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DECEMBER 2022 ISSUE 93

ROBOTIC FRUIT PICKERS
INNOVATING WITH DATA
GREENER REFRIGERATION
TIDAL POWER ON THE TURN

Royal Academy of Engineering

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Front cover

Tidal power has growing potential as a renewable energy source to power the UK.
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WELCOME

With change and uncertainty all around us, it's crucial that we can adapt. Engineers are key to developing the breakthrough solutions that help us adapt when existing ones no longer fit our needs.

For instance, to decarbonise, adapting means bringing new energy sources to the forefront. Tidal energy is one renewable source it's estimated could supply over 10% of the UK's electricity demand. From page 10, read about a blade testing approach that is a game-changer in bringing down costs.

Looking to hydrogen, it is the most abundant element in the universe, yet realising its potential to decarbonise sectors such as steelmaking requires our whole energy infrastructure system to adapt. Professor Nilay Shah OBE FREng on page 8, outlines how the UK can best scale up and use low-carbon hydrogen.

Adapting skills is a theme shared in Katie Ireland's story (page 6), who switched field from oil and gas to renewables when she returned to work after a four-year career break. Seeing the potential of data inspired Katie's career moves, and our article *Embracing data in engineering* (page 15) discusses how innovation using data is driving transformative changes across all engineering disciplines, from aerospace and automotive to energy and construction.

Skills shortages are driving adaptation in our food production. A shortage of seasonal workers has left UK farms in a pinch recently; robotic fruit pickers will help them adapt and in turn prevent tonnes of food crops from being wasted (page 23).

Finally, why not help *Ingenia* adapt? You can fill out our survey with the QR code on page 3 to tell us your thoughts and help us make our content better for you, or contact us at **ingenia@raeng.org.uk**

Faith Wainwright

Faith Wainwright MBE FREng
Editor-in-Chief

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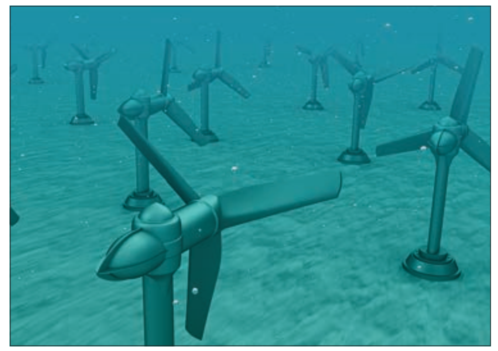


Correction
Issue 92 of *Ingenia* incorrectly stated that Mike Woolgar is Strategy Director at Atkins (New strategies needed for flood resilience, pages 10 and 11). He is Strategy Director at WSP.

IN BRIEF

IN BRIEF

GBBO STARS CELEBRATE ENGINEERING


(From left) Andrew Smyth, Dr Rahul Mandal and Giuseppe Dell'Anno offering up a slice of their 'Time to Celebrate Engineering' cake

On 2 November, engineers and engineering organisations across the country celebrated National Engineering Day with the theme 'Engineering Improving Lives'. Led by the Royal Academy of Engineering, it was an opportunity to make visible all the ways that engineering is shaping a brighter future.

On the day, the Academy enlisted *Great British Bake Off* stars and engineers, Andrew Smyth, Dr Rahul Mandal, and Giuseppe Dell'Anno, to create a showstopper 'Time to Celebrate Engineering' cake. A feat of baking and engineering, the cake featured working clock hands and all the aesthetics of a classic antique clock: a golden dome, a mahogany-effect veneer, and intricate latticework – made from isomalt, chocolate ganache, and royal icing respectively.

During the lead-up to the day, the 'bakineers' also designed a vegan chocolate cake recipe for a competition run by *This is Engineering*, with entrants given the chance of winning a manual 3D chocolate printer, aprons, and cookbooks signed by the bakineers. With entrants tasked with turning the cake 'from treat to tremendous' with an engineering twist, impressive features ranged from mechanically operational to gravity defying.


A selection of the cakes entered in the National Engineering Day competition

In among filming, recipe design, book promotion, and more, the bakineers also found time to speak to *Ingenia* about the link between baking and engineering as well as a (mostly) shared hatred for fondant icing – read it on the *Ingenia* website.

On the day, the Academy also published new research showing just how important engineering is to the UK's economy. The UK is an engineering powerhouse, with the profession adding up to an estimated £645 billion to the country's economy every year – equivalent to 32% of the UK's economic output. The research, due to be published in full shortly, also revealed that hotspots of engineering appear all over the UK, not just in major cities. Aberdeenshire and West Cumbria are among the areas where the highest proportion of the local population is employed in engineering.

Meanwhile, *This is Engineering* also launched two new campaign videos in the lead-up to the day. The stars of these films were Charlotte Wilkes, an apprentice mechanical engineer at the UK Atomic Energy Authority, and Dr Ellis Parry, Founder and CEO of Neumind, an app designed as an aid for people with brain injuries. This brings the video views of the overall campaign to over 58 million since launching in 2018.

To find out more about what baking has to do with engineering and watch the cake being made, visit **www.thisisengineering.org.uk**

PROPORTION OF ENGINEERING EMPLOYMENT

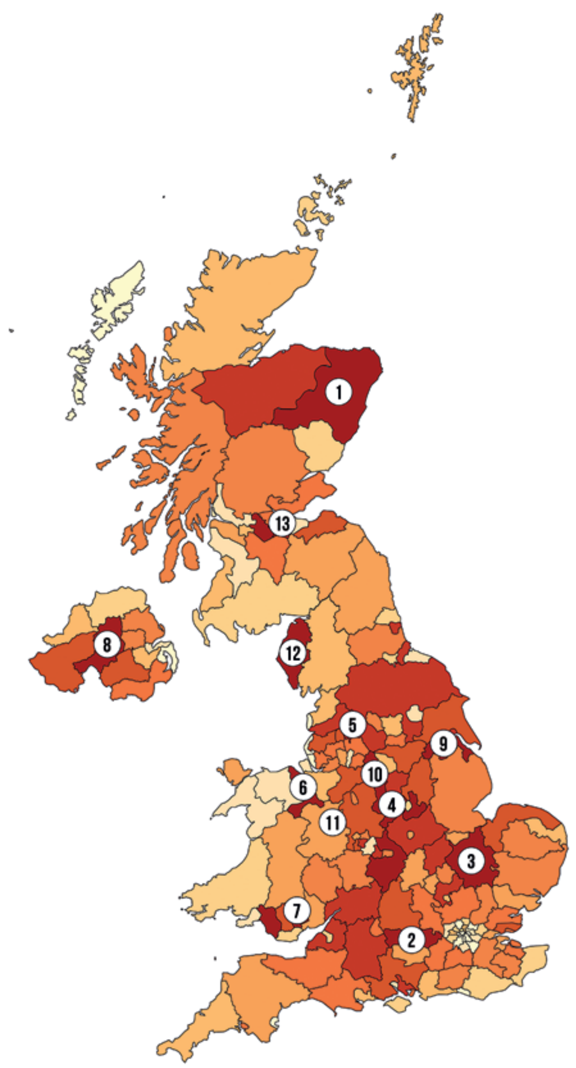
These are the UK's engineering hotspots defined as those areas where a high proportion of the population (between 1 in 3 and 1 in 2 adults) are employed in the engineering economy.

1. Aberdeen City and Aberdeenshire
2. Berkshire
3. Cambridgeshire
4. Derby
5. East Lancashire
6. Flintshire and Wrexham
7. Gwent Valleys
8. Mid Ulster
9. North and North East Lincolnshire
10. South and West Derbyshire
11. Telford and Wrekin
12. West Cumbria
13. West Lothian

Hotspots ordered alphabetically.

KEY *% of the working population employed in engineering.*

16.1% - 19.5%
19.6% - 21.7%
21.8% - 23.1%
23.2% - 24.7%
24.8% - 26.1%
26.2% - 27.3%
27.4% - 27.9%
28.0% - 29.9%
30.0% - 32.0%
32.0% - 44.0%



Data showing the hotspots of engineering across the UK, highlighting the wealth of engineering career opportunities all over the country

PENNY FOR YOUR THOUGHTS

As *Ingenia* looks to the future, we'd love to hear your thoughts about our content. Complete our short survey by 31 December and you'll be entered into a draw to win a £25 Amazon voucher.

Tell us what you want to see in *Ingenia* – are there engineers or engineering projects you think we should cover more? Are there areas of engineering you want to hear more or less about?

Now's your chance to let us know.

If you haven't already, don't forget to sign up to our newsletter too, to stay up to date with our monthly stories and news.

CORNWALL'S FIRST SPACEPORT RECEIVES LAUNCH LICENCE

The LauncherOne rocket, having arrived at SpacePort Cornwall in mid-October © SpacePort Cornwall

In November, a spaceport in Newquay received its launch licence from the UK's Civil Aviation Authority, ahead of the UK's first ever rocket launch. Spaceport Cornwall expects the launch – named 'Start Me Up', after the Rolling Stones song – to take place in early December if the technology is ready to go.

The launch is due to be a horizontal launch, meaning that a carrier aircraft will take the rocket to altitude, before releasing it above the Atlantic, south of Ireland. The carrier aircraft, a modified Virgin Atlantic Boeing 747 named 'Cosmic Girl', will be used for the launch. Meanwhile, a LauncherOne rocket will propel nine satellites into low Earth orbit, while the aircraft will return to Cornwall to land. The satellites will have a variety of civil and defence applications.

The news underlines Cornwall's burgeoning space industry, which plays host to over 55 space companies already. These include satellite communications station Goonhilly and nanosatellite platform and subsystems specialist Exobotics.

MICROGRID TO POWER OFF-GRID CANADIAN COMMUNITIES

In November, Canadian technical consulting company BMT completed full-scale tests of its new smart microgrid prototype, designed to reduce remote communities' dependence on diesel by autonomously managing and distributing energy from renewable sources. The software will help decarbonise off-grid communities including island and indigenous communities. It was tested in Novia Scotia using a tidal energy solution from UK-based company Sustainable Marine Energy.

Microgrids are gaining momentum in the energy transition because of their potential to help decarbonise communities without reliable access to centralised energy networks. They integrate a variety of renewable sources, such as wind, solar, and ocean energy, to enable efficient clean energy in rural areas.

"It does everything you need to operate a microgrid," said BMT's principle engineering specialist, Martin Moody. "It can operate seamlessly between the different in-feeds – storage, local generation, and the grid connection – to suit off-the-grid, local, and indigenous needs. It can monitor the state of battery charge, it can perform peak shaving to level out peaks in electricity use, provide blackout warnings, and much more."

© BMT

IN BRIEF

GET INVOLVED IN ENGINEERING

PERSONAL DEVELOPMENT SUPPORT FOR UNDERGRADS

Are you in second year or above at a UK university, with a passion for engineering, or do you know someone who is? The Royal Academy of Engineering's Engineering Leaders Scholarships programme provides:

- £5,000 towards personal development activities for engineering students with leadership potential
- the support of an Academy mentor
- dedicated training and networking events
- invitations to exclusive Academy events and opportunities
- access to an alumni community of over 300 engineers.

Please send any applications before the deadline, 16 January 2023. The Academy encourages applications from women, and Black, Asian, and other minority ethnic groups who are currently under-represented in engineering, including those studying at post-92 universities. For further details, please email Lauren Pattle at **els@raeng.org.uk**

© Technicians Make It Happen

TECHNICIANS – THE DAVID SAINSBURY GALLERY

Open now
Science Museum, London
This new free interactive exhibition brings to life the world of the technicians, from blockbuster film sets to pharmaceutical labs. You can step inside Shuri's Lab from Marvel Studios' *Black Panther* to see what the role of a film-set lighting technician feels like and even try welding a rollercoaster track.

THE MATHS OF CHRISTMAS

20 December 2022
The Royal Institution, London
Join Thomas Oléron-Evans to explore how mathematical marvels can overlap with Christmas cheer. The talk is based on Thomas' new book, *The Indisputable Existence of Santa Claus*, co-written with Dr Hannah Fry HonFREng, and sure to brighten up the bleak midwinter.

THE UK'S NUCLEAR WASTE AND THE GEOLOGICAL SOLUTION

23 February 2022
Online
This *New Scientist* debate brings together leading thinkers to explore the science behind the geological disposal of nuclear waste: that is, burying it deep underground in a permanent disposal facility **www.newscientist.com/science-events/nuclear-waste-debate**

METALWORK COLLECTION: THE CUTTING EDGE

Open now until 6 August 2023
Millennium Gallery, Sheffield
ICYMI: this collection incorporates objects from Sheffield Museums Industry and metalwork collections, showcasing the diversity and development of the 'cutting edge', from cutlery to industrial tools, and technological advances developed in Sheffield today.

A (VERY) SHORT HISTORY OF LIFE ON EARTH BY HENRY GEE

One of this year's picks from the Royal Society's Science Book Prize 2022, Henry Gee's book takes you through 4.6 billion years of life on Earth: our planet, like you've never seen it before.

HOW I GOT HERE

Q&A

KATIE IRELAND
SENIOR GEOLOGIST

On coming back from a career break, Katie switched fields from oil and gas to renewables, and was awarded 'Returner of the Year' at the 2022 Engineering Talent Awards. Now, in her role at Ørsted, she works on data models to help optimise offshore wind turbine foundations.

WHY DID YOU BECOME INTERESTED IN SCIENCE AND ENGINEERING?

I was interested in geosciences from an early age – collecting fossils and classic dinosaur toys. I studied physics at GCSE and A level and took part in the Physics Olympics at the University of Liverpool and several 'Girls into Engineering' events hosted by the University of Strathclyde. Learning about the Earth and how it worked was always a big driver. I studied physics, biology, maths, and geography at A level and I knew I wanted to study geosciences at university so I chose an MSci course at Durham University.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I knew I loved learning and research so embarked on a PhD on mud volcano systems in Azerbaijan. As it was sponsored by BP, I saw how much more data industry had access to than academia, so decided to do a graduate scheme in oil and gas. This took me to Houston, Russia, Ghana, and Kurdistan, and exposed me to a wealth of geological knowledge and the experience of working with different cultures. I ended up working at BG Group on my specialism in

geopressure and geohazards alongside my day job, which was very rewarding.

Several years later, I had my first child, and after my maternity leave ended, I realised that I wanted to focus on raising my family. Around the time of us having our second child, my husband decided that he wanted to move back into academia, which meant a move up north, away from friends and our professional networks.

Eventually, after four years out of work and the pandemic, I decided I wanted to get back into work, but had no idea what I wanted to do. I was also suffering with crippling imposter syndrome. I applied for a few roles related to my past experience but was very nervous in all interviews. It was then I saw the senior geologist role at Ørsted advertised by STEM Returners, and sent them an email. I had seen the transition that Ørsted had made from an oil and gas operator to the world's most sustainable renewable energy company, which I found extremely impressive. I started the three-month STEM Returners placement in June 2021, was offered a permanent role and have been working for Ørsted helping site wind farms ever since!

Katie during fieldwork in Kurdistan

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

Definitely winning Engineering Returner of the Year at the Engineering Talent Awards in September 2022. It felt like a testament to all the effort that I had put in to getting back into work, transitioning from oil and gas to renewables and also to all the support from friends, family, and most of all, my team at Ørsted.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

I love problem solving and learning new things every day. Every working day is different, working alongside other engineers from different departments and seeing how others tackle issues is fascinating to me.

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

There isn't really a 'typical' day but usually I start work at about 7.30am as I work in the Taiwan project team – mostly from home. My role involves using geophysical and geotechnical datasets to build 3D ground models that help us better understand the ground conditions that wind farm foundations will be constructed in. These models help to optimise engineering of the foundations, as well as identifying any potential geohazards. I work with project team members in different departments to align data and time frames for project deliverables, as well as any external contractors who may be acquiring data for us. I also work part-time so that I am able to pick the children up and spend the afternoons with them after school, which is invaluable!

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

The main thing for me is to always keep learning. Look for opportunities to learn more, volunteer, do internships, apprenticeships … the more exposure you get to different things, the quicker you'll work out what you enjoy and how to achieve it. Be inquisitive and don't be afraid to ask questions – you will find people are always happy to help.

WHAT'S NEXT FOR YOU?

Next is to focus on constructing a new ground model using recently acquired 2D seismic reflection data and geotechnical cone penetration tests. I've also been tasked with leading our department's 3D geological modelling and geoscience competency group, so I am looking forward to developing new initiatives for that.

QUICK-FIRE FACTS

Age: **37**

Qualifications: **MSci geosciences (Hons) and PhD**

Biggest engineering inspiration: **Julia King FREng FRS, Baroness Brown of Cambridge**

Most-used technology: **Seismic interpretation software or geographic information system software**

Three words that describe you: **inquisitive, helpful, resilient**

OPINION

OPINION

THE CHALLENGES OF CREATING A HYDROGEN ECONOMY

A new report from the National Engineering Policy Centre (NEPC) says that hydrogen is likely to play a critical role in achieving net zero, but that the UK needs to act soon to avoid falling behind international competitors. So, how can government and the engineering community ensure this doesn't happen? Professor Nilay Shah OBE FREng, Vice Chair of the NEPC net zero working group, outlines the steps that need to be taken to scale up production and use of low-carbon hydrogen.

Hydrogen is the most abundant element in the universe, yet we still haven't harnessed its full potential for a sustainable energy system, as the UK lacks the infrastructure and capacity needed to produce and use low-carbon hydrogen at scale. It's a highly versatile energy carrier that could help to decarbonise sectors where other energy sources, such as electricity, may not be suitable. But the scaling up of low-carbon hydrogen production that is 'carbon neutral' poses many engineering challenges. Deciding how best to use hydrogen to achieve decarbonisation needs to be made from a whole-system point of view.

What is clear is that few areas of engineering will escape the need to change and develop new technologies and systems to adapt to the future hydrogen economy.

Hydrogen comes in many forms, commonly described as colours. The three most discussed 'colours' of hydrogen, each with its own engineering challenges, are:

- grey – produced from natural gas/coal
- blue – also produced from natural gas/coal but using carbon capture and storage technology to capture and store carbon that would otherwise be emitted
- green – produced using renewable energy to power electrolysis of water.

It takes a high energy input to generate hydrogen of any 'colour', making efficient and low-carbon production a key challenge. Green and blue hydrogen are the most desirable options if we want to create a low-carbon hydrogen economy. Currently, more than 96% of the UK's hydrogen production is grey hydrogen, which is carbon-intensive and not aligned with achieving net zero.

As the cleanest form of hydrogen, green hydrogen could benefit our future power system by providing greater system flexibility, improved energy security through reduced demand for natural gas as a form of energy storage, and as a source for dispatchable low-carbon electricity generation.

However, the UK currently doesn't have the infrastructure we need to meet the government's hydrogen commitments. Rapidly developing the capacity for low-carbon hydrogen production and use will be a big task for engineers across many sectors, including chemicals, industrial heating or long-distance transport.

A pragmatic and carefully managed delivery of the infrastructure needed is vital to maximise hydrogen's potential as part of a net zero energy system. But the use of hydrogen will also need major engineering advances across many sectors, such as in carbon capture and storage technology for blue hydrogen production and electrolyser technology for green hydrogen production, with new infrastructure to produce, store and transport hydrogen safely and reliably.

In industry, such as steel production, hydrogen could play an important role in decarbonisation. Industrial heating currently relies on fossil fuels to run furnaces for manufacturing, but hydrogen could instead be used to produce direct reduced iron, with water instead of CO_2 as a by-product. Hydrogen is likely to be the only viable full decarbonisation option here, but it requires industries such as steel to swiftly prepare to switch to hydrogen.

For some forms of transport, hydrogen-based fuels are likely to be the most suitable and efficient low-carbon energy sources. With further research and development, hydrogen could make a significant contribution to decarbonising aviation, shipping and heavy goods vehicles. Hydrogen trains may also play a role where overhead electrification is too expensive. Hydrogen storage technologies will be critical to its success in transport.

Indeed, hydrogen storage remains a significant engineering challenge to overcome. Hydrogen is much more difficult to store than other gases because of its small molecules, explosive nature and very low liquification temperatures. It requires purpose-built storage with thorough safety standards. It must be compressed or liquefied and then stored in geological sites such as underground salt caverns and spent oil and gas wells. Current storage efficiency ranges between 85% and 98% and depends significantly on the compression ratios.

To advance the hydrogen economy, industries need to invest in the skills and technologies required to integrate hydrogen into their processes, along with continued innovation in compression and storage technologies for hydrogen supply and transport. The underlying policy environment will also be crucial, particularly where public trust in hydrogen's safety is concerned.

Issues relating to standards, safety and the environment are familiar to all areas of engineering. Determining where hydrogen can best be deployed to achieve net zero, plugging the necessary skills gaps, and investing in R&D will also require the appropriate policy. The right policies must be in place for engineers to properly play their part in the hydrogen economy.

The NEPC's report *The role of hydrogen in a net zero energy system* highlighted that the government must rapidly scale up the UK's low-carbon hydrogen infrastructure – focusing on areas where hydrogen offers the greatest value to decarbonisation of the whole energy system.

For this to happen, it recommends that the government:

- invests now in rapid and early pilot projects to determine which end uses of hydrogen can achieve the highest carbon savings and cost efficiencies across the whole energy system
- implements an ambitious but pragmatic roadmap for scaling up low-carbon hydrogen production to meet demand for end uses where hydrogen could become the best or only low- or zero-carbon option available.

Another policy requirement is to manage the risks and dependencies when scaling up hydrogen value chains – the journey that hydrogen takes from production to transportation, storage and end use. The government must act now to:

- implement low-carbon hydrogen standards that include emissions throughout the production and supply process
- build up regulators' capability to robustly enforce and monitor crucial regulations, including low-carbon hydrogen standards for producing blue hydrogen
- execute further hydrogen safety assessments
- manage the supply risks associated with critical scarce materials needed for producing green hydrogen.

In keeping with the systems nature of the transition to a hydrogen economy, within five years, the government must also:

- address skills gaps relating to carbon capture and storage, renewable electricity, and hydrogen to enable widescale deployment. Some studies have suggested that the UK's offshore oil and gas workforce can expect to have a medium transferability to blue hydrogen and carbon capture and storage. Skills needed to produce green hydrogen are similar to the chemical industry and only minor upskilling will be needed. However, for both blue and green hydrogen production, further research is required to understand the skills gaps, develop a green skills strategy to sufficiently upskill the workforce for these emerging sectors and ensure a just transition for the UK's offshore energy workforce
- encourage an international market in low-carbon hydrogen by fostering the development of globally assured standards and certification mechanisms.
- invest in research and innovation to reduce/remove the need for critical scarce materials required for electrolysers for green hydrogen production, such as platinum, iridium and yttrium.

Hydrogen could play a significant role in a future net zero energy system, so engineering businesses must consider how to upskill their knowledge of hydrogen's applications and assess their readiness for implementing it. The engineering community needs to prepare for hydrogen to become more prominent in the future; don't sit passively waiting for it to sneak up on you.

BIOGRAPHY
Nilay Shah OBE FREng is a professor of process systems engineering at Imperial College London. He is interested in the use of models and process systems engineering techniques to understand and design low-carbon energy and industrial systems. He is a member of the government's Hydrogen Advisory Council, Chief Technology Officer of a synthetic fuels business, and Vice Chair of the NEPC net zero working group, hosted by the Royal Academy of Engineering.

To read the full National Engineering Policy Centre report, please visit ***www.raeng.org.uk/hydrogen***

TIDAL POWER ON THE TURN

TIDAL POWER ON THE TURN

With its predictability, tidal power could be an attractive addition to the portfolio of renewable energy sources for electricity generation. For that to happen, engineers need to be able to test the components that will have to operate in the severe offshore conditions around the British Isles. Geoff Watts describes the features of FastBlade, a new facility that can carry out large-scale accelerated testing of blades for tidal power generation.

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Did you know?

- A 2021 University of Edinburgh study found that tidal stream power has the potential to deliver 11% of the UK's current annual electricity demand
- Tidal power is a renewable and predictable energy source – tides can be accurately forecast throughout the year
- The UK has the second-strongest tides in the world – after Canada – so could be an ideal place for tidal power generation

Might tidal power generation be on the verge of rising? Gas, coal, nuclear, hydro, solar, and wind have all featured in the continuing debate about the strengths and weaknesses, costs, and benefits of different electricity sources. But tidal power has been largely absent from the discussion – no surprise given its, so far, tiny contribution. This neglect could change following the opening of a new facility managed by the University of Edinburgh School of Engineering.

Called FastBlade, it has been built at a cost of £4.6 million to test large turbine blades of the kind used to extract energy from tidal flows. To mix a metaphor, the opening of FastBlade in May 2022 could be a straw in the wind: a hint that tidal power is on the turn.

An aerial view of the tidal power station on the estuary of the Rance River, which supplies 0.12% of France's power demand. It generates power by channelling water through turbines when the held water level is higher than in the tidal estuary. A main road also crosses the dam, allowing vehicles to travel between Dinard and Saint-Malo © Shutterstock

TAPPING TIDAL'S POTENTIAL

Wind power accounts for slightly more than a quarter of the electricity generated in the UK. That wind rather than water should have been a preferred source of renewable energy is understandable. Wind, a low hanging fruit among renewables, is widely available. Wind turbines are relatively straightforward to build and to access for maintenance. By contrast, tidal currents strong enough to provide usable energy at a reasonable cost are relatively uncommon. Tidal turbines have been (and still are) expensive, and harder to install and maintain. So, Europe's tidal streams remain barely tapped – and roughly half of them lie in UK waters.

There are several options for tapping the power of the tides. The most familiar, known as tidal range, is by building a barrage across an estuary or creating an artificial lagoon. As water flows in and out of the lagoon, it travels through channels fitted with turbines.

One of the oldest tidal lagoons is on the estuary of the Rance River in Brittany, France. Opened in 1966, Rance Tidal Power Station has a peak output of 240 megawatts (MW) from 24 turbines. It was the world's largest tidal power station until 2011 when the Sihwa Lake Tidal Power Station opened in South Korea, with a total power output capacity of 254 MW.

The geography of the UK's Bristol Channel and Severn Estuary has prompted proposals for a barrage linking its English and Welsh sides, or for a tidal lagoon constructed off a section of the South Wales coast. These major engineering projects have so far been rejected on grounds of cost or damage to the environment or both.

There are several alternatives to barrages when it comes to tapping tidal energy. One approach is tidal streaming, which operates in deeper water and generates power using natural currents that occur as the tide changes. It relies on an underwater equivalent of the wind turbine. An upright pillar holds the rotor up above the seabed. As the tide ebbs and flows, so the rotor turns. An alternative approach is the floating turbine, with rotors suspended beneath a securely moored float. One current project that uses this approach is the O2 prototype built by Orbital Marine Power. With a capacity of 2 MW, Orbital describes the O2 as 'the most powerful tidal turbine in the world'.

In 2021, the *Proceedings of the Royal Society* published a review of tidal energy production in the UK. This identified just 10.4 MW of installed and operational generating capacity. Setting that beside the more than 300 Terrawatt-hours (TWh) of electricity that the UK generates every year underlines the still minuscule contribution of tidal streams. But, as the report's authors point out, the future could be markedly different. They estimate that tidal streams could yield 34 TWh/year for the UK, equivalent to more than 10% of current electricity demand.

Tidal streaming depends on technologies that have yet to reach the commercial maturity of wind turbines. In reaching any such goal, a facility such as FastBlade would play an essential role, not least because blade failure is the most likely cause of downtime in generation.

Tidal turbine blades are usually made of carbon or glass fibre. Typically 8 to 10 metres long, they are shorter and stiffer than wind turbine blades. This difference is needed because water is much denser than air and each blade must cope with a greater load per unit length. Testing for strength and suitability of design is essential.

O2 IN THE ORKNEYS

One of the current generations of tidal turbines that has attracted much interest is the Orbital O2. A floating machine, it was built in Dundee in 2021 by the Scottish renewable energy company Orbital Marine Power, and then towed to its present location at the European Marine Energy Centre (EMEC) Fall of Warness site, off the Island of Eday.

The mooring site is an area where the Atlantic Ocean meets the North Sea, which is known for its fast-flowing tidal currents.

The O2 comprises two rotors with a total surface area of 600 m^2, the largest ever on a floating tidal turbine. Both rotors are 20 metres in diameter and mounted on 18-metre-long hinged legs projecting, one on either side, from a 74-metre-long floating tubular platform.

Out of the water the O2 looks like a long thin-bodied aircraft fitted with wings and oversize propellers. When immersed in the sea, and in action, the hinged legs holding the rotors are angled downward from the float at roughly 45° so that the rotors are below the sea surface and in the fastest-flowing region of the tidal current. Bringing the arms back horizontally raises the rotors to the surface for inspection and maintenance.

The float is anchored in position by four chains attached to the seabed. The rotor blades can be turned through 360°, so avoiding any need to reorient the platform with each turn of the tide.

The O2 has been operational and exporting electricity to the Orkney grid since July 2021. It is expected to offset about 2,000 tonnes of CO_2 each year and power 1,700 UK homes.

Thus far O2 has lived up to expectations, presented no unanticipated problems, and is planned to remain in operation for 15 to 20 years. During this time, it will be integrated with a hydrogen production facility and battery storage at EMEC to create 'green hydrogen', part of a plan to bring a full-blown hydrogen economy to the Orkney Islands.

The O2 out of the water and how it looks when placed in the water, with the legs holding the rotors positioned downwards, below the sea surface © Orbital Marine Power

(Left) The FastBlade system in action, with a tidal blade in place, ready to be tested. (Right) A close up of the speckle pattern applied onto the blade's surface © FastBlade

BLADE TESTING

FastBlade bills itself as "the world's first rapid and super-efficient testing facility for tidal turbine blades and other composite structures". While it can be used for other applications – ranging from aerospace to bridge building – as the name suggests, FastBlade's planners always had fatigue testing of tidal turbine blades in mind.

FastBlade is the outcome of a partnership between the University of Edinburgh and the engineering company Babcock International, with the support of a £1.8 million grant from the Engineering and Physical Sciences Research Council (EPSRC), and is located in Fife's Rosyth Dockyard.

Formally opened in May 2022, FastBlade's centrepiece is a large test hall that houses the rig to which blades are attached. They are then subjected to an accelerated simulation of the loads that blades would have to bear during a lifetime of peak tidal flows. Two overhead 10 tonne travelling cranes can lift blades from the delivery vehicle and lower them on to the test rig.

The rig itself, sunk more than two metres into the ground, is a steel structure that is 12 metres long and 2.5 metres wide. Testing is carried out on single blades. At one end of the rig is a vertical steel wall to which a blade for testing can be bolted horizontally and parallel to the long axis of the underlying base. The structure is designed, for obvious reasons, to be rigid. Any small residual bending it may exhibit has been accounted for during the rig's initial calibration.

During a test, hydraulic rams apply loading stresses, designed to stimulate the force of the tidal flow, to the blade from beneath. The use of rams to apply the stress is necessary because of the shortness and relative rigidity of tidal turbine blades. Resonance testing – with blades induced to resonate under their own mass without the application of external pressure to bend them – is effective only with the longer, lighter, and less rigid blades of wind turbines.

FastBlade's rams use hydraulic pumps, operating at a rate of 800 litres per minute, to deliver the loads on the blades. Regenerative hydraulic technology – its first use in a test facility of this kind – recovers energy between cycles to reduce the energy consumed. In a conventional system, the pressurised fluid that drives the forward movement of the rams is simply allowed, between each stroke, to return to atmospheric. In a regenerative system, as the fluid depressurises it repressurises the fluid driving the pump's next movement. This recovers some 80% of the required energy, which makes for less expensive testing.

Each cycle of loading and unloading represents one rise and fall of the tide. The rig can complete a cycle in a second. In practice, it will take three to four months to simulate the stresses of 20 to 25 years' continuous use of a blade, and to perform other tests, such as the extra loading that wave action or turbulence might cause. A full test programme might require as many as 10 million cycles. The system is set up to use four hydraulic rams, which will typically be used when testing a turbine blade. Other objects being tested might need

Testing blades at the end of their working lives can show how used blades have coped with the real-life stresses of years spent under load in the sea

differently distributed or greater loading so extra rams can be added as required.

Sensors distributed across a blade's surface allow investigators to measure and record a blade's response to stresses. Accelerometers, position monitors, and strain gauges measure how blades respond to repeated loading. To generate digital images, pairs of cameras focus on a random spectral pattern sprayed onto the surface of the blade through a computer-generated stencil. 3D images of the blades' motion are then used to develop computer models.

FastBlade can also conduct static tests to assess blade stiffness and the extent to which they may deform under load. Such testing can reveal potential weaknesses and can indicate possible improvements in the design of future blades. In addition, testing blades at the end of their working lives can show how used blades have coped with the real-life stresses of years spent under load in the sea.

FastBlade hosted its inaugural tests on a decommissioned blade from the Deepgen III 1 MW prototype tidal turbine. The project, LoadTide, subjected a 5.25 metre blade to a sequence of tests. Provided by the European Marine Energy Centre and made by Tidal Generation Limited, the blade came from an earlier tidal energy project. Before the research team could start testing the blade it had to remove a protective layer of antifouling coating. The blade survived a series of more than 30,000 cycles, the equivalent of about 22 years of accelerated fatigue loading.

As part of the initial run of testing, FastBlade could fully commission the unique digital displacement hydraulic system as well as the bespoke control software. FastBlade plans to use the lessons learned from the LoadTide project to further improve both the controllability and energy efficiency of future tests.

LEVELLING UP

At present, tidal stream power is more costly than wind power. The standard metric for comparing the economic performance of different generating methods is the levelised cost of energy (LCoE). This is the ratio of the total lifetime cost of a project to the energy output over that lifetime.

While offshore wind currently costs about £37 per MWh, tidal comes in at something under £200 per MWh. Daniel Coles, a research fellow in the School of Engineering, Computing and Mathematics at the University of Plymouth and lead author of the Royal Society review paper, is among those who have reservations about LCoE methodology. They believe that it disregards the whole system costs (the changes in the costs of constructing and operating an entire power system resulting from adding a new technology) that renewable power projects incur, as well as the wider socioeconomic benefits that come with the development of a new technology. But he is optimistic. "The cost of tidal energy is now coming down at a much steeper rate than those of wind and solar," he points out. "These cost reductions are driven by learning and technology development." With their earlier adoption, wind and solar have already reaped the benefits of this rapid cost reduction phase.

A weakness of most renewable energy sources is their inability to provide a round-the-clock base load. This is also true of tidal power, which also varies, but it does offer total predictability. Unlike the sun and wind, tides are reliable, almost like clockwork. No other renewable energy technology can guarantee a particular power output at a certain hour of the day or night on a date, years into the future.

The full potential of tidal turbines will not be realised until there is sufficient confidence to deploy them not in ones or twos but in multi-megawatt arrays, much as already happens with offshore wind turbine farms. The European Union (EU) is one of the prominent current backers of the technology.

In line with its green policies, the EU's €26.7 million FORWARD-2030 project aims to accelerate the commercial deployment of tidal energy alongside wind generation, battery storage, and green hydrogen production. Its objectives are to reduce the LCoE of tidal energy, enhance its environmental and societal acceptance, prepare for future volume manufacturing of equipment, further reduce carbon emissions, and enhance tidal power's integration with other energy systems. The scheme is supported by a pan-European consortium and led by Orbital Marine.

While arrays of tidal turbines are likely to find a place in the overall mix of energy sources, it is difficult to predict how soon this will happen, or to what extent. Enthusiasts speak of new green jobs, export opportunities, and economic benefits to coastal communities, and point to a clutch of international tidal stream projects with upbeat acronymic titles such as TIGER and ELEMENT. But realists will remain conscious of a further comment from Daniel Coles: "To really accelerate and grow, [tidal] is going to need what the wind and solar industries have benefited from, which is continuous and reliable subsidy support for the next 10 to 15 years."

Geoff Watts spoke to Daniel Coles and Dr Fergus Cuthill, Senior Experimental Officer and FASTBLADE Manager at the University of Edinburgh's School of Engineering, for this article.

EMBRACING DATA IN ENGINEERING

Data is sometimes considered dry and boring, but it is an important asset that can open up significant opportunities when used well. In engineering, it is being used in multiple ways to accelerate the transition to renewable energy and reduce unnecessary use of resources. Barry Hodgson, Director of Strategy and Antonia Kontaratou, Data Scientist, from the National Innovation Centre for Data, highlight ways that data has been used to make changes in engineering and outline how an investment in skills can accelerate these.

EMBRACING DATA IN ENGINEERING

Did you know?

- Data science is an exciting discipline that's becoming increasingly important across many industries, including engineering
- Since 2014, the government has invested more than £2.3 billion in data and AI
- However, there is a skills gap with as many as 234,000 roles in data science that need to be filled in the UK

Using data to gain insights has become a major priority across all industries in recent times, with the ability to capture and process data opening up many opportunities. In engineering, data is transforming whole industries, through use of real-time analytics and machine learning for predictive maintenance for example, as well as allowing engineers to efficiently manage large-scale physical assets by generating virtual representations as digital twins ('Creating a virtual replica', Ingenia 87). Data is fast becoming the world's most valuable resource.

The untapped potential of data-driven innovation to boost productivity, create new products and services, and create new businesses and jobs has led to major investment from both the UK government and the private sector. The government has invested more than £2.3 billion since 2014 and has a 10-year vision to transform the UK's data capabilities via the National Data Strategy and National Artificial Intelligence (AI) Strategy. Venture capital investment in data-driven AI companies is also skyrocketing. In 2021 *Tech Nation* reported that UK AI companies received $3.3 billion between January and August that year, already surpassing the $3 billion invested during the whole of 2020.

Open data in particular – which the Open Data Institute defines as data that anyone can access, use or share – is already used by hundreds of UK companies to offer new insights into everything from travel to recruitment. Transport for London (TfL) and the Ordnance Survey are two of the most high-profile data providers, which has fuelled the creation of dozens of popular apps, particularly in relation to travel planning and geo-location.

Innovating using data is hitting the mainstream and making transformative changes across engineering disciplines, from aerospace and automotive to energy and construction.

MAKING USE OF DATA

Data science is an interdisciplinary area where (mainly) three fields intersect: mathematics and statistics, computer science, and business knowledge – although this is specific to where it's being applied. The aim of using data science is to extract insights and uncover patterns from data that can be in unstructured formats – such as images and audio – or structured formats – such as tables with rows and columns. Often, these disparate formats also contain meaningless data items, known as noisy data.

ELECTRIFYING A MAINTENANCE FLEET

ENGIE is a leading energy and services company focused on producing and supplying low-carbon energy, and performing energy services and facility maintenance. In the UK, ENGIE has a fleet of 2,000 vehicles for its maintenance and service engineers, many of which are fuelled by diesel. Before transitioning to using electric vehicles, ENGIE wanted to know how many charging points it needed and where, with the ultimate aim of installing charging points so that engineers' vehicles can be charged while they work.

ENGIE worked with the National Innovation Centre for Data (NICD) to develop its new 'Go Electric' data model, which aims to ensure that transitioning the company's fleet to electric vehicles causes minimal disruption to its activities. The team designed a model to identify the best locations for electric vehicle charging points while measuring the impact on productivity. To do this, they used telematics data from 54 ENGIE diesel vans over a six-month period to understand the engineers' journeys. The data described routes between 300 buildings in the Wakefield area, to understand where engineers stopped and for how long. After initial data cleaning and exploration, the team used mixed-data programming models, optimisation, and event-driven simulation to identify key charging locations.

Go Electric has now been used across Wakefield, Manchester and Rotherham. ENGIE is also using the model to support its own clients to achieve the same fleet-transition objective.

As data science evolves, so does the data science process workflow that's usually followed to complete a project. This workflow is defined by four main phases, which are usually interconnected:

- business understanding, which involves scoping and planning the project. It's imperative to address the 'right' question before diving into the relevant data.
- data preparation and understanding, which focuses on importing and aggregating data from various data sources, cleaning it by correcting incorrect or inaccurate data, and then wrangling the data by mapping it to more valuable formats for the task at hand.
- modelling, which involves building and evaluating a model to define assumptions about the data-generating process, to find patterns or to make predictions about unseen data.
- deployment, in which the model is integrated into a software environment suitable for users and is regularly checked and updated.

Data science is multidimensional and involves many related tasks. Consequently, it has led to many job specialisations, including data analysts, data engineers and machine-learning engineers, each focusing on specific parts of the process, with many overlapping skills and blurred boundaries. There are challenges associated with all these roles and their associated tasks that are common to many scientific disciplines including engineering.

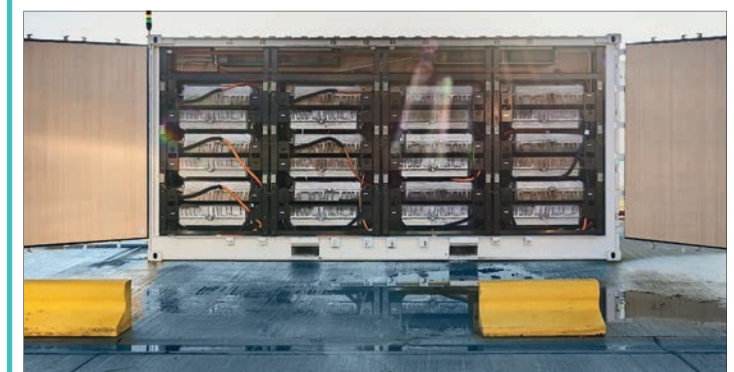
DATA CHALLENGES

One of the biggest barriers to successful adoption of data science is insufficient investment in data engineering. This focuses on building stable and optimised data systems and development and deployment ecosystems, to support the data science process. There are, for example, increasing demands for data storage and management skills. This is for several reasons, including the large volumes of data being collected and analysed; growing requirements around high computational efficiency, and the need to run engineering simulations that can explore behaviours under variable conditions. Another reason is to understand emerging computing paradigms, including edge computing, in which system architectures will be decentralised, moving computing and storage closer to the data source to deal with issues such as unpredictable networks, latency and bandwidth limitations. These are all data engineering skills and taking advantage of these methods and tools can help build robust systems, to handle high-volume and high-velocity data flows that can be scaled and adapted.

Data analytics is the science of analysing data to extract valuable insights, and it is becoming a core skill set for engineering. Now, tools developed to handle large and complex datasets have enabled large-scale, real-time analytics. Four broad categories – descriptive, diagnostic, predictive, and prescriptive analytics – can be used depending on the requirements. Descriptive analytics focuses on using historical data to identify trends and relationships. Civil engineering, for example, uses descriptive analytics to identify relationships between parameters that interact and affect the stability

Civil engineers use descriptive analytics to analyse factors that affect the stability and rigidity of buildings to earthquakes © Unsplash

MAKING SUSTAINABLE ENERGY STORAGE MORE RELIABLE



A stacked battery bank for electric vehicles © Connected Energy

Connected Energy (CE) is an engineering-led innovator in energy storage, with its systems in use across the UK and Europe. It specialises in technology systems for grid decarbonisation by repurposing second-life electric vehicle (EV) batteries. This will help the transition to more sustainable, but intermittent, power generation methods such as wind or solar by storing excess generated energy and discharging the batteries when solar or wind generation is low. Importantly, by redeploying partially degraded EV batteries in stationary storage, CE almost doubles the usable lives of the batteries before recycling.

The project with NICD initially focused on developing models to better understand how battery health degrades over time. Initial time–series forecasting exposed a need for more accurate data, by performing several physical experiments and creating a cloud-based automatic data-cleaning pipeline to process and store this data for future reporting and investigation. This allowed CE and its external customers to access periodic descriptive reports, via PDF or dashboard.

As a result, CE's reporting and monitoring process improved greatly, ensuring that batteries are discharged equally, and outputs are highly accurate. Improved data accuracy has increased confidence in offering warranties on second-life battery systems, improving the attractiveness of the overall offer.

Engineers use time-series analysis to forecast traffic for transport planning, to design transport management solutions © Unsplash

and earthquake rigidity of buildings. Similarly, mechanical engineering uses descriptive analytics to identify trends in equipment performance and spot faulty machinery, to reduce the time taken for failure recovery and increase productivity.

Predictive analytics is used to make predictions about future outcomes using data-driven models. Here, classical statistical methodologies, machine learning and deep learning techniques are all used for predictive modelling, depending on the task, type and volume of data available. In practice, predictive analytics can be used in various fields of engineering. In transport planning, for example, engineers use time–series analysis for traffic forecasting to design transport management solutions. Electric vehicle (EV) engineers can use models to predict the ability of EVs to complete specific journeys for given battery levels and collaborate with transport engineers to determine the optimal locations of charging points (as in 'Electrifying a maintenance fleet'). Chemical engineers use predictive analytics to calculate chemical properties of mixtures and materials. A model trained on spectrometry data for mixtures, for example, could predict the chemical components of an unseen mixture to ensure that it meets the specified requirements, before being further used in production. This is a major asset to improve productivity and support quality assurance.

Finally, diagnostic analytics is used to identify causal relationships by comparing trends and investigating the reasons behind them, such as a drop in performance, whereas prescriptive analytics uses data to determine an optimal course of action. Electrical engineers use the prescriptive analytics to design an optimal power grid that avoids failures and outages in a building by introducing interventions to prevent costly maintenance activities and downtime.

However, while harnessing the data analytics skill sets is vastly improving the efficiency and accuracy of solutions and driving progress, finding people with these highly technical skills is becoming a major problem for most industries, including engineering (see 'Building data skills'). This is a problem that will need to be solved, if data science is to be used to its full potential to unlock innovation across sectors in the UK.

OPTIMISING HULL PROTECTION

Dry dock hull inspection © AkzoNobel

AkzoNobel is a global expert in paint and coatings, and owns familiar brands such as Dulux. Its products are used to decorate homes and businesses, protect infrastructure such as pipelines and turbines, and to coat aircraft, vehicles and marine vessels.

Working with NICD, AkzoNobel focused on the performance of anti-corrosive coatings, which help to protect its customers' boat hulls from everything from saltwater damage to barnacle adhesion. Although they can last for up to 30 years, ships need to check back into dry dock every five years for inspection. Vessel operators want to keep time in dry dock to a minimum, to save time, money and fuel. AkzoNobel was looking for a way to allow customers to predict how their hulls were holding up, without having to wait for a docking or expensive dive inspection.

The project developed a new approach to handle data capture. This included data cleaning and identification of the most informative characteristics in the data (feature extraction), across AkzoNobel's internal coating and vessel inspection data, along with external data describing vessel movements and global water conditions. The datasets used were too large to be processed locally so the project performed batch processing in the cloud for this task. After evaluating several classification algorithms, the result was a random forest classifier (a commonly used machine-learning algorithm) that can accurately predict the level of corrosion present on a given vessel. AkzoNobel was then able to develop a minimum viable product that could offer real value to its customers.

BIOGRAPHIES

Barry Hodgson has over 25 years of experience in both commercial and academic environments, working exclusively around software innovation and research. His ideas, generated from working in successful software spin outs and academic research, led to the creation of the NICD, where he focuses on addressing the data skills gap to improve overall UK productivity.

Antonia Kontaratou obtained her PhD in computational statistics from Newcastle University. She helps organisations discover new data technologies and develop the skills they need to tackle their data science problems. She is currently focused on deep learning.

BUILDING DATA SKILLS

Data science is a relatively new discipline, and the skills required to address more complex problems are highly specialised and wide-ranging. The 2021 report *Quantifying the UK Data Skills Gap* found that there were as many as 234,000 data roles still to be filled.

As demand for data skills continues to accelerate, engineering will need to remain creative about ways to recruit, retain and retrain its existing workforce. A change in engineering education can also ensure that all engineering graduates are equipped with the data science skills they will need to drive innovation over the coming decades and help to install a data-driven culture across engineering businesses.

Apart from the technical and coding skills that a data scientist should have, the ability to work collaboratively and communicate their findings in an audience-specific way are equally important. Typical challenges for data scientists include combining the appropriate scientific tools, the responsibility of aggregating various data sources, preparing the data and asking the right questions.

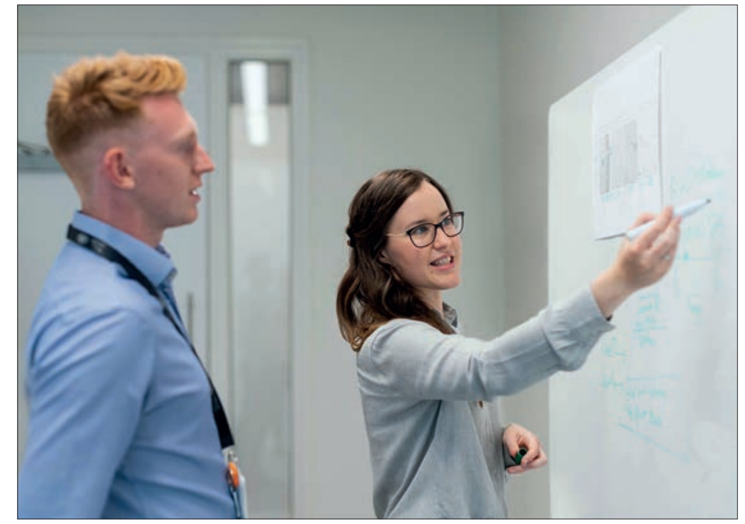
There are numerous paths that someone can take to become a data scientist. In recent years many universities have added bachelor's degrees in data science to their curriculum. Similarly, more and more universities offer relevant master's courses that usually accept candidates with undergraduate degrees in IT, maths, computer science, engineering, physics, or related fields. For people who want to acquire a more focused background, a PhD can provide them with not only in-depth technical knowledge but also transferable skills to apply edgy techniques in industry and of course in research.

But hiring new talent is very competitive and demand is vastly outstripping supply, so upskilling existing employees is a viable alternative. Training presents a perfectly good way to get upskilled, providing the employer accepts the constraints. It can take months to learn the ideas behind one data science skill and years to become proficient.

Alternatively, consultancies can offer employers the comfort of a team approach and a broader set of data expertise. Outsourcing data skills can enable projects to progress immediately, but it will need a healthy budget.

There are also some pragmatic downsides for the business when knowledge is outsourced. When the consultants hand over the deliverables and leave the premises, will the business really understand what is happening under the hood, as insights are served up from a shiny new analytics dashboard? Will it realise when the dashboard has become inaccurate because the data on which the model was trained is now unrepresentative? It is therefore imperative that the data scientists left in the business ensure that all the relevant knowledge is transferred from the consultancy team.

The talent supply gap and the problems that industry faces to upskill employees, has led to new ideas around ways to engage existing talent on data-driven problems.



One model, run by NICD, supports an organisation's existing workforce to better understand its own data. NICD's team of data scientists brings skills covering data wrangling, analytics, scalable compute, machine learning, visualisation and more to address an industry problem. Upskilling is achieved through collaborative projects, where organisations use current business problems (resolved by using their own data) as the testbed to build relevant skills. These projects focus on innovations, creating efficiencies or exploring new products and services that can be integrated into their existing infrastructure to maximise impact. This engagement method also removes the need to take employees away from the 'day job' to undertake external training and allows the organisation to understand the relevant data skills required to address their own business needs.

The outcome of projects like these is to leave collaborating organisations with a solution that they understand, built from the ground up, which they can continue to develop using their own in-house talent and skills they have obtained on the journey.

© BP

PHASING IN GREENER REFRIGERATION TECHNIQUES

Food ready to be shipped in temperature-controlled containers © Adobe

PHASING IN GREENER REFRIGERATION TECHNIQUES

Did you know?

- Some of the most polluting road vehicles are those with onboard refrigeration. However, these are essential to keep food waste in the supply chain at a minimum
- This is because larger trucks and lorries often use diesel-powered engines with fewer emission standards than regular engines
- Phase change materials – a bit like the ones used in hand warmers – could be used to keep perishables at the right temperature instead

It's a sobering prospect: a third of all food produced for human consumption is wasted. While there are many things that can be done at home to cut down what goes into the food bin, how about before it reaches you? Today, refrigerating vehicles in the food supply chain are some of the most polluting ones on the road. Luckily, greener alternatives are in the works. Dr Anna Ploszajski spoke to design engineers Lin Cong and Derek Chapman about one potential option: phase change materials.

According to the latest Department for Transport report, in 2020, domestic transport produced 24% of the UK's total greenhouse gas emissions, making transport the largest overall emitting sector. Not enough is being done to change this – there was a mere 3% reduction in emissions from domestic transport between 2009 and 2019. Some of the most polluting vehicles are those with onboard refrigeration, which is imperative for the transport of perishable food and medicine.

What's more, 13% of all food is lost after harvesting and before being sold, due to insufficient cooling and temperature control in the supply chain. Engineering a better solution for transporting perishables could therefore contribute towards meeting the government's targets of the UK becoming a net zero economy by 2050.

Current vehicular refrigeration systems work in the same way as your fridge at home. A compressor compresses a gaseous refrigerant, which causes it to heat up. This hot gas flows through condenser coils on the outside of the fridge. It loses heat to the environment and condenses into a liquid. The pressure of the liquid drops down as it is passed through an expansion valve and it becomes a liquid/vapour mixture. Then the refrigerant flows into evaporator coils, where it evaporates and expands into a low-temperature, low-pressure gas, making these coils – and therefore the inside of the fridge – cold. The gas then returns to the compressor where it becomes a liquid again, and the cycle continues. A thermostat measures the temperature inside, and automatically initiates this cooling cycle when the inside of the fridge reaches the upper limit of acceptable temperature.

In smaller vehicles, this system takes power from the vehicle's main engine, but larger trucks and lorries use an auxiliary engine – usually diesel-powered. There are fewer emission standards for these extra engines than there are for standard vehicle engines, so these systems are noisy, polluting and increase fuel consumption. Furthermore, they are based on a thermostat system, which means the temperature inside fluctuates within a range. They're also reliant on the engine running, putting the contents at risk in the event of breakdown.

The challenge, then, is to engineer a portable cooling and temperature control system that doesn't rely on diesel-powered engines.

ONLY A PHASE

One solution is switching from a conventional refrigeration system to one based on solid-to-liquid phase change materials (PCMs). A familiar example of PCMs is sodium acetate heat pads, like the ones in hand warmers. Click the flexible metal disc inside the liquid-filled plastic pouch and crystallisation is nucleated in the supersaturated solution of sodium acetate. This phase change releases pleasantly warm heat. The pads can be reset by placing the pouch in boiling water, thereby re-dissolving the sodium acetate.

The material itself remains at a constant temperature during the phase transformation. The heat energy released or absorbed by the material during the transformation is called latent heat, and it's this that could be exploited in PCM-based systems for refrigerated vehicles.

In the vehicle, the PCMs can be encapsulated into tubes, beams or plates inside an insulated unit. The melting or freezing point of the PCM can be selected to match the ideal storage temperature of the perishable produce. The idea is that the system can be 'charged' (the equivalent of boiling the sodium acetate heat pads) by plugging it into the electricity grid at night when demand and prices are low, and then provide cooling in the vehicle during the daytime. If the temperature inside the unit becomes too warm, the material will melt, absorb heat from the unit and cool it down. If it gets too cold, it will freeze and release heat, thereby helping to maintain a steadier temperature.

The PCM materials in these systems must be carefully selected to have freezing/melting temperatures that match the requirements of the goods being transported. Often these are paraffins, salt hydrates or salt-water solutions, with modifications and additions to provide long-term performance and stability. Hubbard Products Ltd is one company developing PCM and systems that they believe will make an impact on the food transport sector.

PROTOTYPING PHASE CHANGE COOLING

To prove the concept, Hubbard tested a prototype of a PCM-based refrigeration system in Spain that represents a hybrid between the traditional refrigeration units and a fully PCM-based one. "This system combined a PCM storage tank with a conventional carbon dioxide-based refrigeration system," explains Lin Cong, design engineer at Hubbard. In it, the PCM tank was used as a subcooler – a component that deliberately cools the liquid refrigerant in the condenser coils before it expands, making the conventional refrigeration cycle more efficient.

The researchers found that this hybrid system increased cooling capacity by 5% and reduced electrical power consumed by 18%. "The PCM-based passive cooling unit part also served as a backup source of cooling in the event of unexpected shutdown of the conventional cooling system," says Lin.

The potential savings from PCM systems depend on how cold the fridge unit needs to be, and also the ambient temperature outside; long and hot summer periods are particularly challenging. The cost of Hubbard's proof-of-concept system involved prototyping and commissioning one-off components; the engineers hope that by upscaling and engaging with the tank and coil suppliers to achieve a single source design, they could reduce the price at least by half.

But the path to realising the potential of these technologies isn't straightforward. While conventional refrigeration units are heavy, each PCM-based unit contributes to the weight load onboard. The more food crates there are, the more units will be onboard. If the total weight of PCM-based units onboard is too high, this could reduce fuel efficiency. As a result, developers and manufacturers must cooperate to ensure PCM modules are used in the supply chain effectively. This could be achieved with several approaches, including calculating the PCM weight according to the cold load requirement; using favourable PCMs with high latent heat, or fully replacing the refrigeration units with PCM modules and recharging the material at a charging port station. It will also need initial financial investment, in order for cost and fuel savings to follow.

Future developments of these materials include formulating solutions with larger latent heat and thermal conductivity, adding gelling agents to avoid phase separation and trying to limit corrosion on parts, either by using more compatible container materials or adding corrosion inhibitors. Their green credentials also rely on the energy used in the

> *"Currently, there is major demand during daytime and significantly reduced demand at night. It's incredibly inefficient to start and stop power generation facilities regularly, so there is a lot of wasted energy. Using PCM technology in the cold chain is one way of addressing this"*

'charging' processes coming from renewable sources. So, it could be necessary to liaise with energy suppliers to ensure the energy stored in the PCMs comes from sustainable sources. "The results we've seen from the testing that we've done are very promising," says Derek Chapman, Design Section Manager at Hubbard.

The potential applications for PCMs extend beyond road transport. PCMs used in static settings – like a cold room, for example – would work "like a battery," says Derek. "During high energy cost and demand periods, we can significantly reduce the electrical load required for the system. Then, at low energy cost and demand periods, we can recharge PCMs [the equivalent of boiling the sodium acetate heat pads to reset them]. It's not necessarily a huge efficiency gain but it can be a huge gain in terms of cost, and if it's done on a large enough scale, it could have big implications for demand in the national grid."

"Currently, there is major demand during daytime and significantly reduced demand at night," adds Lin. "It's incredibly inefficient to start and stop power generation facilities regularly, so there is a lot of wasted energy. Using PCM technology in the cold chain is one way of addressing this."

These static applications could be used in energy-efficient buildings and supermarket fridges. They could even be incorporated into textiles, embedding microencapsulated PCMs into the fabric, to serve as smart, temperature-regulating clothing.

And the future of the sector is promising. "There are numerous exciting opportunities for aspiring engineers in the food and drink industry," says Derek. "Robotics and automation in factories and warehouses, and refrigeration design for maintaining the cold chain from farm to fork all requires mechanical and electrical engineers to name but a few. The impact that food and drink engineering has on the world is so massive, but it often gets overlooked."

BIOGRAPHIES

Lin Cong, a design engineer at Hubbard Products, was awarded her PhD by the University of Birmingham. She has a profound knowledge and experience in thermal energy storage and cold chain.

Derek Chapman is a design engineer for Hubbard Products with a master's degree from the University of Sheffield. He has 12 years of experience in the research and development of new refrigeration systems and technologies.

Thanks to Ilias Katsoulis and Ashwaq Mohammed for their contributions to the article.

FRUIT PICKERS WITH POTENTIAL

Robots could have a place picking and packing fruit and vegetables, reducing the amount of food waste that is increasing because of a shortage of seasonal workers © Dogtooth

FRUIT PICKERS WITH POTENTIAL

Did you know?

- Each year, more than 60,000 seasonal workers are needed to harvest the UK's fruit and veg crops
- A shortage of workers has resulted in tonnes of fruit and veg going to waste
- Engineers are developing specialised picking and packing robots that could help plug the gap caused by this shortfall

Dozens of engineering enterprises are trying to find ways of picking fruit and vegetables with robots. Nearly all of them have focused on strawberries. Dominic Joyeux asked Professor Simon Pearson, Dr Duncan Robertson and Dr Atif Syed how much progress these companies have made so far.

The UK, like many north European countries, depends on seasonal migrant workers to harvest many of its crops. It is estimated that 63,000 part-time agricultural workers are needed in the UK annually. At the beginning of 2022, the government had allocated 40,000 seasonal agricultural worker licences, but the Russia/Ukraine war dealt a severe blow to the size of the labour force, with many of 2021's fruit pickers coming from these two countries.

The shortage of visas and delays in visa-processing have resulted in farmers leaving hundreds of tonnes of asparagus and millions of bunches of spring onions unpicked. Many other crops have been lost and ploughed back into the soil, harming the nation's self-sufficiency in food production.

Growers and researchers have been working hard to find robotic solutions to help cover some of the jobs that seasonal workers do. The pace of development has quickened so rapidly that most companies and observers involved feel that human–robot cost parity will soon be reached. Within two, three or four years commercially viable robots could be picking and packing some of the UK's summer crops.

WHY STRAWBERRIES?

Many companies developing horticultural robotics have focused on harvesting strawberries. It is a crop that is universally popular and always in demand. However, many things can affect business success, including diseases, or problems with packing, transport and harvesting. Robotics could help with all these issues and, in turn, be applied to other agricultural crops.

In northern Europe, most strawberry growers employ a 'tabletop' system, whereas in southern Europe, Australia and the US, farmers favour traditional on-the-ground growing. With robots, a standardised approach to how the crops are grown may develop in the future, but for now, developers are designing robots to cope with different farm set ups.

Tabletop systems usually have plants set 1.5 metres high. Pickers can conveniently view and pick fruit without having to kneel or bend to the floor. Plants are in lined growbags so that the plant doesn't touch the soil – being exposed to wet and moist soil for too long can lead to fungal diseases. Strawberries are so-called because straw used to be put under the plants to keep them clean and avoid soil splash, which can blemish the fruit.

Whereas most domestic growers buy June-bearing strawberries that produce one large harvest in late spring or early summer, many commercial growers use 'everbearers'. Everbearing strawberries, cultivated in polytunnels or large greenhouses, can produce fruit from the end of May to the end of October. The UK's prototype machine-learning picking robots already ply their trade during these months, with some then transferring to Australia to further develop their picking skills.

Horticultural autonomous robots need to be built to withstand mud, rain, dry bumpy ground, and dust for hours at a time © Dogtooth

HOW DO THEY WORK?

Most companies developing robots have started their journeys from scratch. They are each developing their own ways of enabling their robots to see, grip, evaluate, transport, and pack fruit. The businesses know that if they can master strawberry picking, which is tricky, then they should be able to adapt their methodology to other crops.

Dogtooth Technologies is one of the most advanced robot fruit-picking companies in the UK, with 70 of its fourth-generation robots already picking tabletop strawberries commercially. Dr Duncan Robertson, the company's Co-Founder and CEO, says that the fifth-generation robot will achieve the same picking costs as humans. It will be demonstrated to customers next year with first deliveries in 2024/25. Human pickers can pick 15 to 30 kilograms an hour at a cost of roughly 50p a kilo and commercially viable robotic picking must be comparably cost effective. At the moment, picking robots are slower and not as dexterous compared to humans, but they can work longer hours and at night.

The first challenge for developers is to enable the robots to model their three-dimensional environments. Dr Robertson first worked with Mat Cook, one of Dogtooth's three co-founders, at Microsoft Research in Cambridge helping to develop Kinect, the motion sensing add-on for the Xbox 360 gaming console. Dr Robertson says that although depth-sensing cameras work well in some applications, they perform poorly outdoors. Instead, Dogtooth's robot uses vision systems based on simple RGB colour cameras. Dogtooth, like others, has used deep learning neural networks to train its vision systems using data provided by human annotators. These machine-learning algorithms enable its robots to interpret their environments using images as input.

By using a stereo camera comprising two cameras set a few centimetres apart, Dogtooth's robot can judge depth from 2D images, and therefore create detailed geometric 3D models of its surroundings. Dr Robertson says: "Our robot takes images of the growing strawberry plant and can understand what each pixel in the image means. It can distinguish individual strawberries and stalks as well as background elements such as leaves and polytunnel infrastructure. It can tell if a strawberry is sufficiently ripe, or if not, how long it is likely to take to ripen." This ability to judge the health and amounts of future fruit is an important advantage that robots have over human pickers.

Dogtooth deliberately doesn't rely on cloud computing resources for real-time picking. This avoids picking interruptions caused by network failure. It also reduces the data needed, and cost, for individual robots. It uses its AWS Cloud resource for higher latency functions such as processing the day's data to inform the grower about expected future yields. Dr Robertson continues: "And when it spots a ripe strawberry, our system then directs the robot's end effector [the device that picks] to accurately grip its stalk and cut it."

PICKING THE FRUIT

Every company developing fruit picking robots seems to have devised a different end effector. Some are cup-shaped and embrace the fruit before breaking or cutting the stalk, others grip the fruit using soft 'fingers'. Some have pincer-like extensions that grip and cut the stalk so as to avoid touching easily bruised soft fruits.

Dogtooth's end effector comprises a pair of slender grippers and resembles a pair of tweezers. A separate cutting edge extends forward and cuts the stalk above the grippers leaving them holding the single strawberry by its stalk.

Some robots drop picked berries directly into a container, but Dogtooth's carries them to a quality control system a few inches away where, under controlled lighting, the strawberry is scanned to detect 16 types of defects such as bruising, mould and asymmetry before being placed into a punnet or waste chute. Berries are weighed and punnets are filled until they reach the required retail weight.

Dogtooth has improved its fifth-generation robots by adding lithium-ion batteries that

Dogtooth's picking device comprises a pair of slender grippers and resembles a pair of tweezers. A separate cutting edge extends forward and cuts the stalk above the grippers leaving them holding the single strawberry by its stalk. The robot arm then carries the fruit to a quality control system where it is analysed for any defects before being placed into a punnet or waste chute © Dogtooth

double the robots' shift times from 8 to 16 hours. The new robot has been designed to be operated by customer personnel rather than Dogtooth's. The company has also added onboard lighting to enable night picking and improve imaging conditions at tricky times of day, such as dusk and dawn.

Picking at night prolongs the berries' shelf-life. Strawberries rapidly lose their freshness and quality if they spend more than an hour in warmth and sunlight after being picked. Picking at night reduces the temperature and light stress on fruit and maintains better internal and external quality with regards to sugars, colour and firmness.

FLEXIBLE FARM ROBOTS

In July 2022, Simon Pearson, Professor of Agri-Food Technology Research at the University of Lincoln, co-chaired the report *Review of Automation in Agriculture* with George Eustice, who was then the UK government's Environment Secretary. The report found that there was an active and emerging cluster of agri-robotic expertise funded by both private and public sector investment that will be able to replace some of the human harvesting roles on farms.

Simon's own university team has made good progress in several areas of fruit picking. It has teamed up with Saga Robotics to run five proof-of-concept Thorvald robotic vehicles autonomously transporting strawberries from field to warehouse.

Saga already run lightweight Thorvald robots in the US, Norway and the UK to apply UV-C light to tabletop strawberries. This controls the powdery mildew that they are prone to, without using chemical fungicides. Looking like two-metre-tall sunbed arches, the robots go up and down rows of polytunnel strawberries once a week applying UV-C autonomously. Saga has found that this treatment works equally well for grapes. The company currently uses a dozen robots all year round at the 35-hectare Clock House Farm in Kent doing jobs such as spraying, crop forecasting and logistics.

Saga autonomous robots apply shortwave light to strawberry plants to prevent powdery mildew © Saga

The University of Lincoln team has focused on using the flexible Thorvald wheeled robots to fetch fruit from pickers and deliver them to the warehouse. Seasonal agricultural workers not only pick but spend nearly 20% of their time taking the fruit from its growing location to storage or packing facilities. The researchers have been working on programming autonomous navigation and safe interaction with pickers and other obstacles within a farm environment (see *In-field logistics*).

AUTONOMOUS PACKERS

Packing is another area of horticulture where there are labour shortages and retention issues. When fruit and vegetables arrive at packing plants, they need to be sorted manually, graded, weighed, and then placed into packaging. The jobs are invariably repetitive, and the industry is challenged by high turnover and recruiting expenses.

In 2022, Wootzano Ltd developed its robotic system, Avarai, and started working with a leading pack-house corporation that supplies fresh produce to UK retailers.

Dr Atif Syed is the Founder and CEO of Wootzano, and also received a Royal Academy of Engineering Princess Royal Silver Medal in 2022, as well as being a member of the Academy's Enterprise Hub. His invention Wootzkin is a patented electronic skin made of modified

IN-FIELD LOGISTICS

University of Lincoln researchers have spent years working to program wheeled robots to transport strawberries from pickers (human and robotic) in growing areas to storage or packing locations. At the large Kent farm they operate on, the team estimates that 100 robots would be needed to service the 900 pickers **in situ** requiring complicated fleet logistics.

Unlike the dedicated pathways that robots work with in factories, farms are much less structured. There will be other farm workers, unaware members of the public using a public right of way, tractors, trailers, and other moving or static obstacles. This means that the robots' navigation systems need proactive safety features.

Autonomous vehicles' localisation systems require more than the GNSS-based solutions used by combine harvesters. These wouldn't work in buildings and would be adversely impacted by the metal structures found in glasshouses and polytunnels. In addition, the traffic flows of dozens of robots need to be coordinated as robots cannot pass each other where growing tables are a metre apart and often hundreds of metres long. As well as avoiding congestion, they would need to be scheduled to reach the right picker or place at the right time to fully exploit harvesting capacity.

The researchers have devised topological maps with the data structure NEAR: N are the nodes representing physical locations in their geometrical map space; E are the edges connecting pairs of nodes; A is the set of navigation actions that the robot can perform; R is a set of Boolean conditions (true or false) that are used to define restrictions to autonomous navigation on the topology. This framework allows the robot to engage in any navigation action and underpins its learning, enabling it to reliably locate and track humans and robots across a large-scale farm environment.

The University of Lincoln's Thorvald robots are equipped with LiDAR (light detection and ranging) sensors and cameras that enable them to comprehend their immediate surroundings. This helps when meeting human pickers who have summoned them to transport their fruit or if they unexpectedly meet humans who have come across their path, ensuring that the robots don't impact or get too close to them © University of Lincoln


The Avarai in action © Wootzano

elastomer, which is used by the Avarai robot. It contains metal electrodes that can be stretched without causing damage to the sensors within, measuring force and pressure.

Avarai is a collaborative robot (cobot) system that works alongside humans. It can estimate weight, trim fruits to size, identify defects, measure quality, pick, and gently place into punnets or other packaging.

Dr Syed says the Avarai cobot: "has been designed so that the relationship between the robot hand and the robot eye – the camera – is dynamic. So you can place the product anywhere and as long as Avarai can see it and reach it, it will, in real-time. It took 20-plus patents using algorithms and software to enable that, but it's resulted in reduced cost on the hardware that ensures our customers get a product that is comparable in cost to human labour. There's no need to reinvent the wheel, but sometimes you have to redesign it to make it more cost effective!"

Wootzano is currently working on a commercial pilot line for packing vine tomatoes. By the end of 2023, Atif expects the Avarai robotic system to be fully commercialised for table grapes and vine tomatoes, and then scale up substantially thereafter to pack other fruit and vegetables.

DELIVERING AGRICULTURAL ROBOTS

Leaders in the agricultural robotics field say that the optimism and excitement created by their rapid progress must be balanced with the reality that widespread adoption is a few years down the line.

Dr Robertson adds: "The UK has enormously innovative growers and they are enthusiastic early adopters of new technology. But we need the UK's horticultural industry to be thriving in order to have the money to invest in robotic automation. Without adequate supply of seasonal agricultural workers that is impossible."

In 2021, nearly 8,000 tonnes of berries worth £36 million were left to waste because of a shortage of pickers. As a response, some of the UK's bigger producers have been developing farms in Senegal, Spain and Portugal so that they can continue supplying the UK market.

Professor Pearson says: "One of the reasons I undertook the government's automation review with George Eustice MP was to ensure that the science evidence in this field is correct. Science and engineering have got a really important role to play in making sure that the facts are presented clearly so that we carry on getting investment in robotics, that we don't lose farms in the process, and don't cause massive disruption in supplies to shops."

In 2020, UK farms produced about 2.5 million tonnes of vegetables and 650,000 tonnes of fruit. Together, these two agricultural strands generated nearly £3 billion worth of business. Agricultural robots have the potential to help grow these production levels by stepping into jobs that people don't want to do. Exactly when the picking robots will match human costs is difficult to pin down, but Professor Pearson adds: "I'm asked that all the time, but I think it will be in three or four years.

BIOGRAPHIES

Simon Pearson is a professor of agri-food technology and Founding Director of the Lincoln Institute of Agri-Food Technology at the University of Lincoln. The institute specialises in developing interdisciplinary solutions to key challenges within the agri-food sector, not least with the application and development of robotic and AI systems. Before joining Lincoln, he spent 15 years within the farming industry and supply chain.

Dr Duncan Robertson is the CEO and Co-founder of Dogtooth, a technology startup that develops and sells autonomous robots for picking delicate berry fruits such as strawberries and raspberries. Over the last two decades, Duncan has had a pivotal role in the success of several high-growth technology startups created to exploit emerging machine-learning capabilities in new commercial applications.

Dr Atif Syed is the CEO and Founder of Wootzano, a robotics company that develops dexterous robotic solutions that can delicately pack soft produce with ease. Dr Syed earned a PhD in electronics/bionanotechnology and engineering from the University of Edinburgh and has since received the Princess Royal Silver Medal for his patented electronic skin, Wootzkin, which allows robots to feel as humans do.

Thanks to Professor Marc Hanheide, Dr Grzegorz Cielniak and Dr Amir Ghalamzan for their help with In-field logistics.

FULL STEAM AHEAD FOR DIALYSIS

For Professor Clive Buckberry FREng, successful engineering needs an injection of artistic thinking, along with a dose of physics and the ability to use pictures to make a point. He spoke to Michael Kenward OBE about how this combination took him from a leading role in the automotive industry into medical technology, as Chief Engineer and Technology Officer of Quanta Dialysis Technologies, which won this year's MacRobert Award for engineering innovation.

"Everybody thinks I'm a physicist but I'm a mechanical engineer," insists Professor Clive Buckberry FREng. The misconception is understandable, given his erstwhile role as head of vehicle physics at BMW. "I always wanted to do engineering design," he says. It all started because he was good at technical drawing. "It was the only O level and A level that I was ever any good at, so that's what I did." When he joined Rover/BMW after graduating, he soon learned that physics provided him with many of the tools that he needed to understand engineering challenges.

"Physics underpins most of mechanical engineering. I never talk in terms of engineering. I usually bring it back to first principles. Then I do experiments, to validate the theory, usually in the lab." Over the years, Professor Buckberry has used this approach to understand engineering challenges from the noise and vibration in cars to the operation of machines for kidney dialysis.

He admits that his engineering career didn't get off to a flying start. His school exam results weren't good enough to guarantee him a college place. Fortunately, he had a training job at local engineering company, Ruston Bucyrus. "If you can get a place, we'll still sponsor you," the company told him. The company wasn't bothered that his A levels didn't make the grade that Trent Polytechnic college had specified. It was still happy to sponsor him if the college would let him in. So, when he rang the college to tell them he had got two Es instead of two Ds (as well as a B in technical drawing, his favourite subject), but still had sponsorship, they told him to come in and give it a go. If it didn't work out, he could switch to a higher national diploma (HND). "It was literally that conversation – I remember, at 10am in the morning – that gave me a passport to the future." In the event, he got on just fine at Trent.

Professor Buckberry recounts his early experience not just to explain how he got where he is today, as Chief Engineer and Technology Officer of Quanta Dialysis Technology (Quanta), but to reflect on the current state of engineering education. "Could you imagine that happening now? There's an emphasis on getting the best grades and everybody wants to go to a Russell Group university. And they have to pay; I got paid to go."

The government's investment paid off. Professor Buckberry not only survived that first year, but he also emerged with an honours degree in mechanical engineering, followed by an 'MTech' in engineering design at Loughborough University. His degrees got him a job with Rover Group, then a part of BMW. His first thought had been a career as a design engineer, working on new cars. "I got to the design studio at Rover and they were doing some fantastic things there." They had even won the Royal Academy of Engineering's MacRobert Award, he recalls. But the thought crossed his mind that he could get pigeonholed in design. "I can almost remember thinking, actually I'm going to be a door-handle designer for 40 years."

FROM DESIGN TO PHYSICS

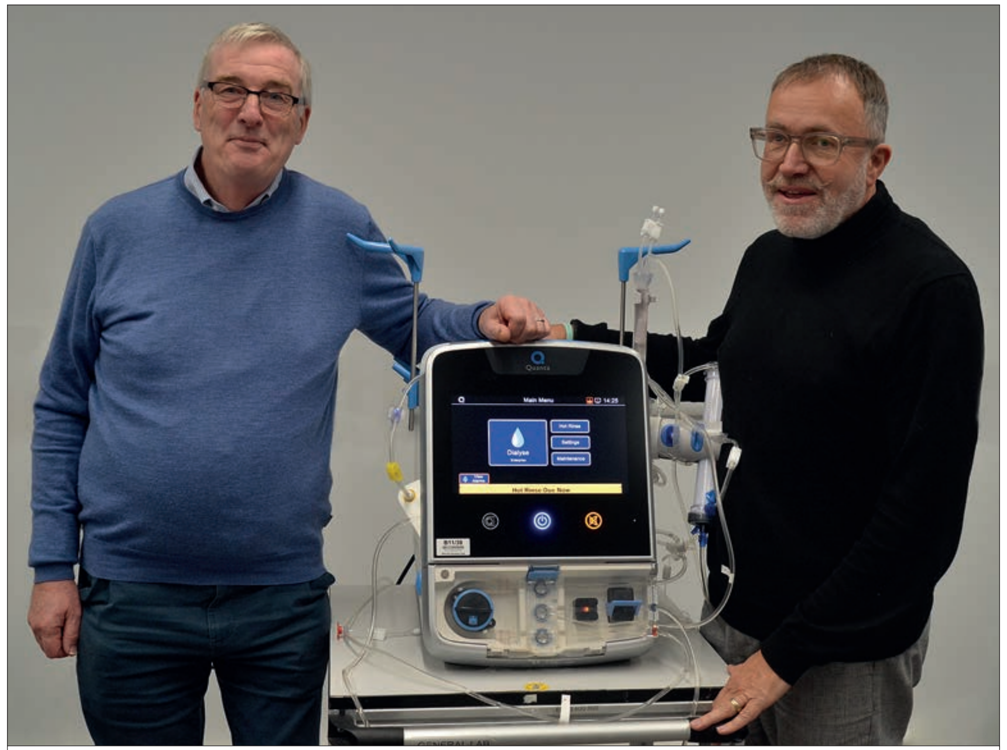
Design then took a back seat: Professor Buckberry began to use physics to understand and solve engineering problems. He worked as a Technical Manager in the Applied Optics Laboratory at Gaydon, which, to this day, is the R&D focus of Jaguar Land Rover. "I did lots of work with holography," he explains. These were the early days of applying lasers to engineering. Back then, 30 years ago, you almost had to have a physics degree to use the tools. "It was quite fundamental work. People just thought I was a physicist." With no academic training in physics, he says, "I always had to go back to first principles. That's when I started to ask physics type questions."

The team at Gaydon was picking up on earlier work by VW's engineers on vibration using "a large ruby laser". Professor Buckberry used a TV camera and Nd: YAG (the type now used to remove tattoos) lasers for interferometry experiments instead. The optics team studied a range of topics, including vibration in car bodies, windscreens, and brakes alongside Heriot-Watt University. In one project, it made transparent engines out of sapphire so that their optical techniques could compare real-world measurements with computational fluid dynamics (CFD) models. He delights in explaining that it resulted in a successful sponsored PhD project at Loughborough University. The academic research took about three months, he says, followed by three years deciding what to write up.

The group also pioneered the use of lasers and fibre optics to measure stresses and strains in car bodies and components in what are called 'speckle interferograms'. Professor Buckberry turned some of this work into his own PhD at Cranfield University on real-time speckle pattern interferometry. In a novel move, the university allowed him to do the research in industry rather than on campus. "I could still do the day job, and then do the PhD in the evening." This was a new approach at the time, that has now become commonplace.

Around this time, Professor Buckberry was drawing on his background and ability to draw to refine his approach to 'selling' the engineers' work to managers. "To get management to buy into something, a picture paints 1,000 words, particularly for engineers. We always used to say at BMW that if you show them a colour picture in real time of complex behaviour, they'll sign it off."

Professor Buckberry's passion for visualising pervades his approach to solving engineering challenges. "I think of how lucky I was just being able to draw." He traces some of that back to his degree course at Loughborough in engineering design. "It's not so much about STEM – science, technology, engineering, and medicine," he explains, "it's about STEAM." The A is the arts, the creative element. "You need that inventive, creative bit to make the rest of it work, in any industry."



Professor Buckberry (right) with Quanta's Systems Engineering Director, Keith Heyes, both members of the original team of engineers developing the technology now utilised in SC+

Professor Buckberry eventually led a department of about 120 people at BMW. "I was running vehicle physics at the time, which was responsible for all of the aerodynamics and acoustics." But he then faced a decision. When BMW decided to divest itself of the Rover business, Professor Buckberry was invited to relocate to Germany. By then he was embedded in the uses of physics, especially optics, and had the chance to become engineering director at Melles Griot, a company that specialised in lasers and optics.

A NEW DIRECTION

Shortly after, he then faced another choice: move to Cambridge with the company or stay near his wife's family in Warwick. Confident that he'd find something to do, they decided to stay. It didn't take long: a job ad took him to a company called IMI Vision, an in-house ideas operation tasked with helping its parent company, IMI Plc, one of the UK's leading engineering businesses. IMI Vision, as he describes it, was there to help the plc to "reinvent itself" through organic growth in new areas.

IMI was active in many different sectors that could use engineering input. One business area was machinery for dispensing soft drinks. It was Professor Buckberry's and others work in this area that laid the foundations for the dialysis machine that won the 2022 MacRobert Award. It was one of the projects that IMI Vision hoped to turn into a new business. IMI already made dialysis machines under licence. It wanted to move up the food chain and devise its own machine. That meant going back to the components and looking for a better way of, for example, cleaning valves that got clogged up with deposits during dialysis. This was true teamwork, with attention to the laws of physics playing a key part. Looking for a solution to the problem of clogged valves, Keith Heyes, an original member of the project team, remarked: 'Well, you can't beat the laws of physics. You're always going to get precipitation." The team already had a solution to hand: use disposable components based on valves made for orange juice dispensers. The project was ultimately spun-out from IMI to create a new company, Quanta Dialysis Technologies.

QUICK Q&A

What inspired you to become an engineer?
Watching Tomorrow's World and Horizon on the BBC as a child.

Favourite project you've worked on?
Rover K-series optical engine with full access for laser-based imaging of combustion.

What are you most proud of?
Creating Quanta from the initial ceremonial exchange of £1 to raising more than £400 million of investment.

What's your advice to budding engineers?
Ask lots of questions and don't be afraid to do the experiment and get it wrong the first time trying.

Best bit of the job now?
The sheer variety across engineering, production to clinical application.

Which engineering achievement couldn't you do without?
My glasses.

Most impressive bit of engineering to look at?
Stonehenge.

What do you do in your spare time?
Astronomy with my 18 inch Dobsonian telescope and tinkering with my Manx Triton motorbike.

Professor Buckberry used his ability to visualise what is happening when he wanted to understand the inner workings of the dialysis machines made by Quanta Dialysis Technologies (Kidney dialysis – the take-home option, *Ingenia* 62). "One of the things we did with the dialysis machine – to get it to work and understand how the cartridge worked – was making a machine with a transparent door. The cartridge is transparent, so we could then see the fluid flows within."

Quanta won the MacRobert Award for the SC+, a compact and portable dialysis machine "allowing more flexible and accessible care for patients with renal failure". As Professor Sir Richard Friend FREng FRS, Chair of the MacRobert Award judging panel, said: "Recent success comes on the back of Quanta's considerable journey as a company." As he put it the success took "persistence, innovation and unconventional thinking".

MEDTECH MEETS CYBERSECURITY AND BIG DATA

Developing a new approach to kidney dialysis is hard enough without having to tackle cybersecurity and software reliability in the process. But the team at Quanta had to tackle these challenges before the US Food and Drug Administration (FDA) would even think about licensing its systems. At the same time, there was growing scrutiny of medtech safety in general, after patients experienced problems with, for example, breast implants, stents, and hip joints.

With the rise of the Internet of Things and big data, the software issue was important enough for Quanta to step back and reassess what it was going to launch. "We had to go back to round one with FDA guidance and redo the software for the cybersecurity," Professor Buckberry explains.

Fortunately, Quanta could draw on local expertise in the UK. The engineers took a fresh look at their software after a Royal Academy of Engineering forum on the safety and efficacy of medical devices and systems. Quanta also called upon Dr Philip Bennett FREng who had pioneered the development of technical standards around software. "He recognised that software was safety critical, and it could cause harm in its own right." Dr Bennett was also on kidney dialysis. "He gave us some great guidance and mentoring to help us get our software back in shape."

Quanta was also keen to prepare for the rise of big data and artificial intelligence in medtech. "By 2015, you really were beginning to see the tsunami of what you could do with big data." It anticipated that dialysis machines could become the core around which people would use other medical devices. "There are eventually going to be many personal medical devices and implants that can gather personal data. But that data must be handled responsibly and safely."

Data security wasn't something that you could bolt on to a dialysis machine, so Quanta set out to make it an integral part of the system. In this way, Professor Buckberry believes that the MacRobert Award-winning technology isn't just ahead of the competition medically, it also leads on the software front.

With more than 40 sensors, each machine can monitor the progress of a dialysis session. For example, Professor Buckberry can demonstrate the system and remotely log into company's portal to see a network of machines and active treatment sessions. He can see that the machines are operating as required, and all the patient data is anonymised.

The dialysis machines have their own health-checking system that Quanta can watch, in the same way that engineers can constantly monitor jet engines in the air. "We can start to look at the health of the machine. Do we do a service call on that machine? Does it need to come back to base?"

Artificial intelligence on a machine and big data could provide even more benefits for patients in the future. "I think medical devices are a unique opportunity. There are going to be so many personal medical devices or implants that give personal data that then work with your machine. This sort of thing is going to rapidly change healthcare," Professor Buckberry adds.

FINDING INVESTMENT

The engineers had to find a way to continue their R&D after they were told to stop work on the dialysis project, which became the driver for Quanta to be spun-out of IMI. The engineering advances coming out of IMI Vision were disruptive. "It was almost too adventurous for IMI plc to take on. We just made such fundamental differences. You'd need a new type of factory to make the parts and that became a huge capital investment."

IMI concluded that it couldn't sustain what was in effect an internal 'skunk works', where engineers pursued problems chosen to be the most disruptive. By this time, the dialysis system had quietly reached a stage where the team decided to make IMI an offer, asking Martin Lamb, the CEO of IMI Plc, if it could buy the patents. "Out of naivety you say all sorts of things," Professor Buckberry adds, but the offer was serious enough to interest Lamb. The company even offered to put up 80% of the money for a new dialysis business, to back the seven founders. Inevitably called 'the magnificent seven', the team then raised enough money, with second mortgages and the like, to acquire the patents. "There was a ceremonial signing of the papers, and the patents were handed over for a pound."

That was in 2008. "We had a year to make a prototype and to get the funding from venture capitalists (VCs). Then the problem was, how do we find VCs? The engineering was the easy bit."

Professor Buckberry relates a complicated saga of chance acquaintances, neighbours, and friends of friends who happened to know some VCs. "We were suddenly on the VC merry-go-round across Europe, pitching for money. The first few times you do it, your 'elevator pitch' is all over the place. We're engineers, not salesmen." The team was asking for £12 million. "It's not exactly an easy pitch, is it?"

The MacRobert Award-winning team at the Royal Academy of Engineering's Awards Dinner in 2022. The new award joins Professor Buckberry's RAC Dewar Trophy from 1995 for advances in automotive industry technology. As he says, there can't be many engineers who have collected two such leading awards in such diverse industries as automobiles and medical technology. "For someone who has got no A levels per se. I'm quite chuffed."

It didn't help that when they were trying to raise money for a medical technology (medtech) startup in 2008, there was a financial crash. They made it, with what Professor Buckberry believes was the biggest deal in Europe for medical devices, at the time.

After another five years of engineering work, Quanta began to seek medical certification for its dialysis system. The team also had to go back to the drawing board when the wider medtech community realised that it had to navigate the emergence of the Internet of Things (IoT), big data, and related concerns about data security.

Professor Buckberry paints a picture of a business that, after about a decade of steady progress, ran the risk of stumbling into the so-called financial 'valley of death', a period that faces many tech startups, where the original backers, usually smaller investors, are starting to run out of money. "We're not making any credible returns at that point in time. We can't scale up manufacturing because we haven't got the money. And we can't really switch from prototype parts to volume manufacturing. It was just a whole vicious loop, when you don't have enough money to scale up, but you need to scale up to make the money."

Thankfully a chance conversation on the side of a rugby pitch in Queensland, Australia, brought in another investor. "He was quite savvy. He just saw the opportunity. He liked the story. He said, 'Okay, I'll fund you'."

Once again, the money came from outside the UK. "None of our VC funding has come from the UK," adds Professor Buckberry. "Our initial investors were VCs in Munich, Dublin, and the National Bank of Greece."

The fresh backing took the business through the valley of death. More recently, with US Food and Drug Administration (FDA) clearance in December 2020, Quanta reached a stage where it could adopt a more conventional funding model. "Investors were just knocking on the door. You could not turn them away fast enough," says Professor Buckberry. In June 2021, Quanta raised $245 million to fund the next stage of its growth. In the past 18 months it has gone from about 110 people to 270.

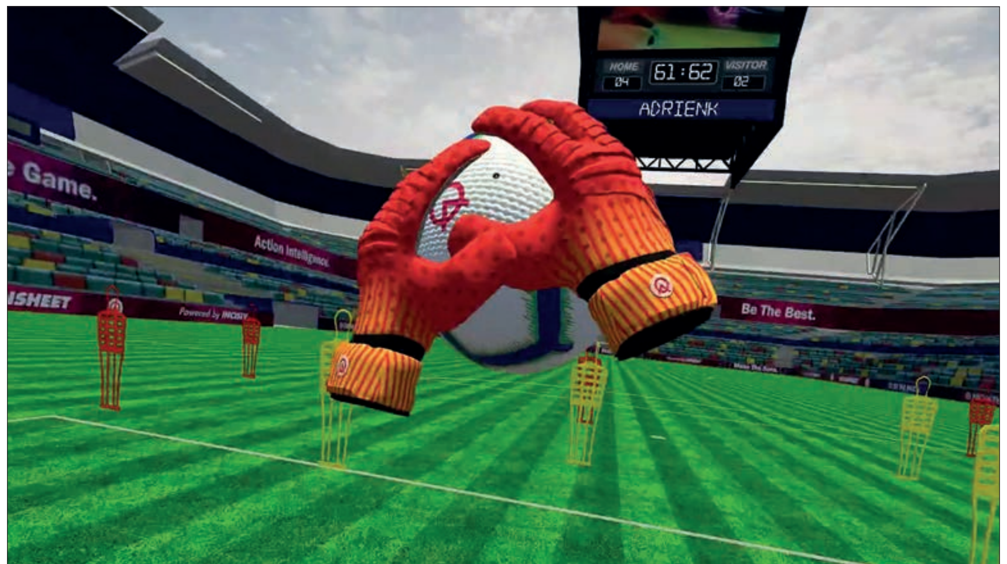
As Quanta's Chief Engineer and Technology Officer, Professor Buckberry sees his strength as an ability to take "more of a helicopter view of the technology". He has stepped in as engineering manager from time to time, but he always likes to look at the bigger picture. "I get to see all the challenges in the business. I get all see all the new opportunities. It's great to be able to have that freedom to play again."

CAREER TIMELINE AND DISTINCTIONS

Studied mechanical engineering, Trent Polytechnic, **1979–1983**. Master's in engineering design, **1984**. Team Leader, Applied Optics Laboratory, **1984–1995**. PhD in TV holography, **1994**. Team Leader, Vehicle Physics, BMW, **1995–2000**. Engineering Manager, Melles Griot, **2000–2003**. Honorary Professor, Heriot-Watt University, **2001**. Director of Science and Technology, IMI Vision, **2003–2008**. Chief Engineer and Technology Officer, Quanta Dialysis Technologies, **2008–present day**. Elected Fellow of the Royal Academy of Engineering, **2011**.

BEND IT LIKE A SIMULATED AVATAR

Some of the most mind-bending goals ever scored have relied on a free-kick-taker's ability to curve the ball in a way the goalkeeper can't anticipate. Training to save these is no easy task. Now, Belfast startup INCISIV just might have a helping hand with an ultra-programmable virtual reality technology.



Footage from CleanSheet from inside the Meta Quest © INCISIV

Lightning-fast reflexes and mental toughness are non-negotiables for any goalkeeper. But what about training for those improbable goals with an unpredictable spin? From the banana shot to the knuckleball – also called *maledetta* (cursed) in Italian, or *folha seca* (dry leaf) in Portuguese – it's incredibly difficult for goalies to anticipate where the ball might hit the net.

That's one scenario that Professor Cathy Craig, the Founder and CEO of Belfast-based startup INCISIV, set out to address with her virtual reality (VR)-based training tool. "Twenty-five years ago, there was a very famous free kick by Roberto Carlos that bent round the wall and came back into the net," says Cathy. "I thought about the goalkeeper: 'what does that mean for them? Is a ball with spin more difficult to stop? If so, why?'."

At the time, Cathy was a lecturer in experimental psychology at the University of Aix-Marseilles, and wanted to understand the goalkeeper's visual perception and decision-making processes. She settled on using VR to dig into this – which in 1997 was clunky, heavy, and incredibly expensive. "It cost €10,000. The scene was a very rudimentary green rectangle. The ball was a sphere. The posts were just cylinders. The movement of the ball was determined by a time series file that was read in," she says.

Nevertheless, when Adidas's football innovation team was giving classes at the university, Cathy was asked to speak to them about her work. Impressed, Adidas helped her find subjects to test it out on, connecting her with elite teams such as Olympique de Marseille, Bayer Leverkusen, and AC Milan.

Over time, as VR headsets got drastically cheaper and better, Cathy realised VR could become more mainstream. Thanks to this, plus all the expertise Cathy gained from working with high-level players, INCISIV and CleanSheet Pro were born. "[It] was really built on that early research where we'd have a deep understanding of the movement response of the goalkeeper – in milliseconds, really, which involved recreating different scenarios or different types of shot."

THE INGREDIENTS OF A REALISTIC GOAL

The software combines two elements: a session generator and motion capture system. The session generator creates the different types of shots and is built on complex physics modelling. "I'm not a physicist, but I had to learn about the dynamics of ball flight. Now, you've got very strong physics engines that are incorporated into lots of software programs to generate more realistic content. So, we've used that plus the expertise of our programmers to make it more realistic," Cathy explains. Meanwhile, the motion capture system uses real-life players kicking footballs to animate the avatar. "It's really important that it's as close to reality as possible."

When a coach chooses a shot from the animation database to pit the goalkeeper against, the software shows the ball's trajectory to the goal. The user can place the ball, put in a defender, and see the ball elevation, horizontal distance, foot contact, and more. Then, analytics show a breakdown of the shots, successfully saved or missed.

Essentially, it allows users to program any kind of goal, in any sequence. "With VR, you can give everybody exactly the same bouquet of shots. In real life, you could never do that. So, you can figure out who really is your best goalkeeper and why," says Cathy. "You don't need somebody in your team that can actually kick that shot."

This is one thing that makes the consumer version of CleanSheet so appealing. INCISIV first launched it in response to requests to its TikTok. To raise awareness of CleanSheet Pro, the company had begun making TikToks analysing free kicks and goalkeeper responses. Now, some of INCISIV's videos have millions of views, and since launching on Meta's App Lab in February, CleanSheet has been purchased over 30,000 times. The software also launched on ByteDance's Pico store in November.

While not as advanced as the pro version (only the head and hands are tracked, rather than six points of motion on the body), Cathy says it gives people the ability to train seriously and have fun. "You've got kids saying, 'I wasn't starting for the school team. Now I am and we're winning everything'," she says. Furthermore, CleanSheet's strong user community has even suggested new features and game modes that INCISIV will be rolling out in the coming months.

The user setup for the consumer version of CleanSheet, used with the Meta Quest headset
© INCISIV

CRACKING THE COACHES

The CleanSheet Meta app has become its own way of raising awareness of the pro version – despite being spun off it in the first place. For example, the Israeli national team was using the game and making enquiries about more advanced capabilities. "We're going, funny you should say that!" she laughs.

This could help INCISIV further develop its business model because, despite the vast sums of money available to clubs and the 'marginal gains' mindset of the elite sporting world, clubs can be surprisingly resistant to adopting new technologies. "Everybody focuses on strikers, but actually to keep a clean sheet can mean the difference between relegation or promotion – being in the Champions League or not, which is worth millions," she says.

It's certainly true that no one else has an equivalent technology that's grounded in so much science. "Twenty-odd years is not an insignificant amount of time to spend on this problem – we know how to harvest this behavioural data and draw meaning from it," says Cathy.

And there have been some fascinating learnings from it. For instance, the team has shown that for curved free kicks, the goalkeeper should wait to get a better handle on the ball's trajectory before responding. Then, there's the wall. "That's one of the biggest debates," says Cathy. "I'm like, 'how is that helping the goalkeeper?' You actually block the view of the ball and our research showed that initial occlusion of the ball gives you less time to read the trajectory and can actually hinder performance. You'll find attackers will bend the ball over the wall, use it to their advantage. CleanSheet Pro allows you to look at what might be the best placement of the wall for your players. Everybody's different – some people like to have that occlusion, others don't."

Ultimately, the technology's grassroots popularity and results speak for themselves. The Belgian team who used CleanSheet Pro finished top of their league last year, their goalkeeper with the most clean sheets. Perhaps CleanSheet will make the *maledetta* a little less cursed.

EYES ON THE INNOVATORS

***Ingenia* is keeping a close eye on the startups using their engineering know-how to disrupt the status quo.**

Planet-saver: **Notpla**'s biodegradable plastic alternative has been shortlisted for the Earthshot Prize

Obsydian's machine that inscribes under the surface of diamonds to make the diamond industry more traceable and ethical featured on BBC News

Heroic: **Open Bionics**' life-changing bionic arms are now available on the NHS to eligible patients

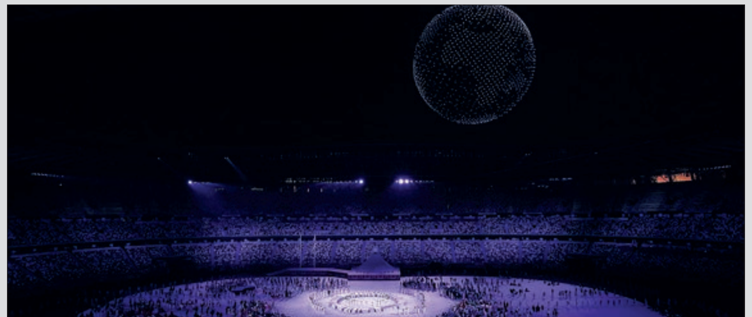
Congrats to sustainable brickmaker **Kenoteq**, which won the public vote at the Dezeen Awards in the 'Sustainable Design' category

Getting warmer: **Tokamak Energy** has achieved the highest output results by a private fusion energy company ever

HOW DOES THAT WORK?

COORDINATED DRONE LIGHT SHOWS

From London's new year fireworks to the Tokyo 2022 Olympic opening ceremony, coordinated drone displays are creating spectacular light shows in the night skies, with clever engineering creating a system that can be flown safely and repeatedly.



A drone display moves into the stadium during the Tokyo 2022 Olympic Games opening ceremony © Lui Siu Wai/Xinhua News Agency/PA Images

Drones – or uncrewed aerial vehicles (UAVs) – are a widely used technology, with uses ranging from filming in hard-to-reach places for TV shows and films, to carrying out remote maintenance, to monitoring the weather or getting that perfect photograph.

In recent years, coordinated drone light shows have become more prominent. These displays are performed by illuminated, synchronised and choreographed groups of drones that arrange themselves into various aerial formations, from cars and words to moving patterns and animals. While the drones themselves are not unusual (How does that work? Drones, *Ingenia* 73), they are fitted with LEDs (light-emitting diodes) in different colours to light up the night skies.

Coordinated drone fleets came to prominence in a 2012 TED talk about autonomous robots that swarm or flock, sense each other, and form teams, delivered by Professor Vijay Kumar, the University of Pennsylvania's Dean of Engineering. That same year, a coordinated display of 50 drones over Linz in Austria at the Ars Electronica Festival was the first of its kind and set the world record for 'most UAVs airborne simultaneously'. Since then, drone displays have been used for advertising purposes, PR stunts, and at major events such as Olympic and Paralympic ceremonies. In March 2021, the world record was broken by luxury car brand GENESIS, which flew 3,281 drones in formation above Shanghai to announce its arrival into the Chinese market.

To create these shows, designers first put together a storyboard and timeline that shows the required images and effects, then software engineers create a synchronised flight path for each individual drone. Advances in technology have made it possible to fly hundred of drones together – a complex algorithm directs the drones to where they need to be throughout the display and onboard cameras and proximity sensors ensure that they don't collide in the air. For the drones to act as a swarm, each drone communicates and shares data with its neighbours – knowing the intended shape of the display via the algorithm and communicating with drones in the immediate surroundings is enough to form the intended shape. Drones do have limited processing power in their onboard computers, but technology is advancing all the time so in future they could move adaptively by themselves without needing to be programmed in advance.

A ground control station sends the unique program via radio signal to the drone and when the time is right – the batteries fully charged and the flight area clear – the drones set off to complete the storyboard in the sky. The ground control station is operated by a pilot, or pilots, who continuously monitors the flight paths. They are also usually aviation experts with specialist knowledge of airspace restrictions and laws prohibiting drone use, as well as having a keen eye on the weather – displays can't happen if it's raining or if there are high winds.

While coordinated drone light shows are being seen more regularly, several factors do limit their use, including high costs, the time and labour needed to produce them, and regulatory and safety approvals. They could also potentially disrupt birds' flight patterns. However, drone light shows could be an environmentally friendly alternative to fireworks: drones don't produce any polluting emissions or loud noises, are reusable, and reduce the risk of wildfires in places with drier climates.

So, while you're still more likely to see such displays at big events or for advertising purposes, a coordinated drone light show could soon be at your next local Guy Fawkes Night celebration.