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MAKING STEEL SUSTAINABLY
TECH FOR NATIONAL SECURITY
INTERACTIVE PLAY INSTALLATION
MINING METALS BENEATH VOLCANOES

Royal Academy of Engineering

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WELCOME

Ingenia brings readers insights into why engineering matters, the rich variety of engineering fields of work, and the diversity of careers engineers pursue.

In the field of electronics, we feature Eneni on page 6, a robotics engineer, who started out as an engineer when she began taking apart household appliances as a child to see how they work. At the national scale, His Majesty's Government Communications Centre (page 15) has a thriving apprenticeship programme as part of its work to keep us safe – former apprentice Holly shares how motivating she finds the purpose of her work. On page 34, Africa Prize for Engineering Innovation winner, Anatoli tells how he developed a novel alarm system that enables neighbours to work together to keep their communities safe.

As engineers innovate, almost all fields rely on the use of materials, therefore innovation in sourcing and obtaining materials in line with a net zero future also requires imaginative engineers. We bring you, firstly, the example of perovskite, a family of crystalline compounds, which may hold the key to dramatically cutting the carbon emissions arising from steel production (page 10). And secondly, our article on mining volcanoes for metals (page 20) reveals the engineering challenges involved with extracting a metal-rich salt solution that could address the scarcity of materials vital to green technologies such as batteries and wind turbines.

Please let us know what you think of the issue at ingenia@raeng.org.uk or via Twitter using #IngeniaMag. Also, don't forget that you can subscribe to our e-newsletter via our website.

Faith Wainwright

Faith Wainwright MBE FREng
Editor-in-Chief

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IN BRIEF

WIND TURBINE PIONEERS WIN QEPRIZE

Winners of the 2024 Queen Elizabeth Prize for Engineering, Andrew Garrad (left) CBE FREng and Henrik Stiesdal (right) © Jason Alden

Samiha Nasher (left), one of the finalists of the Create the Trophy competition, receives a 'Highly Commended' award from judge Rebeca Ramos (right) © Jason Alden

The winning trophy design, created by Sunil Thakkar

On 6 February, the 2024 Queen Elizabeth Prize for Engineering (QEPrize) was awarded to Henrik Stiesdal and Andrew Garrad CBE FREng, for their work in advancing the design, manufacture, and deployment of high-performance wind turbines. Their achievements have enabled wind energy to deliver transformational impact in diversifying the global energy mix.

Over the past four decades, Stiesdal and Garrad's engineering inputs have phenomenally increased the size of individual wind turbines and the scale of the wind farms in which they are sited, as well as their engineering and economic performance. Credited for the early technology and critical advances as the industry has evolved, the 2024 Laureates have each pioneered a system that is present in almost all modern wind turbines operating both onshore and offshore in the market today.

Key to Henrik Stiesdal's recognition is a three-blade turbine, initially designed in 1978, that represents what is sometimes described as the Danish concept. Leading notable developments in proprietary blade manufacturing technology throughout the 1990s, Stiesdal's innovation, which operates upwind of the tower and allows twisting of the blades about their own axis (pitch control), has significantly enhanced the scale and efficiency of modern turbines.

Andrew Garrad is primarily honoured for the BLADED computational design tool. This allows engineers to model a complicated turbine system in its entirety and to predict its behaviour with the confidence needed to permit manufacture of these huge machines. It has been used all over the world. Through the consultancy company he cofounded, which supported the industry through design consultancy, testing, measurements, energy evaluation, and technical due diligence, it has allowed the rapid expansion of the global manufacturing base.

The 2024 QEPrize Laureates were announced by Lord Browne of Madingley FREng FRS, Chair of the Queen Elizabeth Prize for Engineering Foundation, during a reception at the Science Museum in the presence of HRH The Princess Royal.

The 2024 QEPrize Laureates will each receive £250,000 and a unique trophy, designed by the Create the Trophy winner Sunil Thakkar, aged 17, from India. Sunil Thakkar designed the trophy based on the imagery of a plant, symbolic of the fruitful results and prosperity stemming from engineering innovation. She took inspiration from how far women in STEM have come. This year, the designs of two finalists from trophy competition, Nandan Ambure and Samiha Nasher, were also highly commended by judges.

AI HELPS DOCTORS ASSESS LUNG CANCER

Scientists at Imperial College London have combined medical imaging with artificial intelligence (AI) to extract chemical information of lung tumours from medical scans. They have used AI to non-invasively classify lung cancer types and determine whether a cancer is likely to progress.

Patients with symptoms of lung cancer are usually diagnosed with either chest X-rays and computer tomography (CT) scans and occasionally by metabolomic profiling, which provides more detail, but is more time and labour consuming and requires a tissue biopsy.

The researchers trained their AI model to look for correlations between patients' metabolomic profiles and features of their CT scans to develop an assessment tool called the tissue-metabolomic-radiomic-CT (TMR-CT). Tests using the TMR-CT on patients with only a CT scan available resulted in reliable predictions of patient outcomes and cancer classification. This means that doctors could use the technique to help guide treatment decisions, or when it's not possible to obtain a physical tissue biopsy from a patient.

In the future, the researchers hope to use their method for other cancers that can be difficult to obtain biopsies from. It could also be incorporated as an algorithm as part of the software loaded onto commercial medical imaging scanners.

A patient undergoes a CT scan © Mufid Majnun/Pixabay

US SPACECRAFT LANDS ON LUNAR SURFACE FOR THE FIRST TIME SINCE 1972

On 22 February, Odysseus, a spacecraft built and flown by Texas-based company Intuitive Machines, successfully touched down near the Moon's south pole. It was the first time that a commercial company has launched and led the journey to the Moon, and the first US lander in 50 years.

Odysseus landed closer to the Moon's south pole than any other spacecraft. The Moon's polar regions have attracted interest because of the speculated ice hidden in deep craters that never see any sunlight. If ice is found, it could be used for fuel and for astronaut hydration.

The spacecraft left Earth on 15 February from Cape Canaveral, Florida, on a SpaceX Falcon 9 rocket for its eight-day voyage to the Moon. The craft transmitted data and images for several days before running out of power. Carrying six scientific instruments for NASA, its key aim was to investigate lunar dust behaviour. The journey will help prepare for NASA's Artemis mission to land humans on the Moon's surface by 2026.

The Odysseus spacecraft before launch © NASA/Intuitive Machines

NEW FUNDING ENSURES UK ROLE IN SPACE EXPLORATION

The UK Space Agency has allocated funding to support British scientists and engineers working on global missions to the Moon, Mars and Venus as part of the Space Science and Exploration Bilateral Programme. The projects allocated a share of the £7.4 million funding demonstrate both UK excellence in space science and technology and foster international collaboration with other space agencies including NASA, the Canadian Space Agency and the Japan Aerospace Exploration Agency.

UK universities including the Open University and Sussex, Aberdeen and Cambridge will receive funding. One project at Royal Holloway will help develop software for the Chandrayaan-2 Moon orbiter at the Indian Space Agency, which aims to detect ice beneath the south pole of the lunar surface. The University of Leicester will also investigate the potential of water ice as a resource on the lunar surface, by developing a Raman spectroscopy instrument for iSpace's commercial rover and lander missions to the moon.

Dr Paul Bate, Chief Executive of the UK Space Agency, emphasised that the funding "highlights the value we place on sharing knowledge and expertise with our counterparts overseas to break the boundaries of space exploration". Andrew Griffith MP, Minister for Space at the Department for Science, Innovation and Technology, highlighted that the projects are "putting the UK at the heart of some of the most important global space missions".

EUROPE MINE SET TO BE TURNED INTO A GIANT BATTERY

A disused mine in Finland will be transformed into Europe's first giant battery. It is intended to store up to 2 megawatt-hours of renewable energy during excess production to help balance Finland's electricity grid. The mine, located in the central Finnish town of Pyhäjärvi, was Europe's deepest zinc and copper mine before it was decommissioned in 2022, resulting in plenty of unused vertical space.

The battery system will repurpose existing mining infrastructure and will store electricity in the form of gravitational energy, resulting from the changes in height of a heavy mass. During peak production, the mass will be lifted by winches through the 530-metre-deep auxiliary shaft. When there is power demand, the mass will then be lowered to generate electricity through the winches, which become generators. The storage system, known as GraviStore, was developed by engineers at Gravitricity, a Scottish company that creates underground energy storage systems. The company successfully generated power at a demonstrator site in Edinburgh in 2021 and hopes that this new project will pave the future for its technology to be used in repurposing mines approaching their end of original service life. Systems like this are likely to become increasingly used as the world relies more on renewable energy sources such as solar and wind.

© hangela/Pixabay

GET INVOLVED IN ENGINEERING

INNOVATION LATE WITH LADY MACROBERT

8 April
Stratosphere Dynamic Earth, Edinburgh
This event will showcase exciting technology demonstrations from winners of the MacRobert Award – the UK's most prestigious and longest running award for innovation in UK engineering. Visitors can also enjoy an exclusive preview of photographs by artist Ted Humble-Smith that highlight the story behind some of the winners and finalists.
To book visit **www.edinburghscience.co.uk/event/innovation-late-with-lady-macrobert**

The event is part of Edinburgh Science Festival – the UK's largest annual science festival, which caters to all ages, with a programme of exhibitions, events, workshops, performances, screenings, and discussions. The family-friendly event offers interactive exhibitions and workshops focused on everything from spaceships and weather to dinosaurs and the workings of the human body, which adults and children can enjoy across Edinburgh.
www.edinburghfestivalcity.com/festivals/edinburgh-science-festival

STEMETTES WORKSHOP

11 April | 10am to 5pm
Bristol
Join Stemettes and insight in Bristol for a food and fun-filled workshop exclusively for girls, young women and non-binary people aged 5 to 25 to create an app or website, experiment with AI and solve problems for a more sustainable future.
www.stemettes.org/events/create-experiment-solve-insight-in-bristol

DO DATA DECEIVE OR INFORM?

20 April
Online or in-person (Royal Institution, London)
Emma McCoy, Vice President, Pro-Vice Chancellor and Professor of Statistics at the London School of Economics, will talk about the important role of data science and AI literacy in our increasingly digital world, addressing pitfalls and applications of these skills, as well as tips to avoid biases in the quest for accurate results.
To book tickets, **visit www.rigb.org/whats-on/do-data-deceive-or-inform**

BEES: A STORY OF SURVIVAL

From 4 May
Liverpool, William Brown St
This exhibition, in partnership with award-winning artist and sculptor Wolfgang Buttress, explores the tale of bees and their relationship with the natural world. It brings together art and science and features cutting-edge technology.
www.liverpoolmuseums.org.uk/whatson/world-museum/exhibition/bees-story-of-survival

THE BIG BANG FAIR

19 to 21 June
Birmingham, NEC
Registration for this year's Big Bang Fair is now open. Providing schools with a wealth of interactive activities and STEM inspiration, students can access careers advice and meet with scientists and engineers.
Visit **www.thebigbang.org.uk/the-bigbang-fair** to sign up.

HOW I GOT HERE

Q&A

ENENI BAMBARA-ABBAN
CREATIVE TECHNOLOGY MANAGER, ROBOTICIST

Eneni was one of the 2023 stars of the Royal Academy of Engineering's This is Engineering campaign
© This is Engineering

Eneni Bambara-Abban got her start in engineering by taking apart a toaster as a child. Today, her many roles include robotics engineer, technologist, and Founder of The Techover Foundation, an NGO that supports underserved communities into technology.

WHY DID YOU BECOME INTERESTED IN SCIENCE AND ENGINEERING?

From a young age, I was always taking things apart, trying to understand how they worked. I didn't really understand that at the time I was reverse engineering them. The kettle would go missing, and the toaster – and there I was tinkering about with them! When I was about five or six, we went to a flea market. There was this Black doll – and this was the 1990s, all the BABY borns were white. I was already excited just seeing a doll that looked like me – but it also had a speaker in it and could walk! I was so mesmerised. I remember thinking, what is this magic?

I didn't know what kind of engineering made a doll like that possible, but I knew that I wanted to be a person who could build that. And later on, asking 'Jeeves' (an early search engine), we found out it was robotics. And thus started my journey into becoming a robotics engineer.

HOW DID YOU GET TO WHERE YOU ARE NOW?

At school, I did the sciences, maths, everything that you would advise somebody to do if they wanted to be an engineer. I applied to the best engineering schools but after college, didn't get the grades in my A levels. Eager not to give up, I wrote a letter to the engineering department at the University of the West of England pleading with them and saying how I'd always wanted to be a robotics engineer, with an example of a robot I built. Thankfully, they offered me a chance to go on their [engineering] foundation course and after that I went onto my first year at uni.

University was very up and down, but [I] ultimately finished it after being inspired at the Young Women in Engineering awards. I was about to drop out. I was in my final year and it was so hard, especially being the only Black girl on my course. I often felt like I didn't belong there.

Dr Shini Somara was at the awards the year I attended. Her speech was incredibly motivating – I felt like she was talking to me and telling me not to give up. So, I had a little prayer to God – if you help me finish this degree, I promise I will pay it forward and help get other girls into STEM. And then I graduated, and was like 'oh dang, now I gotta keep my promise to God!'. Since then, I've been fighting for women's equality and equity in the STEM industry.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

In 2021, at the height of my engineering career, I had to deal with many microaggressions and sexism – all kinds of things. I remember feeling so defeated, like my purpose was to help others, and I didn't feel like I was being respected or helping anyone.

I travelled back to Nigeria, [where] I did high school. I remember thinking I [could] have more impact there. I curated a workshop in collaboration with Arduino [an prototyping platform to build electronic devices] where I taught girls from northern Nigeria how to build their first robot, how to code, but really how to dream. They were all fascinated by the Arduinos – and I was very impressed by just how well they built the robots for their first attempt! So yeah, for me it was a very enlightening moment that propelled the birth of my NGO, The Techover Foundation.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

The fact that you can think of something in your head and translate it into a real tangible thing in front of you. I just think that's so amazing. Honestly, I see it as a superpower that anyone can have, as long as you're passionate about engineering, and you stay curious.

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

No two days are the same for me. I have a few different jobs, the main one currently being creative technology

Eneni in the robotics lab at The Engineering & Design Institute London (Tedi) © This is Engineering

manager for the British Council where I'm exploring how screen-based media, using new technologies from XR to AI, overlap and intersect with conventional art forms. I'm also a freelance robotics engineer working on custom projects for my varied clients. I also have a company called Anime and Chill where I run anime and gaming events in London to over 4,000 members, creating a safe space for those often marginalised within these industries.

Last but certainly not least, I run my NGO, the Techover Foundation. This year we have plans to go to the Philippines to advocate against child marriage and push for girls' participation in STEM-specific education. Every day I have a mini meeting with myself to make sure I'm clear on my to-do list, otherwise things get very chaotic very quickly.

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

I've not really had the typical linear career where you start as an intern or junior and then you work your way up, and I like to think I turned out okay! While you're young, TRY IT ALL. Start building things at home outside of school or on the weekends. Try your hand at coding from a YouTube tutorial. Or maybe you're not a fan of university and want something more practical? Well, consider looking into an apprenticeship!

Whatever type of engineer you want to be, is the type that you should be. There's no rulebook. I have made it my mission to push the narrative that you don't have to look one way or have a specific route into engineering to be an engineer and I truly believe it.

WHAT'S NEXT FOR YOU?

Our workshop in the Philippines is definitely a big one. I want to go into communities that I feel could really benefit from tech and show them they can do things that empower them. Before that, I'm doing an exhibition where I want to feature women, girls, and non-binary people working in STEM and doing amazing things.

My movie *STEM* is also in the works, which focuses on a diverse group of women thriving and flourishing in STEM. It's a bit like *Hidden Figures* mixed with *Girls Trip* or *Sex and the City*. We've had talks with Channel 4, Netflix… things are getting exciting and we hope to increase entry and retention of women in STEM through our film.

QUICK-FIRE FACTS

Age: **30**

Qualifications: **undergraduate degree in robotics; postgraduate degree in data science and artificial intelligence; scrum master (project management)**

Biggest engineering inspiration: **Hiroshi Ishiguro, a robotics engineer at the University of Osaka. He was one of the first people to build a robot that looks exactly like him, down to the face, the mannerisms, the body language. I honestly think he's one of the coolest people on the planet**

Most-used technology: **probably my Raspberry Pi 4 and my laptop**

Three words that describe you: **tenacious, inquisitive, empath**

OPINION

ENGINEERING SKILLS FOR THE CLIMATE EMERGENCY

Engineers have a crucial part to play in developing the innovative solutions that will help us achieve net zero. As Alice Delahunty FREng, President of UK Electricity Transmission at National Grid, explains, it's not too late to respond to the challenges of the climate emergency – but only if we fast-track vital engineering skills into our economy before 2030.

Climate change is the challenge of a lifetime, and switching to renewable energy has a considerable part to play in reducing our carbon emissions. The energy industry is changing rapidly and working hard to make this happen.

In 2020, zero-carbon power outstripped fossil fuel in the UK's electricity mix in 2020 for the first time since the Industrial Revolution. Back then, Thomas Edison's Holborn Viaduct coal plant – opened in 1882 and the world's first coal-fired power station – could light 1,000 lamps. Today, a single rotation of a wind turbine off Scotland's coast can power a home for a day.

But we know we need to do more and continue to focus on transitioning to greener energy.

TACKLING THE CLIMATE EMERGENCY

How do we achieve this? People are the real catalyst for change. They are the innovators who will develop, build and operate the infrastructure we need to deliver cleaner energy. They're the engineers and technicians who will continue to provide and implement the solutions and play a vital role in tackling one of the world's greatest challenges.

Yet, we still need to increase the number of people with the engineering skills required to meet the scale of the challenges of both the climate crisis and the development of an advanced economy. There is still much to do to achieve diversity in the engineering workforce.

In many ways, my own career echoes the path of the energy transition – beginning as an engineer at coal-fired power stations and then gas generation plants across the UK and Europe, moving to lead offshore wind projects here in the UK and be part of the UK's offshore wind success story – and now as President of National Grid's transmission business.

I believe this breadth of experience gives me an overview of the entire industry and hopefully means I can advocate for the rewarding opportunities available while demonstrating first-hand the importance of retaining and retraining our existing talent to support the demand for green jobs.

ENGINEERS OF THE FUTURE

Undoubtedly, engineers will play a key role in reinventing industry, energy and the world around us. New disciplines will emerge and familiar ones will evolve. As recognition and understanding of the vital role engineers play in shaping our world increases, so too will the expectations that engineers engage widely and can convey the impact of sustainability on innovation, and how their technical expertise serves to future-proof products and services.

The number of cross-cutting skillsets needed for 21st-century engineers are not significantly covered in either academic or vocational education. We need to reframe what and how engineers and technicians think and act, and make systemic changes across education, skills and employment, using a strong evidence base to demonstrate impact and change.

National Grid's *Building the Net Zero Energy Workforce* report found that our industry must recruit 400,000 jobs between now and 2050. We need a strong pipeline of talent that combines technical expertise, with broader business and leadership skills and a passion for climate action.

The report also found that more than half of UK adults want to work for a company helping the country reach net zero, suggesting this is a large, untapped motivator and passion for people of all ages and backgrounds.

The next 30 years will see the emergence of new jobs, while some traditional roles will change or decline.

Investing in retention and retraining, plus working collaboratively with government and unions, means the industry can help ensure a fair energy transition, where workers of all backgrounds and ages and from every community in the UK can play their part.

ADDRESSING THE GREEN SKILLS GAP

There is also much work to do to inspire the younger generation to choose STEM (science, technology, engineering, and mathematics) subjects at school and to support them in taking engineering and technology pathways into vocational and higher education.

At National Grid, our £1.3 million partnership with social enterprise Connectr, launched as part of the London Power Tunnels project, which is rewiring South London, provides 85,000 students across 168 London schools with the tools to pursue green and STEM-based careers. This is part of our ongoing commitment to help the UK plug its green skills gap and inspire STEM leaders of the next generation.

But we need collaboration and coordination across a wide range of stakeholders. We need a grassroots movement in schools where children are provided with clear examples of where subjects and learning can take them: practical examples of how mathematics can be applied to everyday life; the role of physics in helping us to understand how the world works; and how chemistry can help to transform lives through the innovation of new products.

BUILDING A DIVERSE WORKFORCE

A diverse workforce in a supportive environment is crucial to delivering net zero. We need different perspectives, new ideas, and greater creativity to help us solve one of the world's most pressing current challenges.

In the UK alone, we know that the transition to net zero will create hundreds of thousands of green jobs. However, Boston Consulting Group has found that by 2030, only a quarter of these green jobs may be held by women.

And yet National Grid's own research has shown that 80% of young girls want their career to make a 'positive contribution' to society, and 83% of women want to help the UK reach its net zero target.

Lack of diversity, in the widest sense, means we lack a whole range of views and ideas, with the risk that engineering is not reflective of the society in which we live.

We must all do more to promote careers in STEM and ensure our work environments welcome everyone to share their diverse skills, cultures, backgrounds, expertise, and insights.

COLLABORATION IS KEY

I'm proud of all the work National Grid and the professional engineering bodies have done and are doing to help tackle climate change and enable the transition to cleaner, greener energy in the UK. We know collaboration is key to reducing emissions as quickly as possible – so we are partnering with industry, academics, and policymakers. As we begin this crucial decade for climate action, we must put people, energy and action at the heart of the solution.

Engineers 2030, led by the Royal Academy of Engineering on behalf of the National Engineering Policy Centre, is an education and skills policy programme rethinking engineering and technology skills for a world in which both people and planet can thrive. To find out more, please visit **www.raeng.org.uk/policy-and-resources/education-policy/engineers-2030**

BIOGRAPHY

Alice Delahunty FREng is responsible for developing, building, maintaining and operating the electricity transmission network in England and Wales. She has held a number of senior roles in E.ON and started her career as an electrical test engineer before moving into research and development, focusing on low-carbon technologies. Alice holds a degree in electrical and electronics engineering and a master's in management science from University College Dublin.

A steelworker tapping a molten sample from the blast furnace to test its composition © Shutterstock

GREENING THE UK'S STEEL INDUSTRY

Virtually every industry on the planet depends on steel. This strong, durable and ductile alloy of iron and carbon is found in many things including paperclips, ocean liners, food cans, and skyscrapers. Steel has made modern life as we know it possible, but it needs to clean up its act. Leonie Mercedes investigates how engineers are working to decarbonise this important global industry.

Did you know?

- Steel is essential for the wind turbines and solar panels we're going to need to get to net zero – so we need to make it more sustainably
- Applying a high enough electric current between the electrodes in an electric arc furnace generates temperatures that can melt scrap steel
- About 70% of steel made in the US is made using electric arc furnaces

Steelmaking is one of the world's most polluting industries, estimated to account for 7 to 9% of our greenhouse gas emissions. According to World Steel, every tonne of steel made in a blast furnace (the dominant method of making steel) produces on average 2.32 tonnes of CO_2.

Cutting emissions by reducing the amount of steel we make is a tall order, as in the years to come, demand for the material is expected to increase in many regions. We'll also need a lot of steel to make the wind turbines, solar panels and other products and infrastructure that support a green society.

In the UK, 15% of all industrial emissions come from the blast furnaces sited at Port Talbot and Scunthorpe. Our ability to reach the government's net zero targets will, in part, depend on our ability to make cleaner steel. What can we do to clean up this carbon-intensive industry, securing a more sustainable future for us and the UK's steel sector?

CLEANING UP IRONMAKING

Historically, most of the UK's steel will have started life in a blast furnace, where coke (a fuel derived from coal), iron ore and limestone are blasted with air at up to 1,600°C. The coke ignites to produce carbon monoxide, a chemical reducing agent. This removes the oxygen from the iron oxides found in the ore, turning them into pure iron. The output: molten iron with a high carbon content, and carbon dioxide. The liquid metal is then transferred to another vessel, called the basic oxygen furnace. Here, a stream of oxygen reacts with the carbon present in the hot metal, producing steel, carbon monoxide and carbon dioxide. (Read about how steelmaking works in more depth on page 36.)

It is the first of these two stages that creates the most CO_2 emissions, through burning fossil fuels (primarily coke), as well as the chemical release of carbon dioxide. So, getting rid of the coke is one way to lessen the carbon emissions from steelmaking. But as coke must be burnt to produce the reducing agent carbon monoxide, you need another way to reduce the iron from the ore.

A short-term solution to decrease emissions is to reduce the amount of coke required in the existing blast furnace process by injecting other reducing agents such as gas, gasified biomass or hydrogen. This approach means we can continue to use existing equipment, avoiding the significant environmental (and financial) costs of demolishing and rebuilding. "If we do [use another reducing agent], then we don't have to change the process entirely," says Joachim von Schéele. Schéele is an expert in green steel working at Linde, a global manufacturer of industrial gases that can be used in steelmaking. "We can use the big assets that we have."

However, looking long term, removing coke from the equation entirely would cut emissions more drastically. This involves exposing iron ore to reducing gases (such as natural gas or hydrogen) at high temperatures – but still below its melting point. Iron made in this way is called direct reduced iron (DRI) and consumes much less fuel than iron made in a blast furnace. On average, DRI creates some 1.4 tonnes of CO_2 per tonne of hot metal.

The lowest-carbon approach to DRI would involve reducing the iron ore with green hydrogen, made by splitting water with renewable energy. This is something Linde is exploring, along with startups such as Sweden's H2 Green Steel. However, the technology is still very new: the latter is building a plant and aims to begin production in 2025. It also requires an abundant source of renewable energy. Estimates suggest if the UK's blast furnaces were converted to DRI fuelled by green hydrogen, it would use up to 17% of the UK's renewable energy supply.

GOING ELECTRIC

Electric arc furnaces (EAFs) make steel primarily from recycled scrap steel. Rather than burning coke, they use electricity to melt the metal. For every tonne of steel made in an EAF from scrap, 0.67 tonnes of CO_2 is produced. In future, this process will be even cleaner if the electricity is 100% renewable. For this reason, the steelworks at both Port Talbot and Scunthorpe will be replacing their blast furnaces with EAFs in the coming years.

From an environmental perspective, this sounds like a good move, especially

An electric arc furnace. Its characteristic domed roof is closed over the bowl-shaped hearth. Electrodes protruding from the roof are melting scrap steel inside © Shutterstock

as steel is the most recycled material in the world. It also means we can put the scrap we produce to use, rather than exporting it – in 2022, the UK exported more than 8 million metric tonnes of scrap steel. However, the story is more complicated than that.

For one thing, the availability and quality of scrap steel is variable. There are more than 3,500 different grades of steel, says Dr Becky Waldram from SUSTAIN, a network led by Swansea University researching carbon-neutral, resource-efficient UK steel supply chains. This means that to produce high-quality steel in EAFs, we need a handle on where scrap comes from and what it's made of.

It's like the computing term "garbage in, garbage out", she explains. "If you put rubbish scrap in, you're going to get a rubbish product out the other end … [but] the more you know about the material that goes in, the more confidence you can have in the material that's going to come out."

Sorting scrap steel so that similar grades are recycled together will improve the quality of the steel that can be made in EAFs. "We need to make sure we're looking at circular supply chains, so it becomes more obvious where certain end-of-life products need to go, and how they can be recycled in a more efficient way," Waldram says. However, it's worth noting that there are also emissions and costs associated with sorting. Another consideration for carbon emissions is pre-treatment, which is also necessary before scrap can be remade into steel.

Another way to boost the quality is to 'dilute' scrap with iron. In relative terms, this decreases the amount of residual elements you might find in scrap. Iron from a blast furnace or DRI are both suitable ingredients for the job. "That sort of material will be needed because in general, you cannot put 100% scrap in an electric arc furnace and get a high-quality product out the other end," Waldram says. The caveat is that both blast furnace iron and DRI are considerably more carbon intensive than scrap steel.

That's not all. Certain components in cars, rail, aerospace, and high-tech applications require steel with a precise composition. As it stands, only blast furnace processes can economically provide this. So, without its own blast furnaces, the UK will still have to import virgin steel to the industries that demand it. But blast furnaces abroad still generate emissions, and so do the cargo ships required to move it to the UK.

Finally, while a move to EAF should make the UK's steel industry more sustainable on balance, going all in on the technology has costs. These aren't just financial (although EAFs are estimated to cost over £1 billion each). As EAFs need fewer people to operate, the move puts the jobs of thousands of steelworkers at risk at both sites. At the time of writing, more than 4,000 jobs are to be cut at the UK's key steelmaking sites.

PUTTING CARBON TO GOOD USE

While the days of our blast furnaces in the UK may be numbered, what of the over a thousand others elsewhere in the world? Could capturing and re-using their carbon emissions be a route to keeping them in play?

At the University of Birmingham, Professor Yulong Ding FREng (a member of *Ingenia*'s editorial board) and Dr Harriet Kildahl have developed a way to do just this. In a 2023 paper, the team reports that its approach could reduce carbon emissions from blast furnace steelmaking by up to 88%.

The key player is a material called a perovskite. Perovskites are a family of crystalline compounds with properties useful for energy storage and conversion. Researchers are investigating how to use them in products including solar panels and fuel cells.

Back in 2020, Kildahl was researching perovskites for her PhD with Ding. The perovskite they had developed – a mixture of inorganic (non-carbon-containing) compounds ground up and baked into a slab – bound carbon dioxide at 700°C. When heated to 800°C, it gave off carbon monoxide, while some oxygen stayed bound to the structure. During lockdown, she was intrigued by proposals to open a new coking coalmine for steelmaking in Cumbria. She started looking into how blast furnaces worked. "I started noticing that the inputs of the blast furnace were the outputs of my process, and the outputs of the blast furnace were the inputs of my process."

Kildahl took the idea to Ding, her PhD supervisor, whose background is in steel. "The more we looked, the better it fit." So how would it work in practice?

When iron is made in a blast furnace, CO_2 and nitrogen are generally vented from the top as by-products. But in Ding and Kildahl's innovation, this CO_2 is captured and passed over the perovskite, which sits in a reaction chamber outside the blast furnace. The perovskite splits the CO_2 into carbon monoxide and oxygen.

This lets two things happen. Firstly, the carbon monoxide can be extracted with a gas separation unit and fed back into the blast furnace to continue reducing the iron ore. Secondly, the perovskite becomes saturated with oxygen. Flushing nitrogen – another waste product from the blast furnace – through the reaction chamber liberates the oxygen. This can then be used in the basic oxygen furnace where steel is made. The entire system is closed. According to Ding, on top of the carbon emission reduction, the perovskite will improve the energy efficiency of ironmaking compared to the already highly optimised blast furnace approach.

However, he notes that coke also ordinarily plays an important structural role in blast furnaces, ensuring even gas flow through the molten iron (see page 36). As only a fraction of the input coke is needed for Ding and Kildahl's approach, the team has suggested a ceramic could work in its stead.

So far, they have tested the system with up to 100 grams of material. Now in talks with steelmakers and other members of the supply chain, the next step for the Birmingham team is to try it out at a larger scale. "We're actually expecting that the process benefits from scaling up," says Kildahl. They believe this is because only surface layers of their prototype perovskite slab were being effectively used.

The team has now redesigned the material so that it is porous yet still strong, which should enable more efficient and effective use of the perovskite than in the small-scale tests. Ultimately, it will reduce the input material requirements and hence be even more resource- and cost-effective, says Ding.

Once the team has made these strides, the closed-loop system can be retrofitted to existing plants. "One of the … biggest benefits of the system … is that we're not left with these massive, stranded assets," says Kildahl. "We have to think about people and being able to actually use these blast furnaces to the end of their natural lifetimes. We don't need to lose all the skilled blast furnace workers who've worked so hard for so many years."

It may be too late for the UK's blast furnaces, but steel facilities beyond our borders will be seriously considering how this technology can help them retain workers and plants with many years of use left. While the team initially had blast furnaces in mind, Ding explains it can also be retrofitted to DRI reactors – enabling an even greater reduction in carbon emissions for this type of ironmaking.

THE FUTURE IN UK STEEL

Many routes to decarbonisation already exist for the steel industry, so we are not starting from scratch. Schéele says that the pathway to decarbonisation requires us to consider two things in parallel: What do we need to develop? And what can we do now? "It's a journey, though we should not forget about what we can do today," he says. Short-term focus should be on energy efficiency, he says, noting that first you burn less, then you burn clean.

Port Talbot's steelworks in South Wales, owned by India's Tata Steel, is Europe's second largest steelmaker. The blast furnace here is closing so that the company can open an electric arc furnace instead © Shutterstock

With the UK's remaining blast furnaces set to close by the end of the year, it is important that we act now to ensure a smoother transition to electric arc, says Waldram. This may mean importing DRI pellets and steel slab to help 'dilute' the scrap steel in EAF, she says. "There is going to be a gap in Port Talbot between the blast furnaces closing and electric arc furnaces starting up. There are jobs that people can take on to help in this transition." She adds: "Electric arc is the future, but it's what we do in the short term to get through that transition."

In Europe, the picture is similar. Steelmakers Tata (in the Netherlands), Thyssenkrupp (in Germany) and ArcelorMittal (in France) are all planning to transition to DRI and EAFs within the next two decades. Globally, questions remain about how quickly the world's largest steel producers, India and China – still largely reliant on coke-powered blast furnaces – can decarbonise. However, there has been a welcome overall acceleration in the pace of change. A July 2023 report from Global Energy Monitor, which tracks the world's fossil fuel and renewable energy projects, showed that 43% of planned steelmaking facilities will be based on EAF technology. A year before, this figure was at 33%.

Back in the UK, various organisations are moving to find ways to save the jobs at Port Talbot and Scunthorpe and to ensure that steelworkers' skills, developed over many generations, are retained. Another outcome of ensuring some continuity for the industry is the potential to inspire future generations. "We need to be inspiring them to get into manufacturing, not saying we're closing everything, and you can't be involved in it," Waldram says. "We need to show young people there are still manufacturing jobs in the UK, and they can help us move towards a more sustainable future in steelmaking."

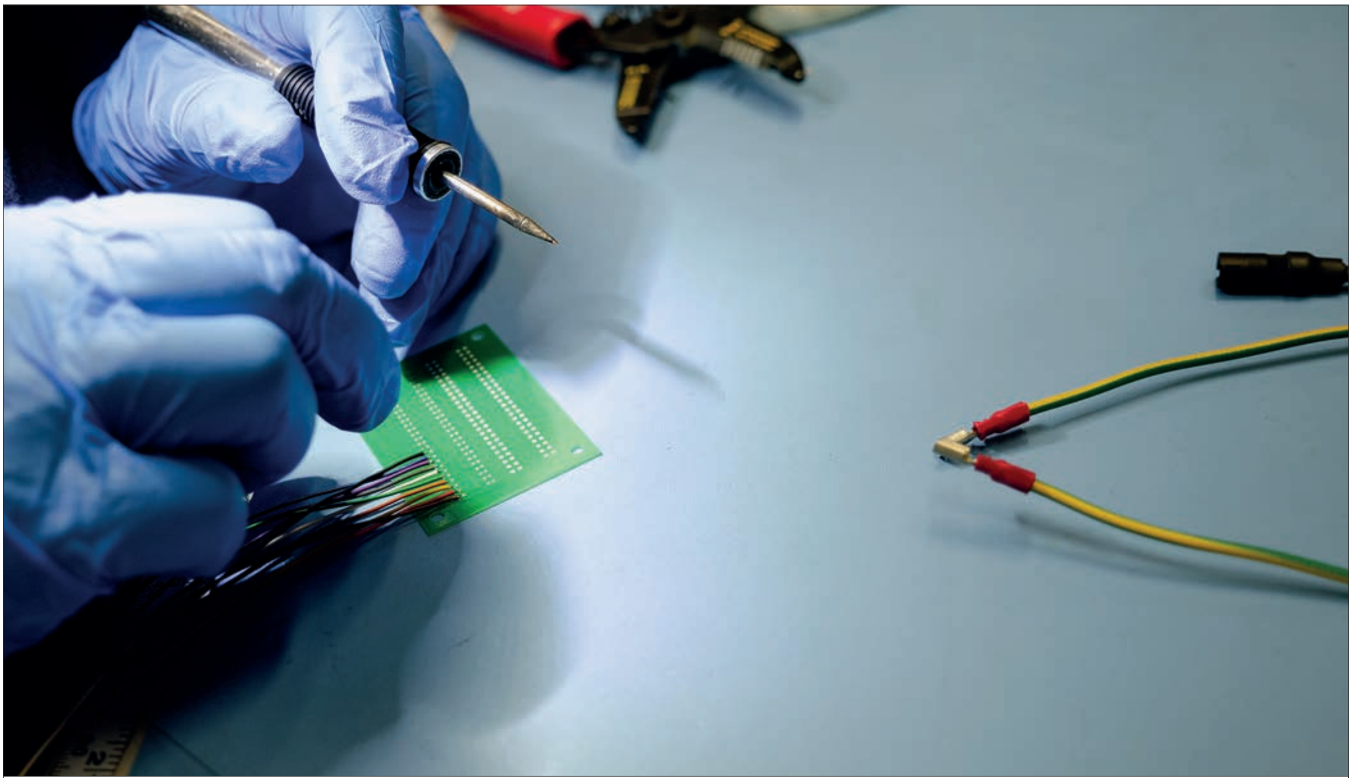
BIOGRAPHIES

Joachim von Schéele is Director of Global Commercialization at Linde. Based in Munich, Germany, he has been working with process and manufacturing industries across the world. He is focused on decarbonisation including use of hydrogen in steel, metals, mining, and other hard-to-abate industries.

Dr Becky Waldram works at Swansea University, as the Impact and Engagement Manager for the SUSTAIN Future Steel Manufacturing Research Hub. This project focuses on greener, cleaner and smarter steelmaking technologies.

Dr Harriet Kildahl completed her PhD in chemical engineering in 2022 at the Birmingham Centre for Energy Storage. She is now helping industry decarbonise in her role as an ESG (environmental, social and governance) consultant at Inspired ESG, and is an Honorary Research Fellow at the University of Birmingham.

Professor Yulong Ding FREng is Founding Chamberlain Chair of Chemical Engineering at the University of Birmingham. His current research interests are in energy materials, energy process engineering and industrial decarbonisation, and he leads Birmingham's steel decarbonisation taskforce.



HMGCC imagines, creates and crafts solutions to support national security organisations, from intelligence collection gadgets to secure communications systems © HMGCC

THE SECRET WORLD OF NATIONAL SECURITY TECH

Attracting a new generation of the best engineering talent is at the heart of national security's bid to stay ahead of rapid technological advances. His Majesty's Government Communications Centre (HMGCC) explains more about how this is done.

The HMGCC campus at Hanslope Park has a staff of engineers, scientists, technologists, CAD designers, and cyber experts, plus buildings full of high-tech specialist kit © HMGCC

'James Bond' is often the name people utter when they first hear about the work of HMGCC – His Majesty's Government Communications Centre.

But there is no fictional super-spy at HMGCC. A pioneer in national security engineering, its work is very real, confidential in nature, vital to the country's safety, and far flung from fiction.

More dramatic is the rapid progress in areas ranging from AI to intelligence gathering and cyber, which can pose both threats and opportunities to those working in national security.

For this reason, HMGCC has accelerated its drive to draw in fresh, new talent through its doors, as well as creating opportunities to work more openly with academia and industry.

Part of the draw of working for HMGCC is that you can do work that you cannot do anywhere else.

When national security organisations need a tool or technology to support a piece of work – whether that is a gadget to help with intelligence collection, or a secure communications system to help government operatives stay safe in potentially dangerous locations – HMGCC will imagine, create and craft solutions to help this happen.

At its Hanslope Park site, just outside Milton Keynes, it has an expansive campus complete with buildings full of high-tech kit for carrying out specialist functions. Its staff includes hundreds

The Hanslope Park site has an expansive campus complete with buildings full of high-tech kit for carrying out specialist functions. Its staff includes hundreds of engineers, scientists, technologists, CAD designers, and cyber experts – all tested to the limit every day in their work for national security

of engineers, scientists, technologists, CAD designers, and cyber experts (to mention just some of the roles) – all tested to the limit every day in their work for national security.

"The key for us in staying ahead of the swift pace of technological advancement is the talent we can attract into our organisation," explains HMGCC's CEO, George Williamson. "We do this in a number of ways: running apprenticeships, holding regular rounds of recruitment, and drawing on expertise from external sources such as universities and industry.

"We create amazing tools and technologies here at HMGCC. So many of the people who come to work for us are those who enjoy the creative aspect of engineering, solving unique problems and, at the same time, doing all of this work for the good of national safety."

THE APPRENTICESHIP ROUTE

One method used for continuing to attract a new generation of engineers and technologists is apprenticeships.

HMGCC is now marking 10 years since the launch of its successful apprenticeship programme, with hundreds of new engineers and technologists having successfully passed through HMGCC's on-the-job training.

Apprenticeships at HMGCC are currently run in software development, IT, electronics, production engineering, and electronics assembly, with applications invited from September. They are aimed at those aged 18 and over.

The organisation's Head of Recruitment, Sam, explains: "In software, for example, we recruit people from apprentice level to graduates. One major benefit of our apprenticeships is our on-the-job support. People can join us thinking there is an expectation that they need to know it all, but our organisation is brilliant at transferring knowledge and making sure people can learn those key skills."

She continues: "You can be yourself in this organisation, you don't have to be something you are not. Diversity is important to us and people come to us from all walks of life.

"Apprentices with HMGCC find they are making a difference while learning – they really have a chance to make a difference while taking on all of these new skills."

A BRIEF HISTORY OF HMGCC

Founded in 1938, HMGCC started life as a specialist in overseas bespoke wireless communications. It was set up as a new team to help maintain secure communications with overseas outposts in the event of war with Germany.

Previously the main method had been to send encrypted, morse code messages over the international public telegraph network but the risk was that these could be easily intercepted by a hostile country. A new method was developed, to put in place a private network, sending encrypted messages over a shortwave radio, linking directly to and from overseas premises.

A small communications team was put together to create this wireless network, an engineering support team, operating using the name 'His Majesty's Government Communications Centre'. The organisation grew rapidly during the Second World War. By 1945 it had about 7,000 staff with a wide variety of skills, carrying out many roles.

For many HMGCC apprentices, this opportunity can lead to a lasting career with the organisation. Currently more than 90% of apprentices stay on to continue their work as full members of staff – after having been interviewed and following a recruitment process.

Apprenticeships are fully funded by HMGCC and include the opportunity to gain several accredited, professional qualifications. Salaries start at £21,116, which goes up each year of the apprenticeship, subject to passing the year.

HMGCC also participates in the government's student bursary and development scheme for undergraduates, known as CyberFirst. This gives participants the opportunity to receive an annual bursary, paid summer internships and the potential for three years of employment. The scheme covers a range of activities that give people the support, skills and experience in the world of cybersecurity.

SOFTWARE ENGINEERING WITH A PURPOSE

It was 10 years ago when Holly became one of the first apprentices to walk through the doors of HMGCC – a mysterious place she had previously known little about. Aged just 19 at the time, Holly had a flair for technology and she was keen to find out how she could discover more about the alternatives to university.

A decade later, she is a fully fledged employee and hasn't looked back. She soon found out why Hanslope Park, home to HMGCC, was such an unknown entity – with the focus of its work on providing tools and technologies to support the organisations working in national security.

She also found out that the kind of projects she could now work on

TURING'S DELILAH PROJECT

Computing pioneer Alan Turing built his speech encryption system, called 'Delilah', at Hanslope Park during the Second World War © HMGCC

Just a few miles down the road from Bletchley Park, Hanslope Park in Buckinghamshire was also once the workplace of modern computing pioneer Alan Turing. Following his work on Enigma at Bletchley Park, Turing first moved to Hanslope Park where he lived in a cottage onsite.

With most staff living on-site, there was an active social life that he took part in, playing chess and card games in the mess and attending dances. He gave evening lectures on mathematics and circuit design on site. It is believed Turing was nicknamed 'the prof.'

Turing's workspace was in the main laboratory, which once stood on site at Hanslope Park. There he developed a speech encryption system called Delilah, working closely with Donald Bayley, a recent graduate in electronic engineering. Turing ran a competition to give the project a name. This was won by Robin Gandy who it is believed suggested that it should be called Delilah as she was the 'biblical deceiver of men'.

By the end of the Second World War, Turing and Bayley had succeeded in making a working prototype. They demonstrated the system in operation to high level visitors, usually by playing a recording of a Winston Churchill speech through it. At this point it was still effectively a prototype and more work would have been needed to produce a system that could be used in the field.

It is likely that the original prototype lived on in storage with other wartime equipment at Hanslope Park. Much of this was eventually broken up or taken off site.

"The area I work in now is what keeps me here today – it is just so interesting and I honestly think everyone I work with is a genius, so many of them are world leaders in their field. It is an interesting type of job and, due to the nature of the work, it's not really something you can do anywhere else"

would not be the types of challenges she would face anywhere else. Now working as a software tester in security research, she says the exploratory nature of the role, which is all about discovery and testing for many different types of scenarios, was what appealed to her about the job.

"When I started my apprenticeship there, I had never heard of HMGCC. When I found out more about it, I thought it sounded fun and it was all very exciting," she recalls. "By the second year of the apprenticeship, we were more hands on and we were able to work in different software areas.

"The area I work in now is what keeps me here today – it is just so interesting and I honestly think everyone I work with is a genius, so many of them are world leaders in their field. It is an interesting type of job and, due to the nature of the work, it's not really something you can do anywhere else."

Since that time, hundreds of people have completed HMGCC apprenticeships – many of whom have stayed on to pursue careers at the site.

Working for the national security mission, and the knowledge that your work is helping keep the country safe, is a major draw for many candidates to the apprenticeship programme.

"I really wanted to be in a role where there was a broader purpose than money – a sense that there was a greater purpose behind the work," says Holly.

"Having done an apprenticeship, there have also been lots of financial benefits for me, not least that I don't have a student debt as everything has been paid for by work, I don't have to worry about any of that. When I was in the sixth form, I saw that the university fees were going up and I came across some information about apprenticeships."

She adds: "Starting here at such a young age, I never really thought about long-term goals at that time. I initially just thought about getting to the end of the apprenticeship. Now it has been 10 years and I just think it has gone by so fast."

Working in software testing, Holly recognises the fact there are fewer women than men taking on roles in this area. She is keen to encourage other women into roles like hers and is pleased that HMGCC is one technical employer making strides to rebalance the workforce.

She says: "Working in my area, I know that sometimes I can be the only woman in the room – but we do have some amazing women working here at HMGCC who are great role models. I would like to see more women coming into engineering and technical roles, and I do know that at HMGCC there is a strong support network."

A UK-WIDE INNOVATION NETWORK

Recently, HMGCC also launched a drive to work more openly with wider industry organisations and academia. HMGCC Co-Creation is an initiative run in partnership with the Defence Science and Technology Laboratory (Dstl), which allows more work to be carried out with the companies and institutions at the forefront of technological innovation, to help the UK solve some of the most difficult problems facing those working in the service of national security.

The initiative does not share anything secret, but issues challenges through a set of collaborators, who tap into networks of industry and academia to analyse where work is being done already in areas of interest to national security. Through HMGCC Co-Creation, these outside organisations are then given funding and support to work with experts at HMGCC to help advance and develop these ideas and solutions.

George Williamson explains: "Going forward, we are really excited about the opportunities that these new ways of working will offer us, helping us to build on our technical capabilities at a time when the pace of technological advancement is extraordinary."

THE HMGCC NETWORK

Interested in finding out more about HMGCC's apprenticeship programmes? Visit **hmgcc.gov.uk/our-teams/apprenticeships**

Prospective industry and academic partners can find out more about HMGCC and Co-Creation scheme at **hmgcc.gov.uk/co-creation**

MINING VOLCANOES FOR METALS

© Benjamin Leon

Did you know?

- Mining is the extraction of valuable geological materials and minerals from the Earth's surface
- Volcanoes include a layer of brine, which could provide metals needed for our electronic devices and the energy transition
- Engineering has a key role to play in mining these brines

Green technologies such as batteries and wind turbines depend on a range of important metals and minerals. With concerns about environmental damage from conventional mining, scientists and engineers are exploring alternative sources. Stuart Nathan explores whether metal-rich magmatic brines found underneath volcanoes could hold the answer.

Generating and storing electricity requires materials with particular magnetic properties, such as rare earth metals for the static magnets in wind turbines. Perhaps most urgently, we need lithium and cobalt, which are essential components in batteries. While we have previously obtained these materials by mining, we are now acutely aware of how this industry can harm the environment: we need new sources and ways to find them.

The seabed is one potential source of minerals – geologists have found nodules composed of oxides of manganese and iron, often mixed with compounds of other elements. However, obtaining these would involve dredging the seabed, which poses a threat to local ecosystems, and the whole idea of 'seabed mining' has become a controversial issue.

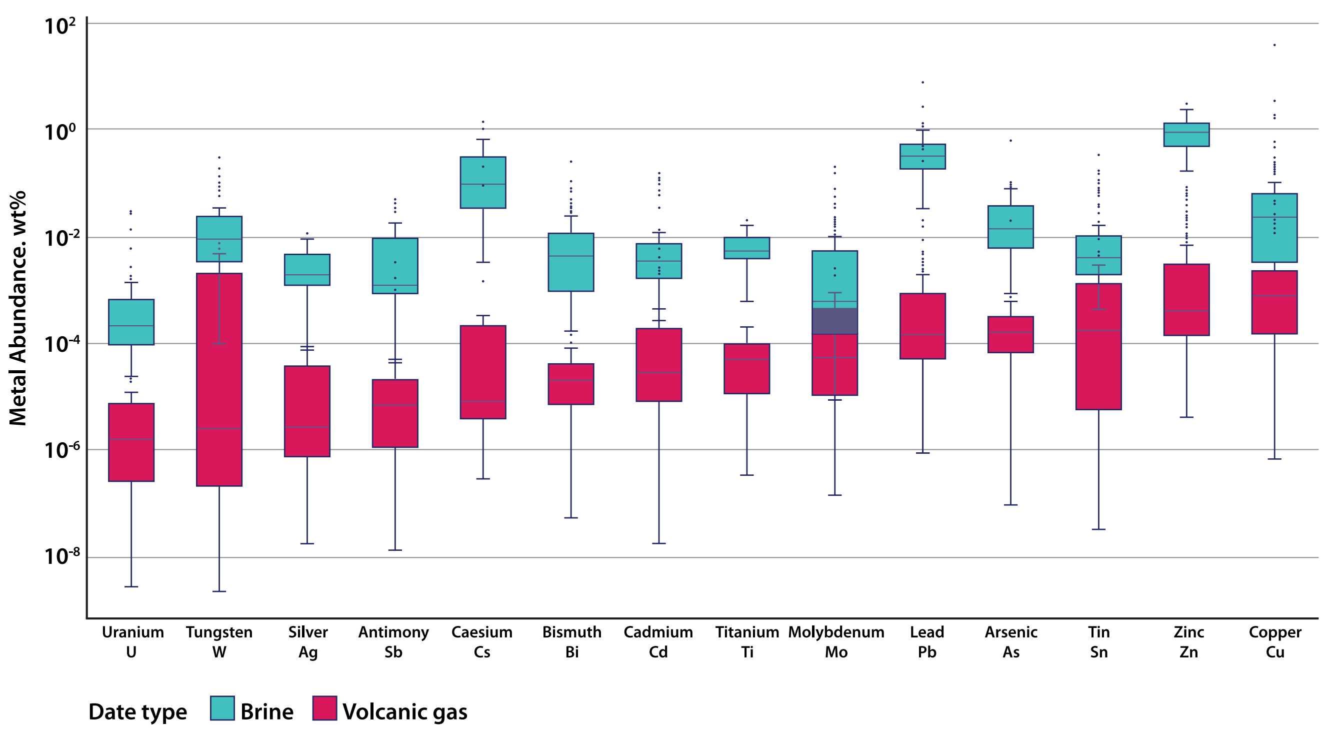
Another possible option for essential metals is volcanoes. Alongside the molten rock – magma – inside volcanoes, there is a lesser-known substance: magmatic brine. Earth scientists believe that this dense solution of metal salts could address the scarcity of materials.

FLUID CONTENT

Many types of brine – highly concentrated saltwater solutions – form in association with volcanic systems, and contain significant amounts of dissolved metal ions, explains volcanologist Professor Stephen Sparks FRS from the University of Bristol. "You can have groundwater leaching through cracks and permeable rock to form saline solutions, for example, and these brines could also be useful," he says. "But magmatic brine forms from the magma itself." Solid rock can contain water, such as in hydrated salts or that dissolved into the minerals that comprise the rock. When friction between tectonic plates melts rock to form magma, that water becomes part of a homogeneous molten solution. Through a series of complex geological processes associated with volcanic activity that take place over millions of years, mineral-rich brines accumulate in the sub-surface.

About 10 times as concentrated as seawater, it's this brine that is of interest for its metallic content. "It tends to occur between the surface and the magma chamber," Professor Sparks explains. "Many, if not all, active volcanoes are likely to generate brines underneath." Extinct volcanoes are also likely to have associated brine, as solidifying magma forces water out of the lattice of crystallising minerals.

The liquid brine tends to lie two to four kilometres below the surface in lens-shaped deposits. Engineers routinely reach these depths already in Hawaii and Japan, where they drill to access hot rock for geothermal energy but typically avoid exploring areas where magmatic fluids might be anticipated.



This figure shows compositions of magmatic brines and volcanic gases for representative sodium chloride contents of 50 wt% (weight percent) in brine and 1 wt% in volcanic gas, and listing the metals along the x-axis. Across the broad suite of metals, brines show the most enriched metal signatures, up to three orders of magnitude higher than volcanic gases. Figure adapted from an article, 'Mining the brine', by Olivia Hogg and Professor Jon Blundy FRS in *Geoscientist*, summer 2022

Magmatic brine already provides some elements. For example, it is extracted and processed to yield bromine in Japan and lithium from the Smackover formation in Arkansas, US. Non-magmatic brine deposits from salar brine (concentrated brine found underneath salt flats, such as those in Chile and Bolivia), already yield lithium. "The extraction of lithium from geothermal brines has been researched for 50 years and for a long time has been technically feasible," explains Valentin Goldberg, a geothermal energy specialist at the Karlsruhe Institute of Technology. "The problem so far was that, when the cost of lithium is low, conventional resources (such as hard rock mining and salar brine) were cheaper, and thus geothermal lithium was not cost-competitive."

"These brines can contain any element in the periodic table at concentrations ranging from a few percent by weight down to parts per billion," says Professor Jonathan Blundy FRS, Royal Society Research Professor in earth sciences at the University of Oxford. "We can find precious metals, base metals, lithium, and even rare earth metals all contained within them. The exact metal endowment depends on the type and location of the parent volcano. This would be a viable alternative to scraping polymetallic nodules off the seabed – and it would do less damage to vulnerable ecosystems."

Scientists use magnetotellurics, a process that uses variations of the Earth's magnetic and electric fields to measure the electrical resistivity of its sub-surface, to locate brines. Brines have high electrical conductivity and can be found using a device similar to a very large metal detector. Professor Sparks explains: "Underneath many volcanoes, like Mount St Helens in the US, you can see regions of very high conductance. The most likely explanation is that there are brines underneath those volcanoes. Unfortunately, rocks saturated in small amounts of brine can still be very conductive. These methods tell you that brine is there, they even tell you the volume of rock which has brine, but they don't necessarily tell you how much brine is there."

Professor Blundy explains that determining brine's composition is a matter of sampling. Scientists employ geochemical modelling to estimate the likely metal content, then use drones to collect samples from volcanic vapours to reconstruct the brine chemistry and deploy geophysics to image the sub-surface.

Engineers have several roles in harvesting and processing magmatic brines. They are already working at geothermal energy sites with magmatic brine extraction potential in New Zealand, Japan, Iceland, and Germany's Rhine Valley

Goldberg adds: "We can try to estimate the brine chemistry from surface outflows. The fluid chemistry of thermal surface springs can give you already a lot of information about the sub-surface temperature, reservoir type and potential extractable ions." However, he warns that it isn't easy to determine whether a particular deposit will be a commercially viable site for mineral extraction as it will depend on flow rate, raw material concentrations and possible extraction technologies.

Other methods to determine the brine's composition involve analysing deposits found at the surface, says Professor Sparks. "You can look at the minerals that have formed in the brine-forming magmas, which will include small amounts of volatiles and melt, as well as fluid trapped in the crystals as they grow."

HARVESTING AND PROCESSING

Engineers have several roles in harvesting and processing magmatic brines. They are already working at geothermal energy sites with magmatic brine extraction potential in New Zealand, Japan, Iceland, and Germany's Rhine Valley. The most obvious role is comparable to oil drilling: operating the drill itself to reach depths of about 4 kilometres and ensuring the integrity of the borehole. "You need to drill into rocks at temperatures around 400°C, and the brines can be aggressive and highly acidic," Sparks says. "The borehole needs to be lined with a material strong enough to stop it collapsing. Engineers will have to ensure that the lining material can withstand the heat and corrosion by the brine."

Isabelle Chambefort, Energy Futures Theme Leader with GNS Science, a New Zealand research institute that focuses on geology, geophysics and nuclear science, is investigating brines as an offshoot of work on geothermal energy. She says: "The key challenge in engineering right now is maintaining the well. At high temperature and pressure, you can easily have a collapse of your well at depth."

One advantage of mining brines rather than seabed nodules or conventional ores is that brines contain fewer impurities. "A benefit is that you don't have to process rocks to extract metals, as nature's done that for you," says Professor Sparks. "So, there are potentially fewer environmental issues associated with mining. Intrinsically, it is easier to extract a brine containing lots of metals, than to mine a lot of rock, and then have to do a lot of chemical engineering and metallurgy to get to the metals back into solution and purify them."

However, Professor Blundy adds that "there might still be problems. You might find toxic unwanted metals, such as arsenic or mercury." He says that we should also consider other issues. For example, there could be induced seismicity, like that associated with fracking, when processed fluids are reinjected into the sub-surface.

Another role for engineering is in processing brines. This could involve the same chemical engineering processes that refine crude oil, which starts with a complex natural material that is processed to give simpler products, in this case purified metal salts. After that, melting the metals might require electrolysis to spur on the chemical reaction. Here, another advantage of drilling into hot rock is likely to come into play, as geothermal energy could provide the electricity needed. Using hot rock as the heating source to generate electricity is well-established. In New Zealand geothermal energy provides 17% of electricity and in Iceland, over a quarter. This could make metal purification self-sufficient and non CO_2-generating, says Professor Blundy.

There are several chemical engineering processes under development for extracting lithium from brines. Some of these are already in industrial use, for example with salar brine or residual brine from desalination plants as their starting material. Of particular interest are so-called direct lithium extraction (DLE) processes, which are currently being considered and trialled to extract lithium from geological (non-magmatic) brines in Cornwall. DLE is a multi-stage process: initially it filters the brine to remove any biological contaminants, then concentrates it using selective membranes or ion absorption to remove only lithium compounds from the water. The aqueous residue will be reinjected into the well, and the purified lithium-containing solution further processed using fairly simple inorganic salt chemistry. A more recent discovery is lithium-ion imprinted membranes – an attempt to mimic biological processes in which ions selectively pass through cell membranes, which is still

Magnetic brine could be a new source of lithium, which will increasingly be needed for batteries in electric vehicles
© Shutterstock

being studied for its potential to be scaled up for industrial application. In the UK, Imperial College London's chemical engineering department has a highly active research group looking into selective membrane development.

THE FUTURE FOR BRINE

Professor Blundy has been involved in exploratory brine operations, working on drill core samples from Japan, Italy, the Caribbean, and Indonesia. He is part of a consortium of academics from the University of Oxford and its Oxford Martin School working on a project to establish a geothermal power plant on Montserrat, a collaboration with the UK Foreign and Commonwealth Development Office and Department for Energy Security and Net Zero. The team proposes to drill an exploratory well at the island's active volcano, aiming to reach only the hot rocks above the magma chamber and not the chamber itself. This is the culmination of five years' work in de-risking the processes needed to extract magmatic brine and will help to quantify the small risk of inducing volcanic activity. Samples already obtained from Montserrat contain small amounts of copper, zinc and lead.

Meanwhile, Goldberg is currently investigating mineral extraction from magmatic brines at geothermal sites in Chile. He believes that continuous production of lithium from magmatic brines will begin before the end of the current decade. The Upper Rhine Graben, also known as the Rhine Rift Valley between Frankfurt and Basel, also has four locations that are promising for lithium and is the target of international projects funded by the German government and the EU.

There is likely to be little magmatic brine in the UK – there are long-extinct volcanoes in Scotland, and may be some brine deposits below the igneous rocks of the bed of the North Sea and near the Hebrides. However, there is, of course, the work in Cornwall looking at extracting lithium from geological brines. Also, several British Overseas Territories, such as Montserrat and Ascension Island host much younger, dormant volcanic systems that hold promise. Regardless of the exact location, UK-based engineers and innovation can play a key role in the technologies used to obtain the metals crucial to a net zero future.

BIOGRAPHIES

Professor Jon Blundy FRS is an igneous petrologist interested in all things magmatic, from magma generation in the crust and mantle to active volcanoes and hydrothermal mineralisation. He has worked on volcanoes around the world including the Eastern Caribbean, Altiplano, Mexico, Cascades, Kamchatka, Vanuatu, Turkey, and Ethiopia. He is a Royal Society Research Professor at the University of Oxford with a project entitled 'From Volcanoes to Green Mining – Rethinking Igneous Geochemical Cycles'.

Professor Stephen Sparks FRS is Emeritus Professor of Geology at the University of Bristol. His main expertise is in volcanology and in risk assessment of geological hazards. He has contributed to understanding how volcanoes work and the processes that form metal-rich ore deposits from volcanic fluids.

Stuart Nathan also spoke to Isabelle Chambefort, Energy Futures Theme Leader with GNS Science, and Valentin Goldberg, a geothermal energy specialist at the Karlsruhe Institute of Technology for this article.

AN ENGINEERED ADVENTURE

Children explore Climbit – a climbing structure made up of oval platforms suspended from steel pipes and cables – at Belfast's W5 centre

Play areas for children nowadays can be interactive, multisensory experiences, designed by engineers, architects and designers to provide physical challenge and help develop key skills. Neil Cumins spoke to Spencer Luckey, the creator of Climbit – an interactive obstacle course spanning four storeys at the heart of Belfast's W5 science centre.

Did you know?

- Playgrounds were created as long ago as the 19th century, when psychologists introduced them to help children learn about fair play and manners
- The first purpose-built, public access playground was opened in Manchester in 1859
- Play areas and playgrounds help children to problem-solve, think independently and develop their fine motor skills

Children's play areas today have come a long way from a set of swings, roundabout, slide, and a seesaw. Play specialists, designers and engineers are almost turning play areas into works of art, making sure that their creations not only provide physical challenge and help children develop their motor skills, but also inspire their imagination and take them on an adventure.

US-based Luckey Climbers, which creates climbing structures that aim to encourage children's development through problem-solving, spatial thinking, balance, social interaction, and cooperation, transformed the atrium of Belfast's W5 science centre. When the centre opened, its four-storey atrium lay empty and didn't reflect the inquisitive nature of the centre's name (an abbreviation of 'Who, What, Where, When, Why?'), or mirror the numerous interactive child-centric exhibits surrounding the space. W5's developer, Dr Sally Montgomery OBE, approached the company to design and build a structure to fill the atrium, and provide an activity hub for children.

The result, Climbit, is a zig-zagging steel structure holding 99 climbable platforms suspended in wire mesh that creates a three-dimensional maze. The structure, inspired by the myth of the Celtic dragon, was designed to sync with the building's interior, stretching between columns and beams in the walls and floor. Up to 70 children at a time aged between 3 and 16 can enter at the bottom and navigate freely between platforms that are never more than 45 centimetres higher or lower than their immediate neighbours.

"Early on, I decided the best outcome at W5 would be to make no modifications to the building whatsoever," explains Luckey Climber's owner Spencer Luckey. "Part of the mandate of the project was that it had to have a certain number of exits, so the finished layout had an inevitability to it."

The concept evolved from the design needing an exit on each floor. "It was born out of a desire to not have a complicated interface with the building," says Spencer. "There are three safety exits and one entrance proper that everyone uses. There is an exit on the third-floor catwalk, another one in the middle by a balcony that pokes into the space, and a third one on the bridge over the 'head of the dragon'." The exits are largely unnoticed by Climbit's young explorers, who are concentrating on problem-solving their way along the various paths open to them – boosting their motor skills, physical agility and powers of concentration in the process.

FLOATING PLATFORMS

Climbit's free-floating appearance disguises decades of engineering knowledge, starting with the construction of the individual platforms.

BRINGING THE CLIMBER TO LIFE

A view from above shows how Climbit fills the atrium and how the lighting design complements its appearance

Spencer and the team of designers carefully considered the lighting surrounding Climbit, ensuring that it enhanced its appearance as an interactive art installation. The sculpture is uplit and purple and white light pick out the reflective underside of each platform, causing them to shimmer. The uplighting was also designed to pick up children's shadows as they explore inside and cast shadows onto the walls of the atrium to create a range of changing shapes.

As the W5 centre is located in Belfast's historic dockyard and just across the river from the Titanic Museum, the lighting design also uses several water-themed elements. Projectors shine 'ripples of water' across the atrium, create an underwater illusion when paired with the shadows from the climbing children.

As well as being supported by wire mesh (which is yet to be added in this image while the structure was under construction),Climbit's platforms are held in place with wire rope

They have been vacuum pressed to bond four sheets of 10-millimetre plywood together, then trimmed to produce smooth rounded edges; there are no sharp surfaces anywhere inside the installation. Platforms are coated in an extra skin of poplar veneer to enhance their rigidity, sprayed with iridescent car paint to reflect the installation's dynamic integrated lighting (see 'Bringing the climber to life'), and topped with a grippy layer of eco-surface rubber flooring.

The structure consists of a robust tubular steel frame and plastic-encapsulated steel cable mesh, which criss-cross the atrium and combine to suspend and enclose the platforms. The steel wires are 4.7 millimetres in diameter and are anchored to the top and bottom of every platform. The intricate net prevents the platforms from moving – even under their maximum live load of 1.26 kilograms per square metre. Alongside these uncoated steel structural cables are lengths of vinyl-coated wire rope, which has been fed through drilled holes dotted 10 centimetres apart along each platforms' circumference to create a pattern.

"The vinyl rope was weaved on-site by hand, and it looks like it's one continuous fishnet fabric," says Spencer. He explains that the wire supports a maximum weight of 160 kilograms on each platform: "The breaking strength of one of those vinyl-coated wire ropes is 545 kilograms, and with between 12 and 25 ropes going through every platform, it's incredibly strong. The larger cables have a different kind of fitting and are meant to carry a lot of the load, but it's the friction that builds up on the edge from the vinyl-coated mesh that really makes it so secure, stitching it all up like shrink-wrapping."

Working in tandem, the mesh prevents the platforms from rotating horizontally, while the cabling supports them vertically. "The platforms became much more stable once all the mesh was added," Spencer adds. "It's an integral part of the system that makes the whole thing feel static and safe. It's important that kids go in there and don't feel like they're on something that's moving, because I want to instil confidence in them to progress higher. It's also much stronger – if you have a lot of moving bodies wiggling around, things tend to fall apart!"

The wire rope also serves another purpose: encasing each platform and ensuring it's impossible for children to fall. Even 15 metres in the air, they're cocooned on each level, able to freely move to other platforms but unable to stray beyond the various routes engineered into the design. "The routes that the children take inside has an inherent logic to it, like a staircase," says Spencer. "You share the same space and circulation is dictated by the placement of the platforms. The layout is designed so that children won't fall multiple times, with short distances between the platforms." Children can only climb down one level at a time, while limited headroom means they are on their hands and knees most of the time, further reducing the risk of falling.

MODULAR CONSTRUCTION

Spencer acknowledges that digital design software has made the process of designing a new installation far easier than when the company was founded by his father in 1985. "When my father started this company, he would imagine something and then do drawings before making a model. The model would take up a lot of the process time compared to the designing part. Using computer modelling, you can iterate and iterate, frontloading the process by designing until it's time to manufacture without having to commit to any given geometry. You can constantly tweak a layout, which is a central part of how things are designed these days. It really benefits the built environment because we can build more complicated designs. For example, at W5, we didn't have to mock the entire thing up prior to constructing it on-site, because we knew precisely what the geometry was." Having built a computer-generated model, Spencer's team of installers then travelled to Belfast, along with the numerous individual components, which were shipped over in two containers from Connecticut in the US. Once in Belfast, the components had to be passed in through the window via crane and the atrium was filled with scaffolding to assemble the steel structure. "We prefabricated all the steel in our own studio, and then we used the computer to locate all the tabs that connect the platforms to the steel pipes," says Spencer. "We assembled the design in the computer, which gave us a virtual mock-up and ensures the tabs are located very precisely."

The result is an extremely rigid structure that can last for years without any attention: "Our products have been very well stress tested. Kids have notoriously prying fingers and they're hard on stuff, so we take quality control and overall toughness very seriously. Every decision we make is based in some way on trying to provide the strongest solution."

Climbit is one of over 80 structures built by Spencer's team across the US, Europe and Asia – and the centre's focus on avoiding simplicity means that it remains one of Spencer's favourites: "The best projects we've done are the ones where the client was very demanding. Great clients make great projects."

INSPIRING PLAYGROUNDS

MONSTRUM's Gathering Place playground on the riverside in Tulsa, Oklahoma. The heron's 'wings' are slides that are almost four metres high © MONSTRUM

Playground designers and engineers are taking inspiration from art when creating play spaces, and sometimes art itself becomes the playground. The Tate Modern's Turbine Hall often plays host to interactive, child-friendly exhibitions, including Rasheed Araeen's *Zero to Infinity* in summer 2023. Visitors of all ages were encouraged to use the exhibition's 400 brightly coloured cubes to stack, tilt, balance, and rearrange to create an infinite number of different structures. In another example of art as the play area, artist Toshiko MacAdam began creating crocheted playgrounds after seeing children climbing in a three-dimensional textured sculpture that she was exhibiting. Her texture playgrounds use thousands of tonnes of nylon, which is knotted almost entirely by hand, and allow children to explore and take risks in a safe environment.

Danish company MONSTRUM's playgrounds aim to become landmarks in their local areas – from giant otters on the Memphis riverside and seven-metre-tall herons in Tulsa that double as slides, to a 10-towered fairytale castle connected by gangways and bridges in north east England. Made up of craftspeople, designers and architects, the company focuses on using sustainably sourced wood and stainless steel in its designs.

Another company focusing on sustainability is London-based Adventure Playground Engineers, which works with local communities to develop play spaces that encompass natural features into their design, either building around or incorporate existing trees into play structures. It also recycles and reuses lots of different materials such as old boats, reclaimed timber and reconditioned slides. Its structures at Tumbling Bay Playground in the Queen Elizabeth Olympic Park features nests built from branches that have been weaved around oak trees.

BIOGRAPHY

Spencer Luckey is a US artist and kid architect whose firm, Luckey LLC, designs and builds climbing sculptures for institutional and commercial clients all over the world. A graduate of the Yale School of Architecture, Spencer seeks to design things that make people feel good about themselves and to foster social connections through shared experience.

ON THE FAST TRACK TO GREEN HYDROGEN

© Ceres Power

Dr Caroline Hargrove CBE FREng believes that chance has played a part in her career. It has taken her from pioneering research in computer modelling of particle interactions into racing car simulators and onto medical technology and the production of green hydrogen.

A plan to study language helped to steer Dr Caroline Hargrove CBE FREng into an engineering career: "I grew up speaking French and wanted to learn English." Studying maths and physics at school in francophone Montreal in Canada, she applied for a bursary for a summer school to study English. She recalls: "It was a lottery, a name picked out of a bag, and I got one." When she arrived for the course at Queen's University, Hargrove was so taken by the scenic campus on Lake Ontario that she decided that it would be a good place to be an undergraduate.

Hargrove had no clear career ambitions. "I didn't know anything about engineering. There were no engineers in my family and schools were terrible at telling you what engineering is going to be like." When she scanned the university's list of courses, her eyes alighted on a degree in maths and engineering. "I thought, 'That's keeping options open'," she says.

After completing her degree, Hargrove wanted to spend time in Europe. "As Canadians you get the opportunity to apply for Commonwealth graduate scholarships to study in the UK, and I got one."

This took her to the University of Cambridge and an applied mechanics PhD in computer modelling of granular materials. Simply solving equations isn't enough to understand these complex, multibody systems – think of solid particles able to flow, such as sand: "You've got to start doing all of these approximations and localised ways of modelling." Hargrove worked on ways of looking at whole systems through the assumptions about what happens at small scale.

That PhD led to a research fellowship and then a lectureship at Cambridge. "I enjoyed it very much," she insists. But after four years, she decided that she just had to work in industry. "It's the problem-solving more than the research that drives me."

Hargrove's move into industry involved one of the coincidences that she credits with guiding her career. She responded to a magazine advert from the McLaren Formula 1 racing team seeking someone to work on modelling. Her CV landed on the desk of an engineer at McLaren she had worked with during her PhD. As Hargrove recounts it, his response was "Oh, I know, she can do this". "So, I got the job."

At McLaren, Hargrove applied the computer modelling that had fuelled her PhD. With the Formula 1 team, her work progressed from trying out design ideas to developing simulators of racing cars in action [see 'Race track models'].

BEYOND F1

After 10 years in racing, Hargrove was one of three engineers asked to set up McLaren Applied Technologies, a technology consultancy to capitalise on work done

RACE TRACK MODELS

McLaren's racing car simulators turned out to be a revelation. "We realised there were loads of really fascinating insight that the drivers were picking out when they were driving the simulator and it was really valuable feedback for developing the car" © McLaren Applied Technologies

Caroline Hargrove admits to being a sports nut and an aspiring gymnast in her youth, but she had no ambition to work in motor racing. Her expertise in computer modelling proved to be eminently transferable when she moved from the University of Cambridge to McLaren. There she continued work on modelling started by a colleague she had worked with during her PhD.

At first, expectations were low. The idea was to model ideas before trying them in cars. "Twenty-odd years ago, it was really slow to run models. So we wrote everything from first principles," she explains. "We derived the full set of differential equations on paper." They then encoded them to run more quickly. "We realised that it was so fast that with a bit more optimisation we could do it in real time." They then started the simulator programme.

Drivers and old-school engineers were doubtful. "It's not going to work for Formula 1," was the sentiment. Hargrove reckons that this scepticism took the pressure off them. No one was screaming that it had to work for the next race. Working on the model, she adds, "was more fun than actually working on the car itself. Because no one had built one of those before."

Eventually they got to the stage where they would never put anything on a car unless it had already been modelled. "It got driver approval earlier than I thought. Because it was definitely not a favourite of the drivers at the beginning."

Hargrove admits that at the start the simulators weren't very good. "The drivers kept saying that their video games were better. But over time, the underlying technologies like the graphics cards got better and so did our simulators."

The simulators turned out to be a revelation. "We realised there were loads of really fascinating insight that the drivers were picking out when they were driving the simulator and it was really valuable feedback for developing the car."

She has said that F1 engineering feels very privileged "because it's like working on big toys". Nothing stands still, in more ways than one. From the beginning of a season to the end of the season, the cars are about 80% different.

Caroline with her father at the Montreal Grand Prix in 1998 © Caroline Hargrove

for McLaren's racing team. In the new business, sports remained in the picture. The launch of the new business was before the 2012 London Olympics. Various sports teams turned to McLaren for help. "I got a lot of stick at the start because I really wanted to work with UK Sport but it wasn't commercially attractive." After a bit of an internal tussle, they were given the go ahead "with the proviso that we weren't going to talk about it, unless it ultimately led to success for Team GB". She ended up working mostly with the cycling team. "They were already a lot like a Formula 1 team. They were very data driven. They knew what they wanted, and it was straightforward for us to support them."

Hargrove's work with McLaren Applied Technologies turned towards applying Formula 1 principles to health and medicine. This meant using sensors and data processing, and inferring as much as possible when you can't directly measure. For example, one medtech project involved working with drug companies to monitor patients on clinical trials. McLaren's engineers monitored biomarkers with few ethical issues, such as heart rate and activity level. "If you're on a drug trial and your activity level goes down dramatically, that's never good. So, it's a proxy for overall health benefits."

The technology group's commercial work also included optimising design and manufacturing. "That's mostly how we brought in revenue. Finding long-term solutions that other people would then fully implement." An odd spinoff

QUICK Q&A

What inspired you to become an engineer?
My love of problem-solving.

Favourite project you worked on?
I have to say Ceres, because we have the potential to be one of the cornerstone clean energy technologies in the world.

What are you are most proud of?
I am most proud of the simulator we built at McLaren because it was a first and truly groundbreaking at that time.

Who influenced your engineering career?
My PhD supervisor, Professor David Newland.

What's your advice to budding engineers?
Keep questioning the status quo.

Best part of the job now?
Working with a great team on a common mission.

Which record/book would you take to a desert island?
I can't answer that, I love reading and could never settle for just one book!

Caroline welcoming Sir Keir Starmer to Ceres Power's Manufacturing Innovation Centre in Redhill © Ceres Power

from racing cars, you would have thought. "100%. I could not believe how useful we were, doing this. When you think, surely they know this inside out already, way more than we do."

PIVOTING TO CLEANTECH

After 20 years with McLaren, and rising to be CTO of McLaren Applied Technologies, Hargrove was becoming less happy about how things were going in the business, which had grown to more than about 600 engineers. Rather than staying on and complaining, or making a bid to run the business, she looked for new opportunities. Running the business wasn't for Hargrove. "I like the technical side. And that's what gets me up in the morning."

A fresh opportunity came in a chance encounter at a dinner with the COO of Babylon, a medtech scale-up company. "They wanted to use more AI and simulation to essentially keep people out of hospital, but also [be] your GP in your pocket." This was pre-COVID-19. While the pandemic threw the light on the need for such technology, it also meant that people were so focused on the virus that it became difficult to do anything else. Throw in the CEO's decision to move Babylon to the US, a much bigger playground for developing AI in medicine, and Hargrove faced new decisions. Not sure that the technology was market ready, she was looking for interesting engineering challenges.

Hargrove had already decided that she would like a deeper understanding of how businesses work. "Doing consultancy-type gigs, you're exposed to quite a lot, but it wasn't the same as understanding how a public company was run." As she puts it, if you want to help technology startups that plan to go public, you need to understand the constraints on listed companies. Someone suggested that she could do this as a non-executive director of a publicly quoted company, where her technical expertise would be valuable. Again, a chance conversation led her to Ceres, a business that developed electrochemistry in the pursuit of net zero through fuel cells and creating green hydrogen.

For Hargrove, the company had two attractions, it was a listed business that she could observe in action, and it was in cleantech. Ceres had been through some ups and downs since spinning out of Imperial College London in 2001, and Hargrove still saw it as a startup, albeit in its teenage years. As it happened, after COVID-19, the Chief Technology Officer wanted to take stock and do something different. As a board member, Hargrove was naturally involved in finding a replacement when the idea came up that she could take on the CTO role.

"Great question," she laughs when asked to define what the CTO does at Ceres. She is there, she explains, "to steer people with common goals. Half of my job is to make sure that we have enough ideas being developed in the R&D space to improve our technology, at the fundamental level. Because what we do at Ceres is quite fundamental level electrochemistry. The other half is to ensure that it works. It has to be economically viable. It has to last – to be robust and have enough life – and be manufacturable at scale."

FUNDAMENTAL SCIENCE

Ceres operates on a blend of fundamental science and usable technology. "These two sides need to work together, because we're a technology licensing company. Unless you keep innovating at the lowest TRL [technology readiness level], we won't be in business for very long."

Hargrove has been CTO at Ceres during a change in direction. Until recently it focused on developing fuel cells built around its proprietary technology. The idea was that fuel cells would play a critical part in decarbonising power. Although Ceres' technology is fuel flexible and can run on natural gas as well as hydrogen, there is ultimately a greater need for a reliable source of green hydrogen.

As Hargrove explains it, without a thriving "hydrogen economy" there won't be as much demand for fuel cells. Currently, the most widely used approaches for creating hydrogen start with fossil fuels, generating carbon emissions that must be captured to keep out of the atmosphere. So, the company decided to focus on creating a greener hydrogen economy.

Ceres confirmed that its fuel-cell electrochemistry could work in reverse, in electrolysis mode. The business is now increasingly focused on engineering electrolysers that can produce green hydrogen, using electricity from renewable sources to split steam into hydrogen and oxygen. This is a way to generate hydrogen, without the carbon load of other approaches. The company's achievements in the area earned it the prestigious MacRobert Award in 2023 ('The clean energy pioneers', *Ingenia* 96).

As Hargrove sees it, there isn't a simple answer to achieving net zero. "We're not trying to say hydrogen is a solution for everything. We're saying, in industrial processes where you need hydrogen to decarbonise them, let's do this with green hydrogen, because we start on this today."

Hargrove is critical of the UK's lukewarm support for technologies like theirs that exist to build knowledge rather than factories that employ thousands of people. "We're not a favourite for receiving grant funding. When you're a licensing company, you don't build big factories that provide jobs. It annoys me because we do provide new jobs that are actually really high-value jobs. I get a bit cross," she says, with an emphasis on when politicians think they should only support industries that manufacture in the UK. "Yeah, but the R&D done by industries in the UK is also excellent." And it depends on the work of a lot of bright scientists and engineers." Those are desirable jobs being created.

Why don't government initiatives like IP generators? "It's frustrating because, as a license model, we have a poster child [in the UK]. We have ARM. It's an inspiration for other startups."

Hargrove also challenges politicians not to dither on net zero, pointing out that if you truly want to eliminate CO_2, you shouldn't hand out permits for oil exploration, and instead set targets to get carbon out of the picture. "We should do things like give ourselves a target of no more grey or brown hydrogen." She suggests setting 2040 as a target, for example, so that companies will take note and investment will follow, instead of saying how it should happen. "It shouldn't be 'we want more electrolysis'. It should be 'we don't want any more hydrogen molecules made from fossil fuels'."

Hargrove recently went back to Queen's University to collect an honorary degree from her alma mater. "I never thought this would happen. I was so touched and humbled," Hargrove said of the honour. Talking to the next generation of engineers, she said: "What I am hoping is the technology we are developing will decarbonise the hard-to-decarbonise industries such as steel and cement. That's a tough sector where you can really have an impact. If we can decarbonise those industries significantly, that is going to be amazing."

CAREER TIMELINE AND DISTINCTIONS

Achieved a first class honours degree in an applied maths and mechanical engineering, **1989.** PhD at the University of Cambridge in mechanical engineering, **1993**. Fellow, Director of Studies and lecturer in engineering, Sidney Sussex College, Cambridge, **1994–1997**. Vehicle dynamics and simulation engineer, McLaren Racing (F1 team), **1997–2007**. Programme Director, McLaren Applied Technologies, **2007–2012**. Technical Director and subsequently CTO, McLaren Applied Technologies, **2013–2018**. Visiting Professor, Nuffield Department of Surgery, University of Oxford, **2015–2018**. Fellow, Royal Academy of Engineering, **2017**. Joined Ceres Power as Non-Executive Director, **2018**. CTO, Vice President AI technologies, Babylon Health, **2018–2021**. Appointed a Commander of the Order of the British Empire, **2020**. Chief Technology Officer, Ceres Power, **2021–present**.

THE COMMUNITY IOT NETWORK PREVENTING BREAK-INS IN UGANDA

After thieves broke into his home and stole $1,500 worth of valuables, Ugandan engineer Anatoli Kirigwajjo wanted to prevent it happening to others. He's developed an Internet of Things-based security system that alerts neighbours so they can rapidly respond to break-ins in their community.

Trust in the Ugandan police has eroded in recent years, says Anatoli, Founder of security device startup YUNGA. In fact, a 2016 report ranked Uganda's police force in the bottom four out of 127 countries. This measured their responsiveness to "internal security challenges"; in other words, how well they are protecting public safety and maintaining law and order.

Anatoli describes the police as underpaid, understaffed and under-resourced. He cites a Hague Institute of Innovation and Law report, in which 80% of Ugandans surveyed don't follow up when taking cases to local police stations. Many don't report at all.

Anatoli points out that more affluent people can hire private security, at about $135 per month. But most Ugandans can't afford to do this. Traditional electronic security alarm systems are even more expensive upfront, ranging from $500 to $1,000 each. Furthermore, the communities that Anatoli has worked with see them as overpriced and ineffective, as the sound of an alarm alone doesn't seem to deter burglars.

Anatoli soldering a YUNGA device in the team's workshop © Tiffany Gravel

For Anatoli, it's also personal. In a series of break-ins, the software engineer lost $1,500 worth of property. So, he decided to start his company, YUNGA, to develop an app that he envisaged would link households to the local police station to call them out for emergencies. But it evolved into something slightly different.

THE 10-HOUSEHOLD MODEL

YUNGA was inspired by a traditional African practice of drumming to call for help within the local community in

EYES ON THE INNOVATORS

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

University of Leeds spinout **Adsilico** has raised £3.5 million to develop its digital twins of the human body, used for testing medical devices

NHS Blood and Transplant is showing staff how to match blood types for transfusion using a virtual reality training app

The device also protects commercial premises such as shops © Tiffany Gravel

emergencies. This practice originated in Tanzania before spreading to communities in Uganda, Kenya and Nigeria. Anatoli describes it as the 10-household model, due to the typical size of communities that use it. "If I drum once, they know I have a sick person. If I drum twice, then I have an attack," he says.

Just like the 10-household model, communities using YUNGA devices find strength in numbers. They're installed in a minimum of 10 houses in a community – usually about 15 homes. Each device costs \$135 – but as a one-off payment, this is much cheaper than alternative options.

The security system is based around a wall-mounted device. For residents, there are three options in the event of a break-in. First, the resident can tap a red button on the screen to trigger an alarm and call for help. Second, there's also an intelligent motion sensor that can activate it, for example, if it's late at night and the resident is in bed asleep. Finally, if the resident isn't physically close to the alarm, they can trigger the emergency response through a smartphone app.

Calling for help in each of these three ways pushes a signal to other community members with networked devices, as well as the local police. In practice, this means when one alarm goes off, all device screens show who's in danger. It capitalises on the bonds between community members, effectively deterring burglars with the promise of a community response to crime.

CONNECTING RURAL AREAS

YUNGA's devices used to communicate with each other using SIM cards and mobile data. But in 2021, the team was forced to switch tack, as a week-long, country-wide telecoms outage meant the devices they had installed for customers had no service.

To prevent this happening again, they instead connected the devices to a long-range network able to operate over much greater distances than Wi-Fi. Called a low-power, wide area network (LoRaWAN), it enabled YUNGA's devices to communicate locally over radio waves, using antennas. The fact that no internet is required means YUNGA's security devices work, even in rural areas.

Another challenge the company has overcome was initially caused by an unlikely suspect: residents' children. Anatoli explains how sometimes young children playing with a parent's phone could trigger a false alarm by accident. This was a much easier fix for YUNGA. The team added software logic to the alarm button, so that it had to be pressed for two seconds to activate the distress call.

INTERNATIONAL APPEAL

So far, 1,700 households have installed the YUNGA device. It has prevented 216 break-ins. "What we are hearing is that there's a very great sense of security when they know that they have really armed the YUNGA system within their community," says Anatoli.

New businesses like YUNGA often rely on customers to spread the word about their products. But for residents who have installed YUNGA's device, there's an added benefit in recommending it to their neighbours. It means they can grow their local YUNGA community and improve their own security.

Beyond the happy customers, the Ugandan police are watching YUNGA's success closely too. Anatoli says local forces are trying to understand how they can support communities using the network. It also has international appeal: YUNGA has been approached by the Kenyan and Ghanaian government, as well as people in Nigeria and Botswana. The company was also a joint winner of the 2024 Africa Prize for Engineering Innovation, along with South African medtech startup FlexiGyn.

With this in mind, the team plans on having 30,000 devices installed by the end of 2024. And that's not all they hope to achieve. Aware that some people may still be priced out, they're looking to develop a "super affordable device" – under \$15 – that simply plugs in, with three buttons.

"Our goal is to make sure our customers are safe and that the police can get to them," says Anatoli. "As long as our customers remain safe for us, we are very happy that way."

The University of Cambridge's two new supercomputers, **Dawn and Isambard**, have begun their first mission: designing and simulating fusion power plants

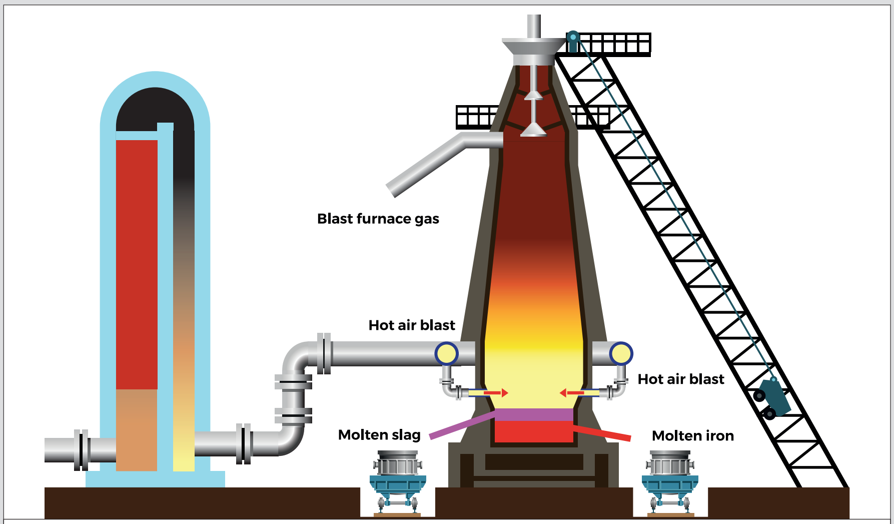
US startup **Figure** has raised \$675 million to develop its AI-powered humanoid robotics

Text to music: **Adobe Research**'s new generative AI tool will help people with no professional audio experience create music

HOW DOES THAT WORK?

STEELMAKING

Humans have been making iron alloys for thousands of years, but only in the mid-19th century could we start making it on an industrial scale. Today, about 1.9 billion metric tonnes of steel are made every year, with China, India and Japan leading the world's production. Leonie Mercedes examines how we get from iron ore to the steel that makes up our world.



Simplified schematic of a blast furnace. A hot stove (left hand side) is feeding a hot air blast into a blast furnace (right hand side), which produces molten slag on the left and molten iron on the right © Shutterstock

Traditionally, steel is made in a blast furnace, but electric arc furnaces are increasingly used as they create less carbon emissions. Steel is an alloy of mostly iron and carbon. Pure iron is soft and weak: the carbon is essential for its strength. However, a carbon content higher than about 2% makes it brittle. So, steelmakers mix up the proportions according to the client's needs. Adding other elements such as manganese, chromium and nickel can improve its properties, making it harder or more corrosion resistant.

There are two main steps to blast furnace steel production. The first is extracting iron from iron ore mined from the earth. A mixture of iron ore, coke (a type of coal that has been baked to drive off impurities such as tar), and limestone are fed into the top of the blast furnace in a specific order. This is called 'charging' the furnace. At the same time, a stream of air heated to about 1,200°C by a device called a hot stove (the 'blast') is supplied to the bottom of the furnace.

As the column of coke, iron ore and limestone descends towards the blast, the coke ignites. The burning fuel in the furnace raises the temperature to about 2,200°C and produces carbon monoxide. Oxygen from the iron ore reacts with the gas to produce carbon dioxide, leaving molten iron, which flows out of the bottom of the blast furnace. Impurities from the ore react with the limestone and coke ash to form slag, which floats on top and can be removed. Because of an excess of carbon, some of the CO_2 is reduced back to carbon monoxide and emitted from the top of the furnace.

The coke also plays a structural role within the column of materials added to the furnace: ensuring the blast passes evenly through the iron ore. To reduce costs and lessen the coke needed, pulverised coal is often injected into the blast furnace with the hot blast. At this stage, the carbon content of the molten iron is at about 4%, so must be decreased.

Next, the hot metal is treated to remove impurities such as sulphur. It is then added to a vessel containing some scrap steel (known as a basic oxygen furnace) – whose role is to lower the temperature, while boosting the iron content. Then, a water-cooled pipe lowered into the vessel blows oxygen onto the liquid metal at about twice the speed of sound. This oxidises the carbon in the hot metal, forming carbon monoxide and CO_2. After 20 minutes or so, steelworkers check whether the liquid steel has reached the desired chemical composition. It may then be refined further, for example, by adding alloying agents.

Liquid steel is then cast into slabs and can be cut and rolled to form different shapes depending on its ultimate use. Large panels may be used for cars, thin sheets to form tin cans, or bars and beams for construction.

In the overall process, the blast furnace accounts for over 70% of CO_2 emissions due to the chemical reduction process and the fuel required to heat the furnace. The basic oxygen furnace is less energy intensive. Typically, it does not consume extra energy, as oxidising the carbon in the molten iron creates heat.

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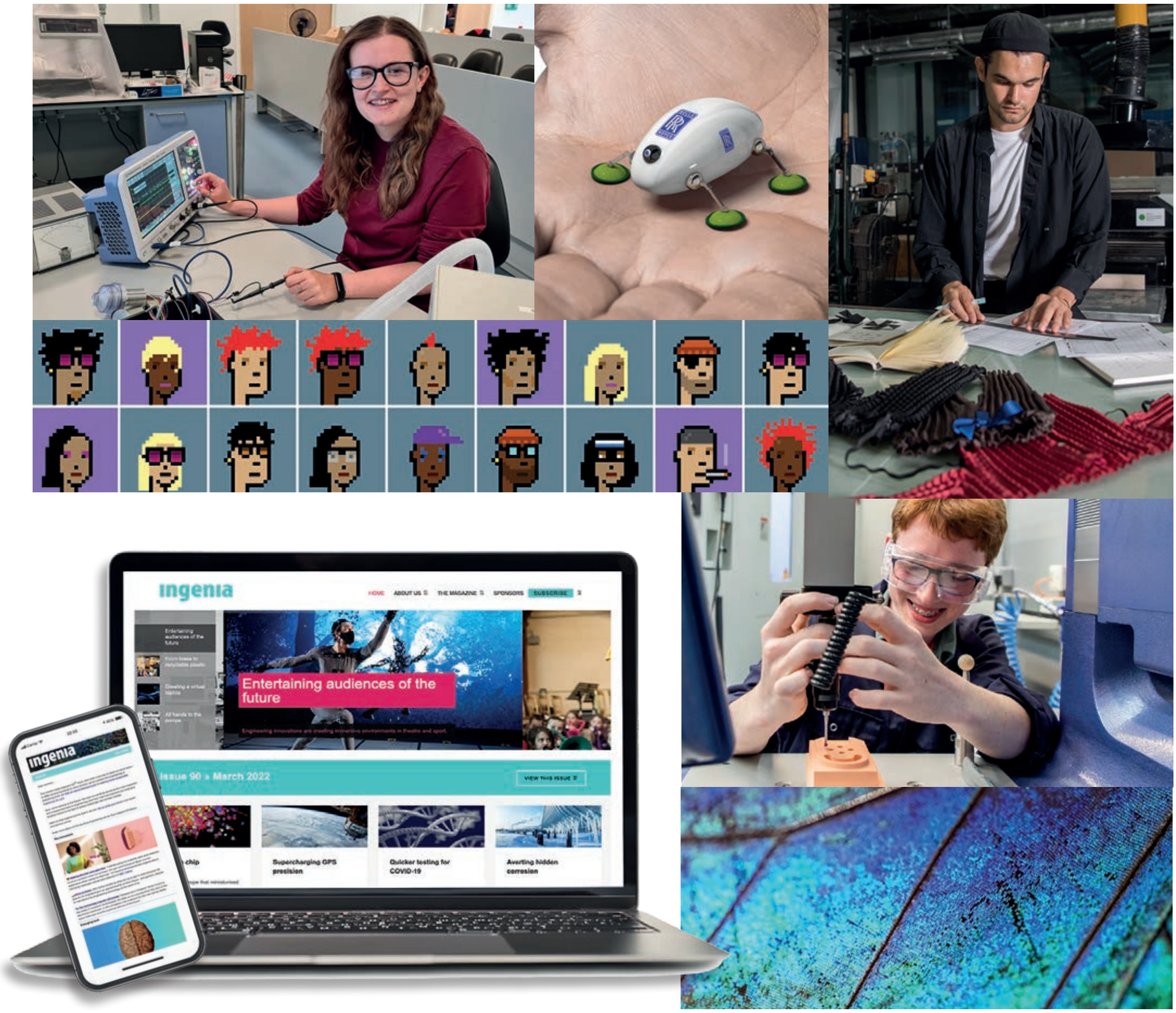

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