ingenia

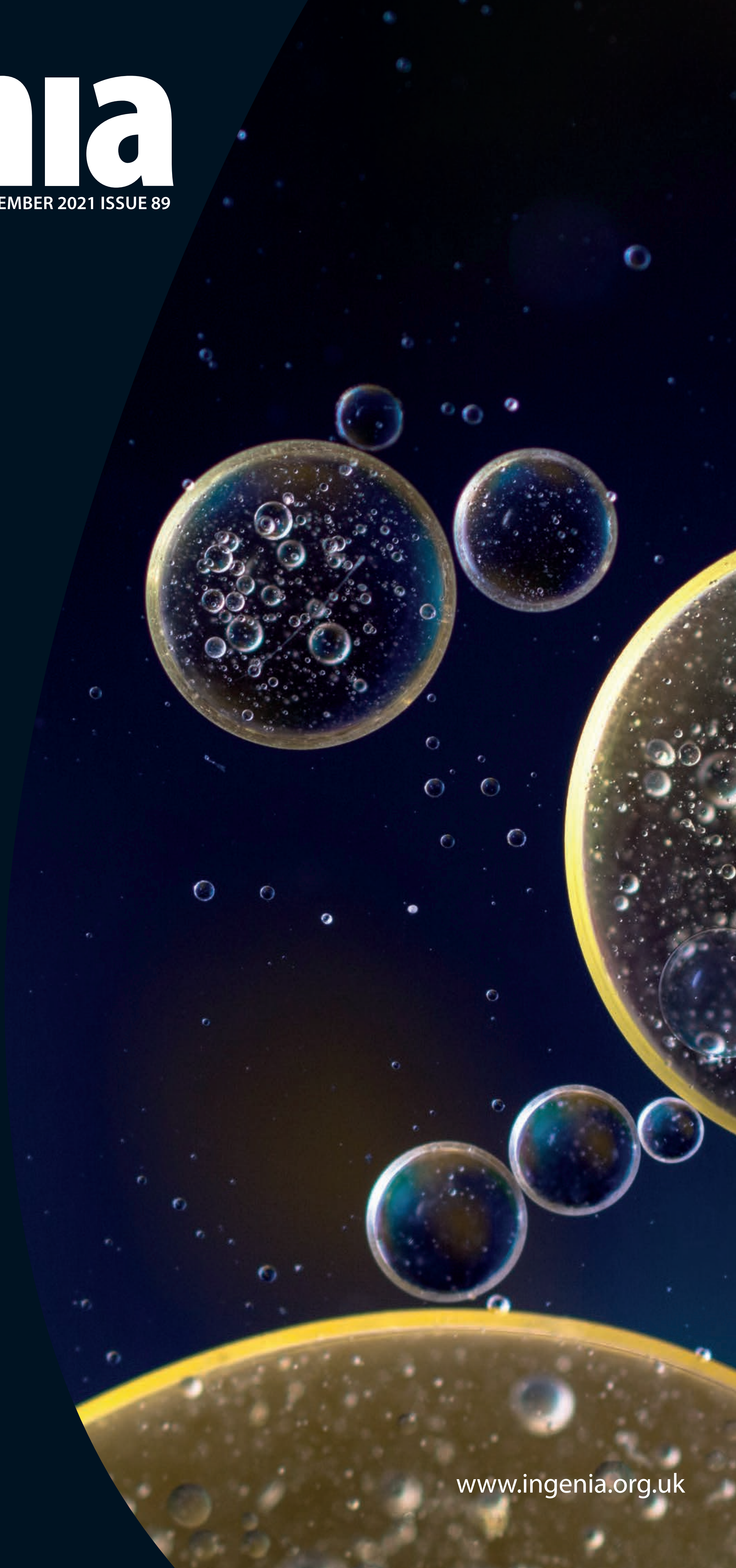
DECEMBER 2021 ISSUE 89

GADGETS FOR JAMES BOND

THE SOUNDS OF LANDSLIDES

MAINTAINING SPORTS GROUNDS

SUSTAINABLE SYNTHETIC FUELS



Royal Academy of Engineering

www.ingenia.org.uk

Royal Academy
of Engineering

Sponsors

The Royal Academy of Engineering acknowledges the generous support of the following organisation for *Ingenia*: Arup

Published by the Royal Academy of Engineering
Royal Academy of Engineering, Prince Philip House, 3 Carlton House Terrace
London SW1Y 5DG
Tel: 020 7766 0600 | Website: www.raeng.org.uk Email: ingenia@raeng.org.uk
Registered charity no. 293074

With thanks to
Andy Coulson (proofreader)
Dominic Joyeux (editorial consultant)

Design
The Design Unit www.thedesignunit.com

Print
Pensord www.pensord.co.uk

Ingenia magazine is mostly recyclable – please remove the cover before placing into household recycling. The inks are vegetable based and the paper produced under Forest Stewardship Council guidelines.

WORLD LAND TRUST™
www.carbonbalancedpaper.com
CBP006075
Ingenia uses Carbon Balanced Paper

Advertising and sponsorship
Rachel Earnshaw
Tel: 020 7766 0720 Email: rachel.earnshaw@raeng.org.uk

Subscriptions
To cancel your subscription or update your personal information details, please contact the *Ingenia* team by sending an email to ingenia@raeng.org.uk

Front cover

Fuels, such as oils like this, can be produced synthetically and from fossil-free sources
© A_Different_Perspective/Pixabay

ISSN 1472-9768

WELCOME

At the COP26 climate summit, world leaders debated the actions needed to address climate change. With the conference behind us, the focus shifts to the work and the people whose ingenuity, practical understanding and grasp of real-world problems is changing our lives for the better. As the Royal Academy of Engineering's President says (page 10): "Engineers understand how to translate ideas and research findings into real-life solutions, and how to make these solutions work at scale."

Engineers are at the forefront of efforts to achieve the net zero goal. For example, they lead development of synthetic fuels that eliminate the need for fossil oil and gas ('Fuel for a net zero future', page 22). And engineers grapple with the ethics of the way forward as solutions are often not cut and dried. For example, is burning wood really better than coal? ('The ethics of engineering net zero', page 33).

When extreme events cause distressing disasters, it is engineers who lead the rapid assessments needed to save lives and get as many buildings and facilities functioning again as quickly as possible. They really can 'make a difference' in the most difficult and dangerous circumstances ('Engineering in the extreme', page 6).

Engineers also play a significant role in the lighter side of life and to the entertainment industry, on and off screen. We look at some of the award-winning innovations that bring to mind James Bond's cunning gadgets ('Q's innovative technology', page 12).

Ingenia wants to hear about the engineers and projects that you find exciting, so please get in touch at ingenia@raeng.org.uk or let us know on Twitter using #IngeniaMag.

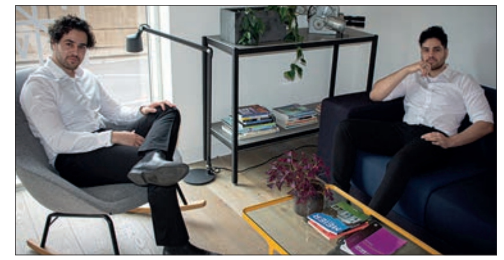
Faith Wainwright

Faith Wainwright MBE FREng
Editor-in-Chief

@RAEngNews #IngeniaMag

CONTENTS

UP FRONT



FEATURES

INGENIA

IN BRIEF

IN BRIEF

INNOVATIVE INCUBATOR ACHIEVES FIRST CLINICAL USE IN THE UK

In November, a new, neonatal incubator, developed and manufactured in Britain, was first used in a clinical setting in a UK hospital to help sustain a premature baby at St Peter's Hospital in Chertsey.

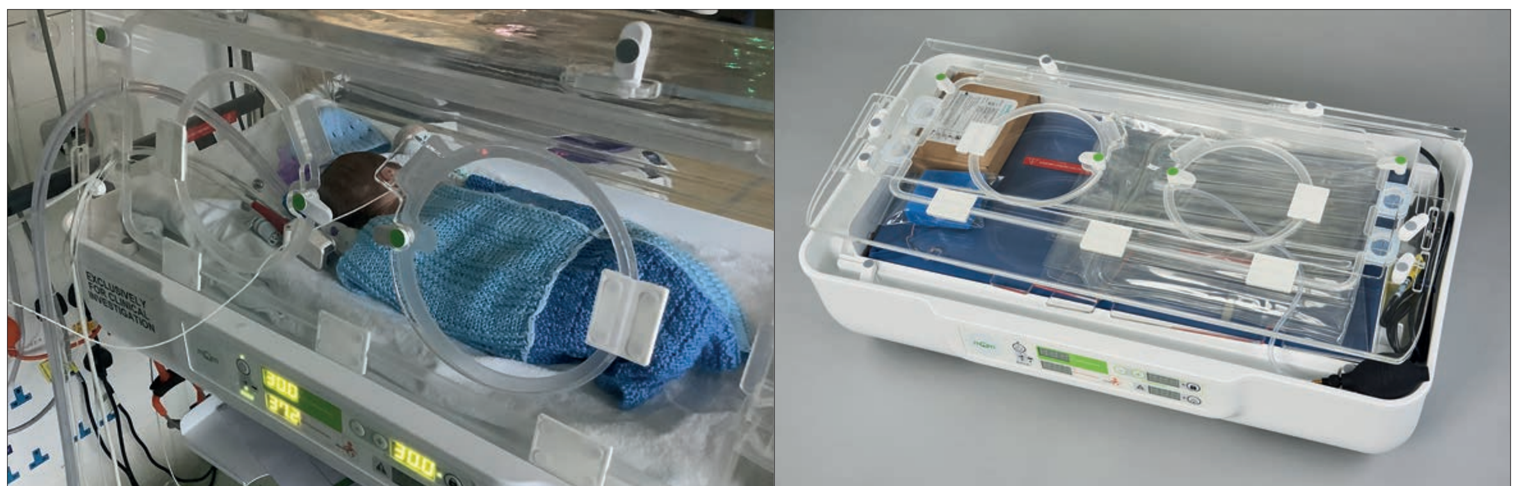
The affordable incubator, created by James Roberts, Founder and CEO of mOm Incubators, and his team, weighs just 20 kilograms and compacts to half its size, making it easy to store and transport. It has also been designed to be easily cleaned; has a replaceable infant compartment; and is energy efficient, so it can run off inconsistent voltage supplies and also has a backup battery. The incubator is designed for challenging low- and middle-income settings, and provides a more flexible option for neonatal care in the UK and other high-income countries.

One in 10 babies born around the world are premature and one million of them die every year. Three-quarters of these deaths are easily preventable through access to thermoregulation, or consistent warmth. However, only a small minority of premature babies have access to conventional incubators, which are regularly inoperable or discarded because of a lack of servicing and spare parts.

James commented: "Sustaining a child's life in our incubator for the first time has been a humbling experience and a monumental step in transforming this dream into a practical reality. It is unacceptable that one million premature babies die each year, when most of these deaths can be easily prevented. An idea that was once scribbled down on paper now has the potential to impact many lives globally."

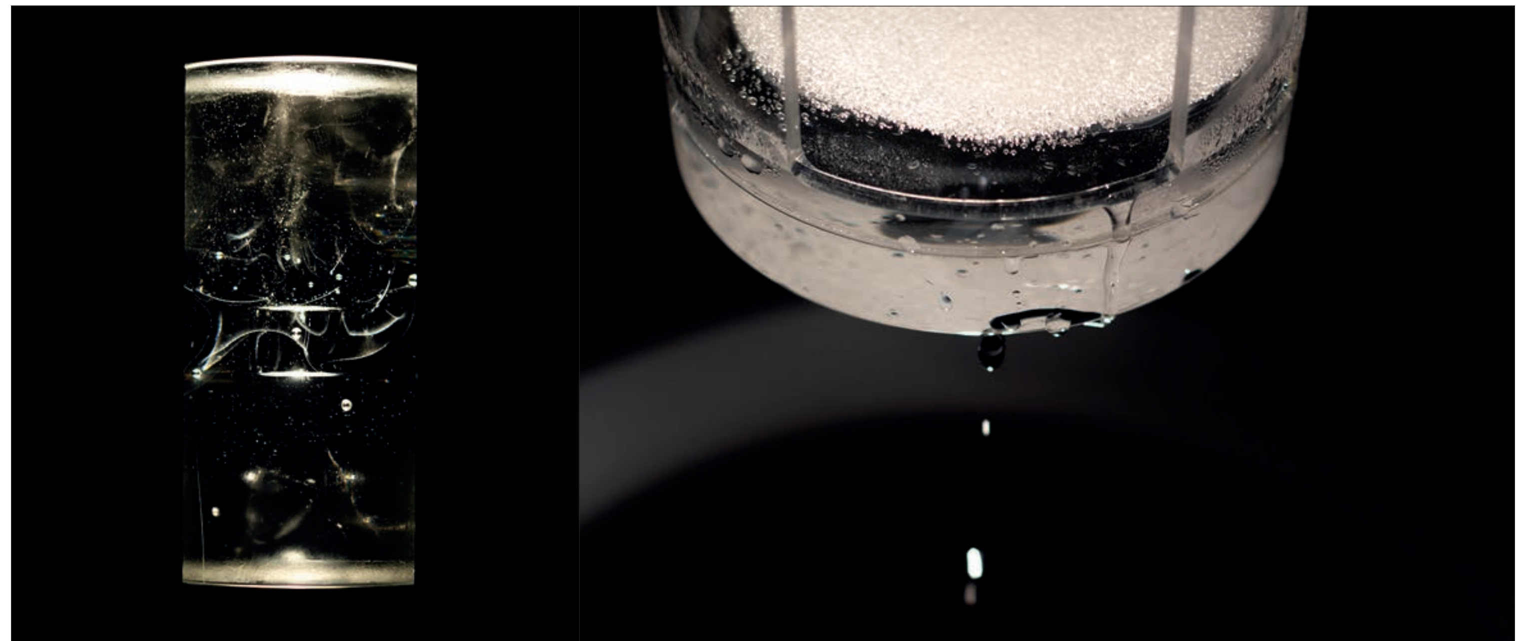
The design is backed by Holly Branson, Virgin's Chief Purpose and Vision Officer, and Sir James Dyson OM CBE FREng FRS. In 2014, James received the global James Dyson Award for his prototype and in 2015 won the Royal Academy of Engineering's Launchpad competition for the UK's most promising engineering and technology entrepreneurs. He also joined the Academy's Enterprise Hub SME Leaders programme in 2019 for coaching, business mentoring and leadership training and is now a Hub member.

Ana Avaliani, the Academy's Director of Enterprise and Sustainable Development, said: "The solutions to today's most complex economic and social challenges lie in the minds of the brightest engineering and tech entrepreneurs – people like James. At the Royal Academy of Engineering Enterprise Hub, we help them transform ideas into reality. We are thrilled to see the mOm incubator in clinical use in the UK."



The cost effective and compact incubator can be easily stored and transported (image of baby used with permission from St Peter's Hospital NICU, Chertsey, and the parents with grateful thanks to both)

SCULPTURE ENGINEERED FROM 250-YEAR-OLD AIR



The artworks featured in the Polar Zero exhibition, created by Wayne Binitie

During COP26, visitors to the Glasgow Science Centre were able to attend an exhibition centred around Antarctic air from 1765, inspired and informed by the urgent need to address the climate crisis.

Polar Zero, an immersive, science–engineering–art exhibition, features a cylindrical glass sculpture encasing an air sample from 1765 extracted from an Antarctic ice core and preserved within. Engineering expertise was critical to the artwork as it is the first time that anyone has attempted to extract ancient air from an ice core and encase it within a glass sculpture. Engineers from Arup devised a technique to make a casing with a void inside filled with fluid, which Robert Mulvaney, from the British Antarctic Survey, then injected the air into. 1765 is a crucial date, predating the Industrial Revolution, after which human activity began to fundamentally accelerate the growth of greenhouse gases in the Earth's atmosphere.

The artworks also use Antarctic ice cores (cylinders of ice drilled out of an ice sheet or glacier) no longer required for research by the British Antarctic Survey. The ice cores contain information about past temperature, and many other aspects of the environment. The ice encloses small bubbles of air that contain a sample of the atmosphere, from which scientists can measure the past concentration of gases (including carbon dioxide and methane) in the atmosphere. The engineers' job was to make sure that the ice didn't disappear too quickly so that visitors could see and hear it dripping away very slowly. They used precise calculations and creative thinking to construct the right level of insulation while still allowing the visitors to get up close to the ice.

The exhibition is a collaboration between the British Antarctic Survey, Arup and the Royal College of Art (RCA), funded by the Arts and Humanities Research Council (AHRC), and is running until mid-December.

The RCA's Wayne Binitie is an AHRC-funded PhD student and the artist behind Polar Zero.

ELECTRIC PLANE CLAIMS TO BE WORLD'S FASTEST


The Spirit of Innovation in flight © Rolls-Royce

Rolls-Royce's battery-powered aircraft, the Spirit of Innovation, has reached a top speed of 623 kilometres an hour, potentially making it the world's fastest all-electric vehicle.

The aircraft reached a speed of 556 kilometres an hour over three kilometres, beating the existing record of 213 kilometres an hour, and set three world records in the process – also averaging 532 kilometres an hour over 15 kilometres and climbing to 3,000 metres in just 202 seconds. The results are being confirmed by the Fédération Aéronautique Internationale, which certifies records for flight.

It was powered by a 400 kW electric powertrain and what Rolls-Royce says is the most power-dense propulsion battery pack ever assembled in aerospace.

The Spirit of Innovation is part of the Accelerating the Electrification of Flight (ACCEL) project. Half of its funding is provided by the Aerospace Technology Institute, in partnership with the Department for Business, Energy and Industrial Strategy and Innovate UK. Rolls-Royce also worked with aviation storage specialist Electroflight, which developed the battery, and automotive powertrain supplier YASA.

Business Secretary Kwasi Kwarteng said: "Rolls-Royce's revolutionary Spirit of Innovation aircraft is yet more proof of the UK's enviable credentials when it comes to innovation. This record will show the potential of electric flight and help to unlock the technologies that could make it part of everyday life."

GET INVOLVED IN ENGINEERING

BAKING IMPOSSIBLE

NETFLIX

Season one of this TV show sees bakers and engineers team up on missions to build delectable, incredible designs for a $100,000 prize and the title of the world's best 'bakineers'. The creations must taste delicious and survive intense engineering stress tests. The bakes, such as an edible boat that floats, edible mini golf courses or an edible skyscraper that must withstand a simulated quake, will be judged by a panel including *Great British Bake Off* finalist and Rolls-Royce engineer, Andrew Smyth.

A MONTH OF MAKING

Online

The Queen Elizabeth Prize for Engineering hosted four weeks dedicated to sustainability, creativity and handmade Christmas gifts. Influencers from the world of STEM have created fun 'making' videos showing people how to make Christmas presents this year rather than buying them, ranging from pewter jewellery to a fizzing Christmas tree. Get inspired at **www.qeprize.org/a-month-of-making**

FOLLOW YOUR OWN PATH: CAREERS IN STEM

Until 3 January 2022

SCIENCE AND MEDIA MUSEUM, BRADFORD

The illustrations in this display show how 14 STEM professionals found their current jobs. An artist from Oldham Play Action Group met with each person and then created a visual representation of their career journey. They show the wide variety of career journeys that people can take. Some people find that school and university is the best way to a career in STEM. Others prefer to do an apprenticeship or try different jobs before they find the one that suits them. These are all useful ways to gain different skills and experiences.


© Mike Massaro

TOMORROW'S HOME 2050

Until 9 January 2022 and online

MUSEUM OF THE HOME, LONDON

Tomorrow's Home 2050 is an immersive installation where the home of the future – 30 years from now – has become a reality. Drawing upon leading research from the UCL Institute of Healthcare Engineering, it playfully imagines how our dwellings could be designed to help us live independently and well as we age and support our changing planet. In-person workshops and activities include family friendly robotics Christmas carolling, while online sessions include conversations with experts on health technology, care, wellbeing, and more.

For more information, visit **www.ucl.ac.uk/healthcare-engineering/home/tomorrows-home-2050**

WASTE AGE: WHAT CAN DESIGN DO?

Until 20 February 2022

DESIGN MUSEUM, LONDON

This exhibition looks at the devastating impact of waste and how a new generation of designers is rethinking our relationship to everyday things, imagining a future of clean materials and how a circular economy could point the way out of the Waste Age. The exhibition showcases the work of designers including Formafantasma, Stella McCartney, The Ellen MacArthur Foundation, Lacaton & Vassal, Fernando Laposse, Bethany Williams, Phoebe English, and Natsai Audrey Chieza, who are reinventing waste in areas from fashion and food, to electronics, construction and even packaging. **www.designmuseum.org/exhibitions/waste-age-what-can-design-do**

ENGINEER THE FUTURE

Online

MUSEUM OF ENGINEERING INNOVATION

On *This is Engineering Day*, a digital artist reimagined masterpieces by Constable, Monet, Pissarro, and Van Gogh to inspire conversations about the engineering advances that could help achieve net zero carbon emissions by 2050. Innovations such as agricultural robots, smart thermochromic windows, vertical farms and flying taxis have been woven into the reimagined impressionist masterpieces to depict what a more sustainable world may look like in the future. The artworks can be seen at the Museum of Engineering Innovation: **www.artsandculture.google.com/partner/museum-of-engineering-innovation**

Three new *This is Engineering* films were also launched, featuring Lucy Hughes, an entrepreneur and inventor of MarinaTex, a compostable alternative to plastic film made of fish waste, and George Imafidon, a performance engineer in Sir Lewis Hamilton HonFREng's X44 racing team that races as part of the Extreme E electric racing series. Watch the films at **www.thisisengineering.org.uk**

BIG BANG FAIR

22 to 24 June 2022

BIRMINGHAM NEC

After a two-year hiatus, the Big Bang Fair will be taking place again in 2022. The event is free to attend and will feature scores of hands-on activities to inspire young people to discover and explore what a career in STEM can offer. Students can hear from exciting scientists and engineers and connect with inspiring career role models. There will also be opportunities for families, home educators and community groups to attend.

Schools can register for a space at the Big Bang Fair from the end of February 2022 and can sign up to the newsletter to find out more: **www.thebigbang.org.uk**

IN BRIEF EXTRA

ENGINEERING IN THE EXTREME

Two young engineers have been awarded Smeaton Medals for their outstanding work in disaster relief in some of the world's most hostile environments. Organising rescues and follow-up work after events such as earthquakes and hurricanes, they have demonstrated how engineers can use their skills to really 'make a difference' in the most difficult and dangerous circumstances.

DR JOSHUA MACABUAG

In 2015 an earthquake in Nepal left 8,500 people dead and several hundred thousand homeless. Engineer Josh Macabuag was part of the team from UK charity SARAID (Search and Rescue Assistance in Disasters) sent to rescue survivors from the collapsed buildings in the disaster's immediate aftermath. By then, he had learned that a disaster's impact goes beyond lives lost. Damage assessment is needed, so people can return to buildings.

After the team had demobilised, Josh conducted damage assessments of key hospitals, schools and government buildings. In one case, his assessment enabled a hospital to reopen so that patients, who had been sleeping outside for fear of aftershocks, could re-enter. But he recognised that the problem was much greater than the 20 buildings he could reopen.

When he was deployed as part of the EU Civil Protection Mechanism (EUCPM) team following 2019's earthquakes in Albania, he recognised a critical gap in coordination of damage assessments. He persuaded government ministers that engineers should start the process, rather than just the immediate search-and-rescue phase. He initiated and led coordination of a new concept – the Damage Assessment Coordination Centre (DACC), operated jointly by the EUCPM team, the UN Damage Assessment and Coordination Team, and USAID. The DACC had two jobs: to help the Albanian government set up its own damage assessment centre with its own engineers, and to coordinate international input. Working with Albanian engineers, 185 engineers from 18 countries quickly assessed around 39,000 buildings so that those deemed habitable could be reoccupied.

In the wake of the 2020 Beirut Port explosion that killed 215 people, Josh led the UK support team from SARAID on a search-and-rescue mission – this time working from the UK rather than onsite. The team set up a DACC in Beirut for follow-up assessments. Having demonstrated its high impact in two disasters, he persuaded the UN's International Search and Rescue Advisory Group to officially adopt the concept as an international standard.

Josh leading damage assessment at a disaster site

An initial rapid assessment can be carried out by a trained engineer in just 20 to 30 minutes per building, answering questions such as: what is the level of damage? Are there issues with the foundations? Are there any other safety issues such as risk of landslides? This may be followed by a more thorough engineering assessment, which requires an engineer with considerable experience in the field.

Career path

Josh graduated from the University of Oxford in 2007, volunteering on low-cost housing and groundwater extraction in rural South Africa before working as a structural design engineer in the UK and UAE. Meanwhile he maintained his commitment to overseas development by authoring a paper on earthquake-proofing buildings in Nepal, co-writing an 'engineer's toolkit for a developing world', and as part of an investigation team after the 2011 Japan earthquake and tsunami.

Josh is now an independent consultant. He advises the World Bank on disaster risk mitigation and insurance companies on catastrophe risk modelling. He is involved in training, lecturing and producing videos to inspire others and transfer knowledge, and continues to deploy after critical events, including Hurricane Irma in the Caribbean in 2017 and the Haiti earthquake in 2021.

THE SMEATON MEDAL

The Smeaton Medal recognises early- or mid-career engineers for 'achievement in hostile or extreme environments', which might for example include storms, pandemics, space, earthquakes, cyberspace, subsea, or cold regions.

Awarded by the Smeatonian Society of Civil Engineers, the world's oldest engineering society founded in 1772, the medal was inspired by the works of co-founder John Smeaton: his Eddystone Lighthouse represented a huge engineering achievement in one of the most challenging environments of his era.

2021 marks the society's 250th anniversary year. Its President is HRH The Princess Royal, who has demonstrated a strong affinity with engineers, as well as an understanding and appreciation of their work.

VITA SANDERSON

Vita Sanderson's most challenging role so far was with Médecins Sans Frontières (MSF) managing a 60-strong team constructing a hospital at Agok in the remote, disputed and frequently war-torn Abyei, between Sudan and South Sudan in 2017 to 2018. The 160-bed hospital included surgical and maternity facilities, a specialised malnutrition ward, and even snakebite treatment facilities. It had to be designed to withstand the region's extreme heat, high winds and heavy rainfall, with foundations appropriate for the notorious 'black cotton soil' – a clay-rich soil that shrinks and cracks in the dry season and expands when wet. It also had to be completely self-sufficient for water supply, power generation and sanitation.

The work involved detailed design, procurement (mostly from Europe, an eight-week journey involving shipping to Mombasa and then by slow and tortuous roads to Abyei) as well as construction of the hospital and all its supporting infrastructure. Construction of the six buildings had to be phased carefully to allow an orderly transition from the primitive tented hospital it was replacing. The hospital was clad in insulated panelling – to protect from the 45°C midday temperatures. It serves a vast catchment area, with some patients walking for many days to attend. As one measure of its success, infection rates in the maternity ward were halved on opening.

Career path

Vita graduated from Imperial College London in 2011 and worked for consulting engineers Elliott Wood while taking time off for voluntary work overseas, qualifying as a chartered engineer in 2015. She realises that she could not have taken on such a challenging role as the Agok hospital without her early training as a structural engineer, largely on the retrofit of existing buildings in London. It helped her develop engineering skills, as well as an understanding of how things work and fit together, how to organise things and develop a programme to get from here to there, and – above all – problem-solving skills and the confidence to make decisions. One of her projects was The Ned, a complex conversion of a derelict 1920s City of London bank into a modern hotel.

Meanwhile she had been volunteering for humanitarian work, which led to her taking leave to go to Bangladesh following the 2013 Rana Plaza factory collapse to conduct structural assessments of some of the hundreds of other garment factories.

Vita at Agok hospital's first completed ward

Vita left Elliott Wood to manage the construction of UNICEF 'transitional learning centres' in a remote area of the Himalayas following the 2015 Nepal earthquake, ensuring the buildings would survive a future earthquake. She joined MSF in 2017, initially in south-eastern Ukraine, retrofitting existing clinics for a new hepatitis C programme, before moving to South Sudan.

Returning to the UK in late 2018, she joined Arup's International Development team where she has managed: a retrofitting programme for 250 schools in Western Nepal; a large school reconstruction programme in Peru; school design guidance for Bhutan; and work in Zimbabwe following Cyclone Idai. In response to the COVID-19 pandemic, she developed guidance for implementing rapidly deployed treatment and isolation centres in poor areas. She has also been working with the World Health Organization and others to provide remote support for health facilities in the Rohingya refugee camps in Bangladesh, close to the Myanmar border.

Vita was elected to MSF's UK board of trustees in 2019, which she does alongside her work at Arup. She is also a member MSF's operation board in Amsterdam. Additionally, she has led research into low-cost seismic construction at the University of Bristol, guest lectures at Warwick University and is contributing to an update of RedR's *Engineering in Emergencies* textbook.

HOW I GOT HERE

HOW I GOT HERE

Q&A

HASSAN AND HUSSAIN MOFTAH

DATA ANALYSTS

Twins Hassan and Hussain Moftah are both data analysts whose work overlaps with data engineering and science.

WHY DID YOU FIRST BECOME INTERESTED IN SCIENCE/ ENGINEERING?

Hassan: From a very young age, I acknowledged how technology plays such an important role in modern society. If implemented correctly, it has the potential to solve an almost unlimited number of problems that humankind faces. This realisation drove me to pursue all things related to information technology and to be a part of creating software that society values.

Hussain: I have always been intrigued as to how software appeared on a screen from a young age; especially as an avid gamer! This first sparked my curiosity and ambitions to study computer science. During my teenage years, I would create games using programmes such as GameMaker and Unity. As I grew older, the sorts of software I started to create became more mature as I began to create websites and apps for fun.

HOW DID YOU GET TO WHERE YOU ARE NOW?

Hassan: While studying for my A levels, I secured an internship at Barclays supporting the Finance Structural Reform Programme through Career Ready, which exposed me to the complex organisational structures and processes in a large company. This experience helped me get through the interview processes and trials to get a job as a data analyst for Xantura and work towards a level 3 apprenticeship. Upon completion, I was promoted to Operations Team Leader, which meant managing a team of data analysts, and simultaneously started a degree apprenticeship with Coventry University. I recently graduated and was promoted to Business Domain DevOps Team Lead.

Hussain: During my Year 11 summer holiday, I carried out work experience as a software tester at 2Simple. When I completed my A levels, I went back to 2Simple and continued working for a year. I then obtained a level 3 apprenticeship with Sphonic to work as a data/business analyst. I then did a degree apprenticeship, also at Coventry University, and became a team lead at Sphonic. Now that I have completed my degree apprenticeship, I am Senior Team Lead.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

Hassan: Teaching myself how to programme in Python and SQL and using it to automate an important part of Xantura's data pipeline. I feel like this is my biggest achievement because it demonstrated to me that I have the capacity to deal with complex problems and that I play an important role within the business.

Hussain: Attaining and completing my digital and technology solutions professional degree apprenticeship. From the day I finished my A levels, I set my sights on achieving a degree apprenticeship as I knew how valuable it would be. My brother and I understood that if we could join a company on a level 3 apprenticeship and demonstrate our work ethic, they would be willing to take us on as degree apprentices – we are very grateful to our respective companies!

Hassan (left) and Hussain (right) both had similar interests growing up, which found them following the same career path. They share knowledge, have access to each other's networks, learn from each other's mistakes, and are hoping to create a tech startup together in the future

WHAT IS YOUR FAVOURITE THING ABOUT YOUR JOB?

Hassan: I thoroughly enjoy solving complex problems – it can be a thrilling journey as you get closer to finding the answer.

Hussain: Coming up with solutions for my clients and then implementing them is by far the most exhilarating thing I enjoy about my role at Sphonic.

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

Hassan: Producing lots of complex SQL queries for analysis and to be used as data sources for reporting tools. Automating any manual processes using Python. Managing members of my team and supporting them with any problems they are facing. Supervising operational tasks and business activities to ensure the desired results are produced and are consistent with the overall company strategy and mission.

Hussain: Proposing solutions for current clients and newly onboarded clients and answering queries throughout the day. Once solutions/workflows have been designed and confirmed with the client, I then begin implementing the solution/ workflow by programming in LUA (a scripting language). When I have some spare time during the day, I help out fellow team members.

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

Hassan and Hussain: First and foremost, clearly define your goals and highlight all the different pathways to achieve them. In our case, our goal was to achieve a degree apprenticeship and so we chose the pathways that were the most effective way to do that. Another piece of advice would be to demonstrate a good work ethic at all times (for example, having the desire to do a task well, being vigilant and organised). Finally, do projects in your own time to improve and showcase your skills.

WHAT'S NEXT FOR YOU?

Hassan: I intend to gain a stronger understanding of machine learning and potentially implement computer algorithms to further improve the accuracy of Xantura's predictive models. I will continue to work on improving my project management skills by obtaining the PRINCE2 Agile certification and work towards getting the Microsoft Azure Data Scientist Associate certification. These will help me achieve my overall goal to become a full stack data scientist.

Hussain: I'm also currently studying to be PRINCE2 Agile certified to further diversify and hone my project management skills and knowledge. In my own time, I have been working on a mini REST API in Python using the Flask framework to screen companies to ensure they meet specific compliance rules and standards. At Sphonic, I want to expand my knowledge of regulating the financial services industry through technology, as well as data analytics.

QUICK-FIRE FACTS

Age: **24**

Qualifications: **Hassan: BSc Digital and Technology Solutions (Honours), Coventry University**
Hussain: BSc Digital and Technology Solutions (Honours), Coventry University

Biggest engineering inspiration: **Hassan: Nikola Tesla, inventor of first alternating current motor**
Hussain: Ibn Al-Haytham, mathematician, astronomer and physicist

Most-used technology: **Hassan: Pixel 5**
Hussain: OnePlus 6T

Three words that describe you: **Hassan: Conscientious, detailed and patient**
Hussain: Ambitious, resilient and reliable

OPINION

OPINION

A SYSTEM IS NEEDED TO DELIVER ON COP26

I spent much of my time at COP26 emphasising how important engineers are to tackling climate change. We simply cannot reach zero emissions without engineering. Engineers will design, create and maintain renewable energy technologies and the infrastructure that delivers that energy to our homes, vehicles and workplaces

Nearly 40,000 people from 197 countries gathered in Glasgow for COP26, the UN's climate change conference. Since then, there has been much debate about whether we are doing enough to keep global warming no higher than 1.5°C above pre-industrial levels. Professor Sir Jim McDonald FREng FRSE, President of the Royal Academy of Engineering, reflects on his experience at COP26, hosted in his hometown of Glasgow, and outlines how engineers stand ready to deliver on the commitments made.


Professor Sir Jim McDonald FREng FRSE

When COP26 finally took place in Glasgow from 31 October to 12 November, the event had been delayed by a year due to the disruption caused by the COVID-19 pandemic. During that time, the world witnessed a series of devastating extreme weather events linked to climate change. Expectations of the summit were naturally high. It needed to deliver significant commitments to action.

And did it? My experience having attended the conference makes me more optimistic than some. Regular attendees of COP conferences told me that this year's summit felt different. The investment and business communities showed up in force and demonstrated their commitment to being part of the solution. If these communities are ready to invest in a net zero future, the challenge now is how we implement solutions at pace and at scale to close the emissions gap, and whether countries across the world have the political will and consistent commitment to collaboration needed to make that happen.

We have seen progress: 130 countries have committed to net zero targets; agreements were made concerning deforestation, methane, electric vehicles, and fossil-fuel financing; and coal was mentioned in a climate pact for the first time. Made possible by careful and challenging negotiations, the Glasgow Climate Pact represents an encouraging increase in ambition, and the strongest framework yet for global cooperation.

However, none of this should take away from the fact that the pact alone is not sufficient to stop climate change by 2050. There is so much more to do, and quickly. The sense of commitment across the public and private sector needs to be matched by accountability, monitoring and measurement of outcomes. The real test is whether action is taken at the speed and scale required. By 2030 we'll know if we're irretrievably short of the target.

Well before then, the world's biggest contributors to carbon emissions need to share more detailed plans about exactly how they will radically reduce them. High-income countries should step up their financial support for low- and middle-income countries, many of which will bear the brunt of the worst effects of climate change, even though historically most carbon emissions were from developed countries. If we cannot meet the already overdue commitment of $100 billion a year of financial support for these nations soon, what hope do we have of delivering on the much bigger and more complex challenge of reaching net zero?

Supporting lower-income countries in transitioning to net zero and coping with the effects of climate change is in fact an opportunity to create new markets and opportunities that everyone can benefit from and should be seen as such. This promised financial support should be seen alongside an estimated requirement for $2 to $3 trillion per annum investment to achieve global net zero by 2050, as reported by the Energy Transitions Committee in 2020.

I spent much of my time at COP26 emphasising how important engineers are to tackling climate change. We simply cannot reach zero emissions without engineering. Engineers will design, create and maintain renewable energy technologies and the infrastructure that delivers that energy to our homes, vehicles and workplaces. They will create digital tools that help us adapt our behaviour to reduce our carbon footprint and track our progress in achieving net zero. They will make, improve, and incorporate materials with a lower carbon footprint into our day-to-day lives, and much more besides. Engineers understand how to translate ideas and research findings into real-life solutions, and how to make those solutions work at scale.

The most important point I made at these events was that the way in which engineers think about systems will be vital. Engineers are used to designing practical solutions to complex challenges that have many different dimensions. Because the products of engineering are such an integral part of our day-to-day lives – whether that's a mobile phone, a plane, our electricity supply, social media networks, or X-ray machines – engineers have to look at the big picture and understand what impact their products and projects will have on the other technologies, people, organisations, and environments they are connected to in order to know that it will work. We call this a systems approach.

All the different ways in which we could reduce carbon emissions will need to work together. So, much like any other products of engineering, we need to think about them as parts of a system and ensure that any one solution doesn't have an unintended consequence or side effect on something else. The commitments made at COP26 will not be achieved unless engineers help those making net zero policies take a systems approach.

This is something the National Engineering Policy Centre is working on. The centre, a partnership of 43 different organisations representing engineers, led by the Royal Academy of Engineering, provides engineering advice to the UK government. Most recently, we have advised on how to identify and make confident decisions – despite uncertainty – about actions that we can take now that will put us on the path to net zero. Actions like helping people to use less energy day to day, making technologies that we already know work – like charging networks for electric vehicles – more widespread, and investing in research and development that can tell us whether new technologies such as hydrogen are viable.

That advice has been received well. It is clear to me that we are being listened to and that the UK government is talking more and more about the need for systems thinking. But it still needs to be put into practice at scale and quickly, while longer term plans are developed. The world is full of great promises, but not as full of great delivery plans. Engineers stand ready to deliver a system that works.

The UK government should be congratulated for hosting such a big summit under exceptional and challenging circumstances. I am naturally very proud of my home city Glasgow for welcoming the world to the conference, and for setting such a good example by committing to reach net zero by 2030. But there is so much more to be done. The target of 1.5°C in global warming is still alive, but only if governments collaborate with engineers to get the job done.

BIOGRAPHY

Professor Sir Jim McDonald FREng FRSE is Principal and Vice Chancellor of the University of Strathclyde. He has been President of the Royal Academy of Engineering since 2019. He was born in Glasgow and studied for his first degree in electrical engineering at the University of Strathclyde, then started his engineering career as a graduate apprentice on the Scottish Electrical Training Scheme. Sir Jim is one of Scotland's most accomplished engineers, and co-chairs the Scottish Government's Energy Advisory Board, with the First Minister.

The James Bond series, both books and films, features an impressive array of gadgets and innovative technology. But these inventions are not always as unbelievable as they may seem © Shutterstock

Q'S INNOVATIVE TECHNOLOGY

As usual, the latest James Bond film, *No Time To Die*, is packed full of gadgets and new technologies. *Ingenia* looks at some of the engineering breakthroughs inspired by, and featured in, the Bond movie back catalogue, including past MacRobert Award winners and finalists.

In 2022, it'll be 60 years since Sir Sean Connery first took on the role of Ian Fleming's secret agent. *Dr No* was the first book to be turned into a movie and so began the highly profitable 007 film franchise. 1962 also saw the global launch of new technologies: audio cassettes, LEDs and computer video games. *Dr No* focused on the US space programme, at a time when Cold War tensions were running high and megalomaniacal villains were still the subjects of on-screen fear, rather than satire.

In this inaugural outing, Bond had a Geiger counter – used for detecting and measuring ionizing radiation – while his adversary communicated with missile guidance systems using radio beams sent via a submersible satellite. Such innovations seemed impossibly futuristic 60 years ago, although *Dr No*'s use of forward-facing technology established a principle of engineering innovation that has continued throughout all 24 follow-up films made by Eon Productions.

Some Bond-related technologies were so far ahead of their time that they depicted items yet-to-be invented, while others were innovations under secretive military development and still under wraps. Sometimes, intelligence services actually drew inspiration from the movies; Fleming was a good friend of CIA director Allen Dulles, who tasked his staff with replicating the poison-tipped shoe daggers used by Colonel Rosa Klebb, the main antagonist in *From Russia With Love*, in her attempts to stop Bond.

To commemorate Daniel Craig's final outing as Agent 007, here's a look at some of the companies whose innovations have shaped – and been shaped by – this cinematic legend. Several are synonymous with Bond, while others are less obviously related, yet they all bear the unmistakeable DNA of the world's most enduring spy.

DNANUDGE

DnaNudge is the first of the MacRobert Award winners in this list. It is one of an exclusive group of companies that have received the UK's longest-running and most prestigious prize for engineering innovation. The firm's pioneering technology taps into the DNA programming shown to dramatic effect in *No Time To Die*. Fortunately, it does so for very beneficial reasons, unlike those of Safin, Bond's nemesis, who uses a DNA bioweapon to malevolently target 007.

DnaNudge focuses on consumer genetics technology that aims to encourage people to choose healthier lifestyles and make more informed choices while shopping.

At its walk-in London store, DNA is extracted from a simple cheek swab and analysed to identify individual genetic risk for key health traits – including obesity, diabetes, hypertension, and cholesterol. The results are then securely loaded onto a compact device – the DnaBean

DnaNudge wristbands can scan barcodes and provide instant feedback as to the compatibility of the products with the user's genotype

– that can then be worn as a wristband. As well as supporting barcode scanning reports on the genetic suitability of certain food and skincare products for the wearer's DNA, the DnaBean monitors inactivity, with the aim of reducing sitting time. The company's NudgeShare technology allows users to shop for family members based on their genetic profile.

The flexibility of this technology was demonstrated when DnaNudge adapted it to quickly create a rapid, lab-free, real-time, PCR COVID-19 test last year. It is now in use in NHS hospitals and healthcare settings around the world. It was this achievement that won the company the 2021 MacRobert Award.

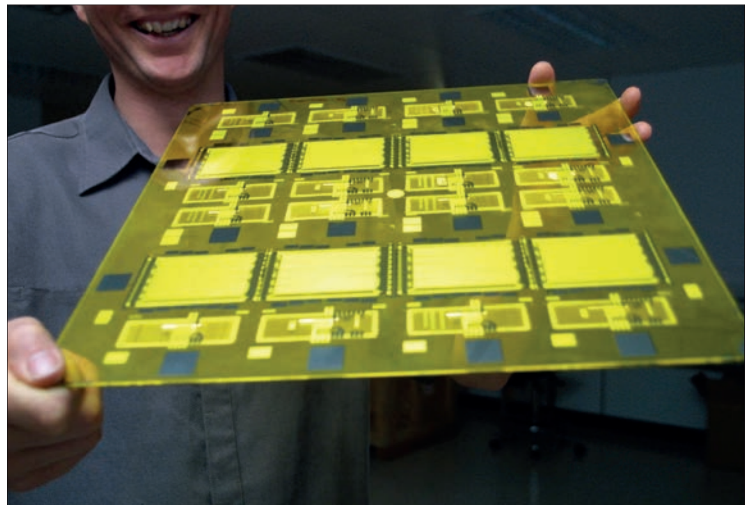
ASTON MARTIN

As the most instantly recognisable Bond brand, Aston Martin's history of engineering innovation stretches back to the firm's Atom prototype of 1940. This futuristic model featured semi-automatic transmission and a monocoque chassis, decades before rival manufacturers adopted similar technologies.

Inside Bond's Aston Martin DB5 that featured in *Goldfinger*. It has his map tracking system set in front of the red-buttoned gear-shift that jettisons the passenger ejector seat © Alamy

Numerous production Aston Martin cars have appeared in Bond movies with the DB5 being the most noticeable, having appeared in eight films. For its inaugural outing in *Goldfinger* (1964), it debuted a map tracking system, an early form of satellite navigation. This was two years before General Motors stated that navigation systems couldn't be offered in a production car, and two decades before Japanese manufacturers developed rudimentary navigation using the now-obsolete dead reckoning principle – the process of calculating the current position of a moving object by using a previously determined position and then incorporating estimates of speed, direction and course over elapsed time. Having been inspired by Goldfinger's portrayal of tracking technology in the film, the CIA attempted to develop its own platform, but was unable to maintain connectivity in built-up areas.

Some Bond-related technologies were so far ahead of their time that audiences struggled to accept them. The cloaking device that camouflaged 007's Aston Martin Vanquish in *Die Another Day* (2002) was based on reflective shield technology being developed at the time by the Ministry of Defence – these light-emitting polymers went on to win the MacRobert Award that same year. Passing an electric current through certain polymers makes them emit light. The MacRobert Award winning team that year, Cambridge Display Technology, was formed to commercialise the technologies that evolved from this discovery. Polymer organic light-emitting diodes (P-OLEDs) offer the potential of a true flat-screen TV or computer display, which can be created on one sheet of glass or, ultimately, plastic so they could be rolled up. They offer many advantages over the liquid crystal displays and plasma displays used in conventional flat panel displays, including lighter weight and lower energy use.



Cambridge Display Technology's MacRobert Award-winning polymer organic light-emitting diode technology

Less controversially, the 10 DB10 models manufactured exclusively for *Spectre* (2015) adopted dot matrix ventilation on the bonnet instead of a radiator grille. The DB10's front end looked outlandish at the time, but electric vehicles nowadays have closed grilles in the absence of water-cooled engines, which require cooling radiators.

SEIKO WATCHES

Seiko is among a handful of companies, along with Aston Martin, whose products have appeared more than once in the James Bond movie franchise. In *The Spy Who Loved Me* (1977), a Seiko LC Quartz digital timepiece was shown printing out a telex on label maker tape. This was almost a decade before the first alphanumeric pagers reached the market – the pagers of the late 1970s were restricted to communicating via beeps or vibrations. It was to be another 40 years before the Apple Watch codified the principle of receiving messages on a watch.

Seiko's next notable contribution to the 007 film canon came in *Octopussy* (1983), when its G757 Sports 100 wristwatch used a homing device to track a Fabergé egg. As with the *Goldfinger* map tracking system, the idea that a watch could offer a GPS location seemed implausible at the time.

However, there were other smart watch technologies in the pipeline – the 1980s saw the first wireless heart-rate monitors being installed in consumer watches, alongside 3D accelerometers. In 1999, a GPS watch made its debut at the Consumer Electronic Show in Las Vegas. However, this pioneering device only had 10 hours of battery life – a shortcoming that would not have impressed Q, the series' fictional head of the British Secret Service's research and development division.

CAMBRIDGE SILICON RADIO

In *Tomorrow Never Dies* (1997), Bond is captured by newspaper magnate Elliot Carver. The megalomaniacal proprietor (quite possibly modelled on a real-world contemporary) is filmed writing 007's obituary on a wireless keyboard. It would be another two years before Bluetooth was launched and made real the concept of wireless peripheral communication across the 2.45 GHz frequency. Similar short-link radio technology had been under development in Sweden since 1989, and this may have served as the inspiration for Carver's computer.

As *Tomorrow Never Dies* drew audiences into multiplexes, the founders of Cambridge Silicon Radio were preparing to launch the company that would become a leading global wireless technology specialist. Its revolutionary CSR BlueCore™ chips, which incorporate a radio transmitter/receiver, won the 2005 MacRobert Award. The technology was a major breakthrough in bypassing the 'noise' produced by electrical signals crossing the small chip, which would normally swamp a radio receiver working with micro-volt signals. Frequency planning enabled the radio component to communicate through the noise of the chip's digital traffic.

Cambridge Silicon Radio's CSR BlueCore™ chips paved the way for Bluetooth connectivity for several devices

The BlueCore™ chips became a prominent platform solution for Bluetooth products, including mobile phones and medical devices, and the first Bluetooth-equipped mobile phone (Ericsson's T36 flip-phone) made its debut three years after Carver's wireless keyboard. Today, even the remastered Nokia 3310 from 2017 has Bluetooth technology integrated into it, reflecting the ubiquity of this RFID-based (radio-frequency identification) platform.

DARKTRACE

As a two-time MacRobert Award finalist, Darktrace's presence on this list is less to do with its products and more to do with the company's back story. It was founded by intelligence experts from MI5 and GCHQ alongside mathematicians from the University of Cambridge, where Bond studied in Fleming's novels. The author would undoubtedly have been impressed by Darktrace's focus on using artificial intelligence and machine learning to identify potential information security breaches, effectively developing an enterprise immune system. This is a new form of cybersecurity based on Bayesian mathematics, hosted in the cloud and offered as a software as a service model (see 'An immune system for computers', *Ingenia* 81).

Darktrace's software explores computing systems as a web crawler might analyse a website. It renders every component in a 3D diagram that lists each port, path, switch, and server. The system then analyses interactions between these disparate components, establishing patterns and permissions from central servers to remote users and everything in between. As soon as an abnormal event occurs, the system will identify this anomaly and react far more quickly than a human could – if they even understood that this event was unusual or potentially harmful.

WHAT'S NEXT?

James Bond was able to make his Aston Martin invisible in *Die Another Day* (2002), maybe that will be a vehicle security option in the future. An inflatable ski jacket that saved him during an avalanche in *The World is Not Enough* (1999) has become a purchasable commodity as a smart motor bike airbag jacket.

Now, we have to see whether the technology debuting in *No Time to Die* remains too fantastical to be developed. Will a folding wing glider that becomes a submersible ever see the light of day? Will the magnets that line a lift shaft and slow the fall of people jumping down it ever be implemented? Only time will tell whether these exciting cinematic moments will be turned into real-world applications.

The Royal Academy of Engineering's MacRobert Award 2022 is open for nominations. Supported by the Worshipful Company of Engineers, the award recognises outstanding engineering innovation combined with proven commercial success and tangible societal benefit. Winners receive a £50,000 cash prize, gold medal and national acclaim.

Details on how and why to apply for the 2022 Award can be found at **www.raeng.org.uk/macrobert**. Applications close on 31 January 2022. For further information, please contact **macrobert@raeng.org.uk**

Words: Neil Cumins

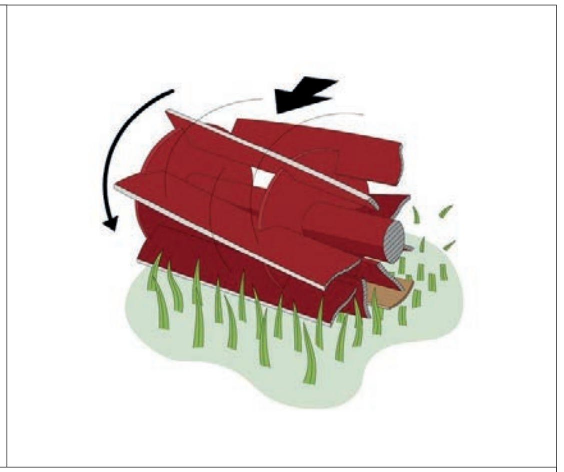
PITCH PERFECT ENGINEERING

Allett, a family-owned company based in Staffordshire, manufactures mowers that are used by sports venues to maintain their pitches, such as Edgbaston, which will host the Birmingham 2022 Commonwealth Games women's T20 cricket © Sam Bagnall, Warwickshire CCC

When it comes to management of turf in sports grounds, expertise generated in the UK is in demand. The UK grounds-management sector is valued at over £1 billion with tens of thousands of people employed in associated businesses and hundreds volunteering at a grassroots level. Dominic Joyeux looks at the reasons why this level of activity, high skillset and technical proficiency have developed and the innovative engineering that has driven it.

Did you know?

- At 2021's European Championships, football stadiums across different countries hosted games with allocated UEFA 'pitch experts' advising and working with the local groundskeeper on each pitch. All bar two experts (from Ireland) were from the UK
- All sports have different height requirements for grass that increase ball speeds, cushion falling bodies when tackled in rugby or lessen the impact on speeding horses' legs on racecourses
- Mowers were first operated by humans or pulled by horses, then steam-powered, then petrol engines were used and now the electric version is set to take over



Left: Edwin Budding patented the cylinder lawnmower of 1830. This model is from 1888 © Wikipedia. **Right: A cylinder mower's sharpened blade cuts across a fixed blade like scissors through paper** © Allett Mowers

The UK has a long track record of having invented – or claiming to have originated – many outdoor grass-based sports such as football, rugby, tennis, golf, croquet, and lawn bowls. To maintain all these outdoor sports turf surfaces, venues have traditionally employed individuals to look after the pitch, track, or course. These groundskeepers or greenkeepers have learned about the quirks and dynamics of their patch of turf.

When the English Premier League was established in 1992, it triggered an upskilling of these turf-keepers. With extra millions of pounds being poured into the game and the need to attract the best international football talent to the country, the pitches needed to improve. A muddy pitch is a great leveller and doesn't allow skills and ability to shine. Television needed an attractive and guaranteed performance, as a postponed match meant loss of sponsors' revenue. It became a requirement for groundskeepers to learn about plant science and new technology was needed to create a reliable and attractive playing surface.

GRASS CUTTING

For hundreds of years, if there was an expanse of grass to be neatly cut, scythes would be used.

Then, in 1830, Edwin Budding, an engineer and inventor, patented the cylinder mower, which produced a clean cut rather than a tearing of the grass. The spiral blades on the machine's cylinder rotated on a horizontal axis working against a stationary blade that lay flat, just above the ground. That same cutting mechanism principle is still used today by millions of amateur and professional mowers.

In March 2021, the British Engineering Excellence Awards' New Product of the Year (Mechanical) was given to the C34 Evolution electric lawnmower. Developed by Allett Mowers, these are already being used by Manchester United's groundskeepers to cut the grass at Old Trafford [see *Mechanical product of the year*].

The future for mowers is definitely electric, both at the domestic and professional level. Austin Jarrett, Managing Director at Allett Mowers, says: "Electric mowers already represent 50% of our home-owner sales. Now that we have cracked the battery capacity and work rates for the professional sports market, we think that our customers will choose to buy only electric mowers by 2025

MECHANICAL PRODUCT OF THE YEAR

The electric Allett C34 Evolution walk-behind mower has three patents pending and is as powerful as its petrol predecessor. The mower is powered by an 82 volt battery system consisting of four 6 Ah Lithium-ion batteries that can cut 6,000 m^2 of grass per charge. The batteries are interchangeable, so can fit other tools such as brush cutters, leaf blowers and chain saws, and take 90 minutes to recharge.

One of the patents pending is for the control-drive system that allows the speed to be lowered when turning. As there's usually quite a lot of juggling at the end of run – such as pulling the mower back and lining up the next drive, which can both damage the turf as well as require upper body strength – reducing the mower speed temporarily helps.

The eight hardened-boron-alloyed blade cylinder makes 95 to 190 cuts per metre and can be sharpened by a novel 'back-lapping' feature. John Gittins, Allett's Engineering Manager, explains: "Rather than buy a separate machine to attach to your mower and sharpen the blades, you can back-lap the C34 E's cutting cylinder. Because it's electric and can be slowed, you can reverse its direction by using a hand-held pendant that makes the operation much safer, as you dictate when it stops. The groundskeeper will then use a cutting paste such as grease with grit in it to sharpen the blades."

The Allett C34 Evolution weighs 160 kg with cartridge loaded and is balanced so that only 12 kg of downward pressure on the wide handle bar is needed to pull up the front end © Laura Malkin, Allett Mowers

and then we'll stop producing petrol-powered mowers."

Electric machines means that there are no particulate emissions at point of use and no need for storing large amounts of petrol on the premises. There is no pull cord to start the mower and less hand arm vibration for the operator, thereby reducing the risk of white finger – a condition caused by long-term exposure to vibrating machinery.

Professional football pitch mowers get a lot of use. During the summer months a pitch will get cut once or twice a day, seven days a week to a height of between 22 and 25 millimetres. During the winter months, groundskeepers tend to mow less than three times a week, let the grass grow to 24 to 30 millimetres, and then double cut the day before game day and once on the day itself.

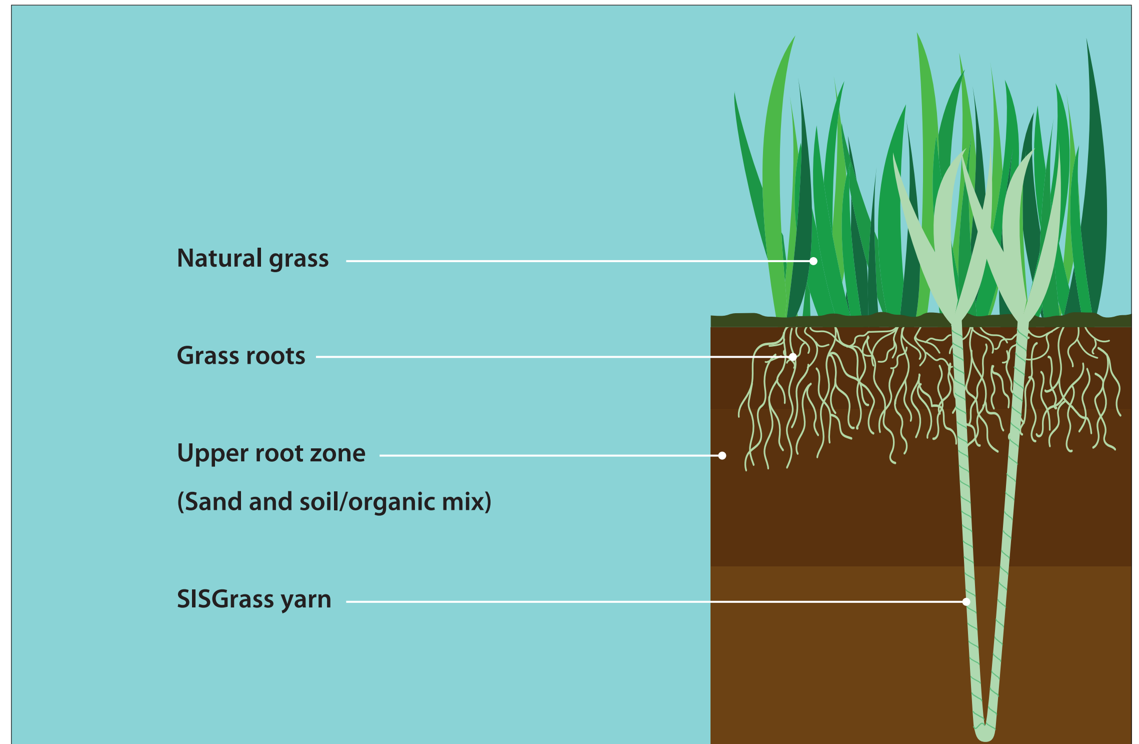
Top models have a three-section rear roller that have double-differential steering (differential transmits equal torques to the roller outer sections allowing different speeds), which makes it easy to turn at the end of a run at a pitch's edge. The centre section always drives and then the left and right independent sections enable one section to spin quicker than the other. It also operates at a different speed from the cutter, which helps when turning corners.

These mowers not only cut grass but help the groundskeeper with a host of other pitch maintaining tasks. They have changeable 'cartridges' that sit just behind and above the front roller that perform different tasks. There is a six-, eight- or ten-bladed cylinder for cutting, a spiked one for aerating, and others will scarify, rake, aerate, and brush. There is also the ability to raise, in 2- or 3-millimetre increments, the cutting blade's height.

PITCH PERFECT

It's only a few decades ago that by the time November came along, football and rugby pitches would resemble a quagmire, with the players covered in mud by the final whistle. In football, there has been a revolution in grounds management and a greater holistic understanding of what makes a near-perfect pitch to play on.

Dr Christian Spring is the Research Operations Manager at the Sports Turf Research Institute (STRI). The STRI provides research and science services to the sports industry all around the world, as well as design and consultancy input. Dr Spring says: "In many ways, a modern football stadium is like an amphitheatre: it has to house a lot of people and give them a good view of the action. Its sides will probably be tall, with a lot having overhanging or sliding roofs to keep the rain off their match-day customers. That means that the available light for growing grass is limited especially in the winter when



SISGrass is an example of a stitched hybrid grass system

the sun is lower, which means that additional technological support is needed to heat the soil and provide light for the grass plants."

There is now an established tick list for achieving a year-round, 60-match playable surface. From the bottom up, there should be geotextile membrane, above which lie drainage pipes set in a gravel drainage layer. Undersoil heating, obligatory in all Premier League grounds, will sit in a sand surround. Above that will be the grass roots, an upper root zone topped by the grass plants themselves.

A relatively recent addition to this upper layer has been artificial grass. It may not be immediately obvious but nearly every club in the top two divisions of the English league has got some kind of hybrid pitch. This will consist of natural grass – usually perennial rye grass – supported by either polypropylene or polyethylene fibres.

There are two main methods used for laying the artificial grass across cricket, golf, rugby, and football pitches. In 2020, Wembley Stadium had the stitching method used to apply 75,000 kilometres of artificial grass 200 millimetres deep into the layers of sand beneath the pitch. Above the pitch, the artificial grass sits a few millimetres below the height of the natural grass. This reinforcement of the rootzone provides shear stability, enabling players to generate large horizontal forces – like turning and sprinting – without taking chunks out of the turf. Wembley's grass-surface now consists of 97% organic and 3% artificial grass.

The other method is termed a carpet system whereby an artificial grass carpet is placed on top of natural grass. It is a quicker method and has a slightly higher percentage artificial content ratio.

Above ground, there are a few more items used to ensure that grass can keep growing within a stadium all year round. Grass needs sunlight, water and nutrients to thrive. Water sprinklers are standard kit nowadays to cover dry periods and LED lighting is being used to help shaded areas of pitch. These are used to replicate the red and blue wavelengths needed for photosynthesis and to ensure grass growth, recovery and the plant's resistance to disease. Photosynthetic LED use is now expanding into other sports such as golf and cricket.

MEASURE WHAT IS MEASURABLE

To apply standards, as well as to research what works best for grass and turf, there is a need to quantify the various types of treatment and conditions. Among the tools used are ones that have been developed for other applications but found to be useful in assessing how a sports surface is going to play. One of these is the Clegg Impact Hammer, originally made for civil engineering purposes to determine the hardness or shock absorption properties of a surface.

Golf uses a half kilo Clegg hammer but cricket and winter sports use a 2.25 kilogram compaction hammer dropping through a vertical guide tube from a half-metre height. The deceleration rate is determined by the ground's hardness and the readout registers the hardness values in units of gravity. For cricket, the test is a good indicator of bounce and pace. For football and rugby, there needs to be consideration of both ball bounce and player impact safety.

A high gravities reading could indicate that a ground has become overly compacted and will need aerating. Too light a reading could indicate the ground is overly soft and wet. Horse racing has its own device called a Going Stick that measures the resistance of ground penetration and the shear – the energy needed to pull the stick back to an angle of 45° thus mimicking the pressure of horses' hooves hitting the ground. The readings are fed back as the track being: heavy, soft, good or firm going.

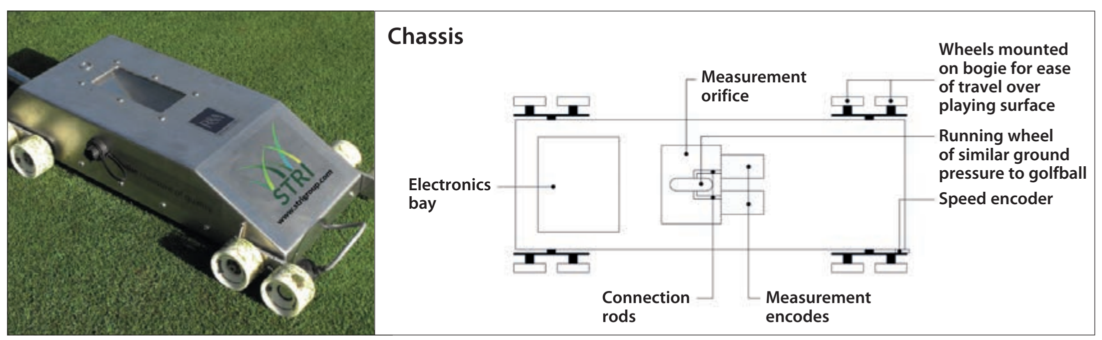
A penetrometer is an instrument used at the grassroots level of the game – in both senses of the word. It is used widely by groundskeepers at a local level looking after sport pitches. Pushed into the ground, it too measures a turf's compactness. The remedy for compact ground in a small area can be a hand-held fork, for a wider area it could be a machine that provides vertical aeration. Grass roots need air spaces in order to grow and if squashed by soil, the grass plant will have difficulty flourishing.

Most sports at an elite level use a sloped instrument that measures how a ball rolls on a surface. The stimpmeter in golf is used by all courses to measure the speed of the greens. It is a small aluminium ramp with a v-groove cut in it that releases the ball when it reaches an angle of 20°. Measuring the average distance with three rolls in two opposing directions will give a rolling length in feet. Usually 10 feet (3 metres) is considered a good green speed. The STRI has developed the Trueness Meter used across hundreds of courses worldwide that looks not just at the speed but the quality of the roll [see *Data deviation*].

The match day trick of disguising a bare patch of turf with fresh grass clippings is no more. There has been a concerted effort by many sporting bodies to ensure that there is a levelling up across the UK's sports surfaces. That the knowledge gained at the top is passed down to grassroots

DATA DEVIATION

The STRI Trueness Meter assesses the amount of deviation of a rolling golf ball and collects data that can be used to inform golf course management. Consultants use the instrument to measure vertical deviation (smoothness) and lateral deviation (trueness) of a replica golf ball. The lower the numbers, the more smooth and true the surface. Smoothness readings of 16 to 18 mm/m and 6 to 8 mm/m would be worthy of a major golf tournament course. Above 23 mm/m and 10 mm/m would indicate that a golfer's shot would have little chance of following the line that they had played. Further analysis of the green would enable advisers to suggest remedies including verti-cutting, rolling, getting rid of thatch, and other measures that would enable the green speed to be kept, without excessive deviation of the ball.



THE TRICKLE-DOWN EFFECT

The days when groundskeepers' sole responsibility was to give their pitch's grass a weekly haircut have gone. The match day trick of disguising a bare patch of turf with fresh grass clippings is no more. There has been a concerted effort by many sporting bodies to ensure that there is a levelling up across the UK's sports surfaces. That the knowledge gained at the top is passed down to grassroots.

The Pitch Advisory Service (PAS), formerly the Grounds and Natural Turf Improvement Programme, was launched in 2014. Originally funded by Sport England and the Football Foundation, it works with several national governing bodies. Run by the Grounds Management Association (GMA) it has recently received additional millions of pounds from the Premier League and the FA.

PAS's aim is to raise the standards of sports surfaces as well as the understanding of sports turf management practices among grassroots sports clubs across England. Jason Booth, GMA's Chief Operating Officer, oversees delivery of the scheme.

Amateur sports pitches at all levels have benefited from the knowledge passed on by the Pitch Advisory Service © Shutterstock

He says: "The trickle-down is not so much the equipment, it's the knowledge. Our toolkit is primarily aimed at the grassroots of football, cricket, rugby league, and rugby union giving free information, advice and guidance.

"Out of the 10,000 grassroots facilities we've visited, assessed and advised, 90% have taken up the recommendations and 86% of those have improved their pitches. We've been able to feedback data-based information to the various governing bodies on what needs to be done and they have invested heavily with tens of millions of pounds to carry over this upgrading of grounds. So increased knowledge leads to increased investment, which gives the clubs lower down the means to buy equipment that reflects the breakthrough innovations proved at the elite level."

There has also been an equipment upgrade across the board. The initial research costs that elite sports clubs pay for become less as the take up becomes greater. So, LED lighting costs have dropped so much that lower league clubs use them now. High-end domestic electric lawn mowers have dropped in price and secondhand top-spec mowers that originally retail at more than £10,000 can be picked up and used by groundskeepers at local club level.

FINISHING TOUCH

There is one inexpensive grass tip that is universally shared by groundskeepers across all sports. When all the hard work has been done with the drainage, the scouring, the hoovering of the pitch with a rotary mower before the game there is one finishing touch that can make the pitch sparkle that little bit more. If it needs it, a groundskeeper will spray liquid iron onto the turf a day and a half before a game. Iron sulphate is a turf tonic that strengthens the grass blade and as Jason Booth says: "I wouldn't call it cheating, spraying paint on the grass was cheating. I'd say it greens up the green, it enhances the aesthetic."

For this article. Dominic Joyeux interviewed:

Austin Jarrett
Managing Director, Allett Mowers

John Gittins
Engineering Manager, Allett Mowers

Steve Robinson
Business Development Manager , Allett Mowers

Jason Booth
Chief Operating Officer, GMA

Dr Christian Spring
Research Operations Manager, Sports Turf Research Institute.

Synthetic petroleum, which is produced from fossil-free sources, is an alternative to traditional fuels © Gordon Johnson/Pixabay

FUEL FOR A NET ZERO FUTURE

Petroleum is seen as one of the greatest evils of global climate change but imagine if we could gain all its benefits without contributing to global warming. Paddy Lowe FREng and Professor Nilay Shah OBE FREng, Co-Founders of Zero Petroleum, write about petrosynthesis – chemical engineering that is being used to create fuels that aim to help achieve net zero.

This is the dawn of a new Industrial Revolution. For 300 years, since the rise of coal mining and drilling for fluid hydrocarbons, we have relied on fossil energy and increasingly on oil for fuels such as petrol, diesel and jet fuel, and for much of our industrial material, such as plastics, textiles, fertilisers and pharmaceuticals.

Despite the drive for a net-zero planet, human nature will make it hard for society to reduce its energy consumption. More and more people expect to be warmer, cooler and healthier and to travel further, faster and more often. Meanwhile the world's population continues to increase and those in low- and middle-income countries should be able to enjoy the same benefits as those in higher-income countries.

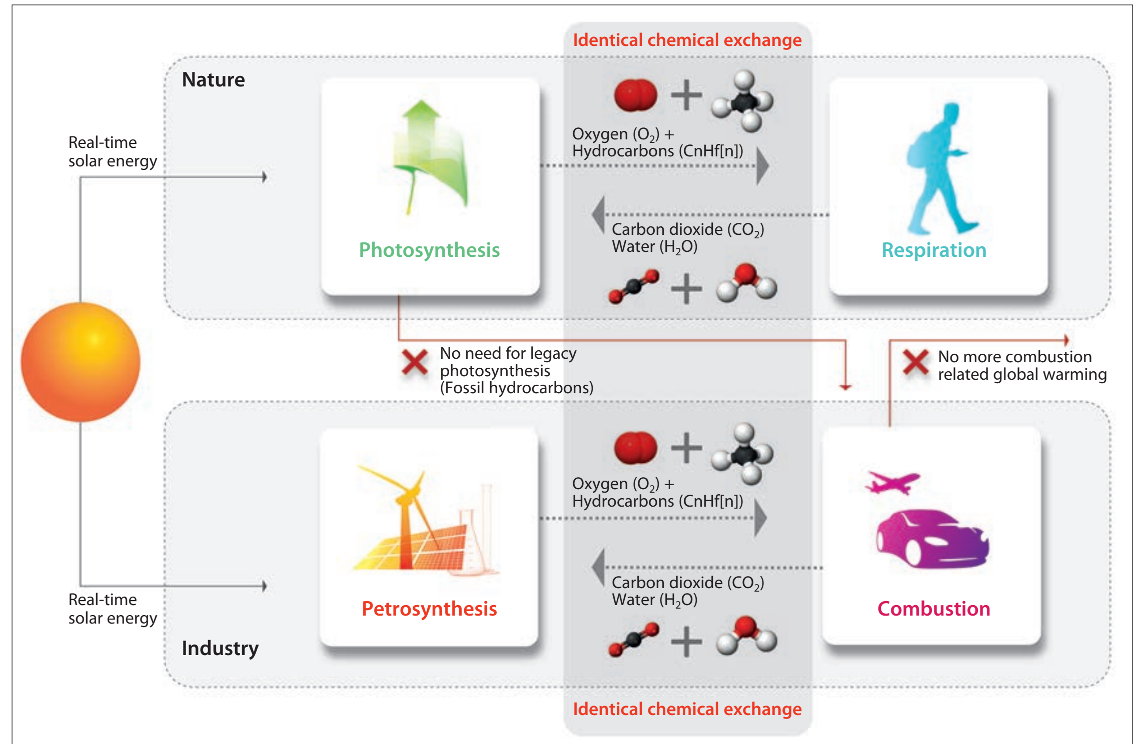
One way to meet our demand for energy that does not exacerbate climate change is to change our linear system of consumption to a circular one, with an indefinitely sustainable supply that does not add CO_2 to the atmosphere.

Did you know?

- Petrochemicals are vital to many parts of everyday life, including pharmaceuticals, clothing and energy
- A synthetic petroleum can be created using chemical engineering to create an alternative to fossil-derived fuels
- Using renewable energy, this chemical process could create a fully circular system

Renewable energy sources, electrification and the development of hydrogen fuels are already addressing this need. But we could further advance this progress towards net zero with synthetic petroleum, a form of petroleum that does not involve fossil hydrocarbons. Petrosynthesis entails a combination of chemistry and chemical engineering in processes that reverse what happens when we burn petroleum, when hydrocarbons combine with oxygen to create water and CO_2. The use of renewable energy to power petrosynthesis then creates a fully circular and sustainable system, which is a scalable substitute to fossil-derived petroleum fuels and materials.

Petrosynthesis is the artificial creation, or synthesis, of organic chemicals, such as hydrocarbons and oxygen from inorganic precursors, principally water and CO_2. The idea is to use non-biological energy, such as hydro, wind, solar, tidal, nuclear, or geothermal energy, to power the process. It is the industrial equivalent of photosynthesis, using neither energy nor material produced by either concurrent photosynthesis (plants) or legacy photosynthesis (fossil fuels).



Petrosynthesis can complete the industrial carbon cycle – in this example using solar energy, but other forms of renewable energy can also be used © Zero Petroleum

SYNTHESIS IN NATURE

Synthesis is a common process in nature. All life on Earth employs carbon, oxygen and hydrogen as primary chemical elements. Plants create hydrocarbons from solar energy by photosynthesis and animals burn off these hydrocarbons through respiration, with the atmosphere working as a huge storage tank for the ingredients.

This circular process is the so-called 'carbon cycle'. It worked perfectly for hundreds of millions of years, with only a very marginal imbalance, which provided the hydrocarbon deposits known as fossil fuels. When society could access these fuels in combination with energy-consuming technologies, it led to exponential development.

The Industrial Revolution changed everything. Fossil fuels drove scientific and engineering developments with immeasurable benefits, including health, mobility, food cultivation, and human comforts. Today's industrialised society now has an almost total dependence on petroleum for energy and materials.

Industrial combustion has the same macro-chemistry as respiration, but as fossil fuels are the product of legacy photosynthesis, rather than being part of an ongoing process, it has turned life on Earth from a circular system into a linear system. Fossil energy and materials are finite resources, consumption causes imbalance and waste – the current model is unsustainable.

RENEWABLE ENERGY

Fossil fuels have enabled development of 'sustainable' technologies, for example from sun, wind, hydro, nuclear fission, and eventually nuclear fusion. These create the carbon-free electricity that will form future

With the support of the Royal Air Force, in just five months Zero Petroleum built from scratch and operated a plant to manufacture synthetic aviation gasoline, culminating in a manned flight in November 2021. This flight earned the Guinness World Records® title of 'first aircraft powered by synthetic fuel'. The fuel delivered identical power without any modification whatsoever to engine or aircraft. The company is now seeking the necessary capital to construct the first commercial-scale synthetic fuel plant in the UK © Zero Petroleum

power systems. However, for some industries, renewable electricity alone will simply not work.

Battery technology for storing and moving electrical energy has advanced and hydrogen has emerged as a solution where electricity is unsuitable. However, the energy density in batteries is typically 50 times lower than current liquid fossil fuels, accounting for the differing efficiencies of electrical and combustion motors. The energy density of hydrogen contained in a tank is better than a battery but is still typically four times below that in fossil fuels.

These factors leave a critical performance gap for a huge range of common and vital assets to the industrial system. Aeroplanes, military vehicles, helicopters, fast boats, and high-performance cars all need a fuel with a relatively high energy density. Perhaps surprisingly, agricultural machinery also lies within this list, most notably the tractor and the combine harvester, arguably the most important machines to have enabled humankind's release from a fully agrarian society.

We will need high-density energy stores in the future, yet the current spectrum of sustainable energy resources does not account for this. Fundamental chemical and electro-chemical constraints mean that technical development is unlikely to close the mass and volume deficiencies of electrical and hydrogen energy stores.

While natural materials are making a comeback, petrochemicals remain vital to many parts of everyday life, from pharmaceuticals to clothing. It will be extremely challenging to overcome our reliance on them, economically and functionally. As a result, petrochemicals remain important: we need fossil-free alternatives.

PETROLEUM REVOLUTION

Petroleum is simply a set of chemicals, hydrocarbons, that we use to produce fuels such as gasoline, diesel and jet fuel and to create the precursors for plastics and many other modern products. Biological substitutes have been developed over decades. These include bioethanol and biodiesel, but they will continue to remain a niche solution at best. A typical field crop is 22 times less efficient than a solar panel in terms of the 'energy productivity' per hectare. As a result, many biofuels are marginal, if not negative, in terms of net energy after cultivation and processing. Even second-generation biofuels that use biological waste are energy and water intensive. Fuels that use petrochemical waste do help to reduce contamination, but they are still fossil derived, so simply defer emissions.

Direct air capture (DAC) can remove CO_2 from the air so that it can be stored in a process called carbon capture and storage. This stores CO_2 underground, for example using mineralisation in basalt rock to sequester carbon into geologic formations. It is therefore still a linear and unsustainable solution with no role beyond a transitionary offset for continued carbon emissions from fossil fuels or to mitigate past carbon emissions by fossil fuels. Reuse or recycling of atmospheric carbon as a raw material for new products is a much more exciting application of DAC.

Companies like Blue Planet, Solidia, CarbonCure, and CO_2 Concrete are converting captured CO_2 to create concrete. The company C2CNT creates carbon nanotubes that are stronger than steel and highly conductive. If scalable, these technologies have the potential to transform buildings and electrical circuitry.

Similarly, petrosynthesis uses CO_2 from DAC to produce synthetic petroleum for fuels and petrochemicals. It is the industrial equivalent of biological photosynthesis. Combustion of its products is the equivalent of respiration in animals; this produces the raw CO_2 that feeds the circular process. Petrosynthesis creates an industrial version of the carbon cycle in biology.

NOT JUST A THEORY

Termed 'a forest in a factory', petrosynthesis can create fuels, plastics, rubber, textiles, and any other hydrocarbon. It is not 'zero carbon' but it is net zero and fossil free. The process is being applied at an increasing rate.

Climeworks, a leader in DAC engineering, recently opened the world's largest facility in Iceland. In this plant a filter captures CO_2 from the air, combines it with water and pumps it 600 metres into the ground where it reacts with rocks. The US company Global Thermostat is doing things differently; rather than burying CO_2, it provides it to customers for industrial processes, from fizzy drinks to plastics manufacture.

The UK company Zero Petroleum has its focus on developing fossil-free petrol, diesel and jet fuel. Founded by Paddy Lowe FREng and Professor Nilay Shah OBE FREng in January 2020, it is the only company operating commercially in the UK to design and manufacture synthetic hydrocarbon fuels. In 2020, it obtained support from Innovate UK for laboratory R&D work to develop synthesis technology. Also being developed by Norsk e-fuel and Porsche, these fuels can be made at scale and used in existing engines as a direct drop-in replacement for fossil fuels. They have the same carbon emissions when burned, but through DAC the carbon is recycled into the production of more fuel, creating an indefinitely sustainable supply.

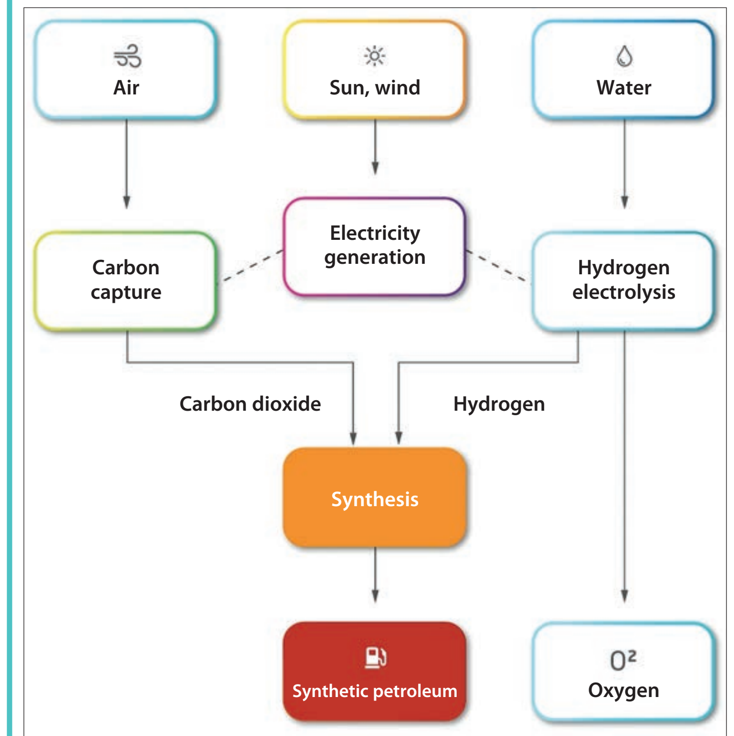
Zero Petroleum has developed a process that uses renewable energy to power an electrolyser, which turns water into hydrogen, along with DAC to take CO_2 from the air. A reverse water–gas shift reactor converts the CO_2 into carbon monoxide. This combines with hydrogen to create a 'syngas' that feeds a Fischer–Tropsch (FT) reactor to create the final hydrocarbon products ('Biofuels journey to the mainstream', *Ingenia* 78).

To produce 1 kilogram of synthetic hydrocarbon, the process uses 1.46 kilograms of water and 3.07 kilograms of CO_2. The electrolysis produces 3.53 kilograms of oxygen. When the synthetic fuel burns it produces the same quantities in reverse.

Some companies are developing ways to harness the sun's power directly as heat without using renewable electricity, such as concentrated solar power. For example, Heliogen and Synhelion use aligned mirrors to reflect sunlight onto a target to create extremely high temperatures within a chemical reactor. The reactor processes atmospheric water and CO_2 first into syngas (hydrogen and carbon monoxide) and subsequently into hydrocarbon fuels by a similar FT process to that used by Zero Petroleum. They call these 'solar fuels', which are an alternative example of petrosynthesis.

Petrosynthesis will also change how companies make the things we wear and the products we use in our everyday lives. The company On is making foam cushioning for footwear for running shoes and yarn using recycled CO_2. The sportswear company Lululemon makes clothes with fabric that uses

THE CHEMICAL PROCESS



Manufacture of synthetic petroleum via the Fischer–Tropsch process © Zero Petroleum

Synthetic petroleum can be made by several chemical pathways. The classic Fischer–Tropsch process, developed in Germany nearly 100 years ago, uses catalysts (typically iron or cobalt) at temperature (300 to 400°C) and pressure (20 to 40 bar) to promote the conversion of carbon monoxide and hydrogen (originally produced by the gasification of coal) into hydrocarbons and water. This is an exothermic reaction. The challenge is to produce the desired hydrocarbons and with the highest possible yield. More modern catalysts such as zeolites are providing these improvements. Within the context of renewable energy, the focus is to obtain best process efficiency as all the hydrogen (green hydrogen) must be expensively generated from renewable electricity by the electrolysis of water. Within petrosynthesis, the source carbon is atmospheric CO_2, which may be converted in a front-end process to carbon monoxide also by electrolysis, or by another catalytic reaction called reverse water gas shift (RWGS), which strips the oxygen using more green hydrogen and producing more water.

carbon from waste materials rather than fossil carbon. Both companies are using carbon recycling technology developed by LanzaTech. This is just the start of circularity, by petrosynthesis, in the clothing sector, which is under pressure to develop sustainable production.

CIRCULAR SYSTEM

Petrosynthesis is not an interim or transitional technology. It will be an essential component of our future fully sustainable energy system. For example a 2020 Ricardo report, *Renewable electricity requirements to decarbonise transport in Europe with electric vehicles, hydrogen and electrofuels,* shows that by 2050 between 84% and 100% of European commercial aircraft will be powered by eKerosene, a type of synthetic fuel. Combining electricity, hydrogen and synthetic petroleum can create a circular energy economy. This is net zero, with each energy format offering its own merits for different applications, each adopted according to performance imperative and/or economics.

Direct electricity is the cleanest and most efficient energy format but it is the hardest to store and the most difficult to distribute. Hydrogen has a medium rating on all factors, clean, relatively efficient at storing energy, and moderately easy to distribute. Synthetic petroleum is the densest energy format, easiest to store and easiest to distribute but the least clean and efficient. These three energy formats can work symbiotically, with excess electricity generated from renewable energy used to create hydrogen and synthetic petroleum, some of which is used in gas-fired power stations during times of darkness without wind.

As an efficient industrial process, petrosynthesis can be scaled up to meet global demand for petroleum while preserving fields and forests for agriculture and nature. Because it is synthetic, petrosynthesis can be refined to create better products, eliminating the impurities in raw fossil fuels to reduce the effect of emissions of particulates, carbon monoxide and nitric oxide.

The technology has been proven to work. The engineering challenge is to keep pushing the boundaries of overall energy efficiency and the quality and yields of products. Process optimisation will need a wide range of engineering specialisms, from material science and catalysis, through to advanced simulation and modelling of thermodynamics and fluid dynamics.

Petrosynthesis, the 21st century's engineering equivalent of the natural carbon cycle, could be a fundamental pillar of future industrial systems. In 1,000 years, people will look back at this transition and understand that fossil fuels were not bad; they were just a vital windfall and stepping stone on the road to human development of a circular civilisation.

Virgin polyester fabric made from recycled carbon dioxide is being used by sportswear companies to make clothing, addressing the issue of sustainable production © Lululemon

BIOGRAPHIES

Paddy Lowe FREng started his engineering career in Formula One in 1987 after graduating from the University of Cambridge. He is widely recognised for his achievements as an innovator and technical director, including leading the Mercedes team to the most successful season ever recorded: 19 wins from 21 races in 2016.

Professor Nilay Shah, OBE FREng is one of the most significant and influential chemical engineers within global academia. He has a PhD in chemical engineering from Imperial College London and is Professor of Chemical Engineering at the university. Professor Shah has received numerous awards, and has a track record of strong industrial engagement and consequent commercial success for research activities under his leadership.

In March 2014, a large landslide occurred at Oso, northwest Washington, USA, killing 43 people and destroying about 50 homes and other structures, as well as nearly a mile of State Route 530. US Geological Society research indicates that the landslide's average speed was about 40 miles per hour, with maximum speeds likely even higher. The area overrun by the landslide was about one-half square mile, and the landslide moved about 18 million tons of soil. The hazards associated with the slope were known but inadequate risk reduction methods were implemented, and this resulted in significant loss of life and damage to the town. It is possible that monitoring instrumentation installed across the slope, such as acoustic emission systems, in conjunction with pre-established response strategies, could have allowed early warning to enable evacuations © Mark Reid, USGS

THE SOUND BEFORE THE SLIDE

Detecting the early warning signs of a landslip by listening for sounds generated within a body of earth at risk of such movement might seem an unlikely proposition. But engineers at Loughborough University think otherwise – and an instrument they've developed to do just this is licensed for manufacturing and could also be applied to monitor ground movement around buried infrastructure. Geoff Watts spoke to them about its development and use.

Did you know?

- Movements in the ground can cause hundreds of millions of pounds worth of damage to buried infrastructure such as pipelines and tunnels
- Technology that detects the acoustic emissions before a landslide could also be deployed to monitor underground movement
- Friction between soil particles rubbing against each create the acoustic emissions that warn of ground movement

The noise created by a landslide – a variable cacophony of roaring, rumbling and crashing – is terrifying, but transient. The slide itself, over in just a few minutes, represents the spectacular climax to a process that may have been building over days, weeks or even months. This precursor phase is also accompanied by sound. Inaudible to the human ear, the tiny ground movements that precede a full-blown slide generate high-frequency vibrations: ground-generated acoustic emissions. If detected, these vibrations can serve as an indication of disaster in the making.

Landslides, while responsible for large numbers of deaths in some parts of the world, can hardly be described as a ubiquitous risk. Buried infrastructure, by contrast, is everywhere: rail and road tunnels; pipelines carrying oil, water or gas; dams; the foundations of structures ranging from bridges to wind turbines; and much else. All these structures are susceptible to damage resulting from movements in the ground that both surrounds and supports them. The UK spends 100s of millions of pounds each year maintaining infrastructure, and this will grow significantly as existing infrastructure ages and more is constructed. However, this spend could be an order of magnitude lower if deterioration is detected early enough using early-warning systems. The UK's existing, ageing geotechnical assets comprise around 10,000 kilometres of rail track; 46,000 kilometres of metal water and energy pipelines; 1,800 offshore wind turbines; hundreds of kilometres of tunnels; and 100,000 bridges, retaining structures and foundations.

Now, engineers at Loughborough University have developed a practicable method of detecting ground-generated acoustic emissions. The instrument they've developed is a useful addition to several other technologies already deployed for landslide warning, each with its advantages and limitations. Looking to the future, Loughborough's research on landslides could also lead to a much wider application of these acoustic emissions when detecting ground movement around buried infrastructure.

Landslide damage to a highway in Peace River, Alberta, Canada
© Alister Smith

MINISCULE MOVEMENTS

The movements of soil particles in unstable ground before a landslide are vanishingly small, but even the slightest displacement will cause these particles to rub against their neighbours. It is this inter-particle friction that generates acoustic emissions. The greater the ground movement, the more each particle will grind against its neighbours, and the more the sound emitted.

One of the hurdles geotechnical engineers have detecting these sounds is that they are poorly transmitted from particle to particle through the ground and, even more challenging, is that their principal source lies well below the surface. Watch a landslide in action and you will see an upper layer of material sliding over a more stable layer. The intersection between the two, the shear plane, is also the region where, before the main slide begins, there is the greatest movement between soil particles, and so the generation of the most intense acoustic emissions.

Neil Dixon, Professor of Geotechnical Engineering, has pioneered Loughborough's approach alongside Alister Smith, Senior Lecturer in Civil Engineering, who is now leading the work on monitoring buried infrastructure. Between them, they developed an instrument to detect the sounds that precede a landslide using a sensor on the upper end of a steel tube lowered into a borehole deep enough to penetrate the shear plane. Depending on the ground in question, the length of tube required may be little as couple of metres, or as great as 20 to 30.

A good test of the instrument is to bury it in a railway embankment. Despite thunderous noise and much shaking it will respond only to the frequencies it is set to detect

HOW TO DETECT AND WARN OF A LANDSLIDE

As with other destructive geological phenomena such as earthquakes and volcanoes, much study and effort has gone into looking for ways of predicting the onset of landslides. The use of ground-generated acoustic emissions is the most recent and novel approach to this endeavour, but it joins a small clutch of existing methods.

Unstable slopes move more readily following heavy rain, so the simplest expedient is a rain gauge to warn of a potential trigger to earth movement. Of more direct relevance is a knowledge of the amount of rain that has not only fallen on an unstable area but penetrated its depths. Piezometers sunk deep into soil and designed to measure the subsurface pressure of ground water offer a more revealing insight into the risk of a significant slippage.

Evidence that movement has actually taken place can be derived in several ways. Aerial photography and satellite monitoring will reveal preliminary surface movements. Detecting the smallest of such movements can be improved by subjecting the images to detailed examination using artificial intelligence systems. But this kind of scrutiny is necessarily intermittent; a weekly or even a daily report may not be enough where a slippage is thought to be imminent.

Physical measurements of the ground itself offer the possibility of more frequent or even continuous risk assessment. Where cracks in the ground surface are already apparent, any increase in their width can be measured directly, or inferred from the tension in wires firmly anchored on either side of the suspect area. Direct evidence of movement at deeper levels can be garnered by lowering an inclinometer into a suitable borehole and periodically checking for departures from vertical of the tube lining the hole.

The detection of ground-generated acoustic emissions allows continuous or near-continuous monitoring of any acceleration in ground movement and is less costly than other methods of obtaining a comparably detailed grasp of what is happening in an area of instability.

A TUBULAR WAVEGUIDE

Inter-particle transmission of acoustic emissions is poor. However, for particles in direct contact with, and rubbing against, the metal tube, attenuation of acoustic emissions along steel tubes is some 100,000 times lower. Vibrations can propagate over tens or even hundreds of metres. Moreover, investigators can choose the thickness and diameter of the instrument's tube to maximise the propagation of high frequencies. Acting as a waveguide, the tube conducts the sounds up to the sensor. The energy generated by the grinding of a single particle is self-evidently small, but the system is listening to the combined output of vast numbers of particles.

Standard transducer technology provides the sensor that converts mechanical vibrations of the wall of the tube into an electrical signal. The rest of the system, not least the computer programme required to process the raw data, was designed from scratch as no other system could do what the team needed. The Loughborough engineers worked with the British Geological Survey, a body well-versed in geological instrumentation, to develop the original version of the device and its software.

The instrument is tuned to respond only to sounds above 20 kHz generated by soil-particle friction. All other vibrations are ignored – the system includes signal filtering and uses a band-pass filter focused on 20 to 30 kHz, which means signals with frequencies outside of this range are removed. A good test of the instrument is to bury it in a railway embankment. Despite thunderous noise and much shaking it will respond only to the frequencies it is set to detect. The system can be solar powered or run on conventional batteries.

PROCESSING THE DATA

An increase in recorded acoustic emissions indicates an acceleration in the movement

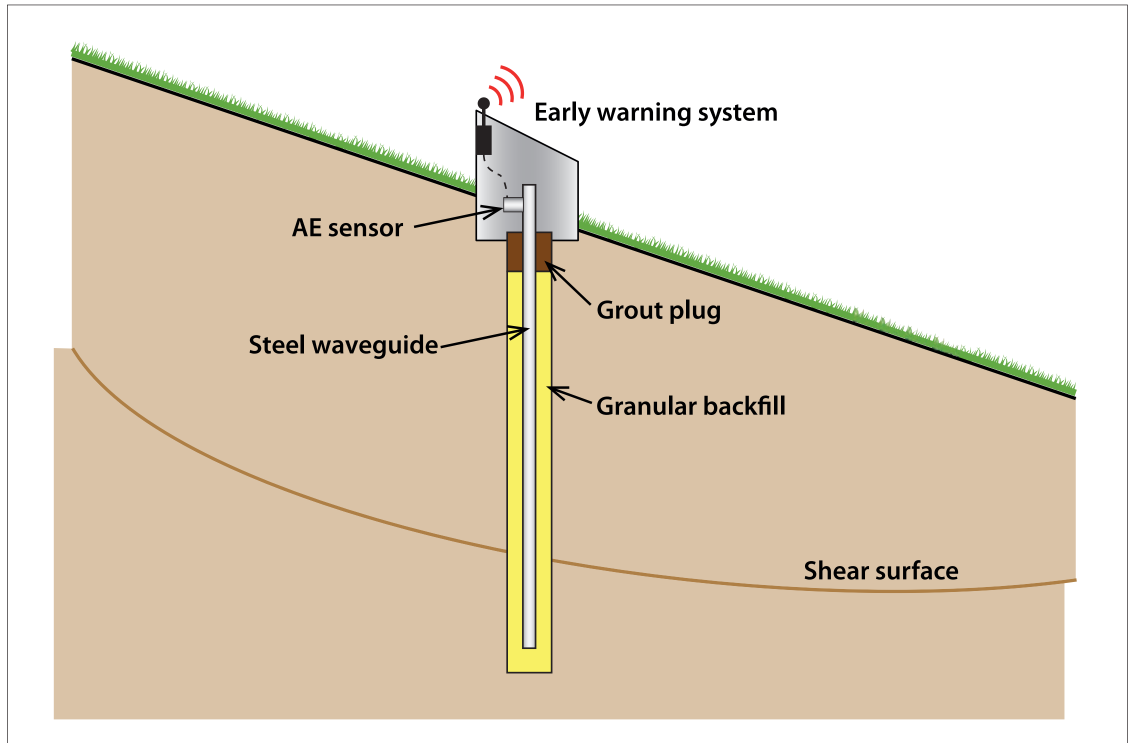


Illustration of the active waveguide system used for acoustic emission (AE) monitoring of slope stability. When the slope begins to move, deformation of the granular backfill generates AE that propagates up the waveguide to the AE sensor where it is measured and processed. If AE trigger levels are exceeded, warning messages are issued to decision makers via telemetry

of a slope. Slopes undergo progressive failure processes and gradually accelerate (movement rate increases) from fractions of a millimetre per hour before full landslide failure occurs. The acoustic emission monitoring approach has been able to detect movements as slow as thousandths of a mm per hour, which demonstrates the system can detect movements in their early stages and provide warning well before full landslide failure takes place. The instrument can be set up to transmit data for expert interpretation by geotechnical engineers, or simply to alert the user when a pre-determined level of activity has been exceeded, and so flag up the need for onsite investigation. In practice, individuals installing the system will normally have the geotechnical background required to interpret the data for themselves.

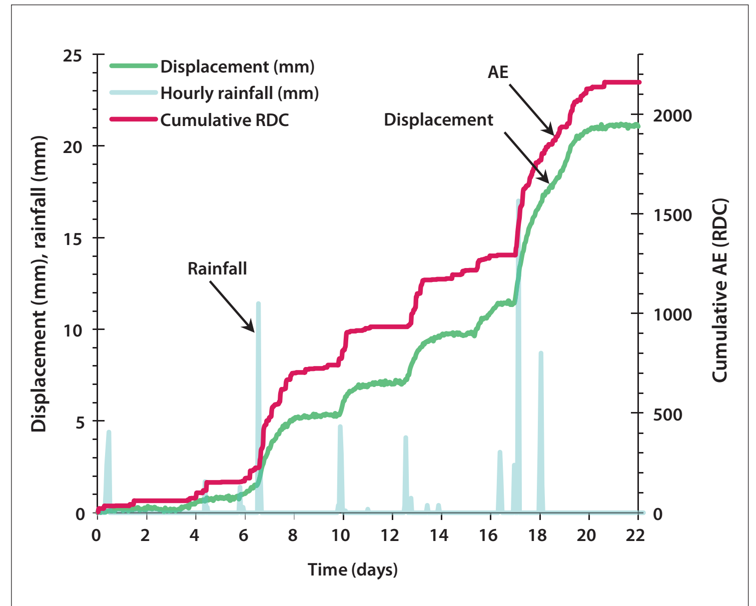
A detailed interpretation of acoustic emission data depends on those individuals knowing the nature of the soil particles. This will vary from site to site but operators installing the instrument can create a considerable degree of uniformity by backfilling the borehole in which the metal tube is located. When those installing the instrument have drilled the borehole to the required depth and lowered the detector tube into its centre, they fill the annular space between the tube and inner surface of the hole with gravel or sand of known physical characteristics. With this knowledge it is possible for geotechnical engineers to translate acoustic emissions data into estimates of the rate of ground movement that would be required to generate it.

Field trials in reactivated slide-prone slopes have revealed a direct relationship between rates of slope displacement and acoustic emissions. Years of experience in several countries, including the UK, Italy, Austria, Canada, Malaysia, and Myanmar, have demonstrated the efficacy of the system, and the Loughborough device has been commercially available since late 2019. As Smith explains, the team could have set up its own company to make and sell it, but this would have been the organisation's only product. In practice, most clients working on a particular project will need to buy a suite of geotechnical instruments: a need that Smith and colleagues could not have met. Hence their decision to look for an existing company to take on the commercialisation. Having reviewed several of the world's leading geotechnical instrument makers they selected Canada's RST Instruments Ltd, a well-established firm operating internationally and with a variety of products including some, such as inclinometers, already used in landslip detection. Smith had never envisaged the Loughborough system as the be-all and end-all of landslip monitoring; he had always seen it as one of several approaches, sometimes to be used in conjunction with others. Many different techniques and types of instrumentation are commonly used in slope monitoring. However, no single technique or instrument can provide complete information about a landslide, and therefore various combinations are usually used.

PROS AND CONS

Besides offering a system of real time and continuous as opposed to delayed and episodic monitoring of unstable ground, the Loughborough device is easy to install and use, and cheaper than alternative methods. Given that many of the countries most troubled by landslides are also impoverished, one of the team's aims from the outset was to develop a relatively inexpensive system. Indeed, Smith and team's plan with RST is to develop a more basic and affordable version of the currently marketed model: one that should make acoustic emissions detection more available to developing countries.

While these high-frequency measurements can flag up worrisome increases in the rate of movement of unstable soil, they cannot reveal the extent of that movement. But an upswing in activity would trigger the deployment of other methods designed to make these assessments.



Measurements from a field trial at a landslide in North Yorkshire, UK. The periods of rainfall reduced the slope's stability, causing surges of slope movement. Subsurface displacement was measured using a Shape Accelerometer Array. The measurements confirm that acoustic emission (AE) activity is directly related to the magnitude and rate of slope movement

MONITORING INFRASTRUCTURE

Using ground-derived acoustic emissions to monitor potential landslides is still the team's only commercial application. However, they are also looking at applying the underpinning technology to measure movements in the ground supporting and surrounding buried infrastructure, such as tunnels and pipelines, which could be susceptible to damage.

This much wider exploitation of high-frequency sound would rely on using the buried structure itself as part of the instrument: as a waveguide to respond to acoustic emissions and propagate them to attached sensors. The number of sensors that investigators would attach to a structure would depend on the nature of the surrounding soil. Pipe or tunnel sensors might be needed every 100 metres or so – but it could be more or less than this depending on a geological assessment of the hazards posed by the ground in a particular region.

Interest in acoustic emissions emerged 60 or more years ago, and their use in non-destructive testing and the evaluation of materials has become widespread. But the technology and, in particular, the computing power then available were not up to the task of interpreting the complexity of acoustic emissions generated by ground movements. Until recently, the only conclusions that researchers could draw with any certainty were qualitative: that the ground in which the infrastructure was buried either was or was not stable. The extent of any instability, and

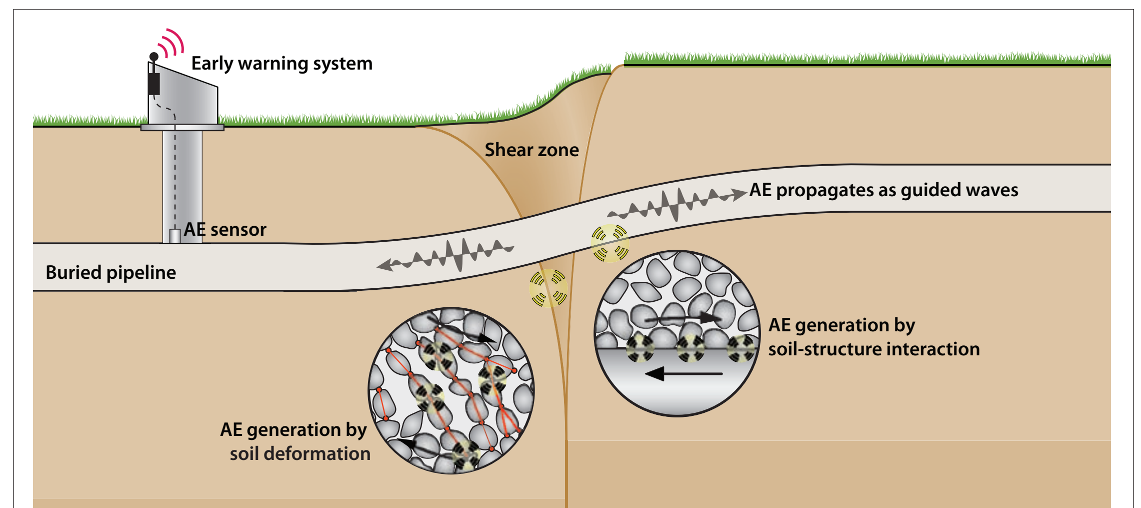


Illustration of the acoustic emission (AE) monitoring concept applied to buried pipelines. The example shows a fault-rupture deforming a buried pipeline. AE is generated by soil deformation and soil/structure interaction, which propagates as guided waves along the pipeline to the monitoring sensors. The monitoring system interprets the AE and sends a warning to decision makers via telemetry

the consequential risks to that structure, were impossible to assess. This severely limited the value of acoustic emission measurements to geotechnical engineers. Only with advances in data storage and analysis did it become possible to monitor in the field for long periods and use the accumulated emissions data to reach a quantitative estimate of the risk posed by ground movement.

This approach is still at an early stage, and the hurdles that the Loughborough team has to overcome are considerable. As already explained, interpretation of acoustic emissions from a landslip detector are simplified by a knowledge of the uniform backfill by which its metal tube is surrounded. Sensors attached to buried infrastructure have no such advantage. The soil particles interacting with its surfaces will be of mixed and unknown nature and geometry, will vary from one geographical location to another, and may even do so from point to point on the same structure.

EXPERIMENTAL ANALYSIS

Smith and other researchers are already tackling these hurdles using laboratory simulations. With buried pipes, for example, it is possible to record the acoustic emissions generated at their surfaces while the materials with which they're surrounded are subjected to artificially induced movements. This makes it possible for researchers to investigate the effect of ground deformation on different materials in different soil types. In the long run, analysis of the recorded emissions should allow operators to assess the degree to which ground movements might affect the infrastructure in that locality, and so the extent of the threat to it. Of course, given the real-world diversity of the ground types in which infrastructure can be buried, there is a deal of painstaking work still to be done.

While acknowledging that listening to infrastructure is still a project in its infancy, Smith envisages a time when many forms of buried infrastructure will be routinely fitted with acoustic sensors: the advent, in other words, of smart structures in which integrity is monitored throughout their lifespan. He compares this to the use of sensors to monitor the health of the human body. Ideally, he says, sensors would be incorporated in the infrastructure at the time of its installation. But he also sees a place for the retrofitting of sensors, a task that should prove relatively straightforward.

The exploitation of acoustic emissions monitoring aligns closely with the contemporary emphasis on sustainability. Monitoring not only the integrity of infrastructure, but also the risks to it posed by changes in the environment in which it is buried, opens the way to more targeted and proactive maintenance. This should extend the life of the structure, and so avoid the need for premature and wasteful replacement. Smith quotes, with approval, the opening words of the UN's Sustainable Development Goal number nine: "Build resilient infrastructure…" That neatly summaries his own goal.

While acknowledging that listening to infrastructure is still a project in its infancy, Smith envisages a time when many forms of buried infrastructure will be routinely fitted with acoustic sensors: the advent, in other words, of smart structures in which integrity is monitored throughout their lifespan

BIOGRAPHIES

Professor Neil Dixon has over 35 years of experience in geotechnical engineering research and practice. He has published over 190 refereed publications and supervised 33 PhD students in areas including slope stability, landfill barrier design and climate change impacts. He co-invented acoustic emission landslide early-warning systems.

Alister Smith leads the Listening to Infrastructure research programme, which is developing acoustic emission monitoring for geotechnical engineering. Alister's research has been funded by an EPSRC Fellowship and the Philip Leverhulme Prize. He co-invented acoustic emission landslide early-warning systems. He is the recipient of a series of awards including the Telford Premium and Hawley Award.

THE ETHICS OF ENGINEERING NET ZERO

Professor Raffaella Ocone OBE FREng FRSE © Photo by Ian Georgeson from the Royal Society of Edinburgh's Women in Science in Scotland 2019 exhibition, on display at Edinburgh Airport until end of January 2022

A research career in chemical engineering that started in oil has taken Professor Raffaella Ocone OBE FREng FRSE on a journey that encompasses biofuels, coal combustion, hydrogen production, carbon capture, and even landslides and volcanoes. On that journey she has pioneered teaching ethics to engineering students and how engineers can use artificial intelligence to make the most of the mountains of data from processing plants.

Few working engineers can say that their photograph greets passengers arriving at an international airport. But anyone travelling to COP26 in Glasgow may well have seen a picture of Raffaella Ocone OBE FREng FRSE at Edinburgh Airport without realising that they were looking at a picture of the first woman to become a professor of chemical engineering in Scotland and someone whose engineering research revolves around attempts to achieve net zero.

Professor Ocone, Chair of Chemical Engineering at Heriot-Watt University in Edinburgh, found time to take a photo alongside her portrait, which she shared on social media, on her first visit to Italy since COVID-19 disrupted life. She took the opportunity to fit in research meetings in Rome before visiting her mother, who still lives in the small Italian village where she grew up and where her father's delight in fixing things was the spark that launched her career as an engineer. "Dad was not trained as an engineer, but he was very good at fixing things. Nothing was thrown away," she says. She confesses that, like her father, she hangs on to things that might come in useful and has a garage full of spare parts that she may never be able to use.

Her interest in 'stuff' guided Professor Ocone's education choices. Italy's schools are less restrictive than the UK's, with no pressure to make early career choices. She loved maths, chemistry and physics, and a desire to do something practical with science nudged her into engineering. When choosing a university course, Professor Ocone didn't know that there was such a thing as chemical engineering, but combining chemistry with maths sounded appealing.

Professor Ocone decided to study the subject and was keen enough on 'chem. eng.' to move into research and study for an MA and then a PhD at Princeton University, working with granular materials. This led to a research career centred on 'modelling of complex reactive systems' and a place as one of the '100 Most Influential Women in Engineering' in 2019.

GLOBAL ENGINEER

Princeton was the start of a career that took Professor Ocone to several countries before she arrived, almost against her will, in the UK. After Princeton she returned to Naples for her first steps up the academic ladder as a university lecturer, but she "didn't like the environment". It wasn't just the problems that women sometimes face in engineering; she soon found that in Italy "the system did not reward merit". The academic life was a far less happy experience than her time in the US. Her boss was Professor Gianni (Giovanni) Astarita, a noted expert in mass transfer with chemical reactions, the field that Ocone had started to research. Astarita had excellent contacts in the research world, so he tipped off Professor Ocone when a friend at UCL in London asked if he knew anyone who might be suitable for a university post at the University of Nottingham. Professor Ocone was working in France on sabbatical leave at the time. "He told me to go to the interview," she says. But with the offer of a permanent job on the cards in France, she was already thinking of moving there.

If anything, she says, this plan removed some of the usual interview pressure. But as the interview with Nottingham progressed, Professor Ocone "thought that they were going to make me an offer." The confirmation came as she walked into her hotel in London, preparing for a weekend with friends: the university offered her the job as a reader in the chemical engineering department.

She rang Astarita whose response was blunt: "take the job or I will never write you another reference". She moved to Nottingham in 1995 and four years later, Heriot-Watt University lured her to Edinburgh to be the first woman to become professor of chemical engineering in Scotland. She was head of the Multiphase Multiscale Engineering Modelling research group and in June 2021 joined the Institute of Geoenergy Engineering to work towards energy transition.

FLUID RESEARCH

Professor Ocone started her research career in the traditional way by following a path laid down by her professor. She then did something that she now encourages young researchers to do if you want to build your own reputation: "find an area that is not so linked to what your supervisor's done".

At first, her research concentrated on the flow of granular materials (solid particles). She then worked on combinations of particles and fluids, which took her into the world of fluidised beds – one of the fundamental tools of chemical engineering that feature in activities from coal combustion to the production of pharmaceuticals.

Professor Ocone's research has delved ever deeper into measuring and modelling the flow of particles in industrial plant. A shorthand description of her expertise is "modelling complex reactive systems" or "multiphase flow of complex reactors systems".

The oil industry uses fluidised beds in refineries for cracking heavy oil. In line with her ambition to fix things and do something useful, Professor Ocone believes that it is important for academic engineers to work with industry. For example, at the start of her career she worked with modelling processes in Exxon refineries in the USA.

Her research combines measurements on experimental rigs and industrial plant, with mathematical modelling. Working with real data is important and this has taken her more deeply into computational approaches. Professor Ocone's latest moves have been to use artificial intelligence (AI) to tackle the floods of data that fluidised beds can create. As she sees it, AI involves data collecting, analysing and decision-making processes based on anything "artificial", which can be a machine, an algorithm, or a computer program.

Before the pandemic, Professor Ocone travelled to China regularly to conduct research on projects on fluidised beds. The work combined Chinese expertise in using electrical capacitance tomography to measure what happens in fluidised beds with the Scottish team's analytical skills. "We use the data to do the modelling and to see if we can predict the behaviour of these large reactors."

Professor Ocone's interest in AI arose during her EPSRC Established Career Fellowship in Particle Technology. "It is a fellowship about really understanding some fundamental physical behaviour of granular materials." It starts with particle-to-particle interactions. How does one particle interact with its immediate neighbour and then what happens when more and more particles enter the picture?

For all the progress in understanding fluidised beds, some areas of operation still come down to state-of-the-art understanding. For example, fluidised beds have long had to contend with 'clumping' or, as the scientists put it, agglomeration. This is what happens when particles stick together and clog up the works. The fellowship is a six-year programme worth more than £1 million, working with partners that include the Chinese Academy of Science, the US Department of Energy and Syngenta.

As well as interrupting her fellowship, the pandemic has also halted Professor Ocone's regular trips to China, where she has two projects. On top of the EPSRC fellowship, a Royal Society grant supports research with China on fluidised beds in coal combustion. Burning coal is controversial in an era of climate change, but China has already shown that it is not going to abandon it overnight. Although it does want to go about the process efficiently.

Professor Ocone is also working on how to produce hydrogen. Here she works within the university's Institute of Geoenergy Engineering, which has experience in storage of CO_2 and hydrogen, to tackle the process from production to storage.

Geoengineering features in another application of the tools and techniques of flowing particles. Landslides might seem to be removed from fluidised beds, but here too particles are flowing in a fluid. Her group's recent work on landslides shows how versatile the models can be. As Professor Ocone points out, with climate change landslides are becoming more a reality everywhere, so anything that adds to our understanding geophysical flows and the movement of soil particles is useful.

DATA BASES

Computer modelling has become increasingly important during Professor Ocone's research career. "In multiphase flow, we use computational fluid dynamics much more than we used to when I started." She recalls that when she first began her research, in a subject that relies on

It was when working in refineries that Professor Ocone saw just how much data large chemical plants can generate. Chemical engineering is now awash with data from many industrial systems and processes. The challenge can be to gain the trust of industry to let you plunder the data mountains

complicated mathematics, she would write her own computer code.

It was when working in refineries that Professor Ocone saw how much data large chemical plants can generate. Chemical engineering is now awash with data from many industrial systems and processes. The challenge can be to gain the trust of industry to let you plunder the data mountains. "It is not always easy to get data from industry, but the amount of data they have is amazing."

But the development of techniques like computational fluid dynamics (CFD) have done wonders for efficiency. "Many things have been understood through a very clever marriage between experiments and CFD." But you have always to validate what you do. That is why it is important to work with industry and to confirm the models. "We want to make sure that our models can be used, can be inserted in these big commercial CFD codes."

The challenge has become one of finding useful information. This led Professor Ocone to think that AI could help researchers make some sense out of this data. "I got interested in AI during my fellowship," she says. "You need data to do it." AI concerns feeding data into 'code' that can give you answers.

One sign of the rising power of AI is in a new research journal that Professor Ocone is involved in, *Energy and AI*, that hopes to provide a bridge between the two disciplines. She has also used her position as an editor to comment on the rising importance of another discipline that has consumed a lot of her recent time: ethics. Prompted by the outbreak of COVID-19, she has added her long running interest in ethics to AI and her chemical engineering.

THE ONLY WAY IS ETHICS

Ethics came into Professor Ocone's life when her position on the Engineering Professors' Council came together with her work with the Royal Academy of Engineering. As she points out, ethical dilemmas have long been a part of engineering practice. Engineers have a code of practice, but ethics weren't a part of the academic engineering curriculum. "Very few departments used to teach ethics in engineering," she says. This changed when the Engineering Professors' Council and Academy set up a working group on teaching ethics in engineering; Professor Ocone stepped in on the basis that, if no one else wanted to take it on, she would.

Not that she found working on ethics a walk in the park. "I came from engineering where I was dealing more with numbers. Dealing with something like ethics was very very difficult. It is an opinion in some cases. It is a dilemma. It is what you think is right. But you might be wrong."

She traces her interest in issues beyond engineering back to her Italian education, where high school students don't have to choose an increasingly narrow set of subjects. She studied geography, Latin and history for eight years, and philosophy for more than five years so thinking about ethics wasn't as intimidating, or novel, as it might have been for someone with a narrower education. As she says: "I never thought that an engineer should be just a technical person."

Professor Ocone is on the editorial board of a new research journal, *Energy and AI*, which aims to provide an authoritative academic exchange and publishing platform to disseminate and promote the latest progress in the application of artificial intelligence in the field of energy

Another lesson from Italy was the student's approach to political thinking. In Italy, she explains, high school was very political. "We used to strike for everything. 'The heating is not very good today, strike. The water is not very hot today, strike.' When I arrived in 1995, if I asked students in England about politics, they would be puzzled." As she recounts it, their line was: 'We are engineers, give us the engineering problems'. "The students knew how to design a plant, how to choose the pump on a plant, better than I did. I knew lots of science, engineering science, but much less practical engineering."

Undergraduates have changed since the 1990s. Today's students are extremely aware of social issues, she reports. "They question the academics with ethical issues." Universities now also teach engineering degrees with courses on ethics. And there are clear signs that students are increasingly interested in thinking about ethics.

Professor Ocone illustrates the rise in student interest with numbers taken from her own teaching. For a while now, engineering undergraduates at Heriot-Watt could choose a final-year project on ethics. Until recently, the option had no takers. Suddenly this has changed, driven partly by the pandemic. "In the last two or three years, that is one of the projects that students have most interest in."

It helps that degree courses have clear ways of putting ethical issues before students. For example, case studies are a tried and tested way of exposing students to ethical dilemmas. Here Professor Ocone played a key role in her work with the Engineering Professors' Council and the Academy. She is part of the group that wrote the case studies that support many engineering degree courses.

Professor Ocone cites the Challenger disaster as a classic engineering case study for students. The rocket exploded on launch when a seal failed because the material was colder than the design conditions. It is a straightforward technical issue that demonstrates that you cannot extrapolate how a material will behave in different conditions.

However, much as disasters can expose students to ethical issues, Professor Ocone advocates a move away from this emphasis. "This is the way we used to teach it – analyse this disaster based on ethical considerations." Today she advocates a broader approach, and one that prompts engineers to think about the ethical implications of their work when it turns out as expected, without any disasters. "Today we have to be a little bit more careful because we can develop technologies that can have unwanted effects that we cannot predict when we are developing our technologies."

She admits that it isn't easy to anticipate the use and misuse of emerging technologies. It boils down to her view that engineers cannot think about, or teach, ethics as a separate thing. "It should be embedded in the way that we teach engineering. It is important that students relate ethics to their engineering job."

For Professor Ocone, ethical thinking is at the heart of what engineers do. "Ethics should not be simply 'bolted onto' engineering and technological activities, but rather it should be systemic." She takes this even further. "The engineer has to find 'solutions' to ethical problems." She sees similarities between engineering and medical ethics.

Ideas on how to approach ethics in engineering education have changed in the decade or so since engineering degrees first covered the subject. Professor Ocone is currently chairing an Engineering Professors' Council and Academy working group producing 20 new ethics case studies. She is particularly keen for her students to tackle a new one on the ethical issues of "the energy transition". This is an area where she has considered some of the ethical questions we face as the world seeks to achieve net zero. It is important, she believes, to analyse the ethics of the engineering options on the table: "we need to weigh them in the balance or we could end up with as bad a mess as the technologies we want to eliminate."

FLUIDISED BEDS

Fluidised beds are a key technology in coal-fired power stations and chemical processing. Professor Ocone's research group deploys electrical capacitance tomography (ECT) to study what happens in a fluidised bed. ECT involves surrounding a non-conducting mixture of materials, such as a fluidised bed, with a ring of electrodes that measure the distribution of electrical capacitance. Sequential measurements from the array of sensors are a way of understanding the changing flow and distribution of materials.

Fluidised beds first made their mark in the petrochemical industry and coal combustion, but the underlying science and technology are versatile. Her EPSRC fellowship, for example, cites food processing and pharmaceuticals as industries that can benefit from the research. Ocone has used her expertise to address various challenges that promise to have more climate friendly applications. "Gradually I moved towards applications in pyrolysis of biomass and hydrogen production, to see if there are ways to produce hydrogen that are greener than what we do at the moment." She has also turned her work on mathematical modelling to investigate recycling of plastics.

"Too many people also tend to see wood as better than oil or coal because the amount of CO_2 produced by burning a given unit is much lower for wood. This overlooks the fact that you get considerably more heat from burning a unit of oil or coal than from wood. In other words, you have to burn much more wood to produce the same amount of heat, so the pollutant emissions might be more than they appear."

This is the sort of ethical dilemma that engineering students could address. For example, Professor Ocone wrote recently about the idea that we could achieve 'negative emissions' of CO_2 by adding carbon capture to electricity generation from burning wood. "The logic of the negative emissions argument is that burning wood is 'carbon neutral' because trees absorb CO_2 from the atmosphere in the first place, and you are simply releasing it back." The trouble with this idea, she adds is that it considers the process of burning wood in isolation. "It ignores, just as an example, a wider chain of activities including planting and harvesting the trees, converting the wood into chips and then shipping them to the power plant – not to mention storing and using the captured CO_2 once the wood has been burned." But that is just a part of the problem with this proposed engineering solution. "Too many people also tend to see wood as better than oil or coal because the amount of CO_2 produced by burning a given unit is much lower for wood. This overlooks the fact that you get considerably more heat from burning a unit of oil or coal than from wood. In other words, you have to burn much more wood to produce the same amount of heat, so the pollutant emissions might be more than they appear."

In the wake of COP26, such questions are high on the engineering agenda. For lessons on how to approach climate change, Professor Ocone takes heart from how engineers responded to the pandemic. As chair of the Academy's Awards Committee, she took part in the deliberations surrounding President's Special Awards for exceptional achievements in tackling COVID-19. For example, engineers and researchers showed what is possible in their response to the need for ventilators ('All hands to the pumps', *Ingenia* 86) and in the rapid development of vaccines. "We have demonstrated that under pressure we can deliver in a very short time," says Professor Ocone. Climate change is certainly one engineering challenge that needs concerted efforts.

In 2019, Professor Ocone was named one of the Top 100 Most Influential Woman in Engineering by Inclusive Boards and the *Financial Times*

CAREER TIMELINE AND DISTINCTIONS

Research student at the University of Naples, Italy, **1985–1987**. PhD student, Princeton University, US, **1987–1991**. Visiting professor, Louisiana State University, USA, **1992–1993**. Lecturer in chemical engineering, University of Naples, Italy, **1992–1995**. Visiting professor, LAGEP, Université Claude Bernard, France, **1995**. Reader in chemical engineering, University of Nottingham, **1995–1999**. Professor of chemical engineering, Heriot-Watt University, **1995 to present**. Cavaliere (Cav-Knighthood) of the Order of Merit, Italian Republic, **2006**. Fellow, Royal Society of Edinburgh, **2006**. Fellow, Royal Academy of Engineering, **2013**. Caroline Herschel Visiting Professorship, RUhR Universität, Bochum, Germany, **2017**. Awarded OBE for services to engineering, **2019**. Fellow, American Institute of Chemical Engineers, **2021**. Guest professor of multiphase multiscale systems, RUhR Universität, Bochum, Germany, **2021–2024**.

MACHINING TITANIUM COMPONENTS

Titanium has a high tensile strength and is light in weight but notoriously difficult to work with. Ed Mason has developed a way to machine the metal and has built a reputation for producing high-end custom-made parts for titanium bicycles.

Ed Mason's passion is to make things that he has designed himself. After graduating as a mechanical engineer, he gained on-the-job experience with manual machining, fabrication and welding at big UK engineering companies.

At home, Ed started building custom steel bicycle frames, as well as making, assembling, testing, and proving bespoke parts. His aim was to design parts that would be functional, easily serviceable and of high quality. The material he settled on was titanium: it ticked all the boxes he was looking for and has an inherent durability that permits him to make parts that last a lifetime.

Left: Finish-machined cranks installed on a mountain bike. Right: Two components designed by Ed Mason – a seat clamp and top cap. Ed custom anodises all the parts he makes in-house

Titanium alloys have a high tensile strength, are light in weight and have exceptional corrosion resistance. Ed works with 6-4 titanium, a material that has titanium alloyed with small amounts of aluminium and vanadium, typically 6% and 4% respectively, by weight.

Ed set up his machine shop, Dward Design, in Bath working on subtractive machining and machine-finishing additively manufactured components. He uses subtractive machining to shape titanium billets into custom-made bicycle parts. He applies his industrial CNC machine to fulfill contracts for hi-spec cycle parts that are made into bespoke titanium bicycles for companies such as Sturdy Cycles.

Titanium can't be welded because of oxygen embrittlement and work-hardens very easily. It also has a thermal conductivity that results in tools heating up when working on the metal. Ed's machining solutions, after much trial and error, lay in specific tooling and tailormade processes.

Ed's tooling and cutting methods enable the heat generated in a cut to be carried away in the off-cuts, rather than remaining in the workpiece itself. Using tungsten carbide cutters enables him to achieve a higher cutting speed. He uses a strong coolant concentrate to help lubricate the workpiece, keeping the parts at a constant temperature and preventing thermal growth during machining.

Using a higher-strength material like titanium allows the framebuilder to use smaller diameter tubing for a bike than for an aluminium frame of equivalent weight. Riders say that titanium bikes have a specific ride quality over aluminium and carbon bikes. Ed sees this as a direct result of using smaller diameter tubing to reduce stiffness in targeted areas thereby allowing less of the vibration from the road to be transferred to the rider's body.

The last couple of years have been extremely busy for Ed. Cycling was one of the few activities allowed during the COVID-19 pandemic and bicycle sales soared. This in turn led to a shortage of bicycles and bike parts in the UK. Lockdowns in countries that make bikes, the shortage of containers and dearth of HGV drivers has meant that the usual sources of bikes, frames and components have narrowed.

Ed does think that the technique he has honed could be other uses for other additively manufactured metals. He says: "I see applications for well-thought-out additive parts in semiconductor processes, where complex parts with organic geometry are required to be placed into pipework containing chemically harsh gases. In fact, any industry that needs strong, light, corrosion-free components like performance automative and aerospace would benefit."

Instagram: **@dward_design**

HOW DOES THAT WORK?

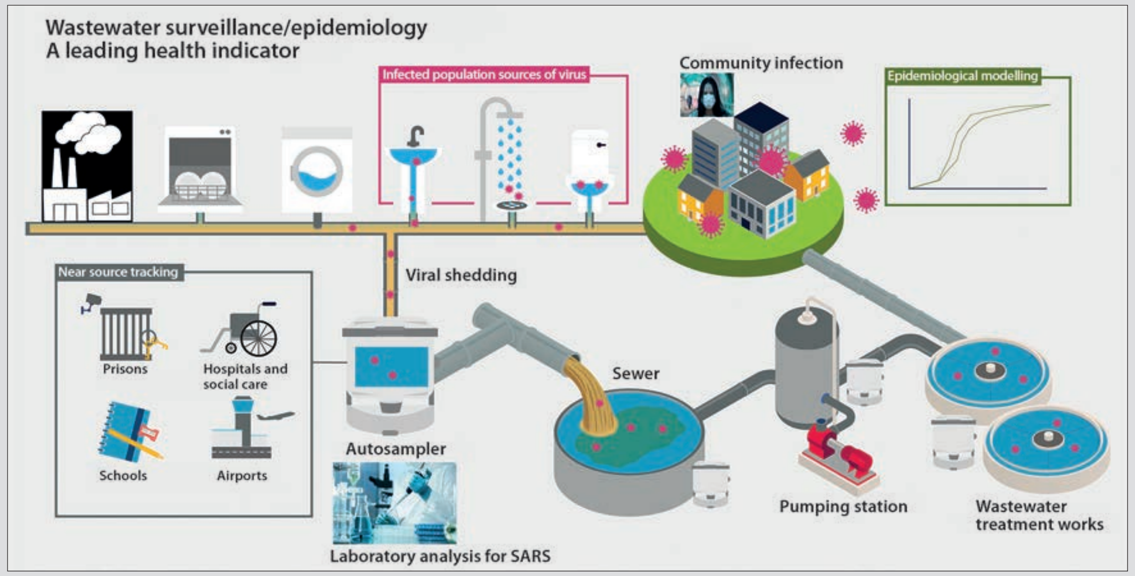
WASTEWATER EPIDEMIOLOGY

Sampling and testing of wastewater is helping governments across the world to track COVID-19 infections on a large scale.

Viruses are some of the simplest biological structures on earth. They are not 'alive' and cannot replicate outside of their host. How do you track infectious disease outbreaks at the scale of countries or continents? Lack of available testing in most countries, either in the form of quantitative methods or medical tests, prevent a public health response to the 'rapidly rising tide' of cases that occurs in easily transmitted infectious diseases. This includes the current pandemic virus – SARS-CoV-2. Testing is invasive, difficult to perform and requires repeat testing of individuals who are susceptible to the disease, so other approaches are needed.

It is common for people infected with viruses to release them in poo and wee. Therefore, one popular approach to monitor outbreaks is wastewater-based surveillance (WBS). Before COVID-19, it was used for monitoring polio and drug use. The value of WBS is that decision-makers can estimate the amounts of disease circulating in the population with only a few samples. In total, tens of thousands of researchers in over 50 countries are undertaking WBS for SARS-CoV-2. Alongside the vaccination roll-out, it is one of the biggest mobilisations of scientists since the Second World War for a single vision.

Grab samples or a dedicated automatic sampling device are set up at various points



in the sewage/wastewater infrastructure. This includes discharge points from large buildings like schools and hospitals, sewage pipes, and at water recycling centres (sewage works). Some countries like China have also started monitoring toilets and the swabs and poo obtained directly from individuals. Thankfully, the UK is not sampling 'at source' yet… Collecting wastewater with respect to COVID-19 is safe; the World Health Organization suggested in 2020 that wastewater does not represent a friendly environment for this virus and so is unlikely to infect people.

However, many challenges remain in the collection, analysis and interpretation of this data. On the wastewater side, municipal sewage is often changed by industry inputs and rainfall from roads and buildings. These inputs to the sewage system do not contain the 'signal', which is the virus fragments (RNA), but contain lots of dilution in the best case or 'noise' in the worst case. On the medical side, one aspect we do not understand well with SARS-CoV-2 is faecal shedding. This is the number of viruses each infected individual will shed in the faeces (in this case) or nose and throat for mass testing. At present we don't fully understand how long people will shed the virus and how long it will be detectable in wastewater. Another question is whether children or vaccinated individuals shed viruses to the same extent. Or how poo shedding changes in people infected with different variants (mutant strains of the virus). These factors are important to interpretation of the data for wastewater surveillance. One further challenge is how to monitor in 'low-prevalence' scenarios – this is where the number of infected individuals drops due to lockdowns, vaccination or natural immunity. Wastewater surveillance has been credited as one of the big success stories of the pandemic, helping governments respond in a rapid way without infringing the ethics and data protection rights of individuals. A major challenge is communicating the results of these surveys to the public in an appropriate way.

BIOGRAPHY
Dr Francis Hassard is a lecturer in public health microbiology at Cranfield University.


ARUP
We shape a better world
www.arup.com
Brentford Community Stadium
© Luke Hayes Photography Ltd