from Jaguar Land Rover and Inmarsat that continue to have a global impact.

AI TECH RECOGNISED FOR GREEN ENERGY TRANSITION

The finalists of the Manchester Prize © Challenge Works

AI technologies to transform how people can heat and better insulate their homes are among the finalists of the £2 million Manchester Prize, which rewards AI technologies that will contribute to a clean energy system in the UK. Each of the 10 teams will receive £100,000 to develop their solutions over eight months, with one winning a £1 million grand prize in March 2026.

Announced by Peter Kyle, Secretary of State for Science, Innovation and Technology at London Tech Week, the clean energy innovations include a nonintrusive system that uses AI to design bespoke panels that turn bricks into radiators, which then warm homes from the outside in. This aims to streamline the process for older housing stock transitioning to using heat pumps.

Other finalists include AI-enabled heat-mapping drones to help councils and housing associations pinpoint social housing stock in need of insulation upgrades more efficiently, and an AI technology to identify materials in end-of-life solar panels and then recycle them into new photovoltaic cells instead of going to landfill.

Energy Secretary Ed Miliband said of the announcement: "Clean power is the economic opportunity of the 21st century and these projects will help households and businesses take advantage of lower bills, in a smarter and faster way than ever before… AI has the potential to help every home in Britain to feel the benefits of warmer homes and homegrown clean energy."

The Manchester Prize, funded by the Department of Science, Innovation and Technology and delivered by Challenge Works (part of the Nesta group), is rewarding UK-led AI breakthroughs that support the public good, including growing the economy, improving public services and helping to create a just transition to net zero.

LEGO COMPETITION REWARDS YOUNG ENGINEERS


© Shutterstock

In May, young engineers from across the country took part in the FIRST® LEGO® League UK Final at Harrogate Convention Centre, with a team from Bradford Grammar School taking home the Champions Award.

Sixty-seven teams of young innovators took part in the national final, presented by the Institution of Engineering and Technology (IET). The event celebrates the creativity, teamwork, and technical skills of young people aged nine to 16, who participated in robot games and presented their own innovation projects to panels of expert judges.

Each team designed, built, and programmed Lego robots to complete a series of dynamic challenges. The day showcased real-world problem solving, with teams presenting innovative solutions that tackle marine issues, such as exploring the complex ecosystems and marine life, and how the oceans effect life on land and at sea.

Winners were also recognised in categories including Robot Design, Core Values, Innovation Project, and Robot Performance. The overall Champion's Award winner will represent the UK at an Open International FIRST® LEGO® League event in Florida.

For more information and to get involved, visit: **education.theiet.org/first-lego-league-programmes**

INGENIOUS PROJECTS TO INSPIRE THE NEXT GENERATION OF ENGINEERS

In May, the Royal Academy of Engineering announced 16 new Ingenious public engagement awards for projects across the UK designed by engineers to engage the public with engineering and inspire the next generation of engineers.

This year's projects focus on topics from girls' robotics and electrical engineering challenges to comics and engineering. This includes Girls' Robotics Challenge, the UK's first robotics competition for girls, focused on space-themed engineering tasks. This project, led by King's College London, will work with students in Years 8 to 11 to build robots, develop skills in coding, design thinking and teamwork, and gain a sense of belonging in engineering.

Many projects are aiming to introduce young people to energy and sustainability, including Black STEAM Goes Green, which will transform the annual Black STEAM celebration into a green engineering and sustainability-themed festival. The project brings together artists, engineers, scientists, and activists to co-create interactive, sustainability-themed experiences designed to inspire curiosity across all ages.

The newly funded projects will engage communities throughout the UK to help reach underrepresented audiences and change perceptions of engineering. The programme provides engineers with training and encouragement to share their stories and engineering expertise with the public.


Students take part in the Girls' Robotic Challenge

To find out about other projects funded by the scheme, please visit the Royal Academy of Engineering website.

GET INVOLVED IN ENGINEERING

© Neil Mewes/Unsplash

NATIONAL RAILWAY MUSEUM 50TH BIRTHDAY

York
27 to 28 September 2025

The National Railway Museum's Station Hall reopens in September, just in time for its 50th birthday weekend. The historic former goods station has been closed since 2023 for an extensive refurbishment project and will have new items in the collection, as well as old favourites. Step inside to see a spectacular new interior decoration, stunning new collection items and the return of timeless favourites. The birthday weekend celebrations will also offer behind-the-scenes access to areas of the museum previously unseen by visitors. Visit the website to find out more.
railwaymuseum.org.uk

© Maiju Suomi/The Design Museum

MORE THAN HUMAN

Design Museum, London
11 July to 5 October 2025

This new exhibition brings together art, science and radical thinking to ask how design can help our planet thrive by shifting its focus beyond human needs. There are more than 50 artists, architects and designers in the exhibition with highlights including a seaweed installation by artist Julia Lohmann, created specifically for the exhibition, that will appear to be growing from the ground of the space. To book tickets, visit
designmuseum.org

FAMILY FUN DAY: BIG SCIENCE

Ri, London
19 July 2025

Families with children aged six to 12 years old are invited to the Ri's family fun day. Activities and demonstration stalls aim to engage families with science in an interactive and fun way, and encourage adults and children to discover and discuss STEM topics together. Activities run throughout the day as well as shows in the Ri's theatre. To find out more and book tickets, visit
www.rigb.org/whats-on/family-fun-day-big-science

ALGORAVE

Science Gallery, King's College London
11 July

Curious about live coding? Join The King's Institute for Artificial Intelligence and Science Gallery London's hands-on workshop where you'll learn to craft your own rhythms using Strudel, a popular and beginner-friendly live coding tool that runs in your browser. No prior coding experience needed – just bring your laptop and an open mind! It's free to attend, but register beforehand at
www.kcl.ac.uk/events/algorave

A.L.EX AND THE IMPROBOTS: HOW TO TRAIN YOUR ROBOT

Edinburgh Fringe
30 July to 17 August 2025

Join the ImproBots at the Edinburgh Fringe in an attempt to train their feisty robot A.L.Ex to be the funniest AI in the galaxy. The show features cutting-edge technology and improv comedy, and is suitable for audience members aged eight and over. Will A.L.Ex become the ultimate comedy machine, or will the ImproBots need help from their human friends? Find out more about this and other science shows at the Edinburgh Fringe by visiting
edfringe.com

HOW I GOT HERE

Q&A

DR MAHMOUD WAGIH
ELECTRONICS ENGINEER

Dr Mahmoud Wagih, this year's winner of the Royal Academy of Engineering's Sir George Macfarlane Medal, is focusing on developing wireless power and sensing technologies using sustainable materials, which could lead to millions of low-waste, maintenance-free smart devices.

WHY DID YOU FIRST BECOME INTERESTED IN SCIENCE AND ENGINEERING?

The earliest engineering I did as a (probably) five- or six-year-old was building up model cities using blocks. Slightly later, I developed a love for cars, of all sizes, and spent a good while on annual family trips to car shows and sketching (conceptual) car designs; I heard then that designing cars was a well-paying job!

Strategy computer games were another hobby growing up, which does include an element of engineering, or engineering management. Seeing PCs develop and become capable of doing more, particularly running more advanced games, made me want to build PCs, which made me go into studying electronics.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I studied A levels in maths and physics, then went to do an MEng in electrical and electronic engineering at the University of Southampton, in a programme where I spent a year in Southampton's campus in Malaysia. During my studies, I didn't have a concrete idea of what I wanted to do. This was until I completed a research internship at the university analysing high-speed signal lines for USB. This sparked my interest in radio frequency (RF) engineering and wireless devices. With this new interest, I graduated earlier, with a BEng, to pursue a PhD incorporating antennas into clothing for wirelessly charging wearable devices.

I have since then mostly remained in academia, from Southampton to Glasgow, where I mainly researched any interesting technical challenges that brought multiple people's work together. I also spent time in industry at Arm, who make microprocessors for almost everything, through an internship and a research secondment. I've recently founded a startup, RX Watt, making chips for sustainable wireless charging of electronics at metre-range.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

Establishing a large interdisciplinary team that makes up our Green Electronics Lab. Being able to build a highly capable team ranging from chemistry, materials, and electronic engineering, to software, is something I am truly proud of.

From a personal perspective, winning the Sir George Macfarlane Medal has been a very happy moment. As a student, winning the best undergraduate project prize at Southampton, despite having struggled with some, or many, courses in my first years of engineering, and later the best PhD in Europe in antennas are two

Mahmoud (second left) and colleagues share their research at Glasgow's Riverside Museum

main highlights. My undergraduate project included designing Bluetooth antennas and circuits for insoles, allowing continuous tracking for step counting, for example.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

My favourite engineering moment is receiving a device that I, or a team member, designed for the first time. It's always a long-anticipated moment that gets me instantly into the lab. Perhaps, it's often the fact that it looks smaller than expected, and it's particularly satisfying when it works as intended.

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

As an academic and startup founder, my day has a mix of management and technical tasks. I am often planning new projects and applying for grants to support them, this could be a few-weeks-long study or a several-years-long programme. I spend a lot of time with my team, either one-on-one or as a small group in the lab. I also prepare many presentations and lectures about our work.

For the more typical engineering work, I am often in the lab to set up a new experiment or see the initial results of testing a new device that was just constructed. I sometimes miss spending more time in the lab 'playing' with the equipment, but I do thoroughly enjoy the variety of activities in a day, and specifically working with others to make their technology work.

As a lecturer, I also teach electronics design, supervise student projects, and sometimes run workshops for school students to get a feel of electronics. Occasionally, I get to do interviews, like this, or with TV/radio, and sometimes deliver an exhibition at a local museum. For example, I was interviewed for CBBC's *Operation Ouch* about our wireless-powered smart bandages, which use UV light to kill bacteria. Another highlight was showcasing my research at the Glasgow Riverside Museum.

WHAT WOULD BE YOUR ADVICE TO YOUNG PEOPLE LOOKING TO PURSUE A CAREER IN ENGINEERING?

If you are considering a degree in engineering, don't let a lack of past engineering experience put you off.

I think engineering is one of the most flexible professions; in a sense that as an engineering graduate, you could end up applying your skills in finance or management. Likewise, someone with a different sciences background, or without a degree, could pick up the engineering skills for a successful career. I have met several successful engineers who came via apprenticeships or had nonengineering degrees.

As an engineering student, spend time talking to other engineers, that could be at job fairs, conferences, or your lecturers, and you will find out a lot more about areas of engineering that you didn't know about. Several successes in my career are a direct result of that.

WHAT'S NEXT FOR YOU?

I'm making the time to get back to the lab to test some of our new biodegradable devices and sensors. Since summer is around the corner, hopefully a quick (sunny) hillwalking holiday is also due.

QUICK-FIRE FACTS

Qualifications: **BEng in electrical and electronic engineering; PhD in electrical and electronic engineering**

Biggest engineering inspiration: **probably Gordon Moore, who defined the growth of digital chips**

Most-used technology: **the internet, rather unsurprisingly**

Three words that describe you: **hands-on, diligent, ambitious**

OPINION

ROLE MODELS FOR YOUNG CHILDREN MEAN A FAIRER FUTURE FOR US ALL

'If you can see it, you can be it' is a phrase often used to highlight the importance of representation and role models. And nowhere is this truer than for women in engineering and technology roles. Alex Knight, the winner of the Royal Academy of Engineering's 2025 Rooke Award for excellence in public promotion of engineering, emphasises why role models in primary schools are critical to a more equitable and inclusive future.

Walk into most primary schools and ask a group of eight-year-olds to draw an engineer. Chances are, they'll sketch a man in a hard hat. That's not surprising – after all, what they're seeing today is a profession still cloaked in outdated stereotypes.

It's time we changed that, once and for all. We've been talking about it long enough.

What we need is a laser focus on the urgency for more engineering role models who are women to step into classrooms and ignite a spark in the next generation. Because the absence of relatable women engineers in the minds of our children isn't just a missed opportunity; it's a quiet tragedy with long-reaching consequences that are, quite frankly, terrifying for the future of society and the planet.

CATCH THEM YOUNG WITH CONNECTION AND REPRESENTATION

Children form beliefs early: about themselves, about the world, and about their place in it. By the age of seven, many have already decided what's 'for boys' and what's 'for girls'. Engineering is still seen as a man's world, so girls start to believe they don't belong there. Boys may also form the unconscious bias that their female classmates don't belong there either. The result – all genders are missing out on an inclusive engineering future.

But when a young girl meets an engineer who is a woman she can relate to, something extraordinary happens. That girl begins to imagine herself in the same role. Engineering becomes not an abstract discipline, but a human one. Her sense of belonging expands.

But this isn't just about the girls. Boys need to see engineers who are women too. They need to grow up recognising that technical brilliance isn't gendered, that leadership doesn't look one way, and that collaboration is richer when different voices are at the table.

THE RIPPLE EFFECT

I founded STEMAZING to empower and equip women in STEM to be the visible role models our young people need to see and engage with. We run a unique online training programme that supports women to level-up as visible role models and deliver a series of interactive STEMAZINGKids sessions in primary schools. In the last five years we have trained over 600 role models and collectively led over 160,000 STEMAZINGKids engagements with children aged 7 to 9 years old.

Our aim is to ensure that every child gets hands-on with STEM experiments, feels that STEM is accessible for them, and sees that pursuing STEM can lead them to a career where they can make a difference doing something they love.

Research from Engineering UK shows that young people who engage in a STEM activity are 3.4 times more likely to consider a career in engineering, and girls who see women as role models are more likely to believe they can pursue this path themselves. This will ultimately lead to increased interest in STEM subjects, greater retention of diverse students through school and into higher and further education, and more equitable outcomes in future careers, but we have to catch them young first.

THE BENEFITS FOR ROLE MODELS

We know firsthand from all our work at STEMAZING, that for the women themselves, becoming a role model is not just an act of generosity – it's an act of personal empowerment. It validates their journey, their presence, and their authority in a field where they may sometimes feel invisible. It builds confidence, strengthens leadership skills, and fosters a sense of purpose that extends beyond their day job.

There is also a profound emotional reward. Watching a young girl's eyes light up with recognition – "She's like me!" – is a moment of connection that stays with a person. These encounters can heal the wounds of isolation some women have experienced in their own careers. They create community across generations.

A FAIRER FUTURE FOR US ALL DEPENDS ON IT

Let's not forget what's at stake for society. Engineering challenges in the 21st century – from climate change to infrastructure resilience to AI ethics – demand diverse minds. Solutions created by a narrow demographic risk blind spots and biases. A more inclusive engineering workforce isn't just a social nice to have, it's a technical and societal imperative.

And yet, despite the clear benefits, we continue to see a bottleneck of underrepresentation. This is where role models make all the difference.

THE CALL TO ACTION: ENGINEERING BUSINESSES, STEP UP

Only 16% of the engineering and technology roles in the UK are held by women. Clearly, this is not enough, and it's not just the UK facing this problem.

However, instead of looking at the problem with a scarcity mindset, you can find ways to be the change you want to see. For example, support organisations that are actively already making a positive impact in this space and ensure women in your organisation feel seen and supported to be visible role models.

That meagre 16% still equates to nearly a million women working in engineering and technology in the UK today. We have about 20,000 primary schools, so that is 50 women as engineering role models for every primary school! That's a number I am excited about, because it shows we already have enough role models to start the ripple effect we've been waiting for.

Businesses must actively encourage and invest in their people to engage with schools – not as a box-ticking exercise, but as a core part of professional development and corporate responsibility. Provide time. Offer training. Recognise the emotional labour involved and reward it. Celebrate those who do it well. And most importantly, value the visibility of your people as a strategic asset, not a soft extra.

If we want a future with inclusive engineering and technology that benefits everyone in society, we need more diverse engineers designing and building these solutions. This means we need more diverse role models in primary school classrooms today.

The question is no longer should women engineers step into the spotlight. It's how can we help them get there right now? Let's bring the future into the classroom – and let it look like all of us.

BIOGRAPHY

Alex Knight is a Chartered Engineer, and a Fellow of both the Institution of Mechanical Engineers and the Women's Engineering Society. After a career of over 15 years in industry, she founded STEMAZING – a social enterprise dedicated to inspiration and inclusion in STEM. Alex is also mentor, trainer, visiting professor, and TEDx speaker. She is a regular keynote speaker at events and schools and has featured on TV shows on Channel 5, Prime and CuriosityStream.

© Shutterstock

TREATING WASTEWATER MORE SUSTAINABLY

Did you know?

- Wastewater treatment removes contaminants from wastewater to make it safe for release back into the environment or for reuse
- The wastewater typically has to go through several cleaning and filtering stages before it can be reused or pumped back into rivers or the sea
- Naturally occurring microorganisms can be used to break down organic pollutants

Towns across the UK are growing. Building more houses inevitably means more sewage and wastewater. Stuart Nathan reports on the winner of the Royal Academy of Engineering's Major Project Award for Sustainability, which demonstrates how innovative collaborative working and an environmentally friendly treatment technology has delivered Scotland's lowest carbon new wastewater treatment works.

About 12 miles west of Edinburgh City Centre, Winchburgh is one of Scotland's fastest growing towns. In 2001, it had a population of about 2,000, and the town will host 3,800 new homes by 2035, with an expected population of almost 15,500 people. This projected growth would overwhelm the capacity of the town's existing wastewater treatment works. Scottish Water needed a plan that would meet the rising demand for wastewater treatment while driving down carbon emissions as part of its commitment to investing in low carbon innovation to improve its services, support housing and economic growth, and protect Scotland's environment.

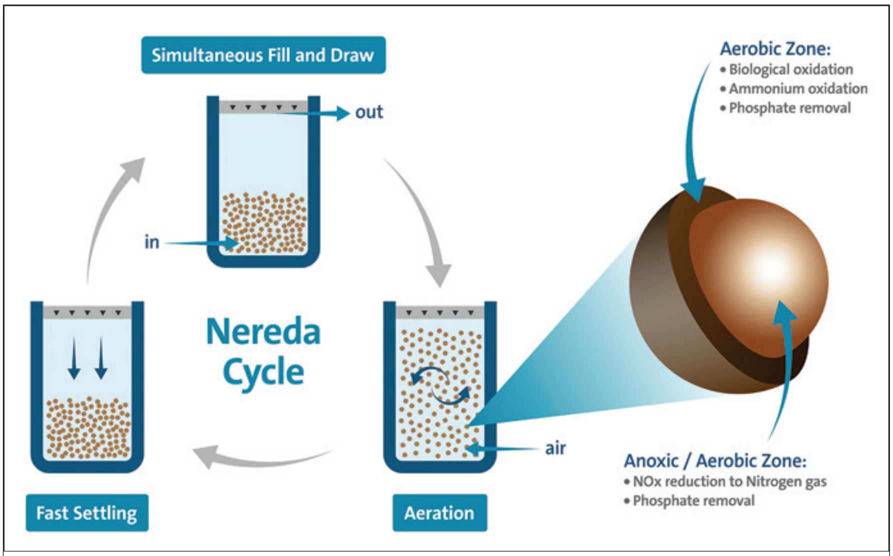
The idea was to replace the existing wastewater treatment works with one that could cope with the increasing population. But it had to be compact. The existing facility was located between a railway and a canal, at the lowest point in the network to avoid excessive pumping, and there was only a small area of land available to build on at the site, as the new plant would be built while the old one was still operating.

Scottish Water already had a model for a similar facility at Inverurie, in Aberdeenshire, where it had built its first plant using Nereda® technology. This biological treatment process, provided by Dutch engineering consultancy and the technology's developer Haskoning, intensifies and enhances naturally occurring processes to allow all stages of treatment to take place in a single tank. This process operates one batch at a time with multiple treatment reactors meaning that increased volumes of wastewater can be treated faster, using fewer chemicals in a smaller site area and with a much-reduced carbon footprint.

NATURAL TREATMENT

Nereda® uses microorganisms that occur naturally in sewage and wastewater to break down organic pollutants. The process drives the natural formation of biological 'granules' that attract organic matter through different biological processes, which then settle quickly to leave clean wastewater. This differs from conventional activated sludge technology, which relies on slower settling floccular biomass and requires larger tanks for both treatment and settlement.

Nereda® improves on the activated sludge process by monitoring and controlling the process conditions, such as aeration rates and temperature.



The Nereda technology was invented in the Netherlands in the early 2000s by Delft University of Technology and Haskoning. It now operates in 21 countries, with about 120 projects worldwide. Operational experience has shown the process typically consumes about 50% of the energy of traditional wastewater treatment processes and requires 75% less space © Haskoning

The granules form naturally when selective pressure is applied. As a result, the microorganisms produce sticky polymeric substances. This means that pollutants such as nitrogen and phosphorus, which usually needs a chemical addition for removal, accumulate into denser granules that settle much faster.

These granules naturally form a layered structure with different levels of oxygen. Each particle effectively becomes a microreactor (which in the older process would need separate tanks). The Nereda® process does not need stirring or any moving equipment. The settled granules are retained in the reactor to treat the next batch of crude wastewater. Using microorganisms to break down the pollutants reduces the need to add chemicals to the sewage and allows large volumes of waste to be treated hygienically.

Excess biomass is removed from the process and is currently sent through traditional sludge processing routes or to help set up new facilities using the Nereda® process. The granules have also been found to contain a high proportion of naturally occurring biopolymers, which can be harvested as a product known as Kaumera for use in a range of applications from bio-stimulants in agriculture through to coatings and thickening agents in manufacturing applications.

Haskoning was brought on board to assess how the process would work at the site and feed that into the design process. "Principally we consider the crude wastewater operating window and the current and future permit requirements of the plant in order to present a reliable solution to the client," says Haskoning's Andrew Dyne. "And then going forward we look to optimise the process performance and plant operations to provide the best value while maintaining the client's obligations. The Nereda® process is flexible, so we can tailor the process to target the performance we need and even optimise it for future requirements."

This performance is assisted by the Nereda® process controller, which uses machine learning trained on data from the site's instrumentation to optimise and predict the conditions in the plant to keep the effluent to the required quality. "It predicts how the plant can operate optimally as the flow and load to the plant changes," Paul Lavender, Director of Water Utilities at Haskoning, explains. "For example, in wet weather the organic composition of the crude wastewater will be more dilute than in dry weather. The Nereda® process controller algorithm anticipates and predicts the treatment conditions required to treat crude wastewater to the required output. By monitoring the inlet quality, it can manage changing conditions to maintain the output quality, while minimising energy consumption."

SUSTAINABLE CONSTRUCTION

Nereda® alone presented many advantages to reduce energy use, says Project Manager Colin Maybury from Scottish Water, but the company aimed to reduce carbon emissions further with the Winchburgh project – part of a commitment to halve embodied carbon by 2026 and achieve net zero by 2040 – led it to consider different methods of construction. Scottish Water's alliance partner ESD – a joint venture between Binnies, Galliford Try and MWH Treatment – had led construction of the Inverurie plant. At Winchburgh, it also had to reduce the build time and keep costs low.

With the project plan starting in 2019, the onset of the COVID-19 pandemic and resulting lockdown firstly meant that the team needed to adapt its usual design process – meeting virtually, which was unusual at the time, and collaborating on the design using BIM (building information modelling) software.

Often used in construction, BIM software creates 3D models where all the components are tagged with their origin and specifications, so users can click on each element to see all the relevant details. "Scottish Water were in Scotland, ESD had people in Manchester and one in France," says Alan Ford of equipment supplier EPS. "We were at our head office in Ireland, and Haskoning were in the Netherlands. We used the 3D model as our main method of collaboration in virtual meetings. That led to an agreed design that we could then use for the next stage of the project."

Building the various units of the plant off site – at EPS's factory in Mallow, County Cork – was another important factor in improving the project's

The Winchburgh site replaces the old treatment works that served the town

environmental impact, Ford explains. "The quality is better, production is better, and there's less waste, which all drives down the amount of carbon emitted during the project. It's indoors and we can control all the conditions. Production rates are two to three times faster than traditional on-site works."

EPS even assembled many of the plant's various subunits in the Mallow factory. "We actually took the on-site team [based in Scotland] to Ireland to witness it being put together, tested and taken apart," adds Ford. "When the lorries arrived on site in Scotland, they knew which pieces were coming in which order and could offload them and assemble them straight away. It greatly reduced construction times."

To help streamline the on-site assembly process, the team developed the 3D BIM model into an animated sequence showing how the on-site team should build the plant, and introduced the dimension of time into the model, known as 4D synchronisation. "It starts with an empty field and builds the elements onto it," Ford explains. "It makes everything very visual. Rather than looking at lines on a chart, you can see easily the multiple construction activities happening at the same place and you can reorder the construction sequence to pull them apart." Maybury adds that 4D synchronisation helped identify if cranes needed on-site were at risk of colliding with structures and solve problems before they occurred. "That was picked up in the animation and changed before it came to site. I've never seen a major project go as smoothly on site as Winchburgh."

Sharing the 4D synchronisation with the suppliers also helped the project run more smoothly, Stephen Fraser, Operations Manager of ESD, adds. "Our suppliers would suggest how we could improve the construction sequence. We learned a lot about how each piece of equipment could integrate into the process to perform better."

The project team also factored in lessons that it had learned from the construction of the previous plant at Inverurie. "That was an important step for us to work with the Nereda® technology, but the plant was built using concrete tanks," explains Maybury. This was Scottish Water's traditional method of building wastewater treatment works, with the tanks cast on site using reinforced concrete. The manufacture of these – particularly the cement component – consumes a large amount of energy and increases carbon dioxide emissions.

The project team decided to use stainless steel for the tanks, reducing carbon emissions the project would have incurred compared with using concrete. "We also recognised what we could do with above-ground pipework, which again reduced carbon emissions from excavation," Maybury says.

"Going to stainless steel was a big step change in terms of carbon reduction and speed of build," adds Fraser. "Concrete is one of the highest-carbon materials you can choose, so replacing it with steel reduced the carbon profile of the project immediately. We also chose steel because of its recyclability, so it improved the lifecycle environmental performance as well." Switching to steel tanks reduced the project's embodied carbon emissions (CO_2e) by more than 500,000 kilograms.

TAKING LESSONS FORWARD

Another important lesson the team learned from Inverurie was that, although Nereda®'s biological activity removes phosphorus-containing pollutants from waste, when the Aberdeenshire plant first started up, "the biology took a little bit of time to get going". Fraser says: "In the older wastewater treatment process, we'd add ferric sulphate, which we just call ferric, to the effluent. It binds to the phosphorus and creates an insoluble compound that settles with the sludge. We decided to put a ferric dosing plant in at Winchburgh, so we could use it in the commissioning phase of the plant, then switch it off and keep it as a standby in case of potential failures in the future." Dyne adds that the dosing plant might be needed to maintain performance as more houses are connected to the Winchburgh sewers and the plant adapts to the increasing volume of waste flowing into the plant. That extra ferric dosing might also be needed in particularly cold weather conditions, which tend to slow down microbial activity.

Haskoning also used the Inverurie plant to help improve the performance

Using steel tanks at the Winchburgh site immediately reduced the project's carbon footprint. The components were prefabricated off site and assembled on site

of Winchburgh. "We can start a Nereda® reactor with no sludge granules in it, by fine-tuning the process to encourage granule growth and then maintaining that growth. But for Winchburgh, we transported some sludge granules from Inverurie that already had the capability to degrade the pollutants in the wastewater. That allowed us to spring forward in the programme and ensure that Winchburgh reached its required performance faster."

The Winchburgh plant became operational in May 2024 after almost three years of construction – completed on time and within budget – and completely replaces the former plant, which is being decommissioned and demolished. Its initial licence is to treat the wastewater of a population of 9,000 people, which will rise to almost 16,500 at its full design capacity. While it is not smaller than the previous site, the use of Nereda® means that only about half the area is needed compared to a conventional plant treating a similar amount of wastewater. The plant includes solar panels on the roof of the site's control block that supply a significant proportion of its energy needs. And there are also on-site electric vehicle chargers to support electrification of Scottish Water's fleet of vehicles.

As part of the community engagement part of the project, which included meetings with local residents and businesses, Scottish Water created an online 'virtual room' for the local community to access information about the project and the teams delivering it on site. "This was particularly beneficial owing to the COVID restrictions in place at the time," adds Maybury. Once restrictions were lifted, community engagement programmes included visits to the site by local primary and secondary schools, to teach them about the importance of water treatment and to inspire students to consider careers in construction and engineering.

Scottish Water is now planning another wastewater treatment plant, south of Edinburgh. ESD is developing the design, which is following the Winchburgh design closely.

With its innovative construction and engineering processes and the environmental and societal benefits produced, the Winchburgh wastewater treatment project is a blueprint for both this and similar projects in the pipeline. The hope is that these will continue to bring similar opportunities to other parts of Scotland, and across the rest of the UK.

BIOGRAPHIES

Andrew Dyne was Water and Maritime Contracts Manager of the Winchburgh project and a senior representative of Haskoning. He has over 35 years' experience delivering complex, multidisciplinary infrastructure solutions across the water, wastewater, energy, waste, and renewables sectors.

Alan Ford is a Chartered Engineer with over 30 years' experience in delivering projects in the municipal and industrial sectors of the water industry. He was EPS Water's Technical Manager for both of Scottish Water's Nereda plants to date.

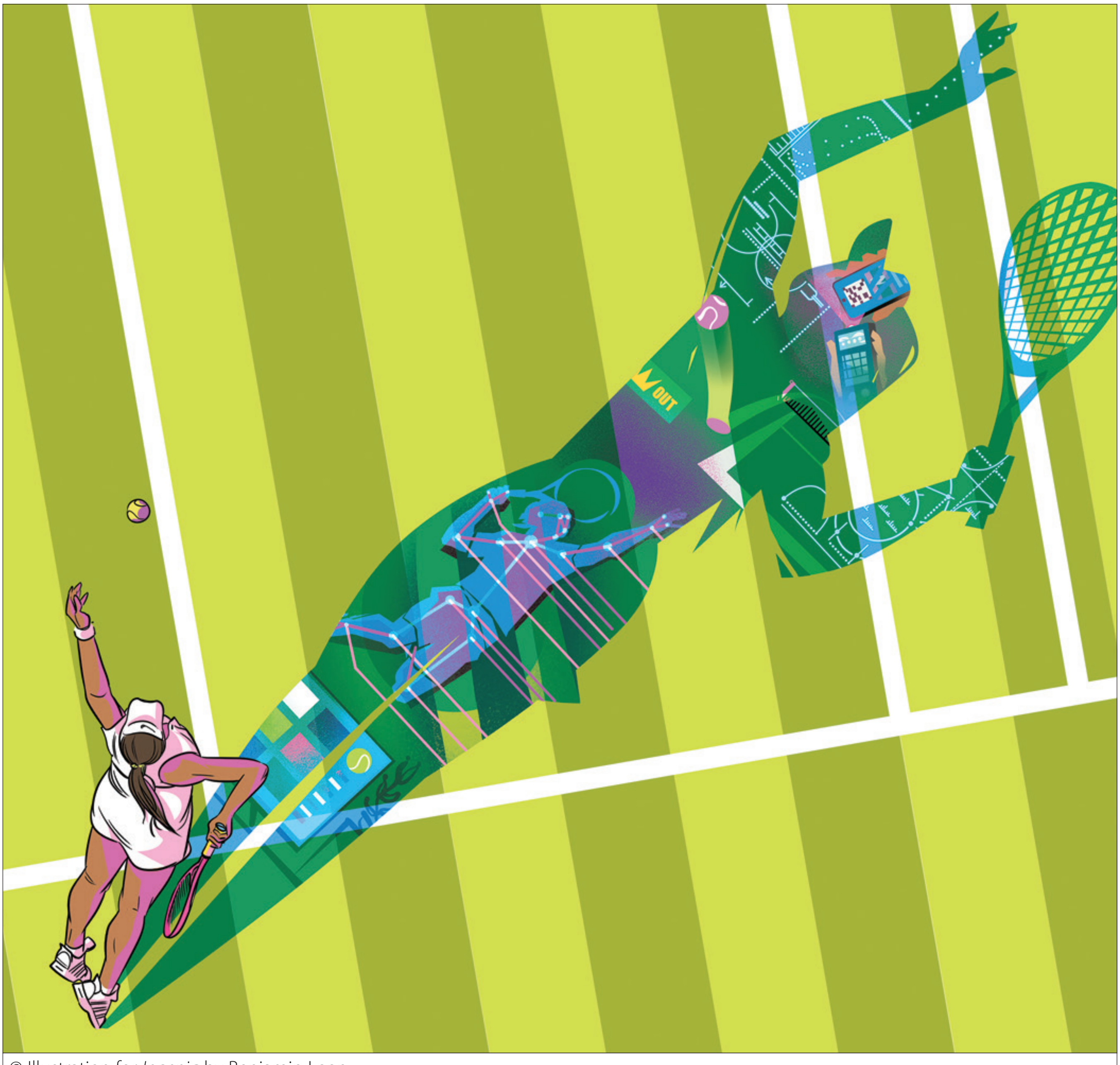
Stephen Fraser is a civil engineer and project leader with over 20 years' experience in infrastructure delivery for Scottish Water via Galliford Try. He specialises in innovative wastewater solutions, team leadership, and performance improvement.

Paul Lavender is director of water utilities at Haskoning.

Colin Maybury is a Chartered Engineer with 37 years' experience in the avionics, mineral processing and water industries. He was Scottish Water's project manager for the first Nereda® plant in Scotland, before taking a similar role at Winchburgh.

The team that won the Major Project Award for Sustainability also includes Jonny Tyler, a commissioning and handover assurance engineer at Scottish Water.

WIMBLEDON'S TECH IS ON POINT



© Illustration for *Ingenia* by Benjamin Leon

Did you know?

- In 2024 the Wimbledon Championships were transmitted live to over 200 territories worldwide and watched by a TV audience of 133 million
- The Championships have a growing digital reach, with a 70% increase in video views on wimbledon.com and mobile apps in 2024. The total audience in 2024 was 670 million across TV, digital and social media
- Innovative technologies and data are transforming the Championships into one of the most technically advanced events on the international sports calendar

Wimbledon may be the world's oldest tennis championships, but it has its proverbial finger on the pulse when it comes to technology. Leonie Mercedes finds out how technologies from body tracking to large language models are enhancing the championships for fans and players alike.

At the end of June, more than 250 of the world's best tennis players will arrive in southwest London. Over two weeks, they'll play 764 games, hitting 55,000 balls across 36 courts. More than half a million spectators will cheer them on, as they munch through more than 38 tonnes of strawberries.

While the players bring their A game, dozens of people will work behind the scenes to bring the game to the fans. This backroom team will be maintaining hundreds of Hawk-Eye cameras, thousands of network outlets, and more than 140 kilometres of fibre-optic cables.

Overseeing all this is Bill Jinks, Wimbledon's Technology Director. Jinks has worked at Wimbledon, or to give it its proper name, the All England Lawn Tennis Club (AELTC), for more than 20 years, first as an engineer at IBM, before joining the AELTC in 2018. Over that time, the club has seen continuous technological transformation, including the introduction of paperless ticketing and Hawk-Eye.

This year, the technology underpinning the iconic championships will evolve yet again, and in ways that may change the look and feel of the game. Hawk-Eye's remit is expanding, while Wimbledon's technology partner, IBM, is providing reams of data and analysis by harnessing generative AI – all with the aim of improving the experience for tennis fans, casual and nerdy alike.

KEEPING THE CLUB HUMMING

"We are a year-round visitor attraction," Jinks says, referring to the club's museum and tours. "The grounds are open all year round for the members – we're a members' club, so a lot of the technology is still on."

In the 50 weeks of the year there isn't a world-famous tennis championship, Jinks and his nearly 40-strong team keep that technology running, including security, CCTV, access control, and booking and payment systems.

"They're the mundane things, but they're the important things," he says. "There's a full IT operation that's running all year round. When we're not doing that, we're planning for the next championships."

In early spring, the team starts its 100-day countdown to the championships, where plans for the tournament are tested and put into action. It will also install extra security cameras and Wi-Fi access points, build media areas, and lay yet more cabling – an additional 35 kilometres of it.

EYES LIKE A HAWK

At the 2025 tournament, one of the most noticeable changes will be seen at the courts' edges. For the first time ever, Wimbledon will join the majority of the ATP tournaments and rely entirely on electronic line calling for all matches, replacing human line judges to rule on whether a ball is in or out of the court.

Hawk-Eye, which has provided the club with ball-tracking technology since 2007, will also take care of the electronic line calling. Its ball-tracking system relies on a 2D vision system, which finds the ball's centre, and a series of about 12 cameras positioned around the court that track the ball's

A line-calling camera is installed on No.3 Court. In the background is a Tournament Information Display, which shows schedule, scores, results, and general tournament information for guests. It is the same LED technology as the scoreboards

trajectory in 3D space over time, at a rate of 340 frames a second. It's this trajectory data that determines exactly where on the court the ball has bounced, and whether it's in or out.

When Hawk-Eye's technology was first introduced, its slow-motion animated replay was solely to accompany the TV broadcast. Then came its formal use supporting umpires in player challenges, accompanied by enthused clapping from the crowd. In 2015, Luke Aggas, then Hawk-Eye's director of tennis, told *Sports Illustrated* that in the early days of the technology, chair umpires and line judges were "nervous they were going to be shown up". However, he added, players are typically only right 30% of the time, so most of the time, the umpire or judge could be confident they had made the right call.

Now, the officiating technology will take care of the 'out' and 'fault' calls that were always the territory of human line judges, though some will remain in place as backups. "Each court has a Review Official, a qualified tennis umpire, who monitors the tracking and camera feeds and is able to advise the chair umpire if something unexpected occurs," Jinks explains. For 'close calls', the tracking system will send data to a visualisation system that generates the images on the scoreboards. These will take only a few seconds to produce and display.

AELTC Chief Executive Sally Bolton said that the club had decided that the system was "sufficiently robust" enough, adding that it takes its responsibility for balancing tradition and innovation "very seriously".

Although some players have complained about electronic line calling, the technology is more accurate than human line judges, and as one umpire put it, doesn't feel the pressure "at five-all in the final set". Sadly for anyone who loves the drama of a player challenge, these tense moments will be no more.

While ball tracking has changed the game when it comes to fair play, tracking the players themselves could unlock insights that improve their performance.

Hawk-Eye's SkeleTRACK, debuted at September 2024's Laver Cup, is a player tracking system that promises "greater accuracy" and "deeper biomechanical insights" into athletes' performance. It uses an array of cameras that track 29 points on a player's body, including shoulders, hips, ankles, and wrists. Image processing and player recognition translates that into those real-time player movement insights.

The insights from player tracking data captured by systems including SkeleTRACK help players better understand their biomechanics, or how they move, so that they can improve their game. "The data is made available to players' coaching or performance teams," says Jinks. These teams are using insights from the technology to help players adjust their technique, improve their efficiency, and reduce their risk of injury.

Tennis isn't the only sport benefiting from player tracking data. Varuna De Silva, a reader in machine intelligence and digital technologies at Loughborough University, used years of player tracking data from the

Premier League to help Chelsea Football Club work out how elite players make decisions while under high-pressure situations. "The decisions could be who to pass to, when to pass, and what to do with the ball," De Silva explains. "These decision-making skills are what makes an excellent player an elite player."

The data gave them an average, or a benchmark, with which they could compare players' performance. It also could be used in coaching to develop drills that would improve certain techniques, and prepare them for certain plays, so they get better at handling that psychological, or what is more accurately described as situational, pressure during play.

BRINGING FANS CLOSER

Every year, Wimbledon's technology partner, IBM, captures 2.7 million data points from the Championships. It's not just the scores. For every single point, there's data on types of shot (forehand? volley? drive?), serve direction, whether there was an error, how it was won, and more.

Over the years, IBM has been finding new ways to crunch and present that data in ways fans will enjoy. AI has opened up many more possibilities to please both the casual tennis viewer and the nerdiest fans.

Slamtracker has been serving fans scores and statistics for more than 20 years. This year, IBM and Wimbledon will introduce an AI assistant to Slamtracker called Match Chat, which can answer fans' questions, such as "who has converted more break points in the match?", or "who is performing better?" during play, and in Wimbledon's distinctive language. IBM has also updated its Likelihood to Win tool, which gives fans a projected win percentage that changes throughout the game. This percentage is generated from AI analysis of player statistics, expert opinion and match momentum. Fans can access these tools through the Wimbledon app.

Evidently, the Wimbledon championship generates an abundance of data – a real treat for tennis enthusiasts, but perhaps alienating to the casual viewer if presented the wrong way. How does the team avoid blinding the audience with science?

"One of our challenges is trying to get the right data for the right experience, for the right users," Jinks says. "Wimbledon isn't just a sports tennis event; it's a cultural institution in the UK."

He knows that for a lot of viewers, Wimbledon is the extent of their tennis viewing. "They may not be regular tennis fans, they may not even be sports fans, but they're always going to tune into Wimbledon. And you have to be mindful that they're not going to understand a lot of the tennis jargon," he says.

For instance, a casual viewer may not have been able to identify Carlos Alcaraz's chip return or high looping forehand against Novak Djokovic in last year's men's singles final, but a tennis buff reading or listening to the match commentary would be able to picture those shots immediately.

"It's finding a balance for the mass audience, but giving them the ability to drill down, if you're a real tennis fan and you want to see all the data," Jinks says. "We provide a comparison of all the traditional statistics, including serve, return and point outcome statistics. For those that want to dig deeper, we compute and compare a shot quality index for serve, return, forehands, and backhands."

How is Wimbledon dealing with generative AI's tendency to, to put it bluntly, sometimes make things up? AI-generated responses aren't always accurate, given they build sentences by making their best guess at what words should come next. As they're trained on vast amounts of data, they do often make the right guess, although they can sometimes generate responses that are nonsensical, or plain wrong, in what we now call 'hallucinations'. To avoid

The Official Wimbledon App, built by IBM, which is Official Technology Partner of the Championships. In 2024, there was an increase of 79% year on year in articles read on wimbledon.com and the mobile app © AELTC/Andrew Bake

this, Wimbledon has a review process in place – a hallucinated game score wouldn't exactly fly under the radar.

In recent years, Wimbledon and IBM have also used AI to generate video highlights and basic commentary. Where earlier AI models would have relied upon 'factual' game data, such as when an ace is hit or a break point comes, to generate video highlights, machine learning models are now a lot more sophisticated.

Using data from the Hawk-Eye system, they can identify the most exciting parts of a match and what's worthy of a highlight, by watching players' movements and gestures – whether players are running wide or fist-bumping a doubles partner – and listening out for a roar from the crowd.

"The model can pick up on those nuances and become better at understanding what a good point looks like," says Jinks, and with "ever-increasing accuracy".

The technology also generates spoken commentary – with optional subtitles – that fans can lay over their video highlights. It's done by watsonx, IBM's AI platform. The large language model that powers the commentary was trained on source material from nearly 130 million documents.

GAME CHANGERS

The availability of match data is transforming virtually every aspect of sport – from officiating and coaching to talent discovery and equipment design. Advances in machine learning will continue to change the game.

"The latest breakthroughs in sensor technology, computing power, computer vision, machine learning, and natural language processing are poised to revolutionise the field in ways that were unimaginable just a few years ago," says John Bronskill, a postdoc in the University of Cambridge's Machine Learning Group. "Professional sports organisations will increasingly depend on data scientists and information engineers to gain a competitive edge."

De Silva is interested in how technologies such as Hawk-Eye and IBM's machine learning platforms, now commonplace in elite sport, can be translated to grassroots level clubs. "We are talking about AI that can work off a mobile phone camera," De Silva says. "It is what we would aspire the technology to do for the world."

We're already starting to see it happen. In 2024 the International Olympic Committee dispatched a team of talent scouts to Senegal in an effort to find the country's future gold medallists. After recording about a thousand young people completing athletic drills, and measuring their performance with an AI-powered system by Intel, it identified 48 young athletes with "huge potential", and one with "exceptional potential", who have been offered places on training programmes to develop their talent, according to the BBC.

READY TO SERVE

As the world's oldest tennis tournament, Wimbledon has to pull off a challenging balancing act of retaining beloved traditions while embracing innovation. Electronic line calling will make the game fairer – it's simply more accurate than human line callers – although their absence will surely be felt by many Wimbledon fans this year.

Over the past 20 years, AI and social media have enabled Wimbledon to engage fans with the sport in new and different ways. "[They've] changed our approach to fan engagement, including both the content we create and the way we create it," Jinks says. What might the next 20 years bring for the fan experience?

"We are always interested in new ways fans are going to consume the championships if they are not visiting the grounds," he says. While the club has discussed the use of VR and AR for many years – it ran an AR pilot with IBM back in 2010 – interest in VR is limited by the level of adoption of the devices that can deliver it.

More broadly, sports organisations are looking for ways to find new fans as live TV audiences dwindle. For example, the Australian Open this year broadcast an almost-live, free-to-watch version of its matches on YouTube. The only difference between these broadcasts and what you could see on TV? The stream was an animated version of the match.

These animations were generated using real-life tracking data from the court, and aired two minutes after the live action. Tennis Australia told BBC Sport that its goal was to "captivate a new generation of tennis fans", and "[make] the sport more accessible and engaging, especially for kids and families".

In terms of content, the animations don't miss any of the actual game content, matching them shot for shot, even if they do sometimes glitch out. Could this be a glimpse into the future of sport spectatorship?

With the first ball of this year's Wimbledon Championships due to be served on 30 June, what should viewers expect this year? "Look out for how we're bringing the data to life in broadcast," Jinks says.

Over on the Wimbledon website, fans will also be able to see visualisations of points played. "You'll see the ball track and the player tracks on screen, if you want to see how the point was played," he adds.

With the club open year round, does Jinks' team ever take a break? "In July, once the tournament's over, we pack it all back in a box, and then go and have a holiday … and then we start planning again."

BIOGRAPHIES

John Bronskill is a postdoctoral research assistant in the machine learning group at the University of Cambridge. He holds a master's degree in electrical engineering and a PhD in information engineering. Previously, he co-founded ImageWare R&D, which was acquired by Microsoft, where he worked for more than 20 years in various technical leadership roles.

Bill Jinks is Technology Director at Wimbledon where he leads the technology team that delivers the Championships. Before joining Wimbledon, Jinks was a distinguished engineer at IBM, where he oversaw complex integration projects and transformation programmes.

Dr Varuna De Silva is a reader in machine intelligence at Loughborough University. He leads a team of researchers in fundamental AI algorithm development driven by real-world requirements, such as team sports analysis and autonomous drone systems.


REIMAGINE
THE FUTURE
OF FARMING
THIS IS ENGINEERING
MEET HALVARD. ROBOT MAKER.
GROWING UP, HE ALWAYS LOVED LEGO.
TODAY, HE WORKS WITH FRUIT-PICKING
ROBOTS TO HELP MEET THE WORLD'S
RISING FOOD DEMANDS.
BE THE DIFFERENCE.
SEARCH 'THIS IS ENGINEERING'

MODELS WHERE SCALE MATTERS

In many engineering systems, phenomena at the microscale and mesoscale, such as combustion chemistry and material properties, influence behaviour at the macroscale, such as jet engine efficiency © Illustration for Ingenia by Benjamin Leon

Thanks to exponential advances in computing and modelling techniques, engineers can simulate physical processes at multiple scales, from the sub-atomic to whole-aircraft systems, and everything in between, writes Professor Kai Luo FREng. But physics-based models come with a steep computational cost – which data-driven, AI-based approaches could help us crack.

Below the wings of the 67-metre-long Airbus A350, two Rolls-Royce Trent XWB turbofan engines work tirelessly. As the aircraft takes off, the turbines rotate up to 12,600 times every minute, producing between 70,000 and 100,000 horsepower. The engines draw in over 1,400 kilograms of air and burn some 100 kilograms of fuel every second.

Inside the combustion chambers of each massive engine, at the atomic scale many thousands of chemical reactions unleash energy that heats the turbulent gas mixture to about 1,700°C. As the hot gases expand, they push through and turn the turbine blades, generating thrust.

Did you know?

- Engineers rely on computer simulations to model engineering systems, saving time and costs when prototyping
- Computational fluid dynamics, one of the most well-known modelling tools, is used to design Formula 1 cars, spacecraft and aircraft, among other engineering systems
- AI and machine learning-based models could save computational time and costs in modelling, but must be trained on high-quality data

The A350, with its engines, is what engineers would call a multiscale system. This is where the phenomena involved – including chemical reactions, turbulent flow, heat transfer, aeroacoustics, and fluid–structure interactions – take place across different scales of space, time and organisation (see 'Scale models').

These scales matter because phenomena and processes at the microscale and mesoscale influence behaviour at the macroscale. For the A350, atomic-scale chemical reactions and mesoscale vortical airflow feed into the thrust that lifts the jet.

When designing anything, be it a plane, battery or a biomedical device, engineers must account for phenomena across multiple scales. They make increasing use of computer simulations to navigate their way through those different scales. Simulation methods for each scale range are an essential part of the engineering toolkit, reducing the need for costly prototypes and physical experiments (see 'Tools that speed up design').

The challenge is to pick the right tool for the scale you want to model, and to balance the desire for accuracy against the speed and cost of computation. In turn, that choice depends on how much data is available to create those computer models and how detailed it is.

In recent years, engineers have shifted from modelling at individual scales in isolation, to multiscale modelling that accounts for phenomena across scales and shows how the different scales interact with one another. But this takes an enormous amount of computational power, if using physics-based modelling.

This is where data-driven modelling could come in. Machine learning (a subset of artificial intelligence) can learn from large amounts of pure data, making it agnostic to the underlying physics and scales. With enough high-quality data, data-driven machine learning algorithms can be trained to simulate across scales at a fraction of the compute costs of conventional multiscale modelling.

SCALE MODELS

Macroscale – systems, phenomena or behaviours seen at large spatial or temporal scales. Collective or bulk properties dominate, and classical laws of physics apply.

Mesoscale – scales that lie between the micro and macro scales in a multiscale system.

Microscale – systems, phenomena, or behaviours seen at extremely small spatial or temporal scales. Here, individual atoms, subatomic particles, or quantum effects dominate.

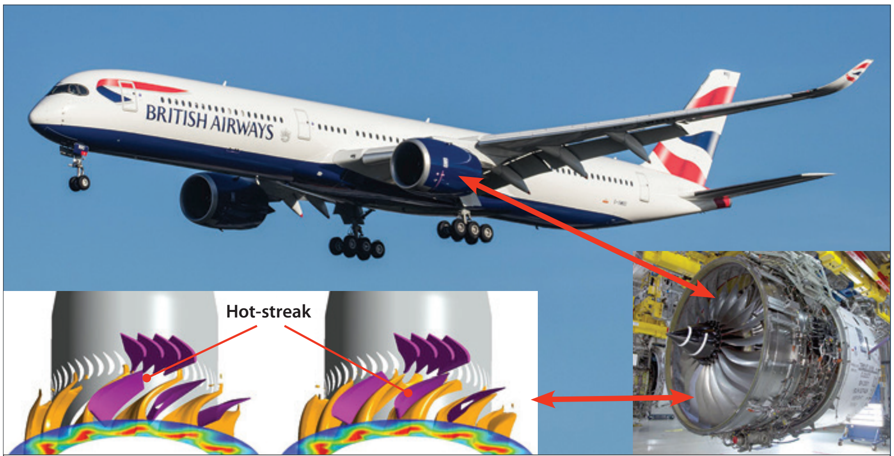
Scales differ between systems. For a weather system, the mesoscale is measured in kilometres (thunderstorms), in between the microscale (turbulence) and the macroscale (large cyclones). For an aircraft, the structure of aircraft wings or landing gear, in metres, and their response to forces, are macroscale phenomena. Grain boundaries within a metal component that determine its strength are organised at the mesoscale in micrometres. The chemistry of jet fuel combustion occurs at the microscale, in nanometres.

MACROSCALE SIMULATION: FOR PLANES, TRAINS AND AUTOMOBILES

Perhaps the best-known macroscale modelling tool is computational fluid dynamics (CFD). Based on the laws of physics and born out of pioneering work in the late 1960s by Professor Brian Spalding FREng FRS and his colleagues at Imperial College London, CFD has become a mainstream tool in modern engineering. Today, all branches of engineering use CFD to analyse, predict, design, and optimise engineering systems such as aircraft, Formula 1 cars, engines, submarines, and spacecraft.

Zooming back in on the example of a plane, the flow of air over its airframe and combustion in the engines are chaotic, highly turbulent and invisible. Engineers must harness these processes to optimise engine and aircraft performance – a formidable challenge. This is where CFD comes in: it allows them to predict and visualise turbulent flow and combustion.

In reality, every system consists of billions of molecules and atoms, but CFD models their average behaviour.



British Airways' Airbus A350, with its twin Rolls-Royce Trent XWB turbofan engines. Insert shows CFD simulations of the flow and temperature fields of the turbines
© Wang and Luo, Energies 17, 873, 2024

It does this by treating fluid flow and even combustion as a continuum. Then, it applies physical laws on a computational mesh consisting of small, discrete elements to predict flow or combustion properties and how they interact with structures.

However, modelling these processes is difficult. The processes involved can span nine or more orders of magnitude in space and time. Key features can range from nanometre-scale through to metre-scale and can unfold over femtoseconds (that's 10^{-15} seconds) or hours. (Physicist Richard Feynman famously called turbulence "the most important unsolved problem of classical physics".)

MICROSCALE SIMULATION: FOR CO-DESIGNING FUEL AND ENGINE

For any aero engine, critical processes happen at the atomic and subatomic scales, which can influence engine performance and emissions.

Burning kerosene, the most common aviation fuel, sets off over 5,000 reactions at any instant. It generates over 1,000 intermediate chemical species, some of which form pollutants such as nitric oxides. These chemicals react inside the combustion chamber at temperatures of about 1,700°C, under about 50 times atmospheric pressure, with extremely unsteady and turbulent airflow. Conventional CFD may be powerful, but it cannot directly capture these processes, because it averages the behaviour of large numbers of molecules and atoms to obtain macro properties.

To understand this seeming chaos, engineers use tools that can model matter at the level of individual atoms and molecules. The most well-known is molecular dynamics, which uses Newton's second law of motion to calculate the trajectories for individual atoms and molecules. A newer development, reactive molecular dynamics, can simulate chemical bond breaking and forming, and consequently chemical reactions.

This type of modelling could come in handy to help the world shift to zero- and low-carbon fuels by facilitating the design of carbon-neutral new fuels, collectively called e-fuels, and catalysts. However, e-fuels, as well as zero-carbon fuels such as hydrogen and ammonia, burn very differently from kerosene. If an engine designed to burn kerosene burns hydrogen or an e-fuel, combustion is likely to become unstable and risk damaging the engine.

Engineers can employ reactive molecular dynamics to design new fuels while using CFD to design new combustion engines, a process called co-design. In the context of transition to carbon neutrality, a variety of new

TOOLS THAT SPEED UP DESIGN

The A350 has about a million components and subcomponents of different sizes. Each engine alone contains over 20,000 components. Every component is painstakingly designed, tested and optimised to ensure performance, reliability and safety.

If engineers used only conventional (physical) lab tests, it would take decades between beginning a design and passengers eventually flying in the aircraft. Computer-aided modelling and simulation significantly shortens the development cycle and reduces R&D costs of new aircraft.

The software tools that help engineers to design and test products include computational fluid dynamics (CFD), computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), and so on.

According to market research firm IoT Analytics, since 2022, an average manufacturer would have spent more on industrial software that engineers use to design products than on the industrial automation hardware that goes into realising their designs. By 2027, manufacturers could be spending twice as much on software as on hardware.


Computational fluid dynamics simulations are widely used to design engineering systems such as Formula 1 cars © Shutterstock

fuels – such as e-fuels and biofuels for aviation, and metal fuels for power generation – may be explored. It is crucial that fuels and engines should be co-designed as a system, rather than treated separately as in the past. Here, atom-level, microscale simulations will play an important role in design for new fuels and virtually testing the properties of new fuels.

MESOSCALE SIMULATION: BRIDGING THE GAP

Bridging the microscale of chemical reactions and the macroscale of a turbofan engine, there are numerous intermediate scales, called mesoscales. The way systems behave at these scales is the most complex and least well understood. Yet mesoscale processes play a key role in determining a system's overall dynamics and performance.

For example, in materials, mesoscale defects and grain boundaries influence macroscale properties, such as strength, elasticity, durability, and conductivity. There are also multiphase flow systems – mixtures of liquids, gas and solids – where mesoscales lie at the phase interfaces, whose thickness is actually in micrometres or nanometres. This is a challenging modelling problem relevant to many areas – for example, cosmetics manufacturing, where the phases are oil and water. Another multiphase system is blood, which contains deformable red blood cells floating in liquid plasma.

Engineers typically use the lattice Boltzmann method (LBM) to simulate fluid flows at mesoscales. It's based on a discrete form of the Boltzmann equation, which underpins much of our understanding of the statistical behaviour of thermodynamic systems. This method has the flexibility to bridge a very wide range of scales, as it is both able to simulate small clusters of molecules (approaching the microscale), as well as approximate the collective behaviour of large numbers of molecules (towards the macroscale).

The UK Consortium on Mesoscale Engineering Sciences (UKCOMES) champions the development and use of LBM as a mesoscale simulation tool. Its work covers net-zero energy systems, advanced manufacturing, multiphase flows and healthcare, among other areas. Funded by the Engineering and Physical Sciences Research Council (EPSRC) and launched in 2013, UKCOMES takes a multidisciplinary approach with close interaction between researchers in physics, chemistry, biology, mathematics, engineering, materials science, and computer science.

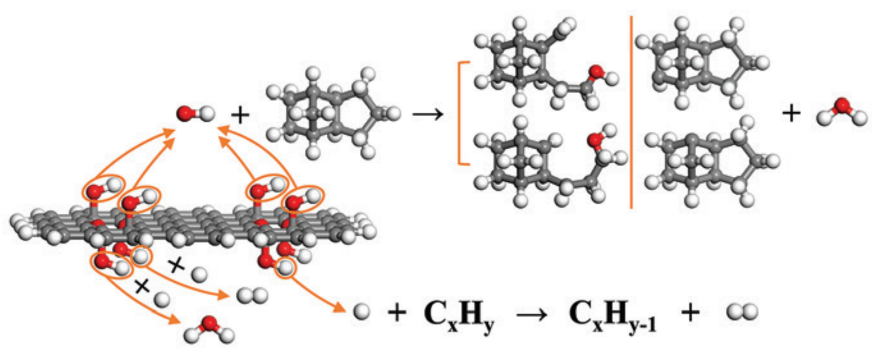
LBM is an active and growing area of research. Because of the way that LBM algorithms are structured, it works very well on GPUs, powerful computer chips developed and widely used for AI today, and many emerging computer architectures. Thanks to this and its ability to bridge scales, LBM has found use in numerous fields. For example, researchers at University College London have used LBM to simulate the charging and discharging of lithium-ion batteries to help to optimise electrode design, which can impact how long batteries last, among other properties.

The LBM approach also has significant advantages in simulating multiphase flow, as it allows phase interfaces to move, deform, break, and merge naturally. In one recent example, from the universities of Edinburgh and Manchester simulated blood flow, including red blood cell transport, through the intricate placental tissue, which could help physicians to diagnose placental disorders

BRINGING IN DATA-DRIVEN MODELLING

The idea that machine learning can bypass explicitly written physics laws and scales, relying on pure data, represents a paradigm shift. It brings significant benefits as well as uncertainties.

Machine learning has already been used to accelerate calculations in combustion chemistry, often by two



Molecular dynamics simulation of chemical reactions of aviation fuel JP-10 with catalytic enhancement of ignition and re-ignition © Feng et al., Fuel 254, 115643, 2019

to three orders of magnitude. At the atomistic level, machine learning has led to molecular dynamics simulations of much larger systems and for longer times.

One company aiming to accelerate macroscale CFD simulations with AI is Austrian startup Emmi, which raised €15 million in seed investment in April 2025. The founding team has developed a transformer model – the same type of deep learning model as OpenAI's large language models – that learns physical laws from data to make faster predictions about fluid flow.

While there are some successful applications in the works, the biggest problem facing data-driven modelling is a lack of quality data. Large language models have relied on huge training datasets – petabytes of text, while Google DeepMind's GraphCast weather forecasting model, a different type of neural network, was trained on decades of meteorological data. For many engineering systems, data are proprietary, and we don't have such rich archives of data on which to train AI models. The quality and consistency of data can also affect the accuracy of predictions.

One important source of training data for data-driven models is the outputs of individual physics-based models, as long as they are sufficiently accurate. This works well in the case of multiscale systems, which are often very difficult to measure experimentally. For example, measuring how the grain boundaries in metal move would involve cutting up the metal – which would then render it impossible to measure its properties. With high-quality modelling data, we can both better understand the physics, as well as using it as an input into data-driven systems – where good data is vital. Therefore, physics-based and data-driven modelling approaches are both complementary and competitive.

But while it has its advantages, data-driven modelling does not depend on a deep knowledge of underlying physics, so it becomes more challenging to interpret the results. Finally, the cost of training models is still too high, although the emergence of efficient large models such as DeepSeek may offer hope for cost savings.

Despite these challenges, data-driven modelling and machine learning open up many possibilities. Because data-driven modelling does not depend on the scales of the physical problems under consideration, it can provide engineering solutions and predictions at all scales, from the atomic through meso to macro. Moreover, the exceptional computational efficiency of machine learning, especially on GPUs, should eventually enable real-time simulations of engineering systems.

Combined with advanced measurement and sensors, the growth in computer power could enable the construction of 'digital twins', computer models of systems that can exchange data with their physical engineering embodiment. This would enable real-time investigation, intervention, control, and optimisation. Several CAE software companies, including Siemens and Ansys, have begun to do just this using NVIDIA's Blackwell GPUs, specially developed for large language models and generative AI. These will allow engineers using the companies' software to build real-time digital twins.

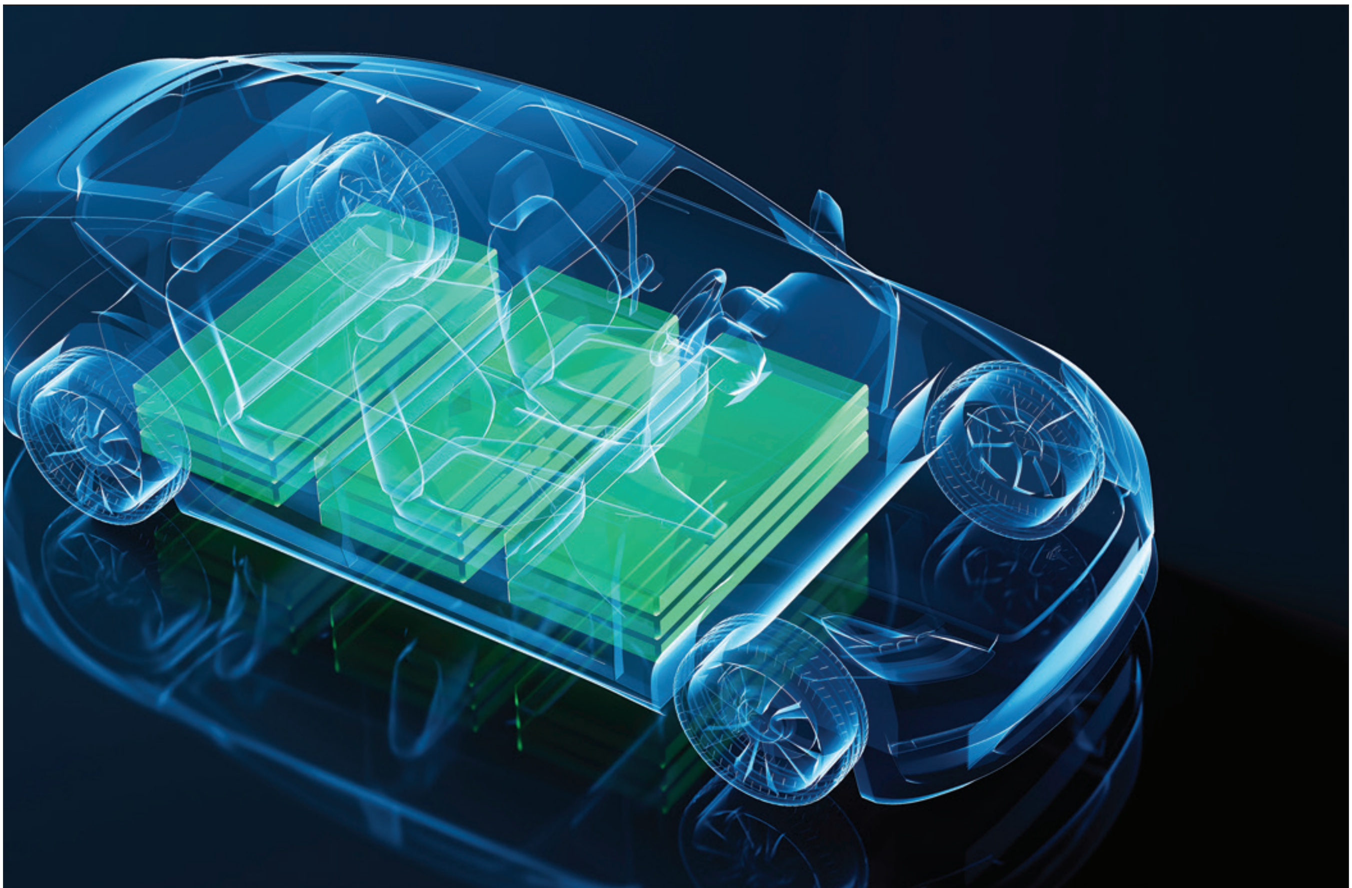
Most importantly, as with other techniques in the AI family, with larger training datasets, simulation based on machine learning could become increasingly accurate, reliable, intelligent, and autonomous. Data-driven modelling and simulation has great potential. We just need the data.

BIOGRAPHY

Professor Kai Luo FREng, Chair of Energy Systems at UCL, and Founder and Principal Investigator for the UKCOMES since 2013, has pioneered modelling and simulation across scales for fundamental and applied research. He won the 2021 AIAA Energy Systems Award "for groundbreaking contributions to multiscale multiphysics modelling and simulation" and the 2025 ASME George Westinghouse Gold Medal "for groundbreaking contributions to digital and AI-enhanced analysis, control, prediction, design, and optimisation of energy and power systems".

A SOLID FUTURE FOR ELECTRIC VEHICLES

Switching to an electric vehicle is an action that more and more people are taking to curb their carbon emissions. However, the use of lithium-ion batteries does pose issues for drivers, such as their increased weight and range anxiety. But these could be solved by solid-state batteries. Neil Cumins spoke to two UK developers to establish why solid-state technology could drive the world's vehicles in future.



Did you know?

- Driving an electric car could save up to 80% of carbon emissions during a vehicle's lifetime, compared with a petrol- or diesel-powered car
- Globally, more than 20% of new cars sold were electric in 2024, and sales topped 17 million
- Lithium-ion batteries used in electric vehicles do have some limitations such as their sustainability and slow charging times, which could be addressed by alternative battery technologies

The challenge of climate change and the need to reduce emissions of carbon dioxide and other greenhouse gases have prompted the rising popularity of electric vehicles (EV) as an alternative to burning petrol and diesel in internal combustion engines. The current generation of EVs rely on lithium-ion (Li-ion) battery packs to keep us mobile; yet the disadvantages of Li-ion batteries have hindered their mass adoption. Scientists and engineers in the UK are playing leading roles in the race to develop alternative technologies such as solid-state batteries.

LITHIUM LIMITATIONS

Firstly, the manufacture of Li-ion batteries requires scarce materials that can be environmentally damaging to extract, such as cobalt and graphite. Some of these materials can come from sensitive regions. For example, most of the world's cobalt comes from the Democratic Republic of Congo, where an ongoing civil war, partly associated with mining operations, has triggered a humanitarian crisis. Most of the lithium used in Europe is imported from Chile, China and the US, increasing carbon emissions through its transportation. Furthermore, global demand for these raw materials is expected to exceed current production many times over.

Analysis carried out for the Royal Academy of Engineering's critical materials report in 2024 found that the EVs projected to be sold in the UK from 2018 to 2040 would require 268,000 tonnes of lithium. A 30% reduction in vehicle battery sizes in the largest EVs sold in the UK by 2040 could save 46,000 tonnes of lithium.

The environmental issues of Li-ion batteries are compounded by the fact that recycling wasn't a priority during their original development, making this a costly and complex process to retrospectively engineer. However, innovations in battery recycling are addressing this through processes such as solvent extraction, which aims to minimise how much battery material is eventually thrown away.

The second issue is that Li-ion batteries offer relatively limited range per charge, often necessitating more or larger batteries in each vehicle. This pushes up weight. Li-ion batteries also require sensors and control systems for fire and thermal management, further increasing weight and reducing range and performance.

Recharging an electric vehicle is slow compared to refuelling a conventional vehicle, which is also typically cheaper to buy. A patchy public charging network makes limited range and long charging times especially problematic for homes and businesses without secure off-street parking.

Various alternative battery designs could overcome some of the drawbacks of Li-ion batteries for vehicles. In *The UK Battery Strategy*, published in 2023, the Department for Business and Trade lists four technologies for 'next-generation batteries': sodium-ion, lithium-sulphur, metal-air, and solid-state.

Out of these, the UK is playing a leading role in the development of solid-state batteries. Solid-state is recognised as being able to address concerns about cost, range anxiety and charge speed, explains Graeme Purdy, the CEO of Ilika, a product development company working on solid-state batteries. "We found that more and more companies were interested in improved electrodes and improved electrolytes. Solid-state is seen as a way to better batteries and a better EV driving experience, which will add momentum to demand for EVs."

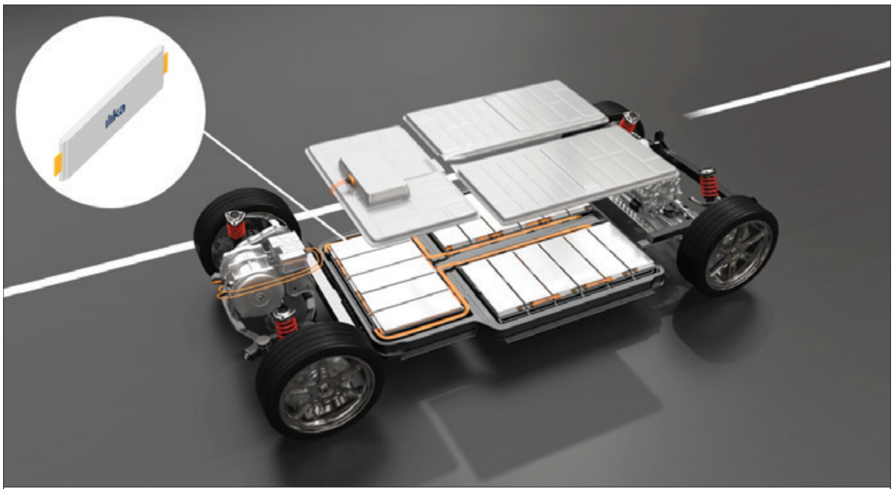
THE HARD CELL

Purdy explains some of the advantages of solid-state cells over Li-ion cells: "In a normal lithium-ion cell, you've got a liquid electrolyte which is the medium through which the ions move." "The electrolytes transfer lithium ions from

ALTERNATIVE BATTERY TECHNOLOGIES

Batteries can be made with a variety of materials and techniques. Different battery technologies could find applications in different sectors. For example, weight is not important in energy storage for power networks. Vanadium flow or sodium-ion batteries, for example, could work better as ground-mounted power sources for masts and antennae, where their relative lack of energy density is also less of a concern.

These batteries do have some advantages; sodium is abundant as an element, for instance. However, despite being a long-established alternative to Li-ion, the high cost of vanadium and issues around its lifecycle could render it unsuitable for vehicles. Similarly, sodium-ion costs more than lithium-ion, with a lower energy density, so it would increase a vehicle's weight.



A 3D rendering of a battery pack including Ilika solid-state cells © Ilika

the cathode to the anode when charging the battery, and then from the anode into the cathode as an electrical current is pulled through it." In a Li-ion cell, a polymer separator divides the electrodes, whereas in a solid-state battery, Purdy adds, you typically replace the separator and the liquid electrolyte with a polymer or ceramic layer.

Solid-state batteries can use various alternative layers: a sulphide or oxide-based ceramic, or a polymer-based electrolyte. Ilika chose an oxide-based electrolyte. As Purdy explains: "The use of an oxide-based electrolyte ensures the layer is both ionically conductive to allow lithium ions to move back and forth, but also electrically insulating so the electrodes don't short the battery." The anode can be made out of silicon or pure lithium metal, giving it a smaller volume and greater energy density compared to the anodes required in Li-ion batteries, which are typically made of carbon or graphite. The battery can store more energy in the same volume, while charging time is cut by eliminating the charging bottlenecks experienced by traditional lithium-ion cells.

SAFER BY DESIGN

While Li-ion does have drawbacks, certain misconceptions have taken root among the public, such as the belief that these batteries are somehow unsafe. "The Swedish Fire and Rescue Department showed last year that EVs were 17 times safer than a normal internal combustion engine vehicle in terms of risk of fire to users of the vehicle," says Purdy. However, that safety comes at an engineering cost: "You have to put in fire management, fire suppression systems, thermal management systems, and also mechanical protection to make sure the battery pack is safe for a vehicle."

If a battery overcharges or flammable electrolytes leak out, the resulting fire temperature can trigger thermal runaway where successive cells ignite over a long period. Reducing the risk of this involves technologies such as fire suppression systems, which prevent and detect fires with early warning systems, spot cooling and extinguishing agents. Similarly, thermal management systems attempt to minimise component degradation and thermal runaway, using either passive or active cooling with air or liquids.

Purdy highlights the nail penetration test: "If you drive a nail through a battery, you get an explosive response with a traditional lithium-ion battery as an electrical short circuit occurs, whereas you get a much more muted response with solid-state batteries." This is because the absence of flammable liquid electrolytes minimises the risk of fires or thermal runaway.

These and other safety gains enable vehicle manufacturers to strip out much of the cost and weight that has hindered Li-ion-powered vehicles. "That means the vehicle is much more competitively priced, and it's got a longer range," says Purdy. If you can reduce the bill of materials by reducing the mechanical protection and battery pack safety engineering, that is reflected in the cost of the vehicle.

Another advantage of solid-state batteries is that you can charge them more rapidly, as the solid electrolyte allows the ions to move more quickly. Purdy cites a recent test where Balance Batteries, consultants in automotive powertrains, modelled an Ilika Goliath solid-state battery pack in a Hyundai Ioniq 5 EV. The model showed a reduction in the car's weight by over 110 kilograms, a bill of materials slashed by £2,500 and charging time cut from 18 minutes to 12.

STATE OF PLAY

In another approach to solid-state batteries, Mauro Pasta, a Professor of Applied Electrochemistry at the University of Oxford, is the principal investigator of the Faraday Institution's SOLBAT Next Generation Solid-State Batteries Project. The £25 million SOLBAT programme brings together seven UK-based companies and institutions to carry out fundamental research on anodes and cathodes as well as viable manufacturing processes for solid-state batteries.

Pasta agrees that cost is central to the long-term viability of solid-state batteries. "There are two ways of tackling the cost argument. You need to reduce the cost of the raw material – about 70% of the cost of a battery is raw materials – or you increase energy density. It's a combination of the potential energy density advantages and cost that leads to solid-state. All the major automotive companies are working on this; everyone knows that if you want to have anything fully equivalent to the internal combustion engine, then solid-state will probably be the best way of achieving that."

Pasta's team is researching materials and battery design to get the performance needed. He also points out that battery recycling is also a focus. "We have a chance to design something that would be amenable to being recycled. You can envision designing a solid electrolyte that can selectively be dissolved to recoup the cathode material. It's important to include a recycling design principle from the ground up – not doing what we did with lithium-ion, where it's now difficult to come out with disposal approaches that are not dirty and expensive."

START SMALL, THINK BIG

While vehicles are central to the adoption of solid-state batteries, the automotive market isn't the only potential beneficiary of this emerging technology. "Historically, you don't go straight to mass production," explains Pasta. "People are looking for retail markets that will appreciate the advantages [of solid-state], and which will allow you to think about scale, generate some of the chemistry, and then move up. In the case of solid-state, it could be portable electronic devices, where manufacturers want energy density in a limited space."

For example, Ilika came to EVs after working on other uses of solid-state batteries. "We've got two product lines," says Purdy. "On the one hand, we've got miniature solid-state batteries that we call Stereax." Ilika makes these batteries using a thin film deposition approach to create millimetre-scale batteries. These will be used in active implantable medical devices, such as blood pressure monitors, smart contact lenses, cardiac implants, and neurostimulators.

"About six years ago, we were increasingly being approached by automotive companies, who were saying 'we've seen what you can do with solid-state batteries for medical devices, and we're interested in improved products for automotive'. That's when we started developing our Goliath product range for EVs." These larger batteries use nickel–manganese–cobalt (NMC) in combination with a high-silicon electrode, which have a higher capacity that traditional graphite electrodes.

CHARGING TOWARDS A BRIGHTER FUTURE

Pasta is confident that solid-state batteries will happen. "In terms of solid-state battery packs that could be implemented in prototype models or high-performance cars, the leading battery manufacturers say that might be coming by 2029. I think we could have a sensible solid-state battery by then, but to then produce it at scale and really gain a substantial portion of the market might take longer."

One complication is that Li-ion batteries are themselves being incrementally improved. "Lithium-ion is a moving target," says Pasta. "More and more solutions are coming up that increase energy density by a few percent, storing more energy by optimising the pack. If something's not superior to lithium-ion in most of the metrics, then the push toward replacing it is not going to be as strong, and it may take longer. That's going to be driven mostly by economics and less by the technical aspect, where you may have a solid-state battery that works, but it doesn't work much better than lithium-ion."

If solid-state cells can be mass-produced at an affordable rate, demand is likely to exceed supply for some time. So, Li-ion batteries are likely to remain in use for some time, with competing battery technologies operating alongside one another. UK scientists and engineers will be well placed to ensure the adoption of solid-state batteries in the transport industry and beyond.

UK BATTERY RESEARCH

The focus of the UK's battery research is the Faraday Institution. Supported by UK Research and Innovation (UKRI), the Faraday Battery Challenge funds projects that, for example, cover degradation and how to extend battery life, safety and recycling.

The manifesto for UKRI support is the *UK Battery Strategy*. Published in 2023, on solid-state batteries, it says: "Experts highlighted solid-state, and cathode research as particular UK strengths, alongside a growing number of start-ups and a relatively strong position in equity investment, especially in next-generation anodes."

In its most recent call for research proposals, UKRI reports that the UK has a healthy startup scene with more than 80 startups that have raised more than $2.4 billion in venture capital investment since 2018.

The UK's battery programme includes the national battery development facility, the UK Battery Industrialisation Centre (UKBIC). Based in Coventry, the home of the UK's automotive sector, this £200 million facility "bridges the gap between battery research and successful mass production". The remit of UKBIC is to "provide battery manufacturing scale-up and skills for the battery sector, help companies develop battery manufacturing processes at the scale needed to move to industrial production."

UKBIC's activity also encompasses battery recycling, through its involvement on such activities as RECOVAS (Recycling of EV Cells from Obsolete Vehicles at Scale). With "over 164,000 pure electric vehicles on Britain's roads", RECOVAS, which ran from 2020 to May 2025, set out "to provide a standardised and reliable route for recycling and repurposing the lithium-ion batteries".

BIOGRAPHIES

Professor Mauro Pasta is Professor of Applied Electrochemistry in the Department of Materials, University of Oxford. His research interests lie at the intersection between electrochemistry and materials chemistry to develop novel materials, devices and systems for energy conversion and storage. He has co-founded three battery startups: Natron Energy, Cuberg, and Project K.

Graeme Purdy is the Founding CEO of Ilika. He has led the company through two rounds of venture funding and floated it on AIM in 2010. Graeme is a Chartered Engineer, a Fellow of the Institution of Chemical Engineers and a Sainsbury Management Fellow.

PROCESSING THE BIGGER PICTURE

Professor Nilay Shah OBE FREng has seen huge changes in the processing industry since he started his career in chemical engineering, from the decline of the traditional petrochemicals industry as a major collaborator, to a growing interest in reducing emissions and the rise of information technology. As he receives the Royal Academy of Engineering's President's Medal, he tells Michael Kenward OBE that his next move takes in broader horizons.

Shah proudly points out that the Centre for Process Systems Engineering (CPSE) is one of just two of the original Interdisciplinary Research Centres that is still in business, now as a joint venture with UCL. With a roster of about 40 academics and 200 researchers, Shah believes that CPSE, where he was director, is the UK's biggest process systems engineering research group

Nilay Shah always knew that he wanted to be an engineer. At school he liked chemistry but was more interested in its application than fundamental science. Chemical engineering seemed like a natural career option. When growing up in Kenya, "there was never any doubt that I was going to be an engineer," he says. His mother called him "the professor," he laughs. He planned to study chemical engineering in the UK then work in Nigeria, but he decided to stay on at Imperial College London after graduating.

He has now spent almost 40 years at Imperial, working in areas from paint-making to vaccine production, and has seen chemical engineering change in ways that his younger self's ambitions could not have foreseen. One of the biggest changes in Shah's time as an engineer has been the growing use of information technology.

Driven by falling hardware costs and growing software power, IT has shaped his career and, thanks in part to his own work, changed the nature of research in chemical engineering. These changes went alongside upheavals in the processing industries that fed off that research. Attention turned from oil refineries and petrochemical plants to bioprocessing, pharmaceuticals and other processing challenges. On the energy front, for example, with the goal of achieving net zero and sustainability more broadly, the focus has moved from processing hydrocarbons to becoming 'carbon free' and the prospect of a hydrogen economy and synthetic fuels.

A PHD IN PROCESSING

Shah's choice of PhD subject led him to study how processing plants plan and schedule their operations. This involved working on the fine chemicals and paint-making operations of ICI, then the UK's dominant processing business. The company was interested in how to run production lines that can deliver a stream of different products. Paints, for example, come in many colours and variants. "Working out the sequence that makes the most sense is quite a complicated problem," says Shah. His research started with a PhD thesis on 'Efficient scheduling technologies for multipurpose plants'.

That PhD was in the Centre for Process Systems Engineering (CPSE), which opened in the late 1980s. This was an Interdisciplinary Research Centre (IRC), an initiative launched in the 1980s by the Engineering and Physical Sciences Research Council to work on topics that crossed disciplinary boundaries and with close involvement from industry. Shah proudly points out that the CPSE is one of just two of the original IRCs that is still in business, now as a joint venture with UCL. With a roster of about 40 academics and 200 researchers, Shah believes that CPSE, where he was director, is the UK's biggest process systems engineering research group.

IMPROVED EFFICIENCY WITH SOFTWARE

At the time, the process industry was beginning to explore the role that computing could play in the design, manufacturing and operation of process plants. The IRC's research made great strides in developing software that helped in this. These were early days in bringing IT to complex processing plants. "We were making a lot of progress on algorithms," says Shah. "At the same time there were dramatic improvements in the hardware."

The research revolved around modelling, simulation and optimisation of chemical and energy processes from the molecular level up to simulating complete chemical plants. That work culminated in the development of a range of tools, including gPROMS, a software platform for building computer models for monitoring and forecasting a processing plant's performance throughout the process lifecycle. The technology has had an impact throughout the processing industry, including oil, pharmaceuticals, consumer products, and food. Its models are used for everything from real-time process plant design and optimisation to operator training.

FROM RESEARCH TO BUSINESS

The spread of industries that the CPSE has covered over the decades reflects the changing shape of process systems engineering in the UK. Shah's research had its roots in ICI's Dulux paints factories – bought by AkzoNobel in 2008 – but the CPSE's tools have much wider relevance. "Now we're much more interested in sectors like pharmaceuticals, agrochemicals, and then the systems engineering aspects of energy."

With this background and his interest in businesses, has Shah ever been tempted to leave academia and move into industry? "I've been asked a few times, but I still really enjoy teaching and research. I don't really want to lose that." Shah sees working with businesses as part of the job of an academic engineer. "I've always been interested in doing things with companies. Either collaborating with companies or setting up companies with colleagues to try to test these things." Shah's current business ventures include Zero Petroleum, a synthetic petroleum startup that he cofounded with Paddy Lowe FREng ('Fuel for a net zero future', *Ingenia* 89). "We can make a drop-in jet fuel and a drop-in gasoline," Shah explains.

Shah sees developing zero carbon aviation fuel as a "classical chemical engineering problem". As he explains, "chemical engineers have been fine tuning fossil-based aviation fuel for decades. Now we realise we need new ones that are fossil free. The problem is jets are still running on those, and jets are not going to change their engines anytime soon."

Always keen on seeing his research out in the real world, as part of developing the curriculum for students at Imperial, Shah took the opportunity of a spell as Director of Undergraduate Studies to develop a 'business for engineers' programme. This required students to write a business plan for their work. Alongside introducing an opportunity to 'think business' into the engineering teaching, Shah has campaigned for a wider acceptance of diversity and inclusion in academia. "I've always felt that engineers are important in society, and they should also reflect the society that they belong to. Secondly, it is unfair that certain people are not getting access to what I think is a very exciting and rewarding profession."

There is another reason why diversity matters. "You get better engineering if you have different perspectives. Most big engineering decisions actually have a lot of societal implications." Diversity brings in that awareness of society. Shah has carried his conviction that diversity is essential for engineers and engineering into his work with the Royal Academy of Engineering, where he has been an active member of the Diversity and Inclusion Committee, advising on a variety of activities that have had a meaningful impact on diversity across the engineering profession. And as Chair of the Academy's Membership Committee, played a key role in the establishment of Fellowship Fit for the Future initiative, which is driving more nominations of engineers from underrepresented groups, and oversaw its implementation.

Shah was in the team that created Process Systems Enterprise Ltd (PSE), a spinout company to commercialise gPROMS with Professor Costas Pantelides FREng as its CEO. Shah was a part of the PSE team that won the MacRobert Award in 2007 for gPROMS. PSE grew to become a market leader in the process simulation market with more than 160 employees and a global revenue of more than £16 million in 2019. Siemens AG then acquired PSE for an estimated £100 million with gPROMS becoming the core of Siemens's process system digital portfolio. The image to depict the gPROMS technology was part of a set of photographs of winners commissioned to celebrate the MacRobert Award's 55th anniversary in 2024

The same concern about societal implications is important in another increasingly important aspect of Shah's work, AI. AI was an esoteric academic pursuit when Shah started his engineering career. He looked into the idea of machine learning in the 1990s but was held back by the lack of computer power and the datasets there to feed the learning. "It didn't really go anywhere."

"We're still getting to grips with exactly what AI will help us with in engineering," Shah says. He has been looking into areas where special purpose AI methods can be useful, for example, in his work on using renewable energy to make

Shah holds the certificate for the Guinness World Record that Zero Petroleum received for the first flight with 100% synthetic fuel, in a collaboration with the Royal Air Force

hydrogen, and to analyse and simplify complex series of weather data. "That's very different from what people think about when they talk about AI."

SYSTEMS FOR A SUSTAINABLE FUTURE

Talk of hydrogen and renewable energy leads into thinking about the future of energy and how to get to net zero. As Shah sees it, we are halfway there. "We've done the easy bit of the energy transition in many ways. This first bit, which has got us a long way, switching off coal-fired power plants, having a lot of wind power, trying to maintain our nuclear fleet. The next 50% is the hard 50%. We have got to electrify transport and decarbonise power completely." He was involved in the Academy's advice to government on the Clean Power 2030 Action Plan, as part of its working groups focusing on decarbonisation of the UK's energy system and the role of hydrogen in a net zero energy system.

That policy input fits in with Shah's belief in 'systems thinking'. "A lot of my research has had a systems element in it. It's something that I've enjoyed but sometimes found difficult to explain to people. Often people want a simple answer, and the answer is often not simple. Most of the things that we need to tackle now are not simple linear problems. They're complex, lots of moving parts, nonlinear, dynamic. So that systems thinking is very important." This

"I've become increasingly interested in being involved with advisory activities with government, getting involved with engineering, evidence and advice."

Shah has spent over 30 years as a professor of process systems engineering at Imperial College London

QUICK Q&A

What inspired you to become an engineer?
Being interested in how things work and taking them apart and usually failing to put them back together properly!

What's your favourite project you've worked on?
The Future Vaccines Manufacturing Hub programme – something that was conceived collaboratively as a concept and turned into reality.

Who influenced your engineering career?
My PhD supervisors, Professor Roger Sargent FREng and Professor Constantinos Pantelides FREng, both Fellows of the Academy.

What's the best part of your job now?
Developing the research missions for our new School of Convergence Science in Sustainability.

Do you have a favourite tool or gadget?
Optimisation software.

Most impressive example of engineering to look at?
I really like the Falkirk Wheel.

What do you think is an overlooked engineering success?
Large-scale, safe and economic production of chlorine for drinking water.

is as important in policy issues as it is for engineering systems and processes.

Shah takes that thinking into the next phase of his career. After running the Department of Chemical Engineering at Imperial since 2016, he is about to become one of four directors – one each from engineering, science, business, and health – of a new School of Convergence Science in Sustainability at Imperial, one of four new Schools of Convergence Science. The plan is to look at ways of addressing the big problems that face society, such as climate change, decarbonisation and sustainability. In a different area, he adds, "Sustainable healthcare is something we want to do jointly with the health school."

The new school will be a way to focus thinking and bring research disciplines together, capitalising on research from elsewhere. No classrooms and no degrees awarded, more "schools of future thought" as Imperial bills them.

The School of Sustainability inevitably takes Shah further into policy thinking. "I've become increasingly interested in being involved with advisory activities with government, getting involved with engineering, evidence and advice." With a focus on climate and sustainability policy, Shah's work with the Academy has also taken in biofuels and technologies for greenhouse gas removal. All of this policy thinking lays the foundations for the new phase of Shah's work at Imperial.

Sha is now planning workshops on such topics as energy, ecosystems, clean air, and water. "I'd be surprised if we come up with something that nobody had ever thought of," he adds. "I think we know what a lot of the big societal challenges are. We're working initially with our internal community to create a shortlist of priority themes, and then we'll road-test those with external partners, like NGOs, foundations, government, industry, and other universities." Then the idea is to establish a set of 'missions' and to become what Imperial dubs "a catalytic force" that can "bring to life an exciting new paradigm for scientific exploration".

This puts Shah at the heart of a 'research system' that already has hundreds of researchers working on aspects of climate, energy and sustainability. The new school will bring in even wider expertise. In his new role Shah will be able to combine his engineering thinking with his policy work to make the most of Imperial's diversity in research in pursuit of systems thinking on a grand scale.

A NEW WAY OF THINKING

COVID-19 presented the engineers at Imperial College London with the same challenges that hit other universities. How do you teach and carry out research in a lockdown? In Shah's case, as head of the university's chemical engineering department, he was also drawn into the national challenge to find ways to solve the many problems that the virus posed. In particular, how could his experience in processing help?

Developing a new vaccine was just a part of the story. There also had to be ways to make it quickly, safely and reliably in huge quantities. Fortunately, Shah had already had the processing side of pharmaceuticals production in his repertoire. "I was interested in manufacturing applied to biotechnology. I realised that vaccines are interesting from this issue of scheduling and manufacturing optimisation."

Shah had started to think about vaccine production when influenza vaccines caught his attention. "Every March health authorities in the northern hemisphere decide on the three or four most likely strains of flu virus that are going to be used for the next vaccination season." Then, from April onwards, vaccines manufacturers make as much vaccine as possible before the vaccination season starts in September.

Shah's team worked with one collaborator to look for ways to improve the production process. "We worked on a particular factory to reschedule their operations so that they could get many more batches out between April and September. The plant has to switch between different strains. They have to do one at a time and then switch back. So, it's quite a complicated scheduling process."

What started off as a project on the production of flu vaccines then moved on to a more ambitious goal of creating new platforms that are, as Shah describes them, "disease agnostic". "The factory is not there just for making influenza vaccines, it could make a range of vaccines depending on what's needed."

Shah's thinking first began around 2015 when an outbreak of the Ebola virus hit the headlines. The then Prime Minister, David Cameron, called on the Department for Health and Social Care to set up vaccine groups to look into the threats to the UK. Along with groups to consider particular viruses, there were also groups on vaccine development and vaccine manufacturing. "We started to explore the idea of rapid response platforms and rapid development processes. So trying to be more responsive." That led to a funding call from the research councils for vaccine manufacturing hubs.

That work continues, says Shah, on developing vaccine platforms, "with an emphasis on support for low- and middle-income countries. We've collaborated with manufacturers in places like India, Vietnam, Bangladesh, and South Africa." COVID-19 underlined the importance of these markets, when many countries were left at the back of the queue for supplies of vaccines. "A lot of countries are interested in developing their own capability. So we're trying to do two things, make these quite advanced platforms, but equally develop them in a way that they are still appropriate to local capabilities."

CAREER TIMELINE AND DISTINCTIONS

Master's in chemical engineering, University of London, **1988**. PhD in process systems engineering, University of London, **1992**. Professor of process systems engineering, Imperial College London, **1992–present day**. Co-Founder and Director, Process Systems Enterprise, **1997–2001**. Director, Centre for Process Systems Engineering, Imperial College London, **2009–2016**. Fellow, Royal Academy of Engineering, **2015**. Deputy Director, Future Vaccine Manufacturing Hub, **2016–present day**. Head of Department of Chemical Engineering, Imperial College London, **2016–2021**. Awarded OBE for services to decarbonisation of UK economy, **2020**. Co-Founder and Director, Zero Petroleum, **2020–present day**. Trustee, Royal Academy of Engineering, **2021–2024**. Director, Convergence School of Sustainability, **2024–present day**.

WAYVE IS SCALING SELF-DRIVING AI AROUND THE WORLD

UK-headquartered $1 billion AI startup Wayve is solving longstanding challenges for self-driving cars with deep learning. Where will its AI go next?

Wayve is testing its fleet of autonomous Jaguar I-PACE cars in London, San Francisco, Germany, and Japan © Wayve

Buckle up: embodied AI is coming. We're well into the era of conversing with AI through a keyboard and a web browser. Our next stop will see AI physically interacting with the world.

It'll start in autonomous cars, which will change the way we move around cities, reduce car ownership, and improve road safety. But they're also a means to hone the intelligence that will ultimately be operating robots in factories and at home. That's the future according to Dr Alex Kendall OBE, CEO of Wayve, seen as one of the UK's leading contenders in autonomous driving.

"ChatGPT is changing the world," says Kendall, "but bringing AI into the physical world in a way that it can interact with us is real – is tangible. And I think it's going to be the biggest transformation we go through in our lifetimes."

Wayve sprung from Kendall's PhD research at the University of Cambridge in 2017, and what was then a contrarian vision for the future of autonomous driving. At the time, most autonomous driving systems were governed by hard-coded rules and a battery of sensors. Kendall was convinced that the future lay in end-to-end learning: where a single neural network learns from raw data without human intervention.

The belief he's held for 10 years is looking increasingly prescient. Wayve's hands-free autonomous cars have now been navigating London's roads (overseen by legally required safety drivers) since 2020. When Wayve launched in San Francisco at the end of 2024, its AI quickly adapted to drive on the other side of the road. The company has since expanded testing to Stuttgart and Japan, and its fleet has carried Bill Gates, Richard Branson and Microsoft CEO, Satya Nadella.

Now 600 employees strong, Wayve is backed by $1 billion from a 2024 Series C funding round led by Japanese investment group SoftBank, with contributions from NVIDIA and Microsoft – the largest UK deep tech round on record. For his contributions to UK engineering, Kendall will receive the Royal Academy of Engineering's Princess Royal Silver Medal in July 2025.

RULE BREAKERS

During his PhD, Kendall saw that traditional, rule-based autonomous driving systems were expensive and inflexible. If you picture a driverless taxi, you might imagine it with roof-mounted LiDAR (light detection and ranging), plus radar and cameras. Thanks to complicated software based on thousands of rules coded by hand, along with a high-definition map of the area, the car is generally safe to let loose on the road. Problems arise when the car encounters a new scenario, also called an edge case. Say, in 2023 when an autonomous car got stuck in wet concrete, or earlier this year when a YouTuber set up a fake wall à la Wile E. Coyote.

"The key question is how do you deal with things you haven't seen before?" says Kendall. "How do you have an intelligent system that's general enough to understand those kinds of scenarios? And there's no better technology [for this] that we know of today than deep learning."

When Wayve was just getting

CEO and Co-Founder, Dr Alex Kendall OBE, is a winner of the Royal Academy of Engineering's Princess Royal Silver Medal © Wayve

started, Google DeepMind's AlphaGo model had not long since defeated a grandmaster in the board game Go, a watershed moment for deep learning. But a Go board is simplistic compared to an autonomous vehicle processing inputs from seven or eight cameras, plus radar and LiDAR sensors. Wayve's model would have to process tens of millions of numbers, 10 times a second.

"We were very scrappy in prototyping what at the time was a real breakthrough in reinforcement learning systems," Kendall says. Their first demo showed a system that learned to drive in a day, trained on camera footage and occasionally corrected by a safety driver. Yet with less than 40 hours of driving data collected around Cambridge by employees, the model could soon drive around the block and correctly respond to traffic lights.

In 2020, Wayve's fleet expanded to London, pretty much no one's favourite place to drive. With its narrow streets lined with parked cars, potholes, relatively few cycle lanes and pedestrians stepping into the road with little or no warning, Kendall calls the city "one of the hardest driving environments". Thanks to tackling this complexity, Wayve now has a single AI that can drive different vehicles and operate all around the world.

These days, Wayve's models are trained on tens of petabytes of data. (By comparison, while OpenAI has not disclosed the total size of the dataset GPT-4 was trained on, it's thought to have been trained on petabytes of text.) Wayve's data comes from its team of chauffeurs and the safety drivers, as well as delivery vans operated by partners such as Asda, Ocado and DPD.

This frankly enormous scale is justified by the importance of road safety, explains Kendall. Reliability is the end goal. It may be satisfying to witness a Wayve car handle an emergency safety response effectively, but the pinnacle of excitement for Kendall is a boring drive with no human interaction or otherwise remarkable moments.

A JUMPING-OFF POINT FOR INTELLIGENT MACHINES

Even with hundreds of petabytes of real-world data, some road scenarios are too rare or dangerous to record. To plug these gaps, the team built GAIA, a generative AI model that simulates moments such as near-collisions, sudden cut-ins or unpredictable pedestrian behaviour.

Wayve's testing fleet is supervised by safety drivers © Wayve

Wayve has also developed LINGO, a model that interprets language as well as vision. Wayve started working on it a couple of years before ChatGPT came out, betting that language could be a rich and efficient source of data for models to learn from. It also lets Wayve's engineers (and eventually passengers) talk to the car and ask it to drive in certain ways or explain its decisions.

"Ultimately, I think the future of robotics is that we're going to want intelligent machines we can delegate tasks to, and to be able to talk to them, to actually instruct them to behave in a way that is safe and matches our preferences," says Kendall.

This hints at the long-term path for Wayve. Kendall sees driverless cars as a jumping-off point for embodied AI – systems that can physically interact with the world around them. Once proven in autonomous vehicles, he believes embodied AI will expand into manufacturing, healthcare and domestic robots – benefiting from the safety and verification abilities of Wayve's platform.

All of this might even make it a better driver. "We're seeing as an AI becomes more and more general, it improves the performance," explains Kendall. "So as our AI learns not just to drive, but to manipulate and to move and understand other objects, I think that'll improve its driving and vice versa."

Wayve's plan is to license its technology, first to car companies and then robotics manufacturers. Nissan will be the first taker, with Wayve's AI due to be landing in its cars in 2027 to support driver assistance.

Tesla, he acknowledges, is one of the few companies building intelligence along with the vehicle. But for other manufacturers and operators, he believes a broad platform is needed. In embodied AI, Kendall believes there will be a trillion-dollar company – and that Wayve could claim that title.

Whatever's in store, he's in it for the long haul. "I much more enjoy the problem and the journey," says Kendall. "The problems are not things that we have an epiphany and solve in one go, it's sustained hard work over, in my case, 10 years, that gets you there."

MEMRISTORS GO MAINSTREAM

Professor Themis Prodromakis designs neuromorphic AI hardware that takes cues from the brain. Aside from slashing AI's energy use, it could also make for smarter spacecraft and brain–computer interfaces.

AI's energy costs are skyrocketing. In April 2025, the International Energy Agency (IEA), which monitors the world's energy use, forecasted that electricity demand from data centres will double to about 945 terawatt hours by 2030, exceeding Japan's entire electricity consumption today.

After 80 years spent making our computer chips in essentially the same way, a radical way to curtail AI's energy use could be to redesign its hardware. For inspiration, engineers often look to the most efficient computer we know of: the one inside our skulls. The brain is more powerful than most supercomputers yet consumes just 20 watts – about as much energy as an LED lightbulb.

Professor Themis Prodromakis, an electronic engineer at the University of Edinburgh and Royal Academy of Engineering Chair in Emerging Technologies, is helping bring such brain-inspired, or neuromorphic, computer hardware closer to adoption by the electronics industry. His work in emerging semiconductor technologies has earned him a 2025 Princess Royal Silver Medal from the Academy.

Professor Themis Prodromakis, one of this year's winners of the Princess Royal Silver Medals © Themis Prodromakis

THIS IS YOUR BRAIN ON SILICON

One major bottleneck for conventional computer chips is that they process and store data in separate physical locations. "What they typically do is fetch the data from the memory, bring it into the processing unit, do some number crunching, and then take the outcome of that and go back and store it in memory," explains Prodromakis.

This back-and-forth both costs more energy and slows computation, an approach is known as the von Neumann architecture (after John von Neumann, who is widely considered one of the fathers of computing). It's served us well – most processors today still use it. But it's not what the brain does.

The brain does not separate memory and processing. It has billions of neurons, each interconnected with up to hundreds of thousands of synapses. These synaptic connections both store and process information locally, enabling the brain's efficiency.

The devices Prodromakis is developing that mimic this ability are called memristors, short for memory-resistors. Applying a high enough voltage changes a memristor's resistance (the memory part), which in turn affects the amount of current flowing through these devices (the computing part). Contrary to other types of semiconductor memories, a memristor's resistive state is retained even when you power off your electronics. This makes them fundamentally different to transistors – effectively the on/off switches that underlie digital computing with its ones and zeros. Memristors can store hundreds of different memory states, making them analogue.

The world we live in is also analogue – take a sound wave, for example. Conventional electronics must convert this continuous analogue sound signal to a quantised digital signal, and later often convert it back again into an analogue output. These transformations are hugely inefficient. Because of this, analogue computing has the potential to be much more efficient than digital, explains Prodromakis.

LAYER CAKE

Prodromakis has been working on memristors since meeting electronics legend, Leon Chua, on a visiting professorship at the University of California, Berkeley, in 2010. Chua first hypothesised memristors' existence in 1971. Prodromakis then began making and testing memristors in his lab, at the time at Imperial College London.

To make memristors is like making a layered cake, explains Prodromakis. (His preferred example: the pantespáni cake.) First, you add a layer of pantespáni, then cream, and then another layer of pantespáni.

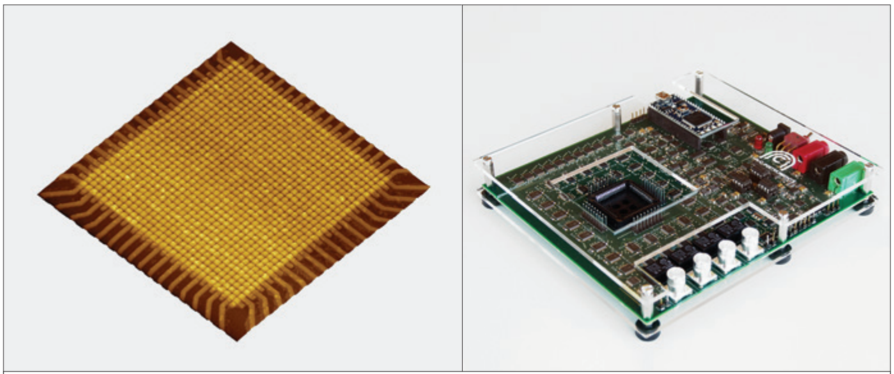
"We do that in an extremely controlled environment, in clean rooms and with very expensive equipment that allow us to control the thickness of the cream and the pantespáni with excellent precision." The middle 'cream' layer is a metal oxide, whose chemistry, and therefore resistance, changes when an electric field is applied.

There are other types of memristors, and other types of neuromorphic hardware, but a big advantage of Prodromakis' metal oxide-based memristors is their compatibility with complementary metal oxide semiconductor (CMOS) technology. CMOS is the process used at most specialised manufacturing facilities, known as 'fabs'.

"Foundries are very, very resistant to introducing new materials into their processes," he explains. "They spend billions on optimising their processes and their cleanrooms, so they aren't very keen to introduce new materials into the mix."

This is why his group designs conventional CMOS circuits and adds a layer of memristors on top, interfacing the new with the old. "A lot of people think memristors are going to replace transistors. Not necessarily," he says. "You still need transistors to control memristor technologies."

To accelerate the technology development and its scaling, Prodromakis has also developed high-performance testing tools, spinning out a company, ArC Instruments, in the process. The company now produces equipment that can test thousands of memristor devices in a few seconds.



(Left) Every yellow node is a memristor, shown on a chip about 1 micrometre by 1 micrometre – which itself is about 100th of the width of a human hair. (Right) An ArC Instruments test board © Themis Prodromakis

Today, its testing equipment and open-source software are used by more than 300 labs in 26 countries, including major industrial R&D sites that are developing next-generation semiconductor technologies.

Meanwhile, memristors are edging towards the mainstream. Major semiconductor foundries such as TSMC offer technologies with different flavours of memristors, says Prodromakis. "It's been fascinating to see over the past 15 years how memristors have transformed from a nascent technology into a mature technology that's disrupting the design and prototyping of modern electronic systems in a major way. My team and I take pride for the small part we played towards this."

A MOTHER SHIP FOR AI HARDWARE

Beyond slashing data centres' energy consumption, memristors could also change where AI runs. Most AI computation, especially training large models, happens in data centres. With chips that consume up to 1,000 times less power, says Prodromakis, this work could happen on smartphones and laptops instead. The upshot of this approach is it could also improve privacy by reducing reliance on the cloud.

Memristors could even lead to smarter spacecraft. High levels of radiation in space can damage electronics, while transmitting data to a base station on Earth slows down decision-making. Memristors could solve both problems. As they rely on ions instead of electrons, they're more resistant to radiation, explains Prodromakis. Coupled with their low power and latency needs, they could make onboard AI processing more viable in space.

But he is perhaps most excited about how memristors could make brain–computer interfaces much more precise, giving us greater insights into the brain's physiology. His team last year bridged their 'artificial neurons' with neurons in the brain of a living rat. "Our memristor-based neural interfaces are about 200 times more energy-efficient," he says. This efficiency boost means more channels can be packed into implants, to reduce noise and more accurately detect neural activity.

He's also still focused on getting advanced AI hardware out into the world. His now 60-person research group files one or two patents each month, and his next initiative is the planned Edinburgh Venture Builder in AI hardware (nicknamed EVA), inspired by the legendary US R&D facility Bell Labs.

With the venture builder, the plan is for EVA to become a 'mother ship' for spinning out companies, that capitalises on Edinburgh's local ecosystem in AI hardware and provide a fast route across the so-called valley of death well-known to deep tech founders and university spinouts.

It's a route that proved its mettle during the pandemic for Moderna's rapid vaccine development, but is new for semiconductors. "This has never been done for electronics and specifically AI hardware," says Prodromakis. "EVA's ambition is to commercialise technologies that deliver the power of a data centre in the palm of our hands."

HOW DOES THAT WORK?

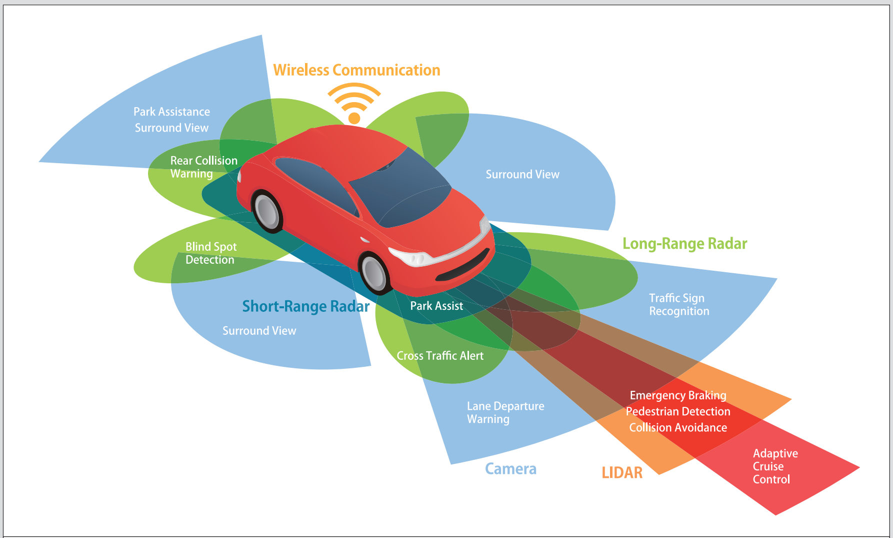
AUTONOMOUS VEHICLES

Autonomous vehicles, or driverless cars, are reshaping the future of transport. They are designed to navigate roads and traffic without human input, using a combination of sensors, software, and AI.

In the UK, trials of self-driving vehicles have been taking place since 2015 in Bristol, Coventry, Greenwich, and Milton Keynes, with British companies Wayve and Oxa spearheading significant breakthroughs in the technology.

Autonomous vehicles are currently not allowed to drive unsupervised on UK roads, with a human expected to remain in control of the car at all times. The Automated Vehicles Act became law in May 2024 and outlined the safety standards and procedures for autonomous vehicles. In June 2025, the government announced that businesses will be able to pilot small-scale 'taxi- and bus-like' services without a human safety driver for the first time from spring 2026, bringing this futuristic vision closer to everyday reality on England's roads.

So, how do autonomous vehicles navigate their environment? The vehicles use numerous sensors to 'see' where they are going and detect potential hazards around the vehicle. These can include cameras, which identify traffic lights, road markings, pedestrians, and other vehicles; radar to measure the speed and distance of nearby objects; and LiDAR (light detection and ranging), which creates a 3D map of the surroundings using laser light. AI algorithms then process data from the sensors to make real-time decisions. This includes recognising objects, predicting the behaviour of other road users and determining the safest path forward. The vehicle's computer-powered control system then translates AI decisions into actions, such as steering, braking and accelerating. Some vehicles also refer to high-definition maps and GPS to help determine their exact location and plan routes.



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The combination of these technologies allows autonomous vehicles to operate with minimal or no human intervention, depending on their level of autonomy. There are six levels of automation for driverless cars. For example, Level 0 means the vehicle has no autonomous features; Level 2, which currently covers cars that are allowed to legally drive on UK roads, is where the car can take over some aspects of driving, such as automatic emergency braking, adaptive cruise control, and parking assist; and Level 5 means complete autonomy with no input from a human.

A significant benefit could be improved safety on the roads. Despite some technology failures during commercial driverless taxi pilots, statistically, autonomous vehicles remain safer than those with humans behind the wheel – they don't get distracted and they stick rigidly to the rules of the road and speed limits. They may also increase efficiency by communicating with other autonomous vehicles to optimise routes and avoid traffic congestion.

The technology still has some catching up to do with human drivers in some situations, such as in poor weather conditions, complex traffic scenarios and in the face of unpredictable behaviour from pedestrians, other road users, and even passing animals. Legislation too, is needed to address liability, but as the technology improves and regulations adapt, we may soon see a future where cars drive themselves.