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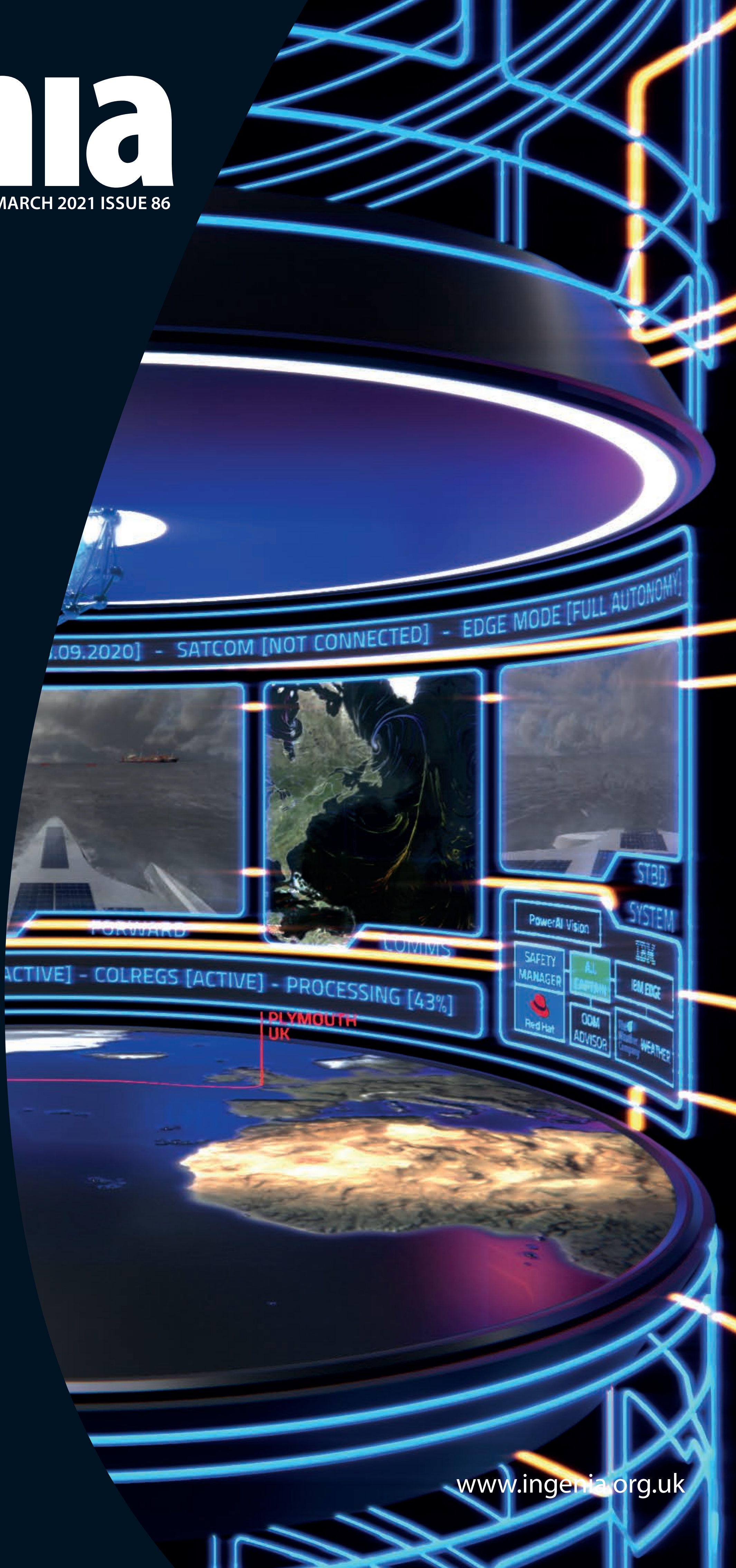
MINING FROM LANDFILL

RAPID PANDEMIC RESPONSE

RECORD-BREAKING WIND FARM

AUTONOMOUS ATLANTIC CROSSING



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Front cover

Visualisation of a digital twin for the Mayflower Autonomous System
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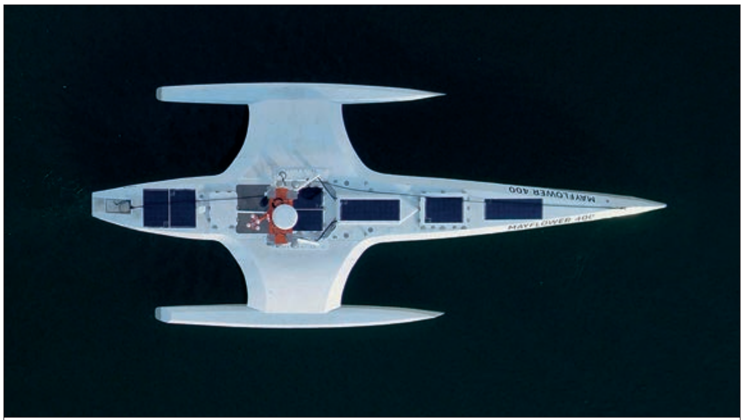

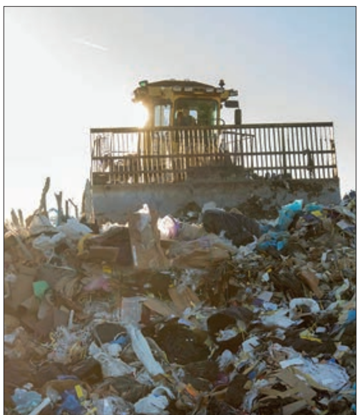

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EDITORIAL

THE FUTURE HAS BEGUN

Scott Steedman CBE FREng

For UK engineering, 2021 started as no other year in recent history. Engineering has never been more visible in the media and in the national psyche.

Chemical engineers continue to work at extraordinary pace to scale up the manufacture and delivery of novel vaccines. Telecommunications engineers are removing 'high-risk vendors' from 5G mobile networks, while software engineers are striving for alternative approaches that will pave the way for 6G communications networks.

The media is full of articles about the potential for digital trade, digital services and digital transformation. Urgent changes in the building sector, to address the Grenfell tragedy, are underpinned by new building regulations that will transform the industry. The HS2 rail link is under construction: the new phase will connect the high-speed service into the existing railway network, reaching Liverpool, Manchester and Glasgow. Advanced manufacturing technologies are replacing historic practices. Engineers of all disciplines are working on large-scale renewable energy projects in wind, hydrogen and electricity storage.

It is essential to accelerate innovation in engineering as we seek strategies for success in a post-Brexit UK, to deliver goods and services in a new, pandemic-dominated world, respond to the urgent risks of climate change and the pursuit of net zero, and to exploit the digital age's unlimited opportunities.

One of the main lessons for engineering from the national response to COVID-19 has been that coordination of effort combined with strong government policy is more effective than innovation driven by individual corporate motivation or simple return on investment arguments. Input from engineers is essential if we are to forge a national strategy that unlocks the full potential for national renewal.

Strong commitment from government as the pandemic struck enabled rapid progress in the ventilator challenge, vaccine development, regulatory approvals, and manufacture. The Department for Culture, Media and Sport, with support from industry, academia and other institutions, is leading a coordinated approach to the challenge of telecoms diversification to improve the security and resilience of the 5G network.

Innovate UK, the non-departmental public body responsible for funding business and research collaboration, has made great efforts to embrace the whole eco-system in its soon-to-be-published five-year strategy for business innovation, working with industry and academia but also with national intellectual property, standards and metrology organisations. Supported by the Ministry of Housing, Communities and Local Government, the Industry Safety Steering Group chaired by Dame Judith Hackitt DBE FREng is challenging the construction sector, clients, owners, and financiers to transform their approach to building safety through-life, from design and build to operation and maintenance, putting people first.

These are encouraging signs that we are starting to come together as a nation more frequently and more effectively to tackle the great challenges and opportunities ahead. Engineers are increasingly called upon to work with policymakers, industry leaders and wider society to agree on the desired outcome and are no longer just expected to 'make it work'.

Time is too short to tackle national imperatives one random step at a time. For every national challenge or opportunity, engineers must step forward and work with government, industry, academia, and all stakeholders to shape, as well as deliver, the vision and strategy the nation needs. They need to do this individually, through their organisations, through the Royal Academy of Engineering and the professional engineering institutions, working in unison wherever possible, for example through the National Engineering Policy Centre. There has never been a more exciting time for engineering or for engineers. It is a whole new world. The future has begun.

Throughout my time as Editor-in-Chief, *Ingenia*'s Editorial Board has worked tirelessly to showcase the achievements of UK engineering. I took up the role in 2004 and after 66 issues, I am delighted to be handing over the role of Chair to Faith Wainwright MBE FREng, who will lead the magazine's development for the next few years. What the Editorial Board and the Academy have achieved over the decades, since the first issue of the magazine in 1999, has only been possible because of the Board members, several of whom served even longer terms than I have, each making their own remarkable contribution to the promotion of the UK's engineers and engineering. I thank them and the excellent editorial team at the Academy, who have shown an enduring commitment to the success of this magazine.

Scott Steedman CBE FREng
Editor-in-Chief

IN BRIEF

LED LIGHTING CREATORS WIN 2021 QUEEN ELIZABETH PRIZE FOR ENGINEERING

LED lighting is 75% more energy efficient that traditional bulbs

On 2 February, the 2021 Queen Elizabeth Prize for Engineering (QEPrize) was awarded to the creators of LED lighting in a livestreamed announcement.

The prize was awarded to Isamu Akasaki, Shuji Nakamura, Nick Holonyak Jr, M. George Craford and Russell Dupuis for the creation and development of LED lighting, which forms the basis of all solid-state lighting technology and is 75% more energy efficient than traditional bulbs.

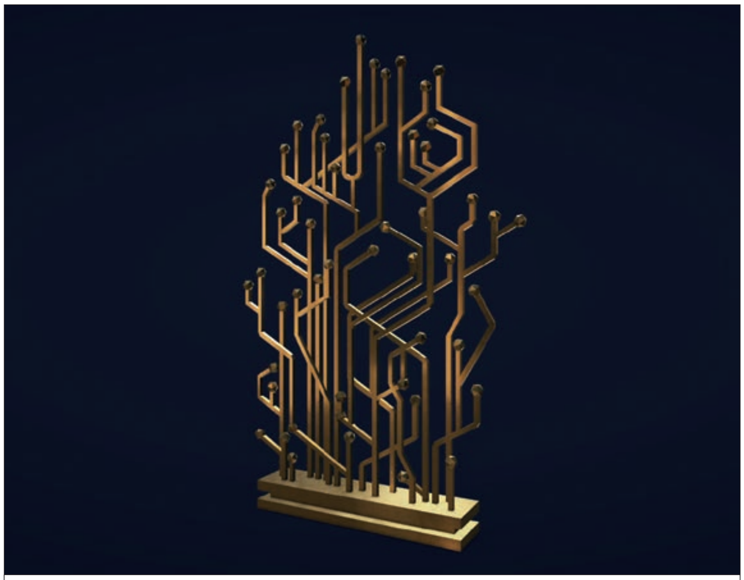
Solid-state lighting technology has changed how we illuminate our world. It can be found everywhere from digital displays and computer screens to handheld laser pointers, car headlights and traffic lights. Today's high-performance LEDs are used in efficient solid-state lighting products across the world and are contributing to the sustainable development of world economies by reducing energy consumption.

Visible LEDs are now a global industry predicted to be worth over $108 billion by 2025 through low-cost, high-efficiency lighting. LED lighting is playing a crucial role in reducing carbon dioxide emissions. LED bulbs last 25 times longer than incandescent bulbs and their large-scale use reduces the energy demand required to cool buildings. For this, they are often referred to as the 'green revolution' within lighting.

On the same day, it was also announced that 20-year-old Hannah Goldsmith from the UK had won the QEPrize's Create the Trophy competition. Open to those aged between 14 and 24 around the world, competitors enter innovative trophy designs to be presented to the winners of the QEPrize. Hannah's winning design combines elegance and complexity and draws inspiration from the circuit boards on which much engineering is done. It will be 3D printed and presented to the winners later this year.

As an indication of the incredibly high standard of this year's entries, for the first time the judges also made a Highly Commended award, recognising the work of 18-year-old Indian student Atharva Gai. Atharva's design impressed the judges with its careful and considered eye for detail and traditional manufacturing techniques.

To listen to a podcast discussion with the winners of this year's QEPrize, or for more information, visit **www.qeprize.org**



Hannah's winning trophy design

MOVIE-INSPIRED DRONES HELP NETWORK RAIL

Network Rail is hoping to explore the many underground caves and mines in its network with a folded-up drone inspired by Ridley Scott's 2012 film, *Prometheus*.

The company has been searching for a device that could travel down a 15-centimetre borehole, enter an underground cave and map its interior for some time. It turned to researchers from the University of Manchester's Department of Electrical and Electronic Engineering, who realised it was a similar concept to a scene in *Prometheus*, where a set of small drones fly through an underground tunnel system, carry out 3D scans of an alien structure and send a map back to the operator.

The drones in *Prometheus* that inspired the drones to be used by Network Rail © Alamy Stock Photo

The 'Project Prometheus' drone must fit through small tunnels, so the team created a folding design where the drone's arms raise up into the flight position once the device has been pushed through the borehole. The drone then detaches and explores the underground space. Due to the darkness and lack of wireless signal, the drone will explore spaces autonomously. The drone will carry a camera that uses lasers and infrared imaging to make 3D maps of its environment.

The project involves a consortium including the University of Manchester, University of Bristol, Royal Holloway, University of London, and Headlight AI, an artificial intelligence (AI) software company. The drone will have its first test flight this spring.

THIRD OF UK SPINOUTS FROM FOUR UNIVERSITIES

In January, a report published by the Royal Academy of Engineering's Enterprise Hub and Beauhurst showed that four universities – Oxford, Cambridge, Imperial College London, and University College London – account for a third of all UK spinout companies.

Spotlight on spinouts: UK academic spinout trends examines where and how effectively innovations developed in universities are being turned into real-world products, processes and commercial successes. Pharmaceuticals, research tools and medtech are some of the UK's largest spinout sectors, and the data also highlights a rapidly developing AI sector.

The report gathers evidence in one place for the first time on the current state of the UK spinout landscape. It identifies a potential trend towards spinouts attracting less new investment but more follow-on funding. The data includes which universities are successfully generating spinouts; their geographic spread; top sectors; investments and who is making them; survival and growth rates and exits; Innovate UK grants; and gender and nationality of leadership.

The report examined trends in spinouts, such as award-winning University of Cambridge spinout H2GO Power

Science Minister Amanda Solloway MP said: "Accelerating the time between concept and commercial application is critical to the UK's productivity, growth and social benefits. I'm delighted that this report will help shine a light on what is required to build successful university spinouts, including how we increase diversity and maximise the commercial opportunities presented by the UK's exceptional academic institutions."

To read the full report, visit **www.raeng.org.uk/spinouts**

EDUCATION RESOURCES FOR REMOTE LEARNING

The Royal Academy of Engineering's education resources have been updated to cater for teachers and students who are remote learning throughout the COVID-19 pandemic.

The Academy's resource boxes, which provide learning activities for use in a STEM club, for a STEM challenge day or to enhance and add context to the curriculum, now come in individual packs that teachers can send out to students. The resources have been developed in partnership with schoolteachers and engineers primarily to engage Key Stage 3 students and enrich the STEM curriculum through hands-on activities and stimulating engineering contexts.

As well as the resource boxes, the Academy's STEM at home portal includes a selection of its science, technology, engineering, and maths education activities that can be easily adapted for the home setting.

The latest *Engineering in a pandemic* resource demonstrates how the engineering community worked together to quickly respond to COVID-19. Challenges include modelling viruses, exploring what happens in an outbreak, investigating lateral flow tests, designing and developing social distancing tools, and testing and trialling different types of surgical masks.

The *This is Engineering: Entertainment* resource explores the essential role that engineers play in the entertainment industry, from tracking sports data and exploring the fourth dimension, to creating light displays and producing a scene in a horror film.

You can find out more about the Connecting STEM Teachers programme and download resources at **stemresources.raeng.org.uk/programmes/connecting-stem-teachers.** Learn more about STEM at home at **www.raeng.org.uk/stem-at-home.**

Teachers and STEM Ambassadors can join a regional network and receive free termly engineering resource packs and training by visiting the website and contacting their local teacher coordinator.

GET INVOLVED IN ENGINEERING

CREATE THE FUTURE PODCAST

Engineering is everywhere. From nanotechnology and the Internet of Things to autonomous vehicles, healthcare, and even your morning cup of coffee – engineering shapes the world around us. Engineers launched us forward from our first use of tools to an era of space exploration, and they will play a central role in solving the challenges of our future. *Create the Future* explores the wonderful world of skill, creativity and innovation that is engineering, and highlights how engineers impact our lives each and every day.

Hosted by science writer and broadcaster Sue Nelson, each episode looks at a different area of engineering and brings together the knowledge, experiences and ideas of both industry experts and young professionals.

Available on all podcast streaming sites.

THE ENGINEERING EDGE PODCAST

Professor Lucy Rogers FREng, inventor and former *Robot Wars* judge, presents a new series of her engineering podcast. The podcast explores how everyday tech can be used in extraordinary ways, and covers topics including how haptic motors are being used to give humans a sixth sense, biohackers, the innovative feelSpace Navibelt that can transform the life of visually impaired people and how to build your own Navibelt using off the shelf components.

https://theengineeringedge.podbean.com/

CREATIVE EARTH COMPETITION

Creative Earth is an art competition for people aged 16 and under from across the UK, run by the UN COP26 Climate Change Conference in collaboration with WWF.

As part of the Together for Our Planet campaign, young people are invited to get creative and show global leaders the world they want to live in. Whether it's green forests and garden cities, clear skies and wind turbines or oceans teeming with life, paint, draw or design a piece of art that shows how you'd like our planet to look in the future.

The UK is hosting COP26 in Glasgow in November 2021, bringing together world leaders to tackle climate change and ensure a better future for us all.

together-for-our-planet.ukcop26.org/creative-earth/

BRADFORD SCIENCE FESTIVAL

Bradford Science Festival's online resources are available online until 31 March 2021. There are lots of fun things to enjoy at home, including videos, activity sheets, games, and radio shows. The Brad Lab has lots of videos to watch and exciting experiments to try out at home, while STEM City gives an overview of careers in STEM and how to get into them. Talks and presentations from the festival include: Black Panther: diversity in cinema, arts and engineering; and 50 Million Tonnes, which looks at how electronic waste can be hacked and used for new inventions.

www.scienceandmediamuseum.org.uk/whats-on/bradford-science-festival

HOW I GOT HERE

Q&A

FELICITY MILTON
SENIOR MANAGER, STRATEGY AND INNOVATION AT ADIDAS


Felicity Milton

Felicity Milton is a mechanical engineer and Senior Manager, Strategy and Innovation at adidas, where she is responsible for digital strategy and business model innovation.

WHY DID YOU FIRST BECOME INTERESTED IN SCIENCE/ ENGINEERING?

Design, sport, maths, and physics were my favourite subjects at school. They also had the added benefit of giving me more time in a workshop or on the sports pitch rather than at a desk in a classroom, which was always a big plus for me! I was intrigued by the engineering in sports equipment too – how can you tune the material in the midsole of a running shoe to provide maximum energy return for a certain cadance and force pattern? Then, you look at the human body, which gets even more interesting! Biomedical engineering is amazing, for example prosthetics that are connected to nerve endings and are an extension of the human body. I always saw engineering as less about jet engines and turbines and more as a way of improving human health and performance.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I didn't choose a sports engineering or specific medical course but decided to keep my options open with a general mechanical engineering course at Durham University. I picked a degree where I could specialise in the final two years, which is when I took modules in biomedical and biomechanical engineering. While at university, I also started competing as a runner, which led to me getting offers from US universities to study and train out there. I applied to the Royal Academy of Engineering's Engineering Leaders Scholarships scheme, which helped fund a trip to a sports engineering conference in Biarritz, where I met adidas's senior director of engineering.

After Durham, I studied an entrepreneurial degree in the US while running for Oklahoma State. As part of that, I founded a business and was suddenly going in a different direction. The product I developed was related to sports engineering – an electro-conductive, graduated compression sock for the Achilles tendon, intended as a rehabilitation product that could be used on the go. I came back to the UK and took a master's in biomechanical engineering at Loughborough University to take advantage of the university's business incubator. The product is still patented and I secured some funding for it but the next step is clinical trials, which I found quite daunting and expensive at the time. Instead, I began an internship at adidas, using my engineering background to work through the whole development pipeline, from 3D design and development to factories and marketing.

The world's first performance shoe made from Biosteel Fibre®. The adidas Futurecraft Biofabric is 100% biodegradable through a fully natural process, moving beyond sustainability into a new territory of bionic innovation © adidas Group

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

It's a difficult question – I've found that sometimes when you're focused on what you're passionate about, things happen easily and it's not about accolades or awards. I'm most pleased about everything I've learned along the way.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

I don't do much engineering at the moment, but I do work very closely with lots of engineers. What I enjoy now is that not every opportunity has to come from a new technology, instead an old technology might be perfect for filling a gap in a specific market.

I also think it's important that engineers are driving new technology from a consumer or environmental need: adidas's focus is on the environment now. We want to achieve a circular economy by creating a shoe made from one material that can be continuously recycled. People could rent a shoe for the duration of its life, then it's taken back, recycled and a new one comes out for the owner. Eventually, the aim is to not even need the recycling process because that uses water and energy, so maybe using biodegradable products that can perform to a high standard instead. This kind of materials science and engineering is fascinating.

WHAT DOES A TYPICAL DAY AT WORK INVOLVE FOR YOU?

The pandemic has had a big impact on my role. At the moment, it's a lot of Zoom meetings and screen time! Before COVID-19, I was really focused on business model innovation and we were experimenting with democratising creativity; using robotic technology and the wealth of design, development, legal, production, digital, and distribution competencies that adidas has to enable creative consumers to co-create our products with us, connecting them to their consumers in the process. Unfortunately, that's all on hold at the moment and now my main focus is e-commerce – our number one, always on store – pivoting our strategy and operating model so that we are able to respond and react to what consumers want and need when other stores or outlets are closed. We wanted to continue to reflect culture and celebrate sporting moments during a very difficult year for consumers and our company.

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

The landscape now is so different, with so many opportunities. The routes into engineering are really exciting, so think about where you want to learn and maybe intern at a startup or smaller platform business model. Bigger corporations and the more traditional route have lots of benefits too, for example being able to make mistakes in a more protected environment. But if you're really passionate and know what you want, be careful not to listen to too much advice! If you're enjoying something, it doesn't really feel like a job and by nature you'll excel at it.

WHAT'S NEXT FOR YOU?

More of the same would be fun! I think at some point in the future, I'll go back to the startup world. I've really enjoyed being able to have an entrepreneurial role within adidas, which is great. Walking that line between the startup world and the corporate world is really what I love.

Health has been at the forefront of all our minds this year, and the work that startups have been doing in this area, especially in the US, has been so valuable. One day I hope to make the transition from sport to health tech.

QUICK-FIRE FACTS

Age: **34**

Qualifications: **MEng in mechanical engineering and MSc in entrepreneurship.**

Biggest engineering inspiration: **Real-time health markets with biomedical solutions to match, and the work evolving from biomimicry to help reverse the impact of climate change.**

Most-used technology: **My Macbook, iPhone and Apple Watch.**

Three words that describe you: **Passion, persistence and resilience.**

OPINION

ENGINEERING SKILLS TO BETTER MEET SOCIETY'S NEEDS

From climate change to the COVID-19 pandemic, the UK – and indeed the world – is dealing with some of the most complex challenges it has ever faced. Engineers have a major role in addressing these challenges, so are needed now more than ever. While the numbers of young people choosing to study engineering and technology subjects are promising, Dawn Bonfield MBE and Professor Bashir Al-Hashimi CBE FREng believe that a change in the engineering education curriculum will help build the skills for a sustainable and inclusive future.


Dawn Bonfield MBE


Professor Bashir Al-Hashimi CBE FREng

There is good news in the rise in the number of young people seeking to study engineering. Those working in engineering, and in engineering higher education in particular, will have been buoyed by the recent data on admissions and acceptances from the University and Colleges Admissions Service (UCAS). This showed a significant increase over the past decade in students applying for technology-based degrees. The intake in engineering subjects rose from 20,000 to 30,000, and from 26,000 to 31,500 in computer science courses*. Acceptances to artificial intelligence (AI) courses have increased by 400%, although actual numbers still only stand at 355 in total in 2020. And there is evidence too that the gender gap is closing. The ratio of UK male to female acceptances in engineering fell from 8.2 to 1 in 2011 to 5.0 to 1 in 2020, although computer science fared less well, with the gap falling from 6.2 to 1 in 2011, to 5.7 to 1 in 2020.

In this positive context, the skills that engineers and technologists acquire to shape the future have never been more important. The UN's Sustainable Development Goals, global aims to achieve a better and more sustainable future for all, are now well and truly established as key drivers for future development. The race to achieve the UK government's target of net-zero carbon emissions by 2050 is another great way of focusing minds and actions.

This outcomes-driven narrative may be what is required to attract even more young people into careers in engineering and technology. Shifting the attention from 'becoming an engineer' to addressing climate change or global poverty, for

Building a world that is fairer, more just, and will help us better meet the Sustainable Development Goals is something that we need a diverse engineering workforce to take on board

example, is more likely to have the desired result. Tackling the climate emergency, accessible healthcare and the environment are big motivations for young people, especially when the challenge is to increase diversity and attract students from groups that are under-represented in engineering. So, it's to our advantage to present engineering as a 'caring' or 'social good' profession, one directly associated with solving problems and making people's lives better.

The outcomes-based argument is equally valid for encouraging working engineers to understand the need for diversity in our profession. Looking more closely at what we produce as engineers, and whether it is truly accessible and equitable for all people and all parts of our society, forces us to realise that in the past we have not paid enough attention to the needs of others when producing our engineering solutions. This has been shown all too clearly with the effects of the COVID-19 pandemic and the Grenfell fire, for example, where poorer communities have been made more vulnerable by inadequacies in our built environment.

There are many other examples of how our approach to engineering and technology builds bias into our work. It has never been more important to address this challenge as we develop new disruptive digital systems based on the use of data, AI and machine learning where built in, and in many cases undetectable, biases will persist for years. However, these are the more obvious examples that show the unintended consequences of some of our engineering solutions. The impacts of our decisions are harder to spot in other examples, such as the apparently uncontroversial specification of a ducting material in a new building, a decision usually made without any knowledge or reference to how this choice of material might negatively and disproportionately affect those who bear the brunt of toxic chemical production.

Many of us are becoming more aware of how the outcomes of our engineering endeavours have implications for social justice. Building a world that is fairer, more just, and will help us better meet the Sustainable Development Goals is something that we need a diverse engineering workforce to take on board.

To support this, and to make the most of young people's motivation, our engineering education must change. We need university courses that inspire thinking and creativity, translating ideas through engineering design to innovation that benefits humankind and the planet. And it will not be sufficient to simply tweak existing curricula to focus on engineering solutions to address an environmental crisis. To address the 21st century's biggest challenges, we need engineers who are increasingly setting the agendas for a different and more sustainable way of living, as well as reimagining a world that pays equal attention to economic, social and environmental impact to create solutions with social value, and who are able to communicate these ideas effectively.

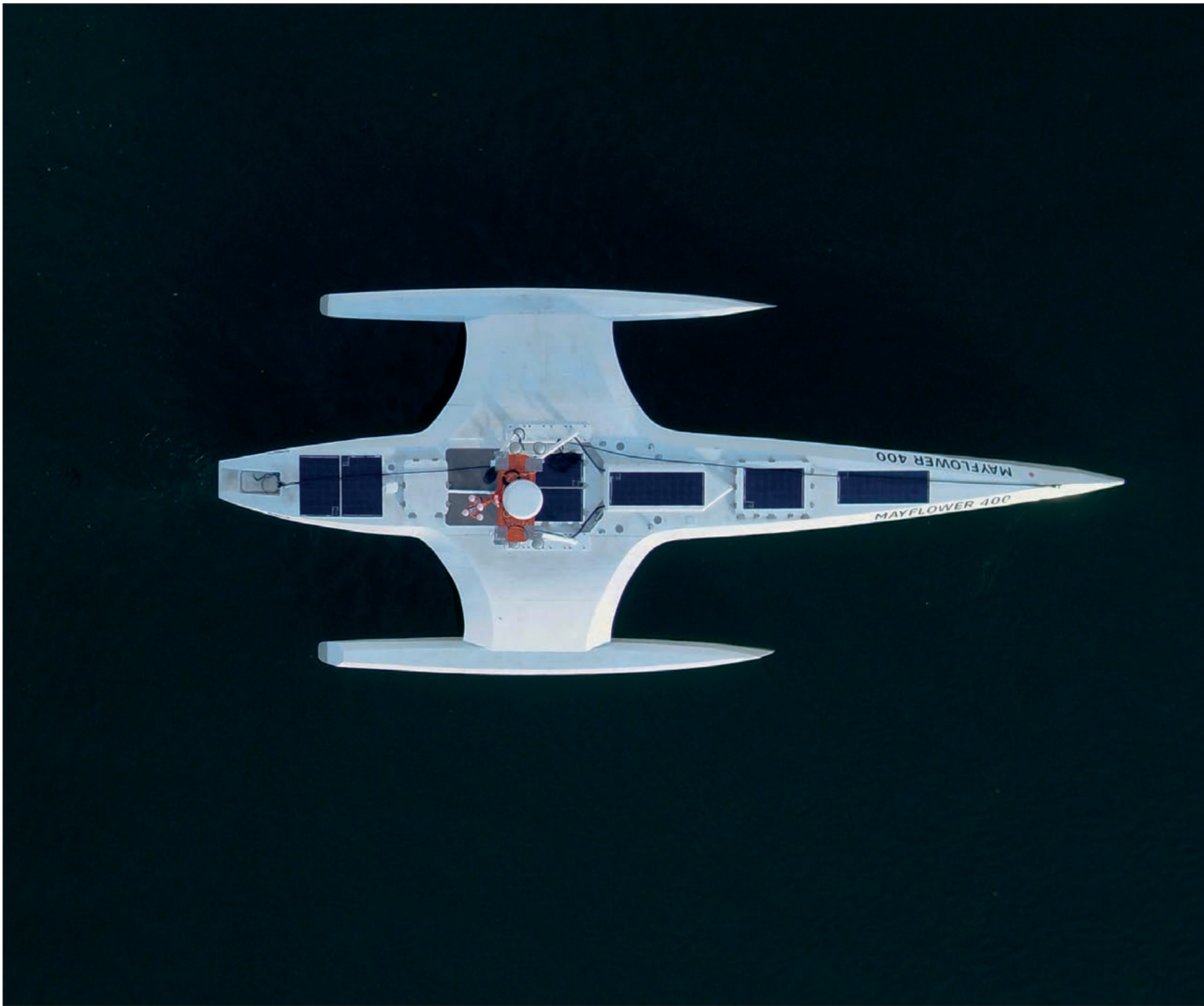
Engineering and technology courses require more industrial input, more knowledge of social science, and real project examples from around the world for students to address. Government funding akin to that announced in June 2020 for AI and data science courses would facilitate this transition. Changes to accreditation, through the ambitious Graduate Attributes and Professional Competency Framework being developed by the International Engineering Alliance for example, are already taking us in this direction. It is heartening to see that some of the UK's own accreditation frameworks are also making the necessary changes to ensure that our future engineers can fulfil their role as creators of a more sustainable and inclusive economy.

BIOGRAPHIES

Dawn Bonfield MBE is the Equality, Diversity and Inclusion Chapter author of the UNESCO Engineering Report, published in March 2021. She is a Royal Academy of Engineering Visiting Professor at Aston University and a Royal Society Entrepreneur in Residence at King's College London. She is a UK representative of the World Federation of Engineering Organisations, and Past President of the Women's Engineering Society.

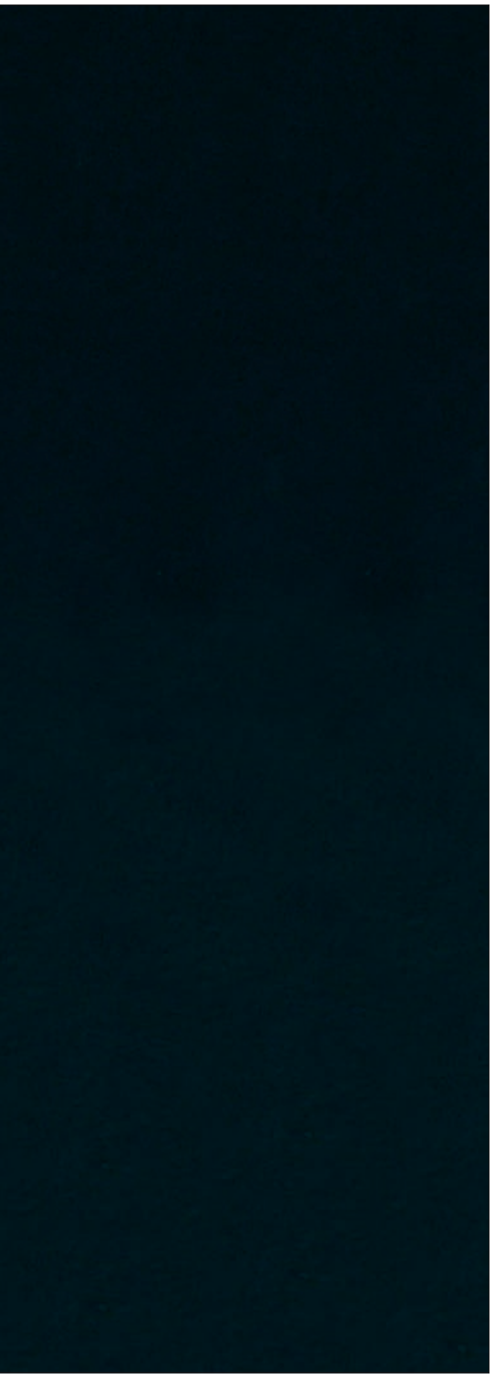
Professor Bashir Al-Hashimi CBE FREng is Executive Dean of the Faculty of Natural, Mathematical & Engineering Sciences at King's College London. He has worked globally on research innovation into energy-efficient and reliable computing systems. He has received numerous awards for his research including the IET Faraday Medal in 2020.

**www.ucas.com/corporate/news-and-key-documents/news/students-turn-technology-university-choices*



The Mayflower Autonomous Ship is preparing to make an unmanned journey across the Atlantic in spring 2021 © IBM

THE MAYFLOWER SAILS AGAIN



A fully autonomous vessel is preparing to retrace the 1620 route of the Mayflower ship from Plymouth to New England. Neil Cumins spoke to Andy Stanford-Clark, IBM's UK and Ireland Chief Technology Officer, about the pioneering technology behind this 21st century mission.

In 1620, the Mayflower ship embarked on a voyage to discover the New World of America. In the US, the arrival and endurance of the ship's English settlers are remembered every Thanksgiving and part of the country's history, while in the UK it is rarely acknowledged.

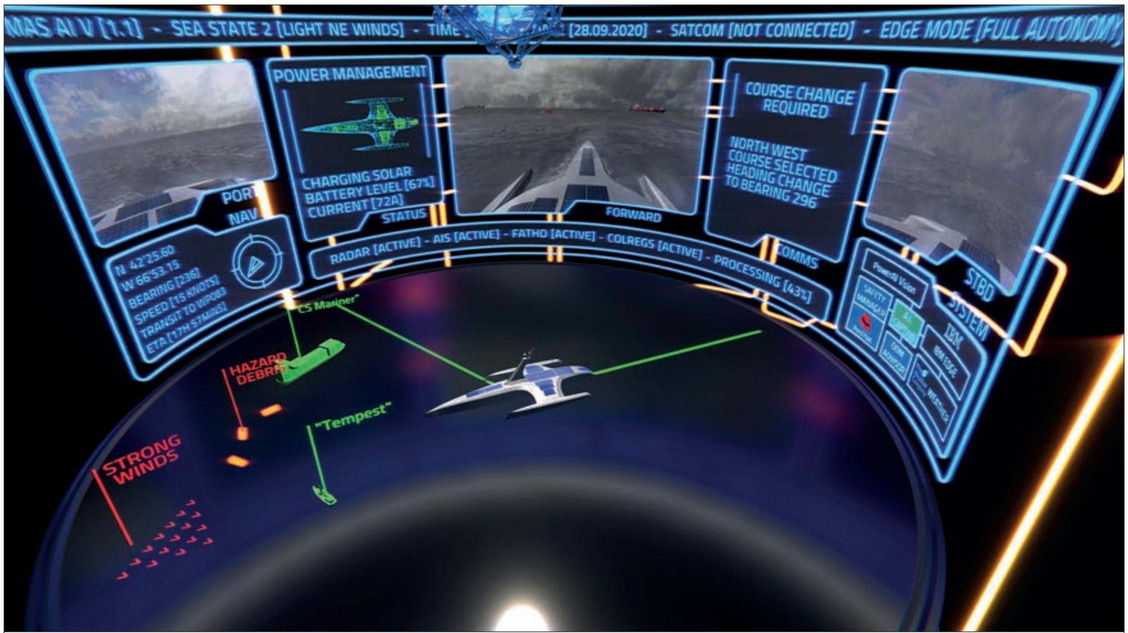
For 10 gruelling weeks, the square-rigged Mayflower ship ploughed across one of the world's most inhospitable oceans, battling howling westerly winds and massive swell waves. This is a perilous journey even by today's standards, and the name of the 1620 ship has been given to a new mission: to create a fully autonomous ship capable of traversing oceans independently, gathering data about critical issues such as plastic pollution, global warming and marine mammal conservation.

The autonomous ship was originally scheduled to set sail in September 2020 from Plymouth Harbour in the UK to Plymouth, Massachusetts, on the 400th anniversary of the original Mayflower's departure. However, this latest voyage has been delayed because of the coronavirus pandemic and will now take place in spring 2021. But what does it take to construct a 15-metre-long ship capable of travelling over 3,100 miles without any crew, charting its own two-week course across an ocean?

THE VESSEL

The Mayflower Autonomous Ship (MAS) project was conceived by Brett Phaneuf, the Co-Founder of American non-profit marine research organisation ProMare. The design and construction contract was awarded to Plymouth-based uncrewed underwater vehicle manufacturer MSubs, whose spinout company Marine AI was tasked with building the

The route of the 3,100-mile journey that the autonomous vessel will take © IBM



Visualisation of the Mayflower's digital twin data showing data sources and the AI captain's decision-making © IBM

core software for the artificial intelligence (AI) captain. Following a chance encounter between MAS's designer and an IBM engineer at a conference in Switzerland, IBM executives were introduced to ProMare as the latter sought a technology partner. Having watched IBM's Watson AI technology win the *Jeopardy!* game show in the US, ProMare knew it needed a 'Captain Watson' for its ship; IBM's array of edge computing and AI-training servers enabled ProMare to appoint a single lead IT partner.

Professor Andy Stanford-Clark is IBM's Chief Technology Officer for the UK and Ireland, and he's been involved with the MAS project for the last 18 months. He points out that although MSubs has extensive experience of automated systems, these are very different from autonomous ones: "Automated systems follow pre-programmed actions, and they wouldn't really know what to do if they got into uncharted waters. By contrast, an autonomous system has learned how to react in a completely unforeseen situation and will hopefully follow the right course of action."

The distinction between automated and autonomous is significant, since there have already been uncrewed Atlantic crossings of remote-control vessels piloted from a command centre. An autonomous vessel less than two metres long also travelled from Canada to Ireland in 2018. However, the MAS is more than simply an empty vessel – it's a floating science experiment, which will be conducting detailed oceanic analysis of everything from microplastics levels to whale song throughout its journey.

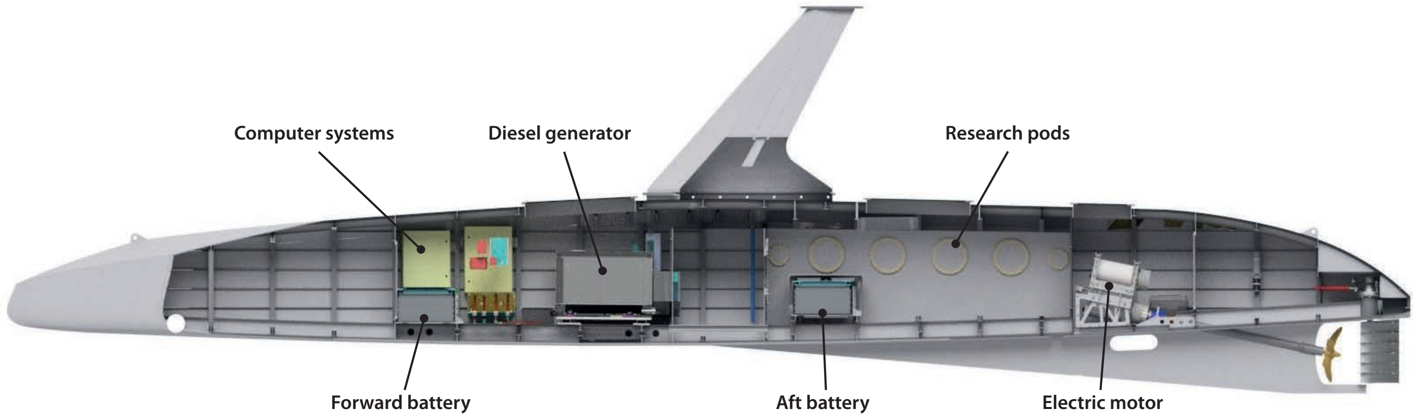
CHARTING A COURSE

Ensuring an uncrewed but fully loaded research vessel can navigate its way across one of the world's largest oceans represents an enormous undertaking. Simply being able to identify objects around it requires huge amounts of raw data, as Andy explains: "We've uploaded two and a half million images from yachts to icebergs, all labelled. ProMare has had cameras installed at its R&D stations in the Plymouth Sound for two years, giving us a ship's eye view with lots of photos of similar things in very different weather and sea conditions." This image library has been fed into IBM's visual recognition software as a building block of the ship's AI captain. The AI captain can view its surroundings and make decisions about how to react according to rules-based logic: "You might have an iceberg on one side and an oil tanker on the other side, a container floating in the water and a storm coming, and the AI has to decide what to do."

The team also carried out extensive tests to characterise how the vessel turns. Andy explains: "If you turn the rudder a certain number of degrees, how many metres does it takes to start turning, what's the turning circle of the ship and its capability for accelerating and decelerating? That way, when we put the AI captain on board we can programme these parameters, and it will have some prior understanding of how the ship will behave."

To predict likely scenarios MAS might encounter during its journey, Marine AI constructed a digital twin and conducted thousands of hours of simulated sailing. "There's an awful lot we can do with a digital twin simulator," says Andy. "These environments have been putting the AI captain through its paces for months, and it's been a key part of the training system. We can put anything we want into the virtual cameras – we can add in a ship and an iceberg, a buoy and a seagull, and see what it would do next." This machine learning simulation has helped to prepare the vessel for a crossing that is likely to be significantly impacted by changes in the weather and ocean. These challenges (and others) will be monitored by real-time sensory inputs including radar with a 2.5 nautical mile range, GPS navigation and a vehicle management system reminiscent of the ones found in electric cars.

Numerous nautical rules have been fed into the ship's automated decision system, but a simpler philosophy underpinned MAS's instructions



A cross-section of the Mayflower shows its different components and systems. In a ship designed to have no crew on board, all available space can be dedicated to the systems and scientific apparatus for experiments © IBM

when encountering obstacles and climatic challenges. "At sea you have longer to react, and you can track the speed and direction of potential obstacles," says Andy. "As a last resort, MAS can just stop in the water, assess the situation and take its time to decide what to do next. In almost all situations, a crash is avoidable." Providing MAS remains facing into the waves, it's very unlikely to capsize.

EFFICIENT DESIGN

To minimise any risk of capsizing, MAS has been honed to ensure optimal performance and maximum stability. A trimaran is an inherently stable design, while the absence of human personnel on board allows incredible space-efficiency. Andy points out: "You don't need a galley, food storage or toilets. An uncrewed vessel sets different design parameters, and sitting lower in the water becomes much easier because you don't need headroom. The vessel's heaviest contents are the batteries that will support night-time travel, and the onboard biodiesel generator to help out if the solar panels aren't able to generate sufficient power."

While the original Mayflower sailed with enough space to store 180 tonnes of cargo for its 140 crew and passengers, MAS is packed with scientific equipment intended to examine oceanic wellbeing, pollution and marine life. The central hull contains a dozen different research pods whose experiments were suggested and devised by academics and oceanographers. Andy explains how a robotic water sampling system will record the density of microplastics across the ocean: "It's going to collect bottled water samples throughout the journey by opening a little tap inside the boat, filling up a bottle, putting a cap on, and placing it in the fridge before waiting for a few hours to do the next one." This fully automated process will be conducted at sea and analysed later in a laboratory along with reams of recorded data on tidal patterns, the depth of the ocean and even the nuances of whalesong as detected by an underwater hydrophone.

Another automated process will be the distribution of automatic identification system (AIS) messages between MAS and vessels in its vicinity. AIS allows ships and boats to safely pass each other, but MAS's instructions will be customised to inform other craft that it has no crew. This complements visual signage and a lighting regime designed to highlight its lack of crew. To further minimise the chances of a collision, the AI system has been programmed with numerous nautical regulation guides like the Safety of Life at Sea (SOLAS) treaty, and the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs).

CYBERSAFETY

While maritime traffic poses one potential hazard, another threat lies in potential attempts by hackers to commandeer the vessel and use it for either piracy or weaponisation. "Marine cybersecurity is a really big area," Andy says, "because people tend to assume once a ship sets sail it's safe and self-contained, but that isn't the case. Ships have a local area network (LAN) and Wi-Fi, and any number of computer systems, IP addresses and satellite communications, which all make them a hacking target." As a result, MAS uses edge computing technology to secure its hardware, permitting secure connections through firewalls: "You have to design it like a company intranet, with all the security and firewalls and VPNs you'd normally need to secure an enterprise system."

The onboard edge devices are essential because there may be lengthy periods where MAS is unable to communicate with the teams on land. Indeed, IBM is assuming it has no communications potential at any point in the crossing. "Any data we do receive back is a bonus," says Andy. "It will be constantly trying to provide operational data from both the ship and the science experiments. We'll be learning from the feedback from the AI systems about how it's doing and how confident the AI vision system is about what the cameras are seeing, with tonnes of data being collected and some of it offboarded during the journey." If data can't be transmitted en route across the satellite link, it will be stored on an SD card and offloaded after the vessel's safe return.

BRIGHT FUTURES

Although MAS's forthcoming journey represents an epic challenge, the ProMare and IBM team is already looking at how this pioneering technology could be advanced further. "Future versions of the AI software will have the ability for experiments to investigate interesting situations that arise. A boat might deviate from its existing mission and go somewhere else, after weighing up the conflicting requirements of the opportunity that's presented itself, the mission objectives and its remaining power. There might even be fleets of autonomous vessels going out and collecting research data. There are really interesting 'hive mind' experiments with swarms of autonomous ships working together to achieve an overall objective."

MAS could also spearhead the introduction of AI serving as a second pair of eyes to a human captain: "From talking to insurers, you can imagine a future where they actually require that kind of system to be on board before they'll insure a ship. There are really interesting developments in augmented intelligence rather than AI, which will have quite a profound impact on the industry." Andy describes a nautical version of the autopilot systems on an aeroplane, leaving the complex take-off and landing to humans but automating everything in between. Historic maritime rules mean only manned craft can currently sail into or out of harbours; the only exception is for vessels with 'eyes on' – someone in attendance watching. MAS will be escorted into harbour by a manned vessel with a short-range radio-control link. However, autonomous port operations are being tested at the Port of Rotterdam, which may ultimately enable autonomous vessels to complete the final leg of their journeys without needing human oversight.

As well as crossing the Atlantic independently, MAS's greatest legacy may be the cutting-edge technology. "It's a wonderful showcase of a whole range of technologies, all working together to solve really gnarly problems," Andy concludes. "It's a chance to demonstrate different pieces of software working together – the cloud and AI vision systems, the Internet of Things and edge computing. We see a great future in AI captain software for the autonomous operation of vessels of many sizes, from container ships down to personal water taxis. We've already had a lot of conversations with people in the military and research sectors who are interested in using this technology in the future, wanting to know how it works and how they can get hold of it. It's getting really busy really quickly."

The technology might be used to operate ferries, such as the floating bridges crossing Norwegian fjords. Personal water taxis could make efficient use of under-utilised urban waterways and simultaneously alleviate congestion on land. Meanwhile, autonomous vessels could transform the exploration of our oceans, increasing our knowledge and understanding of remote bodies of water by conducting real-time analysis under AI stewardship
© Tom Barnes for IBM and ProMare

BIOGRAPHY

Professor Andy Stanford-Clark is the Chief Technology Officer for IBM in UK and Ireland. He is an IBM Distinguished Engineer, a Master Inventor with more than 40 patents, and IBM's Quantum Leader for the UK. Andy is a Visiting Professor at Newcastle University, an Honorary Professor at the University of East Anglia, an Adjunct Professor at the University of Southampton, and a Fellow of the British Computer Society.

HELPING THE GREEN REVOLUTION

Hornsea One's 174 offshore wind turbines generate enough power for one million UK homes © Ørsted

Hornsea One, the world's largest offshore wind farm, has 174 wind turbines that generate enough electricity to supply over one million UK homes. Completed in 2019, the next phase, Hornsea Two, is under construction and is due to be completed in 2022. David Williams, Senior Export Cable Project Engineer, and Muhammad Imran Khan, Wind Farm Commissioning Project Manager, both at Ørsted, explain some of the challenges involved in creating this record-breaking offshore wind farm.

The Hornsea wind farms are located some 120 kilometres off the UK's east coast, close to Hull © Ørsted

The UK government has a target of net-zero carbon emissions by 2050. Cutting emissions from energy generation could play a significant role in meeting this goal. There is already a shift away from using fossil fuels to provide energy: according to the Green Energy Trust, in 2018 33% of the UK's electricity came from low-carbon sources and in 2019, renewable sources generated more electricity than fossil fuels for the first time since the Industrial Revolution.

Offshore wind is on track to become the UK's biggest green energy source. The Committee on Climate Change expects that 75 GW (gigawatts) of offshore wind capacity will be needed by 2050, and in October 2020, Prime Minister Boris Johnson claimed that the UK would generate enough offshore wind power to supply every home by 2030. By 2020, 10.5 GW was installed with capacity set to rise to 27.5 GW in 2026. One gigawatt of this energy is enough to power around 600,000 homes.

A major player in green energy generation is the Hornsea One wind farm. Located 120 km (kilometres) off the Yorkshire coast, it is the first offshore wind farm to generate over 1.2 GW of clean electricity, almost double the world's previous largest windfarm.

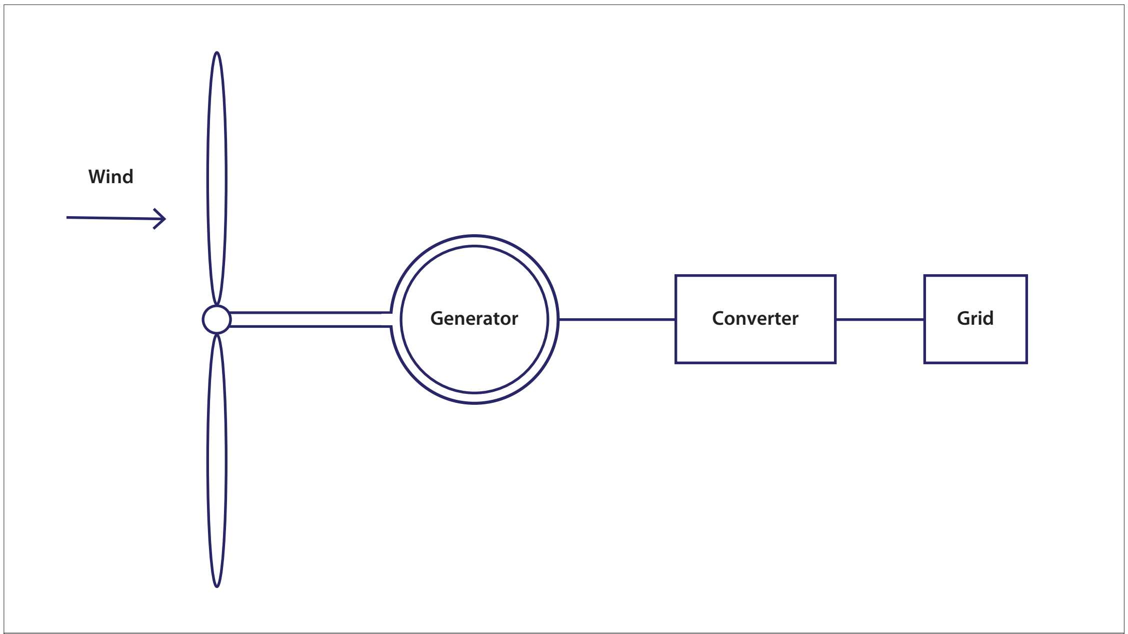
Built by Danish renewable energy company Ørsted, the UK government approved the wind farm in 2014. At the time, Ørsted's largest offshore wind farm was the London Array, about 20 km from the Kent and Essex coasts in waters up to 25 m deep, which generates 619 MW of energy to power around 500,000 homes. Hornsea One was much more ambitious.

CHOOSING THE SITE

Choosing the perfect location for a giant offshore wind farm was the first challenge that Ørsted's engineers faced. The Crown Estate owns the seabed where offshore wind farms are located. Wind farm developers must consider parameters such as water depth, cable landfall options and onshore grid facilities, as well as environmental factors such as designated conservation sites, where the local environment is protected.

Hornsea One is situated just off the UK's east coast, where the seabed is shallow but stable and wind speeds are consistently high. To choose an ideal location, the team

The Edda Mistral, the service operations vessel that the crew live on. During the construction process, 8,000 people worked offshore on the project © Ørsted



Wind turbine blades capture kinetic energy by rotating when the wind blows past them

conducted meteorological assessments across potential spots to measure wind speed and weather, ensuring that the site did not interfere with marine conservation areas. Hornsea One is further from the shore than any other wind farm and covers just over 400 square kilometres, which is three times the size of Manchester.

Because of the site's size and distance from the shore, the crew – including around 100 people who were involved in site management – lived on an offshore platform during construction.

The distance also meant that detailed plans to move the huge and heavy components to the site had to be drawn up. A total of 522 blades, each measuring 75 metres long, were transported from the Siemens Gamesa Renewable Energy blade factory in Hull, Yorkshire. The carefully manufactured balsa wood and fiberglass blades were lifted on to a jack-up barge, a vessel on legs that sails as a normal ship until it is needed for construction. The barge was also loaded with the rest of the turbines' components before setting sail to the site location. Once at the site, the jack-up barge's 'legs' were lowered and stabilised on the seabed to secure it so that the components could be moved around safely.

The Hornsea One wind turbines were secured in the seabed with monopile foundations, a thick steel cylinder buried in the seabed, which then supports the turbine tower. Monopile foundations are suitable for water depths of up to around 30 metres and are currently the most commonly used foundation for offshore wind farms.

THE TURBINES

Each of Hornsea One's 7 MW wind turbines towers 190 metres above sea level, with a blade diameter of 154 metres. A single rotation of the turbine's huge 75-metre-long blades generates enough energy to power a home for over a day. The rotation of blades turns an internal shaft connected to a gearbox or directly to the generator depending on the design of the wind turbine. The spinning of the generator produces electricity, which is exported to the grid via subsea cables, and then on to homes.

The wind speed on the east coast of the UK is among the fastest in the world, and depends on atmospheric pressure, geography and season. The optimal wind speed for Hornsea One's turbines is around 14 metres per second (mps), considered a strong breeze on the Beaufort scale, the kind of wind that would make it difficult to use an umbrella. Ultrasonic sensors on the turbines constantly measure wind speed and direction while automatically rotating the blades to capture as much energy as possible. To prevent structural damage to the turbines, a control system automatically switches off the turbines when the wind speed exceeds 24 mps (a severe gale). The turbine blades also angle themselves 90 degrees towards the wind during periods of extreme weather to reduce the likelihood of damage.

The Hornsea One turbines use a direct drive, which means they do not have a gearbox and the rotor is connected directly to the generator. With fewer moving parts than gearbox turbines, they are quieter and have lower maintenance costs for the wind farm as the teeth and cogs in a heavy gearbox wear out in variable wind speeds. After installation, turbines require regular maintenance. Around 40 wind turbine technicians look after the wind farm and run annual checks on each turbine as well as conducting ad-hoc repairs and maintenance.

Much like the shift pattern on offshore oil rigs, for two weeks at a time, technicians live onboard a service operations vessel. Built to cruise liner standards, technicians have a comfortable stay offshore. An innovative motion-compensated gangway allows technicians to walk to work to the bright yellow transition piece platform, fixed on top of the monopile in the seabed, creating the foundation (see image on page 20).

Technicians work alongside a support network based in Grimsby's East Coast Hub, the world's largest operations and maintenance facility for offshore wind, which had a recent £10 million investment and upgrade. The offshore co-ordination centre is staffed 24/7 to give an extra layer of safety for those working offshore. By constantly

A jack-up barge that has sailed from Hull port with the components on board places its legs on the seabed to secure and lift the vessel so that it can install the blades and components © DEME group

reviewing the weather and assessing the likelihood of lightning, the offshore co-ordination staff can also manually control turbines.

NEW ENGINEERING

Bringing the power ashore is one of the biggest engineering challenges, and for this project it meant developing new approaches. On Hornsea One, engineers achieved a longest manufacturing run of 200 km of cable, doubling the previous maximum AC cable length. They would usually allocate 10% spare cable to cover contingencies and repairs. This meant that a larger storage space was needed and allowances were made for additional manufacturing time.

Array cables connect each turbine to the next one, buried beneath the seabed until they reach an offshore substation. Three offshore substations are positioned near each other at sea. The power from each wind turbine is stepped up from 690 V to 34 kV and then transmitted via a series of ‘strings’ (cables). There are 36 strings in total, split across all three offshore stations. Each string connects four or five wind turbines. As the power reaches the offshore station from the turbine, it is stepped up again from 34 kV to 220 kV and is then transmitted via the export cables to the reactive compensation system (RCS), a point midway between land and the offshore stations (see image on next page). At the RCS the voltage remains at 220 kV and is transmitted back to the onshore substation by three export cables.

At the onshore substation, a final step-up of the voltage from 220 kV to 400 kV allows the power to be connected to the National Grid transmission system. The gradual stepping up of the voltage along the way from the wind turbine to the onshore substation helps mitigate system losses. When the voltage is stepped up, the current reduces relative to the voltage and the power remains constant. This also helps reduce the size of the cables required to bring the power generated back to shore.

As they are out of sight, cables are often an unappreciated necessity that have taken months to manufacture and test. However, they are one of the most important components. Essentially the project’s veins, they carry electricity from source to consumers. The time it takes to manufacture the cables is astounding; production for Hornsea One took over a year and was across two factories.

HORNSEA TWO

Hornsea One began supplying power to the National Grid in February 2019, with the project

In a first for offshore wind, a reactive compensation station (RCS), weighing a total of 4,000 tonnes, was installed halfway between the landfall site at Horseshoe Point in Lincolnshire and the three offshore substations to act as a midway point. It removes the reactive power (the difference between the electricity supplied and the electricity converted into useful power) and sends the active power (useable energy) through cables that connect to the onshore substation. The station is installed on the seabed but sits on legs above sea level © Ørsted

completed in early 2020. This year, turbine installation will begin on Hornsea Two, which is next to its predecessor and 89 km from the coast.

The new wind farm will be larger than Hornsea One and will generate 200 MW more power with fewer turbines. Its 165 8 MW Siemens Gamesa turbines will generate 1.4 GW of clean electricity to power more than 1.3 million homes. Despite having fewer turbines, it will deliver 20% more output than Hornsea One.

The project will use the world's largest offshore substation and will deliver the most affordable electricity from offshore wind to date. "Large infrastructure projects like these have their challenges, but with each project we have built we are able to improve efficiencies," says Duncan Clark, Project Director.

The wind farm still requires the energy-boosting RCS. However, where Hornsea One has three offshore substations, Hornsea Two will have one. This gigantic structure for Hornsea Two will be floated across from Indonesia using a semi-submersible crane vessel that will lift the substation into position.

The UK government incentivises investment in renewable energy with the Contracts for Difference (CfD) scheme, providing developers of projects with high upfront costs and protecting consumers from paying increased support costs when electricity prices are high. With a CfD strike price of £57.50, it means that green energy is now officially cheaper than gas, coal and nuclear.

When Hornsea Two becomes operational in 2022, the two projects will together generate electricity for almost 2.5 million homes, bolstering Ørsted's vision of creating a world that runs entirely on green energy. The cost of offshore wind power has continued to come down and today offshore wind energy is cheaper than new generation capacity based on fossil fuels. The Hornsea One and Two projects mark an important step towards achieving the UK's net-zero aims.

BIOGRAPHIES

David Williams, Senior Export Cable Project Engineer at Ørsted, is a chartered engineer and studied at Cardiff University and the University of Loughborough. He worked on the Hornsea One project for over six years, including on the initial technical design concept and engineering technical support for supply and installation of export cables.

Muhammad Imran Khan, Wind Farm Commissioning Project Manager at Ørsted, studied electrical and electronic engineering at the University of Manchester. Imran works on the Hornsea Two project and has done for 13 months. His remit on includes coordinating stage one commissioning and responsibility for stage two commissioning of the whole windfarm.

LESSONS FROM THE FIELD

Many young engineers spend time working with communities and engineers in other countries to help develop their skills at the start of their careers. Abigail Beall talked to three engineers about the impact working abroad has had on their career paths and outlooks, gaining valuable experience that they couldn't have gained in the UK.

Aakeen Parikh worked with local people to develop an off-grid washing machine during her trip to Minazi, Rwanda

Student engineers collaborate with local people to develop sustainable solutions

Minazi, a remote village in the Gakenke district in the Northern Province of Rwanda, has a water scarcity problem. Being on top of a hill makes it hard for those living there to find water, especially in winter when the small streams that are usually available start to dry up. This means it's not unusual for people who live in Minazi to walk for between one and two hours every day to collect water.

Access to water is one of the UN's Sustainable Development Goals (SDGs), which were published in 2015, to be achieved by 2030. This set of 17 targets aims to create a better world by ending poverty, stopping inequality and fighting climate change. Many of these problems can be solved partly, if not fully, by engineering.

This is why water and sanitation, along with another SDG – industry, innovation and infrastructure – is becoming a mainstream focus for engineers everywhere. In the past few years, an increasing number of young engineers have been working in a voluntary capacity in the Global South to help in the worldwide effort to achieve the goals. While voluntary work like this might sound like a selfless thing to do, the engineers are coming home with skills and experiences that stay with them for life and shape their careers.

In 2019, Aakeen Parikh was part of a group of students from Imperial College London who went to Minazi for three weeks. This was her third trip as part of e.quinox, the university's non-profit organisation that aims to develop sustainable technological solutions in collaboration with rural communities. During this trip, Parikh worked as part of a team trying to improve the water supply to the village. She also helped develop an off-grid rural washing machine, a project that is still in development now.

WATER AND SANITATION

Running and managing projects overseas gives young engineers valuable project management and engineering experience. "On your courses, you're often taught about the physics and design process, but you have very little opportunity to test your knowledge," Parikh says. "If

Professor Guy Howard, Global Research Chair in Environmental and Infrastructure Resilience at the University of Bristol, says volunteering was beneficial for his career because it taught him that a lot of engineering is not really about maths. "A lot of engineering is really the art of the doable," he says. There is a lot of social science involved in engineering that is not necessarily taught in university courses

you're in the field, and suddenly need to develop the truss for a water tank you want to install, you are putting a lot of learning into action."

These challenges might include the procurement of parts and materials, for example, calculating material stresses or working out bending moments to ensure nothing is going to collapse. Another application might be calculating the power it takes to pump water to a certain height. Whatever it is, seeing the theory you have learnt in action is undoubtedly a great way to help understand and remember it.

But the benefits of spending time on projects like this far exceed just practical application of engineering theory. "You learn a lot about the country," says Parikh, "the rules, regulations and procedures that are in place that you are required to follow for your projects." The experience also teaches volunteers about the local people and their lifestyles, challenges and daily experiences. "Engineering projects for development are multidisciplinary and the focus should always be on the needs of the community that you are working with, taking a human-centred design approach is key," she says.

Professor Guy Howard, Global Research Chair in Environmental and Infrastructure Resilience at the University of Bristol, says volunteering was beneficial for his career because it taught him that a lot of engineering is not really about maths. "A lot of engineering is really the art of the doable," he says. There is a lot of social science involved in engineering that is not necessarily taught in university courses.

"Another reason it's very useful, particularly around water and sanitation, is that it can overcome a little bit of what I would see as a deficit in a lot of engineering teaching at the moment in the UK," he says. Apart from one or two notable examples, Professor Howard says the UK has moved away from the concept of public health engineering. At the University of Leeds, for example, there is a Public Health Engineering MSc course run by Professor Barbara Evans that has been going for 25 years.

However, many other courses miss out on information about disease dynamics, transmission, basic microbiology and how engineering plays a part in preventing the spread of disease. "I think for many young engineers, going out into the field brings home to them, 'actually this is what you need to understand'," Professor Howard adds.

The idea that engineers need to understand much more than the physics and maths involved does not just apply to water and sanitation. It is also what Dr Sakthy Selvakumaran learnt when she visited Peru for three months during her undergraduate degree to do work experience with the Centre for Studies and Prevention of Disasters, PREDES, a local non-governmental organisation (NGO). Following an earthquake that had happened a couple of years previously, in some rural areas three hours south of Lima, people were still living in tarpaulin shelters.

Although it was a programme to rebuild houses, the engineers with the NGO worked closely with local people and local government to understand ambitions and build local capacity, training and resilience. "What I liked about the way PREDES was structured was that they were not just engineers," she says. "They're engineers, they're anthropologists, they're community workers, they're architects. They were all of these things. PREDES is a multidisciplinary organisation that understood that it takes more than technical engineers to make a successful piece of work."

EARTHQUAKE RESILIENCE

In the UK, construction does not often need to consider seismic activity. "Peru has a long, interesting history, and it includes traditional construction methods designed for seismic resistance" says Dr Selvakumaran. This includes local building techniques to make houses from wooden frames by putting an extra piece of material, such as cane or reed, in between the frame to make it flexible. This is so that when an earthquake hits, the whole structure will bend. Then, local tradespeople semi-render the outside and paint it. In central Lima, there are buildings several storeys high that have been built in this way and withstood hundreds of years of earthquakes.

Without straying from the traditional methods, the


Traditional building methods are used to construct houses in Peru, using flexible material to ensure houses can withstand seismic activity

engineers at PREDES developed a way of improving upon them. "They made slight modifications with tie wires to make it a little bit more robust," says Dr Selvakumaran. They also built it in a modular way so that one module would be the start of a home, giving owners the flexibility to add modules to extend their homes over time.

Dr Selvakumaran's time in Peru was just before the final year of her undergraduate degree because she wanted to go with enough of a basic understanding to be helpful while she was there, and be able to apply this to understanding the value of the work being carried out. "The hard thing about volunteering, especially when you're an undergraduate, is to acknowledge you're going to volunteer but that you may not be that useful, and that the local engineers are making time to teach you." She says that it's important to treat it as a learning experience, just like any other work experience.

THE IMPACT OF YOUNG VOLUNTEERS

Dr Selvakumaran says her experience in Peru shaped a lot of her beliefs as an engineer and how she has thought about the world ever since. Now, she is a research fellow at the University of Cambridge, where she specialises in risk and resilience of urban environments. She is the Founder of BKwai, a software platform that provides visualisations and data insights to make construction safer, more productive and more efficient.

Dr Selvakumaran studied engineering because she liked the idea of helping people. Her family left Sri Lanka during the civil war, and she grew up in the UK and Canada. After going back to Sri Lanka, and visiting Peru, she realised the importance of infrastructure to the people living in the wake of a disaster like war or an earthquake. "I became a lot more passionate about engineering education, the idea that everyone should have a right to be educated as an engineer," she says. "That actually is a great way to drive progress and support communities in a much stronger way than sending people here and there for a few months at a time."

Dr Selvakumaran also supports the University of Jaffna, Sri Lanka, which opened an engineering school a few years ago. Local engineering academics set up the school from scratch, with a mission of creating competent engineers with social, economic and ethical values, who contribute to sustainable development.

The value of young volunteer engineers in host countries has changed in the past few years, compared to what it was decades ago. "Back at the beginning of my career, in the 1980s and 1990s, it probably was still the case that there were fewer than needed engineering experts in low- and middle-income countries," says Professor Howard. "So, having young UK engineers going out and working on things actually did make up for a genuine deficit."

Volunteers in Peru also worked on landslide defences in the lower Rimac valley, south of Lima

Dr Selvakumaran emphasises the need for engineers to be considerate and careful when working abroad: "engineers need to remember that have just as much ability to accidentally cause harm as they do good."

For Parikh, her experiences working abroad have helped shape her career choices. "I always knew that I wanted to work in international development as an engineer," says Parikh. Having grown up in Mumbai, where economic disparity is as clear as day, Parikh realised that STEM students have the skills to address the biggest challenges the world is currently facing.

"Participating in these student volunteering projects through e.quinox provided me with the opportunity to actually make an impact with my degree," she says. "And it reinforced my feelings towards my goal because the experiences and perspective that you gain is invaluable, reminding you that some people still do not have basic human rights, and access to clean water and education is a basic human right that everyone should have." Now, she is working on a PhD, but she knows she wants to continue working towards international development, particularly in sustainable humanitarian action for rural communities under the poverty line.

Now, it seems there is great value in these experiences for young engineers. But it also inspires within them a direction and skills and perspectives that they couldn't gain in the UK, which means they will continue to have a lasting impact for their whole careers.

FEMENG

Students at the University of Glasgow's School of Engineering have created a network aiming to empower women studying the discipline. Its work includes school outreach, networking, workshops, and international collaborations. For example, in 2019 the group collaborated with the University of Rwanda on 'FemEng in Rwanda'. As part of the initiative, female students from both universities worked together to encourage female Rwandan high school students to study science and engineering subjects in further education. After a successful project, the group started planning for a similar initiative in Malawi, which was launched in 2020.

SAFAD

For over 50 years, students from Cranfield University have volunteered in the global south around the world, as part of the charity Silsoe Aid for Appropriate Development (SAFAD). More than 340 graduate and postgraduate volunteers have travelled to almost 40 different countries, working with local organisations. The group specialises in six fields: water and sanitation; agroforestry; agriculture and soil conservation; education; small businesses; and intermediate technologies. Because of this, students from a variety of disciplines, from environmental sciences to engineering, have participated in the charity's work.

BIOGRAPHY

Professor Guy Howard is the Global Research Chair in Infrastructure and Environmental Resilience and Associate Director (International) of the Cabot Institute of the Environment at the University of Bristol.

Aakeen Parikh is currently pursuing her PhD at Imperial College London. She is an advisory board member for e.quinox and part-time humanitarian design and engineering consultant.

Dr Sakthy Selvakumaran is currently the Isaac Newton Trust / Newnham College Fellow in Engineering and Director of Studies in Engineering at the University of Cambridge.

LIFE AFTER LANDFILLS

UK households produce over 25 million tonnes of waste a year, around 400 kilograms per person (roughly equivalent to four giant pandas). Around 45% of this is recycled, but what happens to the waste that can neither be recycled nor reused? Dominic Joyeux discovered how waste going to landfill is contributing to the circular economy.

The number of landfill sites in the UK is declining and there is a marked reluctance to create more. Ideally, everything that is manufactured could be broken down and reused after use. However, at the moment, after household waste has been sorted into recyclable and recoverable, the rest is sent to be buried.

It had been a long-held European Union (EU) target for all member states to achieve a recycling rate of 50% for its household waste. The UK currently achieves 45% and has made substantial progress since 2000, when it only managed 13% a year and consigned huge amounts to landfill.

The 1999 EU Landfill Directive came with financial penalties and the UK government had been placing an escalating tax (currently just under £100 per tonne) on non-inert refuse put into the ground. As a result,

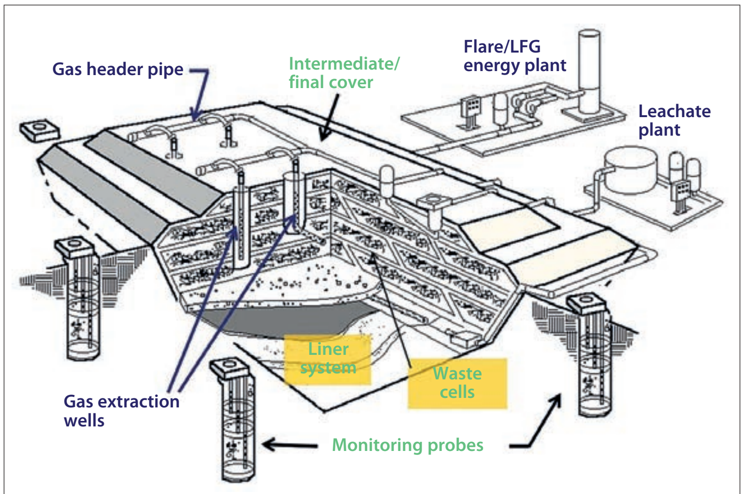
The amount of waste that the UK produces per person each year is roughly equivalent to the weight of four giant pandas © © SUEZ Recycling and Recovery UK Ltd local councils have been forced to look for alternative ways of disposing and reusing their residents' refuse.

For the rubbish that can't currently be recycled, councils have overwhelmingly turned to combustion to stop non-recyclable material being buried in the ground. In 2019, the UK's 53 energy-from-waste plants generated 6,700 GWh (gigawatt hours), roughly 2% of the nation's electricity generation, plus 1,400 GWh of heat.

In addition to more than 500 active landfill sites, there are more than 20,000 historic landfills that pre-date the millennium in the UK. Now, researchers and companies are looking at the feasibility of mining such sites in order to retrieve useful materials and make the land safe to reuse.

MANAGING MODERN LANDFILLS

The reduction in the amount sent to be buried in the UK has coincided with a marked improvement in the maintenance and safety of landfill sites. This has been in large part due to the Control of Pollution Act 1974. The act, and its review in 1978, helped bring an end to the notion of sites as tips and regulated their maintenance. Now, they are highly engineered, have an active life of 20 years or more, and can expect to be maintained for a further 50 years after they are decommissioned.



Landfill schematic showing gas and leachate collection systems
© Wikimedia Commons

Dr Adam Read, working for SUEZ Recycling and Recovery UK, has studied the evolution of landfill. "In essence, the old pre-1974 sites were tips using a dispersion model that runs like this: If you bury rubbish in a big enough area it'll leach, and with rainwater saturating such a large area then it won't be a pollutant. That's before people worked out that water runs downhill and ends up in your watercourse. Add to that the degrading of different materials at different rates, the varying moisture levels below ground, slippages in stacked rubbish, the pockets of methane gas collecting and sometimes exploding, then it became clear that things had to change."

Today, most new landfills follow a similar pattern in their creation and maintenance. The overall site will be split into cells that measure around 10,000 m^2 (square metres) to 20,000 m^2. At the base of each will be a 60 cm (centimetre) layer of compacted clay soil topped with 6 cm-thick high-density polyethylene liner that also lines the sides. A gravel/stone leachate collection layer is placed over the liner that has perforated collection pipes that take the liquid to collection sumps. On top of this is a final layer of geotextile material that provides a separation of solid material from liquid.

Then cells are built up with waste from lorry loads of refuse. As layers of rubbish are built up they are covered with inert soils or matting that help prevent odours and keep vermin away. While these layers are built up, horizontally presented perforated gas collectors are laid in. These are generally 'sacrificial' in nature providing a short-term solution until more permanent retro-drilled gas wells are installed in a completed, or near completed, landfill cell – these will be made from low-density polyethylene measuring between 125 mm (millimetres) to 160 mm in diameter.

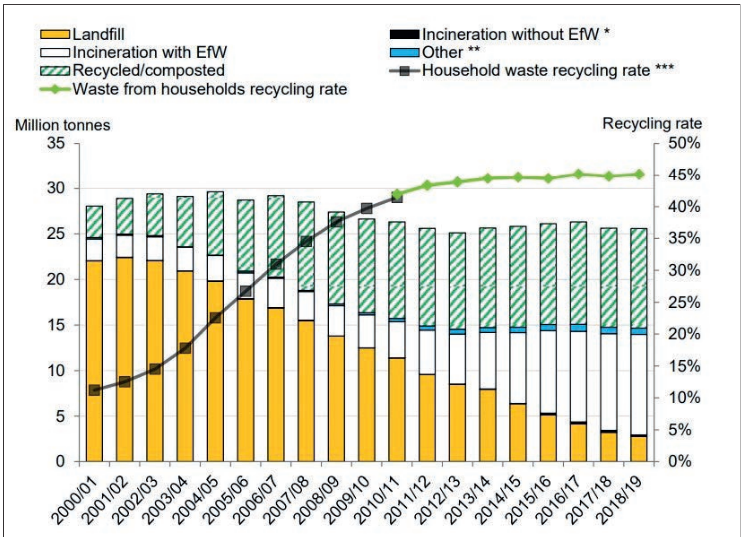
Both sets of pipes are connected to a site-wide gas collection system that leads to an onsite turbine house where the gas is converted to energy. In 2019, 3.6 TWh (terawatt hours) of electricity were generated from landfill gas. This was either used locally or fed to the National Grid.

The leachate sumps (wells) are connected to the surface of a filled landfill cell by vertical pipes or pipes laid on the side-slopes. Leachate is pumped to a treatment/disposal plant being treated onsite and discharged to a connected external sewage network or removed from site using road tankers to a sewage treatment plant.

When cells are full they are capped with compacted clay and a geomembrane. A protective cover soil is laid on top of these, then a top soil and finally cover vegetation. The aftercare for landfill sites includes checking the external gas monitoring boreholes, and managing gas flares, gas boosters and gas clean-up equipment, such as activated carbon systems. Monitoring the leachate wells, maintaining leachate-treatment plants, and checking external groundwater wells and surface water discharge points are necessary and continuous processes for decades after the landfill site is filled.

One landmark landfill site near Birmingham closed in 2015, after taking in over 21 million tonnes of waste in its lifetime. Packington landfill was the first site in the UK to produce electricity from landfill gas, starting in 1990. It is estimated that it will continue generating electricity for a further 20 years from the near-20 miles of pipework at more than 300 extraction points.

Packington landfill site is an example of landraising, rather than landfilling. It is 80 m tall, covers 380 acres and has taken rubbish from Birmingham and Warwickshire. In the foreground is the leachate tank farm. It is maintained by SUEZ Recycling and Recovery



Management of local authority collected waste and recycling rates for England, 2000/01 to 2018/19 © Defra tinyurl.com/kmonhaz

ENERGY-FROM-WASTE

One of the major factors in the dramatic reduction of refuse sent to landfill over the last decade has been the increased use of energy-from-waste (EfW) plants – also known as energy recovery facilities. The 12 million tonnes processed by EfW plants in the UK represents 45% of the nation's 'residual waste'.

Residual waste is the non-hazardous refuse left over once the recycled and reusable materials have been taken out of the rubbish collected from homes. This waste is taken to one of the 53 EfW plants in the UK that burn waste and produce electricity. If the EfW is a combined heat and power plant, then it can produce heat to supply local homes and businesses as well.

Viridor's 10 EfW plants process the most tonnage and, along with Veolia and SUEZ, take over half the UK's residual waste. David Field, Director of Engineering – Energy at Viridor, says that: "France began developing EfW plants in the 1970s and 1980s on relatively small municipal sites that processed between 100 and 150,000 tonnes of waste a year. In the UK, a new plant will be much larger and usually have a baseline capacity of around 300,000 tonnes a year, with most using moving grate technology."

EfW plants follow the same basic steps. There will be a reception area to receive the waste and get it ready for combustion, a thermal treatment that releases the energy from the rubbish and converts it to a transportable form of energy such as electricity or heat.

The process involves feeding the waste down a chute onto a moving grate and into a furnace where it combusts and releases its energy. The residual gases and by-products are held at temperatures over 850°C to ensure complete combustion before being passed into the boiler for energy recovery.

In the boiler, superheated steam is generated to achieve 400°C and around 45 bars of pressure. The heat energy becomes mechanical energy when the steam is used to drive a high-pressure turbine, the gear box turning a generator that produces between 20 to 35 MW (megawatts) of electricity.

The flue gases formed during the combustion process have an emissions clean up to ensure that the final released gases are safe. They are treated with hydrated lime and activated carbon to remove the acid gases and absorb heavy metals, dioxins, furans, and volatile organic compounds. These contaminants are removed as solid ash for further treatment. What is finally let out of an EfW stack will mainly be CO_2 and water vapour.

Incinerator bottom ash (IBA) is the name given to what is left on the floor after the combustion. Its weight is around 30% of the original waste and 10% of the original volume. When the IBA leaves the active part of the

To clean up an old landfill site, VertaseFLI, specialists in contaminated land remediation, will sort through the buried rubbish to retrieve materials that can be recycled or recovered © VertaseFLI

boiler it passes an overband (or drum) electromagnet that lifts out ferrous metals such as steel and iron.

The remaining IBA is passed by an eddy current separator that picks out the non-ferrous metals such as aluminium, copper and zinc alloys. Nearly 250,000 tonnes of IBA metal are recovered each year in the UK, amounting to nearly 1% of all recycled waste.

The remaining IBA consists of various elements including inert brick, rubble, glass, and ceramics. When this has been treated the majority is used for block making and aggregate. Nearly all IBA produced by EfWs is now recycled.

LANDFILL MINING

There are more than 20,000 closed and listed historic landfill sites in the UK with several hundred thousand more spread across Europe. Most can't be seen and have been largely forgotten. Others are remembered when there is a need to repurpose the land – to construct new roads, build houses or schools.

Usually, when specialist companies take on the reclamation of landfills, the focus is on reducing the volume of waste and eliminating possible pollution. Typically they will be working on 'dilute and disperse' landfill sites, 3 or 4 metres deep, where no engineering was undertaken to manage the leachate and ground gas.

To make the works financially viable and render the area environmentally safe, there will often be a trawl to recover material that can be recovered and reused, as well as ensuring that gas and run-off water is controlled.

Around 10% of municipal sites consist of inorganics like concrete, stones, glass, and metal. The metals can be recycled and the rest used for construction materials. An onsite trommel, a perforated rotating drum, allows soil-type material (around 50 to 60% of landfill by weight) to fall out. It captures the inorganic material and the combustibles like plastic, paper and wood, which can be used to generate energy.

In the past, landfill mining has been limited because of the economic challenges involved. To excavate, sort, make safe, and rebury usually outweighs the potential income – it only works financially when the there is a premium on the reclaimed land or the need to render the land environmentally safe.

Now, there are several projects across Europe establishing the possibilities and viability of enhanced landfill mining (ELFM). One of the leading figures researching this area in the UK is Dr Stuart Wagland, Senior Lecturer in Energy and Environmental Chemistry, School of Water, Energy and Environment at Cranfield University. He says: "We have been working with colleagues in Europe on ELFM, which considers landfill sites as a resource, banks of material that we will one day tap into. The ELFM model is not just about reclaiming land – 'traditional' landfill mining – it is about recovering materials and energy and ensuring that there is no long-term environmental damage. Now we need to make sure that the economics add up via cost-benefit analysis."

Up until now, few of the nearly 100 documented projects launched worldwide have made it past a feasibility demonstration, pilot or lab-scale venture. However, the biggest ELFM project in the world has begun in earnest at Remo, a recently closed modern landfill site 60 miles east of Brussels. Group Machiels, a specialist landfill contractor, has already worked on the 50 metre-deep site containing 18 million tonnes of household and industrial waste to stabilise the environment and avoid gas emissions.

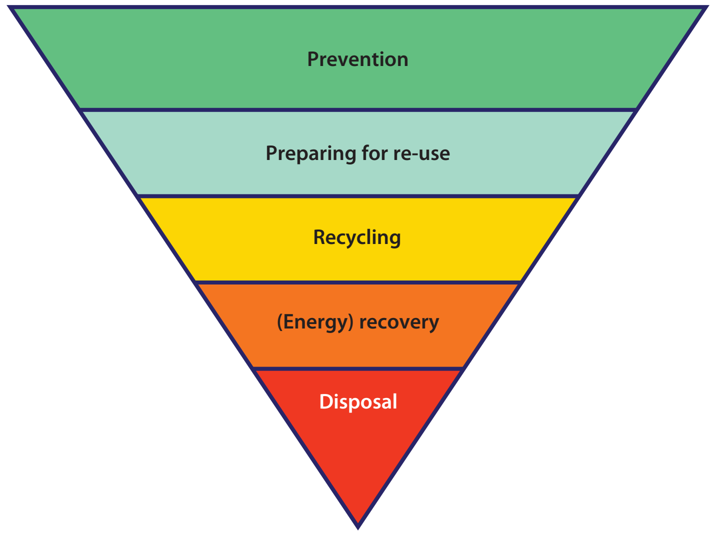
The company estimates that half of the waste can be recovered using onsite recycling plants to separate out metals, paper, card, and plastics. There is special potential in electronic goods such as old TVs or computers that typically have higher concentrations of gold and rare earth elements per tonne than are found naturally in ore.

The remaining waste would be turned into a refuse-derived fuel suitable for thermal conversion into energy. One such idea has been to use gasification with plasma gas cleaning to produce energy-rich synthetic gas (syngas) and a vitrified residue. The syngas will be used to produce methane or hydrogen, while the vitrified residue can be used for producing cement and construction materials.

Another option explored by Cranfield University is to convert excavated plastic into liquid fuels and chemicals through a pyrolysis process (thermal decomposition).

This is a long-term project. Group Machiels thinks it could provide power for 200,000 homes over the next 20 years before turning the site into a nature park.

Proponents of ELFM would rather mine landfills than use energy to mine more virgin materials. Dr Wagland would like to have a Remo-type project to work on in the UK. His Cranfield University team has identified 850 old landfill sites that have high energy and materials possibilities in the UK. The university has assembled a network of landfill managers, engineers and developers to make ELFM a reality in the UK (see www.elfm-network.co.uk).



This waste hierarchy pyramid shows where preventing waste arising in the first place is the ideal, and landfill is the last resort for managing waste

CIRCULAR ECONOMY

Due to the significant number of landfill sites across the UK, ELFM is a key component of critical material security and will contribute to the circular economy. Enhanced landfill mining recovers valuable raw materials and reintroduces them into the manufacturing chain.

At an EU level, the Interreg REGENERATIS project aims to recover valuable metals from former metallurgy sites and closed landfills. Previous work carried out by Cranfield University analysed several samples collected from four different closed UK landfill sites. The samples were prepared to separate the soil-like element, which comprises at least 60% of the material within a closed landfill site, from the rest of the waste. The study observed significant value in the metals it contained, highlighting the potential for closed landfills to contribute to the circular economy through ELFM projects. From just the four sites studied, there was around £104 million in platinum group metals; £280 million in aluminium and copper; £10 million in lithium; and £6.4 million in neodymium.

The recovery of these elements is critical for the sustainability of several industries. The global demand for lithium is expected to double between now and 2024 because of its important role in energy storage, particularly in electric vehicles. The UK is committed to banning the sales of new petrol and diesel cars by 2030, which is likely to boost the demand even further. Other critical metals include arsenic, which is predicted to run out sometime in the next five to 50 years, nickel and platinum group metals. Evidently, ELFM has a role to play in the UK's resilience for critical resources and reclamation of critical raw materials from closed landfill sites.

CLOSED-LOOP ECONOMY

All the big recycling and waste providers in the UK refer to the waste hierarchy pyramid where prevention is the preferred option for waste, and disposal (landfill) is the worst. In an ideal closed-loop economy model, goods would be shared, leased, reused, repaired, refurbished, or recycled.

In practice, a circular economy means keeping waste to a minimum. That is what many of today's waste practitioners and researchers are aiming for. They want to ensure that when a product reaches the end of its life, its materials are kept within the economy wherever possible so that they can be productively used again and again, thereby protecting the environment and creating further value.

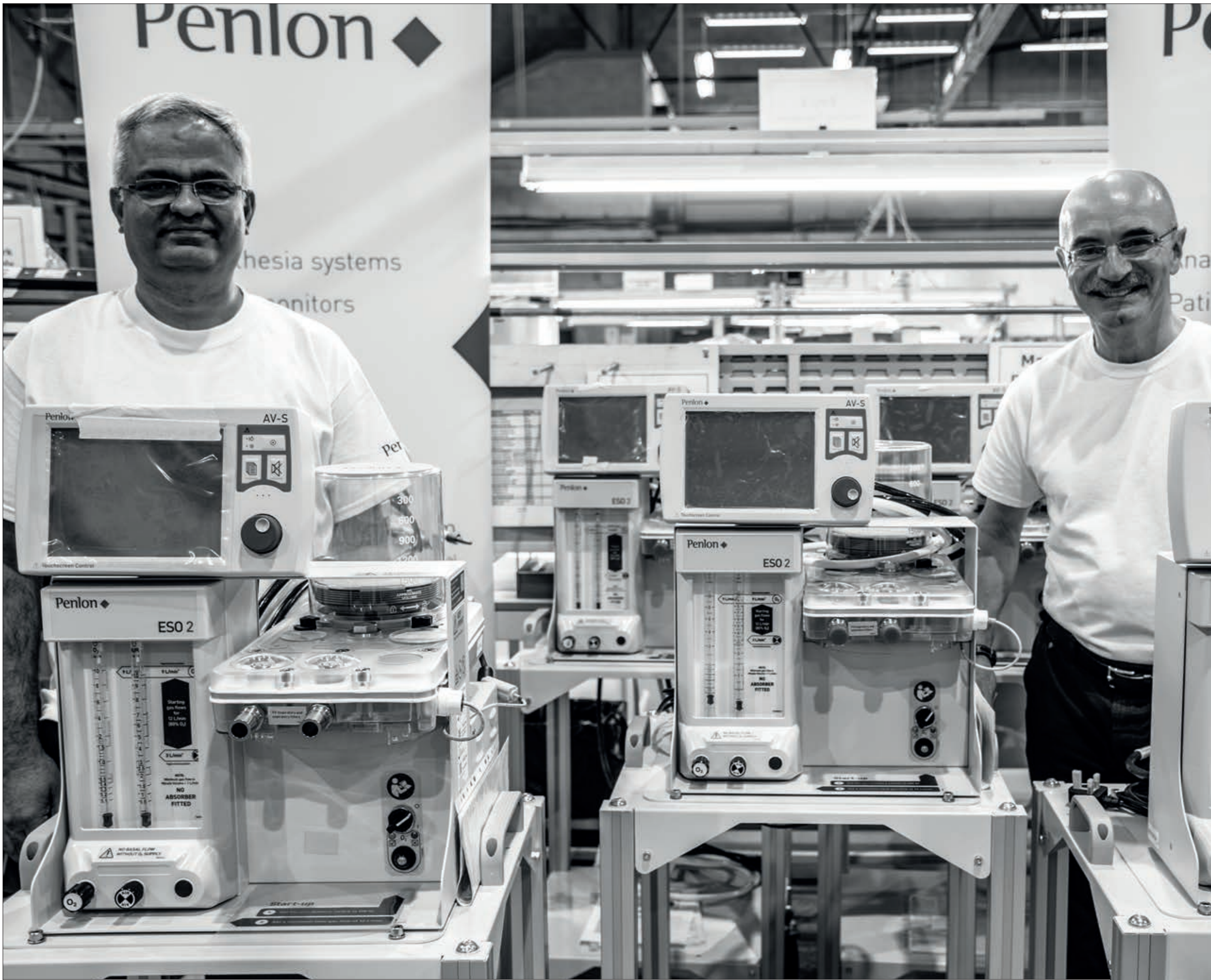
BIOGRAPHIES

Dr Adam Read is External Affairs Director at SUEZ Recycling and Recovery UK.

Gerry Cavanagh is Regional Manager South – Landfill Energy at SUEZ Recycling and Recovery UK.

David Field is Director of Engineering – Energy at Viridor.

Dr Stuart Wagland is Senior Lecturer in Energy and Environmental Chemistry and Deputy Director of Research, School of Water, Energy and Environment, at Cranfield University.



Guru Krishnamoorthy (left), CEO of Penlon, and Dick Elsy CBE FREng (right), Chairman of the Ventilator Challenge UK Consortium and CEO of the High Value Manufacturing Catapult with the Penlon ESO 2 ventilator. The consortium of more than 33 UK engineering and technology businesses from the aerospace, motorsport, automotive, and medical sectors produced more than 13,000 ventilators in 12 weeks in response to the COVID-19 pandemic, and received a President's Special Award for Pandemic Service from the Royal Academy of Engineering © thisisjude.uk

ALL HANDS TO THE PUMPS

When COVID-19 filled hospitals with patients with breathing difficulties, the UK's engineering community rose to the challenge. In record time, engineers from disparate industries created production lines to make ventilators for intensive care units, redesigning equipment, negotiating unfamiliar certification processes, and building new supply chains almost overnight. Michael Kenward OBE discovered how engineering teams achieved this in weeks.

When COVID-19 patients began to arrive in hospitals in early 2020, doctors did not know how the virus would affect them. With flu-like symptoms, early sufferers struggled for breath as the virus attacked their respiratory systems and hospitals faced a surge of patients experiencing breathing problems. Intensive care units (ICUs) were concerned about running out of the respirators and ventilators that could provide oxygen to patients.

The NHS entered the pandemic with 7,000 ventilators. The government predicted early on that the NHS would quickly run out, with little chance of a rapid increase in production. Two established medical device companies, Penlon and Smiths, produced ventilators for different stages of the patient journey. Smiths produced portable ventilators, often used to move patients in ambulances, between wards and in areas where connection to mains power is difficult. These work complementary to a Penlon unit, which is for use in ICUs.

The combined production capacity of the two companies was 100 ventilators each month. The government's forecasts suggested that the UK would need many thousands more. Gearing up to meet the anticipated demand became a priority.

VENTILATOR CHALLENGE

On 16 March, the government put out a call to UK industry to rapidly produce up to 15,000 ventilators for the NHS in just a couple of months. Companies such as Ford, more famous for mass producing cars, and Rolls-Royce, better known for making expensive jet engines, were quick to react. The motor racing industry also stepped in with McLaren, Williams and other Formula 1 teams offering the services of engineers who suddenly saw their racing season stranded in the pits.

Industry was keen to help but, as Dick Elsy CBE FREng recalled at an online Q&A event organised by the Royal Academy of Engineering*, there was a deafening silence as companies thought: "what do we do next?". Elsy, CEO of the High Value Manufacturing (HVM) Catapult, a group of manufacturing research centres in the UK, decided to step in. He called his contacts at the top of the country's engineering companies and, almost overnight, created the consortium that came to be known as VentilatorChallengeUK (VCUK).

This was no simple task. As Elsy put it: "ventilators are intricate and highly complex pieces of medical equipment". The consortium had to balance the need for speedy delivery with adherence to regulatory standards. On 18 March, the government asked industry to throw itself into the production of what it called rapidly manufactured ventilator systems (RMVS). The Medicines and Healthcare products Regulatory Agency (MHRA) published a document with a general specification for ventilators. It was then up to industry to decide how to meet the specifications.

The VCUK consortium concluded that there wasn't time to design a new ventilator, which would take time to get regulatory approval, a task that

"We needed to get to something closer to 3,000 units a week," says Hoare. "A massive scale up was required. It wasn't about a single machine being manufactured by a single individual over maybe 20 hours over a week. We had to break it down into about 250 different activities in what became one of industry's most interesting production lines."

can take six to eight months in normal times. The quickest response would be to work with existing design. On 19 March, VCUK put its weight behind an existing design made by Smiths Group. The ParaPAC Plus is essentially a mechanical, mobile device that has been used in ambulances and hospitals in the UK and overseas for more than a decade. This device would meet the needs of patients in transit and less severe cases in hospitals.

Following a request from the Cabinet Office, VCUK then looked at an idea from Penlon, which had concluded that it could meet the specifications for the RVMS if it took key modules from its original anaesthetics system and built a smaller and less expensive unit. Penlon's ESO 2 was designed to increase the supply of ventilators to ICUs. Within 24 hours, a small team of engineers from the consortium looked at Penlon's technology and decided to scale up the production of that device.

As the virus took hold and wards filled up, the businesses worked against the clock to establish, from scratch, seven new large-scale manufacturing sites; conduct vital clinical trials; set up new parallel supply chains and acquire the required 42 million parts at peak lockdown; and recruit and train a frontline assembly team in a new age of social distancing.

PRODUCTION

By the end of March, 5,000 companies offered support for this venture. VCUK split into two distinct work streams for the Penlon and Smiths devices. 'Team Penlon' was led by Dr Graham Hoare OBE FREng, Executive Director of Business Transformation and Chairman of Ford in Britain. The pre-pandemic production rate at Penlon was between six and ten ventilators a week. "We needed to get to something closer to 3,000 units a week," says Hoare. "A massive scale up was required. It wasn't about a single machine being manufactured by a single individual over maybe 20 hours over a week. We had to break it down into about 250 different activities in what became one of industry's most interesting production lines."

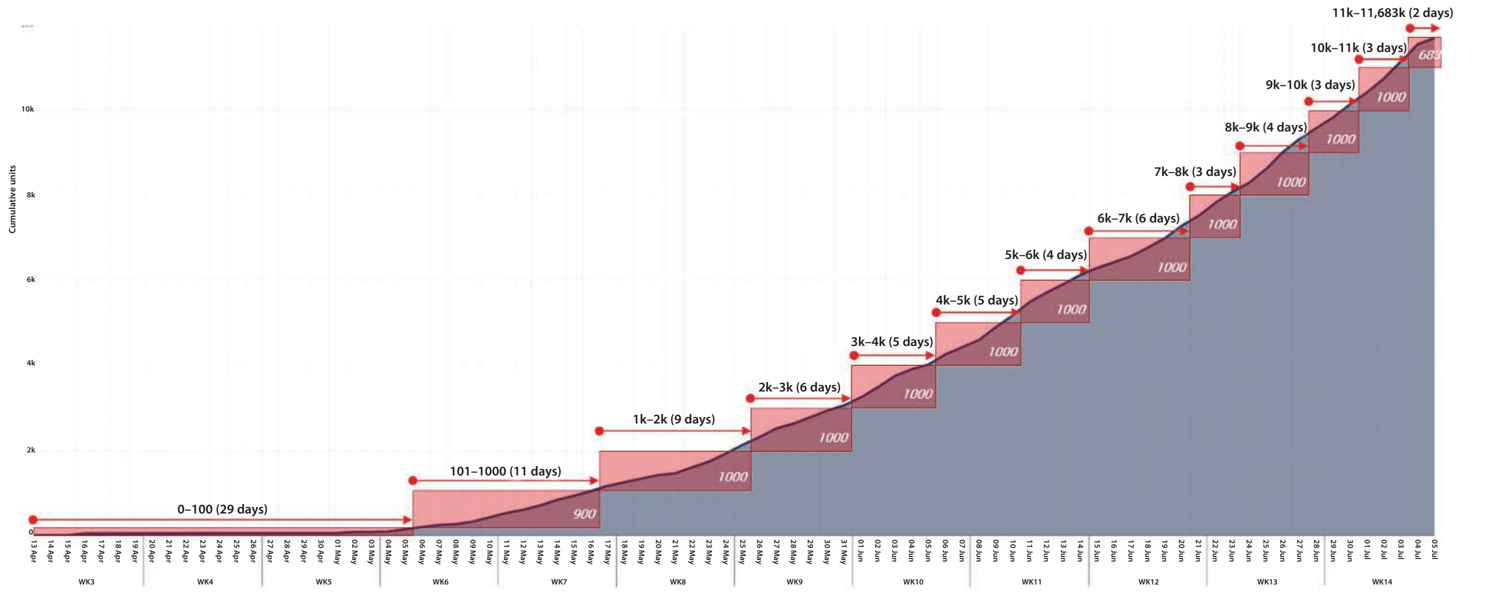
The manufacture of medical devices is highly regulated. According to Penlon, a new medical device typically takes two to three years to develop and launch. As industry started work to meet the challenge, Team Penlon brought in a group of heavyweight signatories from industry, including Ford, Siemens, Airbus, and McLaren, with the HVM Catapult as a focus for the collaboration between the companies. Bringing in engineers from Formula 1 injected a sense of urgency and pace into proceedings while the bigger companies contributed their larger scale processes. The larger medical industry players, including Siemens Healthineers, brought their own special skills and rigour to the process. Siemens was not active in the ventilator market, but has been a key player in medical engineering since the 19th century.

Each player in Team Penlon brought specialist engineering expertise to the challenge of creating a mass production line. The goal was to make, in less than three months, as many devices as Penlon would, in normal times, deliver in 20 years. The production work involved making everything from simple hardware to complex electronic control systems.

Even something as seemingly basic as trolleys to move ventilators required rapid action to manufacture by the thousands. McLaren Group took on the task, a technology business with expertise in simulation, engineering, electronic systems, and high-performance design. As Elsy described it, the Formula 1 team was grounded and there was "an enormous amount of engineering talent sitting there and waiting to get its teeth into something". McLaren threw its weight into the rapid manufacture of components for ventilators, as well as the trolleys.

McLaren Group set up a production line that turned 45 kilometres of aluminium extrusion into 250 trolleys a day. On the broader manufacturing front, in just 10 weeks McLaren manufactured more than 100,000 individual components. As Piers Thynne, Production Director of McLaren Racing, said: "not a single McLaren-manufactured part reached the production line with a deviation from the design or specification."

McLaren also played a key role in the team that worked on producing more of the Smiths ventilators to market. Smiths had



This graph shows the rate of the scale up of the Penlon ESO 2. The first unit of the new model was produced four weeks after the Cabinet Office set the challenge; 12 weeks later there were over 11,000. The acceleration of production was exponential as teams gained knowledge and solved issues. At the peak, the consortium was building 200 times quicker than previously achieved in Penlon. The second 50% of volume was produced in just 23 days, averaging 260 units per day

supplied ParaPAC units for over a decade, but in relatively small numbers.

When it came to mass production, VCUK needed to ensure that there were enough test boxes at each new production site to run final testing on the Smiths ventilators coming off the production line. Mark Mathieson, McLaren's Director of Innovation, explained: "the Smiths device has a very complex production process. It's incredibly rigorous and employs 18 different scientific test boxes to validate all the different components inside that device." With only outdated design specifications available, this was a major hurdle that threatened to halt production of the devices. Instead, McLaren dedicated a team to reverse engineer, design, procure, test, and build 144 new test boxes. It used its extensive Formula 1 network to source over 35,000 parts from around the world and, by working over 12,000 hours in April alone, the team was able to get production back on track.

ASSEMBLY

It takes substantial manufacturing effort to assemble the hundreds of components that go into a ventilator. Airbus offered the Advanced Manufacturing Research Centre (AMRC) Cymru in Broughton in North Wales as a candidate assembly line. AMRC Cymru had opened its doors in November 2019, with a focus on manufacturing sectors including aerospace, automotive, nuclear, and food. Airbus, the first major tenant at AMRC Cymru, had barely started work on next-generation wing technologies when the call went out to the UK's engineering sector to make ventilators.

Working with Airbus UK, AMRC quickly stripped out new equipment intended for work on wings and transformed it into a ventilator production line. Within a week, 500 Airbus operatives were preparing to work four shifts making sub-assemblies to be incorporated with other units into the manufactured ventilators. By 26 March, they knew that their role would be to make two sub-assemblies for Penlon's device on eight assembly lines with 88 operators per shift for each sub-assembly.

AMRC Cymru was one of seven manufacturing facilities set up from scratch as a part of VCUK to complement the production at Smiths and Penlon. There were also 'pop up' factories at Ford in Dagenham, GKN Aerospace in Luton and Cowes, McLaren in Woking, Rolls-Royce in Filton, and Surface Technology International in Hook, Hampshire.

In normal circumstances, it can take a year to create a new factory to assemble something as complex as the Penlon ventilator, with its 700 parts. The first lockdown was far from normal circumstances: the ventilator makers had to move more quickly and set up factories where workers could operate within the constraints of social distancing. Siemens Digital Industries drew on 100 people from its operations in Manchester and Congleton, including apprentices and young engineers at the start of their careers. Within just 48 hours they had created a computer model of the AMRC Cymru plant, using Siemens's plant simulation software to optimise the factory's layout. Ben Apps, a plant layout and virtualisation engineer at Siemens Congleton, described the process: "By creating a digital twin of the AMRC, mapping every inch of

Augmented reality headsets stepped in when it came to assembling ventilators. The Advanced Manufacturing Research Centre (AMRC) at the University of Sheffield rushed Microsoft HoloLens headsets to the AMRC's R&D facility in North Wales. HoloLens played a key part in training the assembly workers, while allowing them to keep a safe distance from one another. The headsets provided guided instructions and mixed reality to support the assembly of ventilator parts, and connected new factories around the country with skilled ventilator engineers at Penlon, Oxfordshire

the available space, and using 3D design tools, we were able to maximise production massively. What was also remarkable was that digital tools enabled us to design the production line virtually in six days, saving thousands of pounds and hours in the real world."

The digital tools also played their part in training the operators who would run the production lines. Siemens took 3D CAD data and converted it so that it could be presented in a standard web browser to make it easier to train 550 volunteer operators from Airbus.

The complete production line of Penlon machines ran from AMRC Cymru to Ford in Dagenham where the ventilator system was built, to Hook where the components came back together, and finally back to Penlon for the final test, which is critical for certification. Team Penlon ended up with around 2,200 people making machines.

"The parts side of the activity was phenomenally complicated," says Hoare. Simply ensuring the supply of the 700 or so parts that came from all over the world was a key challenge. When production was in small numbers, if parts were no longer being made Penlon could draw on its existing stock. That was no good for the anticipated production rates. They even had to reinstate production lines in Israel to produce printed circuit boards. Hoare praises McLaren's supply chain efforts. "They managed it as you would hope a Formula 1 team would manage their supply chain – very timely, very precisely." The team sourced parts from over 22 countries, with the furthest distance travelled by a single part being 5,226 miles.

LOGISTICS

Inevitably, the massive increase in production meant creating a logistics organisation to ensure that everything came together when much of the UK was in lockdown. To handle 3.2 million parts, DHL Supply Chain created a distribution network from scratch. It collected parts from new sets of suppliers and ensured that they ended up at the right manufacturing locations to be turned into ventilators. At the same time, DHL also increased its support for the NHS with deliveries of personal protective equipment (PPE) and supplying Nightingale hospitals.

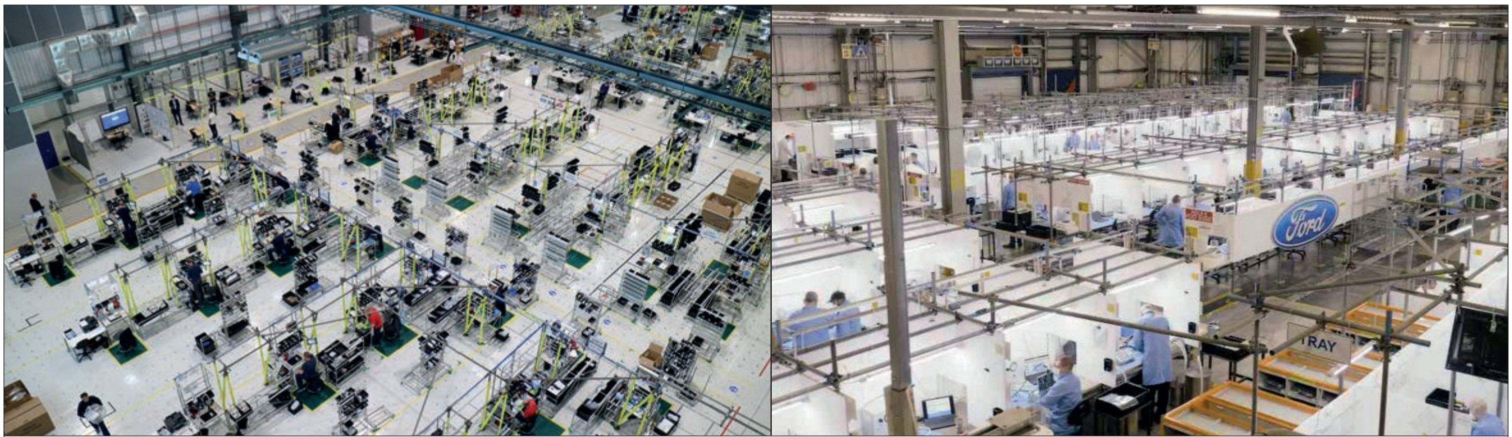
Manufacturing a medical ventilator is a part of a complex chain of events. Before they can be used on patients in the UK, new medical devices must be approved by the MHRA. Penlon and Siemens Healthineers guided the consortium through the intricacies of manufacturing devices according to the MHRA guidelines. It also advised the coalition on assembly and testing and helped to ensure that, from the outset, the venture took on board the MHRA's strict regulation requirements, ensuring that no time was lost in the accelerated production process. As it leaves the production lines, each ventilator requires 30 pages of test and inspection documentation.

By 16 April, Elsy announced that VCUK had secured MHRA approval for the Penlon Prima ESO 2 device, in just under three weeks, and could accelerate production at the Penlon site in Oxfordshire and the new VCUK production lines in Broughton, Dagenham, Woking, and Hook.

As the number of participants shows, VCUK was a complex exercise in engineering management. Alongside creating production lines that could assemble thousands of machines, each made up of 700 parts in the case of the Penlon device, participants in VCUK had to put their heads together to consider numerous seemingly smaller issues where manufacturing meets medicine at the bench level.

COLLABORATION

How did it all work out? While the rest of the country was in lockdown, some of the UK's leading engineers were navigating what was for them unfamiliar territory. Hoare summed up the effort that the UK's engineering companies put into the work when he said: "It was a wild ride for the leaders of these companies. The companies provided everything that could be asked for and more, including teams of exceptionally talented



The socially distanced assembly lines at Airbus, AMRC Cymru (left) and Ford in Dagenham (right

volunteer engineers and technicians to turn these ideas and concepts into reality in the blink of an eye."

"We have all personally learned a huge amount. Our companies have too," says Hoare. When the project got under way, there were none of the usual systems in place for problem-solving, accounting and other tasks. With problems turning up at a rate of about one every 14 minutes at the start of the programme, the consortium had to move quickly: 50% of problems were sorted within two days and all critical issues were resolved within 22 hours, seven days per week, 24 hours a day. "We created cloud-based systems," Hoare adds, which has led to an invaluable database. "All of that is mineable and harvestable." Ford is just one business that plans to mine this repository for lessons for its wider operations.

It was the speed of execution that impressed Hoare, something that he plans to take back into Ford. "The biggest thing," he adds, "is the ability to bring a diverse team together, even though many of us hadn't met personally, and to be able to rapidly trust." Choose the right people, he advises, and then miracles are possible.

Brian Holliday, Managing Director of Digital Industries, Siemens UK and Ireland, has his own take on the success of Team Penlon. "VCUK has been a project of extreme collaboration. This was achieved with ownership culture and leadership without ego. Internal divisions and competitor norms were carefully set aside for the greater good for society. Long hours were worked, sometimes away from families, often from home under lockdown but the team remained focused and passionate knowing that every ventilator produced can save a life."

Unlike much of the response to the pandemic, the ventilator challenge grabbed few headlines during its lifetime. To a certain extent this was a deliberate policy. As Elsy explains, they wanted to be left to get on with the job. After the event, he says, they were much happier to talk, partly because of the story that it tells about the engineers' response to the crisis. "It is a great story. It is a celebration for engineering and engineers. We have got a real determination to play that out fully."

VCUK IN NUMBERS

- 13,437 ventilators, enough to meet the normal demand for 20 years, were delivered to the NHS in 12 weeks
- Production reached a peak of over 400 devices a day
- Parallel supply chains acquired around 42 million parts and electronic components from over 22 countries
- The Penlon ESO 2 contains 365 unique items from 88 suppliers
- The Penlon ESO 2 device achieved full MHRA approval in just three weeks
- The consortium recruited and trained a frontline assembly team of 3,500 workers
- Production involved seven large-scale manufacturing facilities at Ford, Airbus, Surface Technology International, McLaren, Rolls-Royce and GKN Aerospace in Cowes and Luton
- The McLaren Racing machine shop alone manufactured 113,506 individual components

**Information and quotes attributed to Dick Elsy CBE FREng, Chief Executive of the High Value Manufacturing Catapult, were taken from an online Q&A event, organised by the Royal Academy of Engineering, with him and Dr Graham Hoare OBE FREng, Executive Director (Business Transformation) & Chairman, Ford of Britain, on 29 May 2020.*

With thanks to Dr Graham Hoare OBE FREng and John Gardiner from Ford, and Maeve Harte and Rosa Wilkinson from the High Value Manufacturing Catapult for their contributions to this article.

FACING ENGINEERING'S ULTIMATE CHALLENGE

Dr Luisa Freitas dos Santos FREng – with teams to manage in Singapore, the UK and the US – was one of the first people in the UK to experience how the pandemic would affect engineering operations

The past year has been a juggling act for Dr Luisa Freitas dos Santos FREng, Vice President, R&D Global Clinical Supply Chain, at GSK. Throughout the COVID-19 pandemic she has maintained a steady supply of medicines for clinical trials while also being a part of the pharmaceuticals company's pursuit of new therapies for this novel disease. She talked to Michael Kenward OBE about the challenges of managing engineers and scientists in lockdown.

Dr Luisa Freitas dos Santos FREng's first encounter with COVID-19 was back in February 2020. While it may not have directly impacted on her personally a year ago, it certainly affected the work of her team of engineers and chemists in Singapore. They were among the first wave of R&D teams who had to devise new COVID-safe ways of working in response to local lockdown measures and prevent the virus's spread. As Vice President of R&D Global Clinical Supply Chain at GSK's pharmaceuticals business, Dr Freitas dos Santos manages teams that make and supply medicines for GSK's clinical studies, which can mean supplying hundreds of clinical studies taking place around the world. The country, and her Singapore-based team, went into strict lockdown early on. "Almost overnight, we had to introduce measures such as shift working, virtual audits and Gembas, COVID-secure lab and plant operations," she says. This proved to be a trial run for the rest of her groups a few weeks later.

The need to plan and prepare for that scale of unprecedented global disruption and personal impact isn't a normal part of most engineers' training. If anything, it is nearer to Dr Freitas dos Santos's parents' expertise. Her mother is a sociologist while her father is an economist. At school she was interested in science, maths and physics. She enjoyed biology and biochemistry, which prompted her to study for a five-year bioprocess engineering degree at the Catholic University of Portugal in Porto. One reason Dr Freitas dos Santos picked her course was that there was an option to spend a year in industry or doing applied research.

INTRODUCTION TO ENGINEERING

For her year off campus, Dr Freitas dos Santos worked with Unilever near Rotterdam in The Netherlands. This convinced her that she liked travelling. "It was very exciting, travelling and meeting people from different backgrounds, listening to different languages." She admits that Dutch wasn't an easy language to learn, but Unilever was a multinational business, "an R&D setting with a lot of collaboration programmes with other countries." Her supervisor was a British chemical engineer, and everyone spoke English. "You get comfortable not using your own first language," she says. "It opened my eyes, not just to feel confident to move to a new country, but actually seeing R&D within industry."

It was always the application of research that appealed to Dr Freitas dos Santos. "A thread in my career that I still absolutely love is innovation," she says. "It just appeals to me – translating something that can start quite theoretical into something that you develop and put into practice." It all goes back to engineering, she insists. "Engineers like to build things, to find a solution, to solve a big problem, to translate something that works on a very small scale into something that could be available to everyone. The translation of research into development and eventually something that people can hold, like a medicine, that starts from brilliant ideas in the lab." Dr Freitas dos Santos picks an example to explain what she means. "When you see someone with a GSK asthma inhaler in their hands, it makes me very proud to have been one of the many people in the extensive team that made that medicine a reality. It has always been a very large, multidisciplinary team," she adds quickly.

Her introduction to engineering in action was in a very different domain from the pharmaceuticals that she has worked on for more than two decades. At Unilever, she worked in food engineering and rheology. The challenge was to develop shelf-stable desserts for regions where refrigeration was a problem, such as in some more remote areas of South America. So, she set out to study what sort of formulation could withstand inconsistent refrigeration.

The project started on a small scale in the lab, backed up by theoretical analysis and simple mathematical models. That looked promising, so it was time to try things out on a larger scale. "I remember transforming the floor of the pilot plant into a giant sticky foamy layer because I did not quite get the right formulation in my experiments and mixing modelling. Instead of a very nice clear liquid in the reactor, I had this massive amount of foamy gelatine that got everywhere. That was quite a good experience that made me 'very popular' with the rest of the pilot-plant technicians and engineers, as you can imagine," she laughs. "That was one of my first-hand examples of the need to do more work, and predictive modelling on a small scale before you go to a large scale."

Dr Freitas dos Santos says that, far from putting her off, she enjoyed the experience. "I loved it. I said, 'oh my gosh, there is something that I need to solve'. It is not going to be so easy." The experience taught her the importance of talking to more experienced engineers, and the need to learn about scale up before trying things out on the plant. She has followed this guidance throughout her career.

AN APPETITE FOR TRAVEL

Foreign travel remained on the cards after Dr Freitas dos Santos graduated. She won a scholarship from the Portuguese government that allowed her to travel abroad to choose a research programme that interested her. Her university tutor in Portugal was keen for Dr Freitas dos Santos to go to the US, instead she chose the UK. She was drawn to London as a city and to its cultural attractions. "I love modern art," she says enthusiastically. After checking out Cambridge and UCL, she settled on Imperial College London.

Her PhD in bioreactor design involved looking at volatile organic compounds – gases emitted from some chemical processes that may have adverse health effects – and using a biological approach in the control of pollution. Her research took her into waste minimisation and remediation. "I had a real interest, which I still hold, in sustainability. The idea of developing processes and products in a sustainable manner was always of interest to me." Dr Freitas dos Santos continued to support this

Dr Freitas dos Santos in Alentejo last summer. Her two favourite regions in Portugal are Alentejo and Porto and the Douro Valley, the latter her home region, "the most beautiful part of course. I am not biased at all."

activity at GSK. To her, sustainability is also important when making pharmaceuticals.

At Imperial College London she had begun to develop an interest in using biochemical processes to make medicines. There were plenty of researchers in the university working on different cell cultures, mammalian cultures and so on. "There was a lot of excitement at the time in terms of using bioprocessing to produce novel molecules such as monoclonal antibodies. It really captured my interest in pharmaceutical and biopharmaceutical processes." Although this was not her direct research area, Dr Freitas dos Santos confesses to hanging about in different laboratories and departments and checking out what everyone else was up to. "That is still the case. I am still curious and interested in what is happening in the lab next door."

A START IN PHARMA

For Dr Freitas dos Santos, the move into pharmaceuticals happened a while after. Her first plan was to translate her lab research at Imperial College London into a usable technology. Her doctorate, on using bioreactors to treat wastewaters from chemical processing, was the basis for a spinout business, Membrane Extraction Technology (MET) Ltd set up in 1995, which used separation technologies aimed at treating complex halogenated chemical compounds – tricky materials to deal with and render safe for final disposal.

This was at a time when it was becoming more frequent for academics to turn their research into potentially profitable spinout businesses. As part of a small startup team, Dr Freitas dos Santos and her fellow founders could tap into government grants and matching funds from industry, as well as securing venture capital.

MET's first big project was with chemical company ICI at Hillhouse near Blackpool. It was an opportunity to design and install a pilot plant in a polyurethanes production unit at ICI, then still a key player in the UK's chemical processing industry. "It was a fantastic opportunity. It gave me a huge amount of responsibility early in my career." It meant managing safety and containment challenges, setting up a new facility next door to a large phosgene plant. "You can imagine the safety measures required, and the rigour in terms of risk assessment, engineering controls and process safety. I learned an absolutely huge amount. The people I worked with were incredibly generous in teaching me," she adds. "They could have said 'Who is this female engineer turning up from London?'." On top of that, Dr Freitas dos Santos was still under 30, originally from Portugal, and the only woman on a site with hundreds of engineers, technicians and operators.

With MET's business up and running, Dr Freitas dos Santos faced a very different challenge. She had acquired a fiancée who also happened to be a chemical engineer working in the same business in addition to his academic role. "To be honest, it was better not to work together," she explains. That plan worked out. "We are still happily together," she adds. "We have been together for over 26 years."

As a result, she left MET to join what was, at the time, SmithKline Beecham, and now GSK. Her husband stayed on with the startup. Evonik Industries, a world-leading specialty chemicals business based in Germany, eventually bought MET in 2010. "It was fantastic to see it grow and then be acquired," says Dr Freitas dos Santos. "It is a very nice story." Two decades after the origins of the business, it is still cited as an example of successful technology transfer at Imperial College London.

Moving into the pharmaceuticals industry took Dr Freitas dos Santos into new areas of chemical engineering. She joined the business working in R&D chemical development, where researchers take a synthetic chemistry route for a candidate active pharmaceutical molecule capable of producing a few grams. They then translate that chemistry into a robust process that can produce kilograms needed to supply clinical studies, and then eventually tons when it becomes a commercial process for an approved medicine. Dr Freitas dos Santos joined SmithKline Beecham as a part of the chemical and engineering teams that developed that process. "I am very lucky to have worked on a number of medicines that have gone all the way from research to file and launch, and are now taken by millions of patients across the globe," she says. "It takes a long time. A medicine stays with us during development – six, eight, ten years."

Dr Freitas dos Santos at the UK Drug Product R&D Pilot Plant

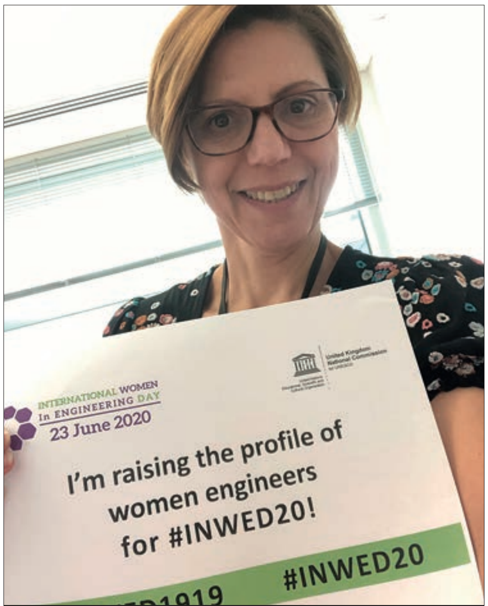
ADAPT AND THRIVE

Dr Freitas dos Santos heads the global clinical supply chain at GSK R&D. Her group supplies pharmaceuticals for the company's clinical studies, which means planning, making and supplying enough medicines to sustain more than 200 clinical studies taking place across all continents. She also manages labelling, packaging and distribution of clinical supplies for thousands of patients, across all the company's therapeutic areas. "We have a lot of strength in respiratory and anti-infectives at GSK. In the last two to three years, the oncology part of the business has grown enormously and given new challenges to our clinical supply chain and our engineering teams, which is fantastic."

As work progresses on a new pharmaceutical, Dr Freitas dos Santos's group works with both the clinical development and the commercial manufacturing parts of the business to develop the processes needed to make new drugs in commercial quantities and collect all the necessary data to support regulatory files. This is not the sort of activity that is easily put on hold while a business grapples with new ways of working during a pandemic. Starting in Singapore, the whole clinical supply chain operation had to adapt. "We didn't lose a single day," she said. "When the virus started moving towards Europe in March, it became very apparent to us that we would have to implement measures in response to lockdowns, first in our UK groups, followed very quickly by the US groups. The absolute focus was the safety of our people across all our facilities, then our continuity of supply to patients. People's flexibility, creativity and commitment has been amazing. We had to introduce rotas, including in many cases working at weekends, to ensure continued delivery while maintaining required social distancing in the labs and in the pilot plants."

Businesses always have contingency plans to deal with unexpected events. "We were very well-prepared in terms of having clear business contingency plans," says Dr Freitas dos Santos. The pandemic put GSK's plans into overdrive. "The reality of this pandemic was that we had to trigger every single business contingency plan we had for every site, for every group, I never thought that I would be doing this simultaneously across the globe."

Dr Freitas dos Santos still sounds amazed and proud that, after a year, her teams continue to operate across all the countries and support all those clinical studies. In all, her team of around 400 people operate at a site in Singapore, three in the UK, and three more in the US. "We quickly established a COVID-safe environment, and once implemented about half of my group remained working on site in our labs, pilot plants, packaging, and distribution lines. We are passionate about helping others and we knew that we needed to keep delivering medicines for critical clinical studies. COVID has made it very clear what we do and the impact we have on people and society." The other half of the group does clinical supply chain management, planning, data and



Dr Freitas dos Santos promoting International Women in Engineering Day in 2020

system support, patient randomisation – all those colleagues are working still from home a year on and doing a brilliant job."

It wasn't just a case of feeding the existing medicine pipeline at GSK; developing better medicines to treat patients with COVID-19 is also a key focus for the industry. So, in addition to the day job, Dr Freitas dos Santos was a part of the company's COVID solutions team. "I had the privilege to join our enterprise effort that assessed the molecules already in the portfolio that could support COVID treatments." The company set out to quickly assess them to see if there was something that could potentially work to treat people suffering from COVID-19 symptoms. They went on to progress one molecule into a clinical study as well as establishing a key collaboration with Vir biotech on another candidate currently in late-stage studies.

DIVERSE WORKFORCE

Another important role that Dr Freitas dos Santos cannot put on hold, and one that she is passionate about, is in GSK's pursuit of diversity in its workforce. She sees this as being far more than attracting and promoting female talent and is part of a group in the company that champions scientific career development and the wider diversity agenda. "You can't just say 'okay, gender balance is much better now' and the work is done," she explains. "I've been able to grow and lead at GSK and I also understand how I'm a role model to many. But of course, it's about more than gender. As a company, we are also looking at a much more comprehensive view of inclusion and diversity." Dr Freitas dos Santos talks of 'full diversity of background'. For that to happen, we must think about engaging people who don't even apply for jobs because, as she puts it, they don't see themselves in those roles. She insists that "if we really want to transform inclusion and diversity, and not just have one or two people as token examples, organisations need to look at how they attract, recruit and develop talent; how we advertise jobs; who we have in recruitment panels. And once in the organisation, we need to use our network of mentors to support career progression, for example this is something we do as part of the GSK Fellows Programme."

Dr Freitas dos Santos believes that it is important to start early if you want to encourage people to enter the profession. For some time, she has worked with school students, especially girls, to improve their understanding of engineering and what engineers get up to. "It is not an obligation, but something that I really enjoy," she stresses. Such visits can reveal how seemingly simple things can influence youngsters. "I remember once when I arrived at a school, I talked about what an engineer does in pharma R&D." Her enthusiasm for engineering wasn't the only factor that struck her young audience. For one teenage girl at least, it was another of Dr Freitas dos Santos's passions. "I like shoes, a lot! I can't remember if I had very bright pink, suede high-heel shoes or one of my leopard-print pairs on," she explains, "but she didn't look at me. She just looked at the shoes and said, 'I never thought an engineer looked like you'."

Dr Freitas dos Santos says that visiting schools and talking to young people about the life of an engineer is just one activity she has missed during lockdown, in addition to seeing her team members across the globe. You can do a lot of things in virtual events she says, but adds: "I like the informal conversations. I like talking to people."

After more than a year working with all those business contingency plans in place, Dr Freitas dos Santos is keen to see some sort of return to normality. "I am looking forward to having everyone vaccinated and going back to normal, perhaps a new normal," she says. She misses the social interactions, internally related to engineering and work, and the family interaction. With her family in Portugal and her husband's family in New Zealand, home schooling their two children has been a priority. "We always relied on travelling for family reasons and having that interaction." At least her teenage children, along with family and friends, have a clearer idea of what she gets up to for a living. She laughs, "suddenly there was a lot of interest in what I do".

BIOGRAPHY

Michael Kenward OBE has been a freelance writer since 1990 and is a member of the *Ingenia* Editorial Board. He is Editor-at-Large of *Science|Business*.

CAREER TIMELINE AND DISTINCTIONS

Studied bioprocess engineering at the Catholic University of Portugal, **1986–1991**. PhD in chemical engineering at Imperial College London, **1991–1994**. Technical Director, MET, **1995–1997**. Joined GSK, **1997**. Fellow, Institution of Chemical Engineers, **2014**. Attended the University of Chicago Booth School of Business, **2010**. GSK Senior Scientific Fellow, **2017**. Fellow, Royal Academy of Engineering, **2019**. Vice-President, Global Clinical Supply Chain, GSK, **2015 to present day**.

FROM FOOD WASTE TO FASHION

Chip[s] Board is turning potato peel into sustainable bioplastics for the fashion and interior design industries to simultaneously tackle the problems of food waste and plastic pollution.

In his previous role as a chef, Chip[s] Board Co-Founder Rowan Minkley noticed the abundance of food waste in the industry. He had studied design at university and so began developing prototypes made from food waste with a housemate, hoping to create sustainable materials for use in design. Knowing that one-third of all food produced becomes waste, Rowan and Co-Founder Rob Nicoll aimed to find value in it and create a true circular economy bioplastic. They discovered that they could make materials from food waste that were easily disposable as well as more durable.

Initially, the pair began by making an MDF substitute from potato waste, but soon discovered that they could make bioplastic materials from industrial food waste. They decided that this route would make more impact as a lot more can be achieved with a small amount of plastic compared to the large quantities needed for MDF. Chip[s] Board has developed a process that transforms potato waste, supplied by McCain, into Parblex: plastic from potato waste. The bioplastic is made from the raw materials before fibre fillers, such as walnut shells and wood flour, are added to strengthen the plastic and give it qualities such as colour and texture. In its simplest form, Chip[s] Board is converting sugars and starches from food waste into a biopolymer without the use of solvents or any toxic by products.

One of the key challenges that the team faced was creating its own laboratory facility for the entire process, which is complex biochemistry involving fermentation, purification and then polymerisation. Ensuring that all these stages work together and are balanced to optimise each part of the process took some fine-tuning. However, building a lab allowed the team to make sure that each part of the process had a minimal environmental impact: reducing energy consumption, removing chemicals, recycling heat, energy or water between the processes. The team is hoping to move to a larger pilot facility in 2021, where these values will continue to play a key role.

A pair of glasses made Parblex: bioplastic from potato waste

Once manufactured, the bioplastic is sold as pellets, which can be injection moulded, heat formed into sheets, or spun into fibres for textiles. The bioplastics are mechanically and chemically recyclable, so can be reused as plastic, as well as broken down into organic matter in industrial composting.

Chip[s] Board won the Royal Academy of Engineering Enterprise Hub's Launchpad Competition in 2018, and Rowan Minkley is an Enterprise Fellow. While some projects have been put on hold because of COVID-19, the team is hoping to expand into bio-based plasticisers, which will allow it to make the material more flexible. Now a team of eight, Chip[s] Board is currently producing samples and setting up a pilot production facility in Yorkshire in the next few months, aiming to start selling directly to the fashion industry later this year.

For more information, visit **www.chipsboard.com**

HOW DOES THAT WORK?

CHATBOTS

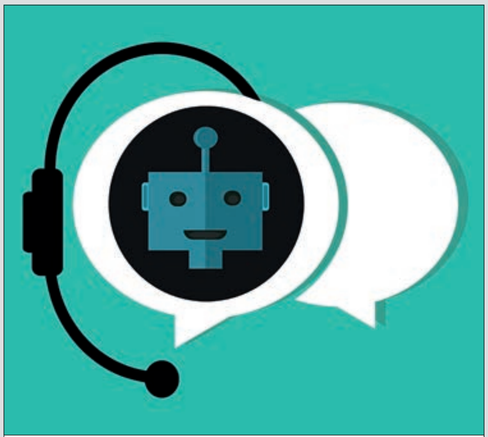
As human interaction online gradually gives way to automated responses, chatbots must impersonate us without attempting to replicate human empathy or enthusiasm.

When visiting a website or online resource, it's increasingly common for a sound effect to herald the appearance of a pop-up window, containing a question like "Can I help?" or "What are you looking for?". It's often accompanied by a thumbnail photo of a person, yet you're actually being greeted by a chatbot – reducing the need for customer-facing staff by delegating basic services to an algorithm.

The word 'bot' describes a piece of software that performs a single repetitive task, and chatbots are designed to simulate human conversation. They provide programmed responses to user inputs, attempting to resolve common queries. The challenge for any chatbot involves interpreting those inputs and questions, before interrogating a database of pre-prepared responses. Having matched the input string to the most appropriate response, the latter is then presented as an answer.

Like many online services, chatbots evolved from rudimentary beginnings. Early examples were notorious for displaying irrelevant responses, while struggling to understand abbreviations or colloquialisms. The introduction of machine learning helped expand the database of predefined scripts chatbots can interrogate. For instance, modern chatbots are programmed to redirect unknown queries to a human, while simultaneously recording this failed interaction. Conversation logs are fed back into the databases powering the bots, so they can see how a transferred query was eventually handled by a human. This helps them to replicate a similar approach in future.

Basic rule-based chatbots allow users to choose from predefined options, following a hierarchical path to ensure every journey reaches a defined (if limited) conclusion. More sophisticated bots support pattern matching for open-ended inputs, with smart feedback loops seeking clarification – "did you mean X?", for instance. Certain words or phrases act as identifying tags, which are linked to pre-programmed responses, and the bot selects what it evaluates to be the most pertinent option. Rules can also help here too; enquiries containing the word 'complain' might lead the bot to automatically defer to a human operator.



The twin end goals of chatbots are (a) full automation with no staffing input required and (b) consumer convenience. Saying "Uber, get me a cab to the cinema" will one day summon a vehicle to your current location (regardless of where you are right now), with a destination of your favourite or closest cinema pre-selected. There's no further input required from you, and no humans needed at Uber's end to complete the transaction © Pixabay/mohamed_hassan

Modern chatbots use natural language processing (NLP) to break a statement into structured data pieces – identifying potential spelling mistakes or separating verbs from nouns. They can often distinguish tenses ("I had a booking" versus "I want to make a booking"), or recognise sentiments like frustration, which may benefit from human intervention. NLP involves two processes – converting input strings into the aforementioned structured data, before transforming that data into a written or verbal response. It also involves distinguishing intents (required actions or requested information) from entities such as booking references or account numbers.

Two related branches of software underpin modern chatbots like IBM's Watson and Microsoft's Language Understanding:

- Machine learning allows the bot to learn from available information and make judgements about how to respond, based on identifying tags. Machine learning bots evolve and mature through use.
- Artificial intelligence (AI) powered bots are able to evaluate context and refer back to previous statements in a conversation – such as not requiring someone to input their account details more than once.

Cutting-edge bots combine machine learning, AL and NLP to accurately replicate the forms of interaction you might expect if a person was responding to enquiries. A cognitive behavioural therapy chatbot developed by Stanford University has successfully been used during the pandemic to improve the mental health of young people, while WHO's Health Alert bot on WhatsApp offers everything from international travel advice to fake news myth-busting. Tech giants like eBay and Lyft have developed industry-leading chatbots that work across multiple platforms and minimise the time required to complete an action. It's thanks to the combined power of machine learning, AI and NLP that these conversations can now successfully be outsourced to computers, rather than to people.

Written by Neil Cumins


SHAPE THE FUTURE OF
MUSIC
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MEET DAVID. CODE COMPOSER. HE'S ALWAYS BEEN OBSESSED WITH MUSIC AND NUMBERS. NOW, HE BRINGS THE JOY OF MUSIC MAKING TO MILLIONS OF PEOPLE BY CREATING INTERACTIVE MUSICAL EXPERIENCES AT TIKTOK.
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