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pacer
A Solid State Group Company

Expansion of High Tech Facility solves Optoelectronics Manufacturing Headaches for UK OEMs

Finding expert resources for niche optoelectronic design and assembly is challenging, as there are very few companies in the UK with the right skills and experience to tackle such demanding requirements. UK-based Pacer International is well positioned to offer OEMs a cost-effective outsourcing option for projects involving photonics, optics, sensing or displays.

Further expansion of their state-of-the-art design and production engineering facility in Dorset now enables Pacer to offer even better engineering services. With a proven track record in providing the quality and reliability needed for military, medical and scientific applications, Pacer's team can address the design and pre-production of modules, assemblies or complete systems.

Pacer's team benefits from over 40 years of die attach and wire bond experience, and the new addition of this technology at the company's Weymouth site greatly enhances their manufacturing capability. The skills and experience of Pacer staff add real value to projects – working closely with customers, Pacer's engineers frequently advise on product and manufacturing enhancements which result in better yields, higher performance, increased reliability – and in many cases, reduced project costs.

Extensive expertise in production engineering and Design For Manufacture (DFM) enables the smooth transfer of products from research and development prototypes into real life production. The multi-disciplinary team in Weymouth offers electronic, optical and mechanical design capability, and can address a wide variety of projects – from assembly and test of a simple optical switch, the alignment of boresight optics over long distances, touchscreen calibration or display alignment, through to full design and production of complex analysers and illuminators.

The recent expansion of Pacer's ISO14644-1 class 7 cleanroom enables the manufacture of complex optoelectronic assemblies involving extremely precise alignment of optical components and lenses to very tight tolerances. Pacer has developed a world-wide network of strategic manufacturing partners, offering high quality, competitive manufacturing solutions with ISO 9001-2000, QS9000, ISO/TS16949 and ISO 13485 approval.

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- Custom display and touchscreen assemblies
- Technical and commercial project management

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this**issue**

Volume 299
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news

opinion

features

our**opinion**

Engineering the climate

From satellite-mounted solar shields to cloud-seeding ocean vessels, there has been no shortage of radical proposals for engineering our way out of climate change.

While scientists have tended to regard such methods with suspicion and as a dangerous distraction from the important business of ending our reliance on fossil fuels, the notion of using technology to actively reverse some of the effects of climate change – and buy humanity the extra time it needs to transition to a zero-carbon world – is gathering serious momentum.

Among those calling for such action are experts at the Intergovernmental Panel on Climate Change (who last year called for the development of technologies able to actively remove CO_2 from the atmosphere) and academics at the University of Cambridge, who last month revealed plans to set up the Centre for Climate Repair, the first research facility of its kind dedicated to climate engineering.

> "This survey paints a more positive salary picture than we expected"

In this issue's cover story (pages 20-23), we look at the developments in this fascinating field and examine some of the technologies which, if deployed at scale, might just help return atmospheric CO_2 to levels not seen since the 19th century.

Elsewhere in this issue, we publish the findings of *The Engineer*'s annual salary survey. As you might expect, we sat down to analyse this year's findings with some trepidation, thanks in part to industry's ever-growing Brexit anxiety. But while this year's survey points to a significant increase in anxiety levels, it paints a rather more positive salary picture than we expected – with average pay among our respondents rising to £51,253, a 6.5 per cent increase on last year's findings. Indeed, 66 per cent of our sample said that they had received a pay rise in the past 12 months, another sign of improvement after the salary stagnation flagged by last year's survey.

An even more detailed breakdown of this year's findings can be found on our website (theengineer.co.uk) where you can also access a benchmarking tool to see how your salary stacks up against that of your peers.

As a final note, we are very excited to announce that after almost two decades with its previous publisher, *The Engineer* now has a new home at the Mark Allen Group. It is a truly exciting development for the publication, and we are looking forward to working with our new owners on the next stage of the publication's long and distinguished history. As always, we welcome all of your views on how we can continue to improve and enhance our coverage.

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ENERGY

Robots to carry out wind farm repair and inspection

New wind turbine blade project could save an average farm £26m in its life

HELEN KNIGHT REPORTS

Wind turbine repairs could soon become easier and cheaper

Human offshore wind farm inspection and repair crews could soon be replaced with the world's first fully robotic team, thanks to a UK project.

The £4m Innovate UK-funded project, known as MIMRee (Multi-Platform Inspection, Maintenance and Repair in Extreme Environments), will develop and test an autonomous crew, consisting of an unmanned vessel, drone and crawling robot.

The technology is expected to save an average wind farm £26m over its lifetime.

Inspection and repair of offshore wind turbine blades is carried out by human technicians working on ropes in extreme conditions. Such inspections can only take place during restricted windows when the weather is good, according to Tony Fong, engineering manager for operational performance at the Offshore Renewable Energy (ORE) Catapult, which is providing its engineering expertise and testing facilities to the project.

"Specialist rope access teams have to descend down each of the blades in order to inspect and maintain them," said Fong.

"The turbines also have to be shut down during this maintenance, which costs the industry money because the turbines aren't generating during this time."

The daily use of crew transfer vessels is also expensive, he said.

The two-year project will be led by Cambridge-based non-destructive testing specialist Plant Integrity.

The robotic crew will consist of Thales' Halcyon autonomous vessel, plus a drone system being developed by researchers at the University of Bristol, and the six-legged crawling repair robot BladeBug, invented by entrepreneur Chris Cieslak.

"There will be a level of communication and teamwork between these systems that hasn't been done before," said Fong.

A system for transporting, deploying and retrieving the blade-crawling robot will be developed at the University of Manchester, while an AI system designed to co-ordinate the mission and allow onshore personnel to analyse data transmitted by MIMRee is being developed at Royal Holloway, University of London.

"The vessel will autonomously navigate its way safely to the wind turbines, and will then perform an inspection using a special camera, also developed by Thales," said Fong.

"This camera should be able to inspect the blade while the turbine is still rotating, allowing us to carry out a good level of inspection without losing any electricity generation."

The on-board drone will then take off from the mothership, and carry out its own closer visual inspection if needed, before going back to the vessel to pick up the crawling robot and place it on the turbine blade.

BladeBug's developer evaluated numerous types of robot for use in turbine inspection, but the complex shape of the blades, including their curvature and the addition of objects such as fin-shaped vortex generators, coupled with the need to travel from one side of a blade to the other, meant a legged robot was the best option, Fong said.

"The expectation is that the robot will be able to carry out more advanced inspections, such as high-resolution imaging and non-destructive sensing, including ultrasound," he said.

An electronic skin, developed by Wootzano, will 'feel' the surface to collect data on the blade surface structure.

The robot will also be capable of carrying out basic maintenance tasks, such as cleaning and resurfacing the blades, thanks to a robotic arm developed by the Royal College of Art's Robotics Laboratory.

"If there is minor damage to the paint surface on the blade, the robot has the potential to go up and smooth out the surface, and apply a little bit of protective paint, to keep the turbine going," Fong said. ■

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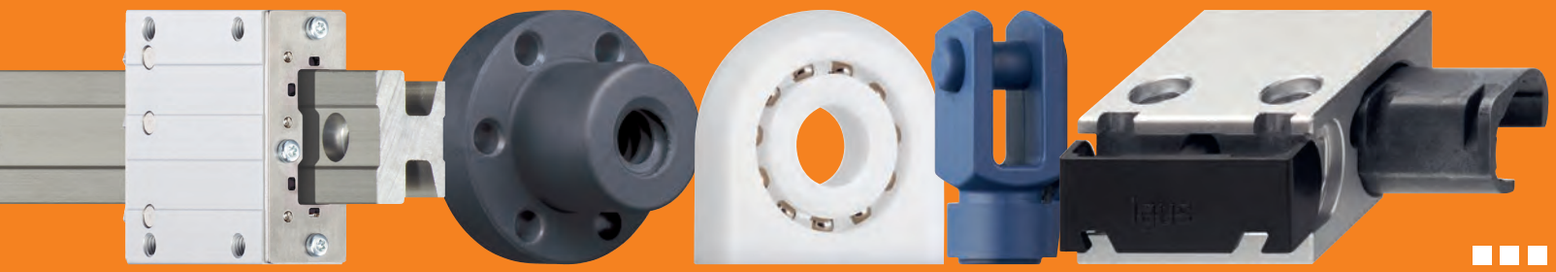

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MATERIALS

Refined brazing to boost engines

Process will improve efficiency

HELEN KNIGHT REPORTS

Stronger and cheaper joining materials that operate at higher temperatures could improve the efficiency of aircraft engines and fusion reactors.

Brazing is used to join even dissimilar and difficult-to-weld materials, and is capable of creating complex, high-strength joints. The process works by heating an alloy – a brazing filler metal (BFM) – between the parts to be joined to form a bond.

However, as the range of applications in which these brazes are used increases, so too do the demands placed upon them, according to Dr Russell Goodall at the University of Sheffield, who is leading an EPSRC-funded project to develop BFMs with improved performance.

Project partners include the UK atomic energy authority, Rolls-Royce, Johnson Matthey and the University of Limerick.

Joining two dissimilar metals with a different alloy can lead to the formation of metallic compounds, which can be brittle and limit the strength of the joint, said Goodall. So the researchers will investigate a new type of alloy, known as a high-entropy alloy, in which similar amounts of many elements are combined, unlike conventional materials that consist of one main solvent and small additions of other elements.

By using these new alloys, they hope to create tougher, higher strength joints without the brittleness.

Some applications, meanwhile, require filler metals that are able to operate at higher or lower temperatures, said Goodall.

"We want engines to be hotter, so we need filler metals that can withstand higher temperatures," he said. "But there are also areas where we need the temperature to be lower, such as for use with functional ceramics that are very highly engineered to have particular electrical behaviours," he said.

One application the researchers will be investigating is aircraft engines, where stronger alloys with improved temperature resistance could be used for more load-bearing and critical components, said Goodall.

"Some of the best-performing high-temperature brazes also currently use precious metals in these applications, so if we can find alternatives that have a higher base metal content, then that will make them cheaper," he said.

The team will also be investigating the use of new filler metals in nuclear fusion reactors.

The inner walls of fusion reactors are covered by water-cooled armour tiles, which consist of thin tungsten blocks with copper alloy water-cooling pipes inside them.

These pipes are brazed using a gold-based alloy, which is expensive and has a low melting temperature, limiting the operating temperature and heat load capacity.

An alloy operating at a higher temperature without damaging the microstructure in the copper pipes would allow heat to be drawn out of the reactor more quickly. ■

ENERGY

Milestone without coal

JON EXCELL REPORTS

For the first time in more than 130 years, the UK has gone for seven consecutive days without using coal to generate electricity.

According to the National Grid Electricity System Operator (ESO), the milestone was reached at 1.24pm on 8 May (the last coal generator came off the system exactly a week earlier on 1 May).

This marks the first time since the launch of the UK's first public coal power station in 1882 (a 92kW, 27-tonne generator which produced DC current at 110V) that coal has been absent from the energy mix for an entire week.

Coal dominated UK electricity production for much of the 20th century. Indeed, until 1990 it was still responsible for 67 per cent of the UK's total, but the so-called dash for gas, and the more recent emergence of renewable generating capacity, has seen coal use fall dramatically.

According to BEIS figures, in 2017, coal accounted for 4.8 per cent of UK primary energy demand.

The latest news, which has been hailed as a major step towards completely phasing out coal by 2025, builds on a number of recent milestones: in May 2016, solar power produced more electricity than coal for the first time, producing 1.33TWh compared to 0.9TWh from coal, while more recently (21 April 2017) had its first coal-free generation day since Victorian times.

ESO director Fintan Slye expects to see many more coal-free periods in the months and years ahead.

"As more and more renewables come on to our energy system, coal-free runs like this are going to be a regular occurrence," he said.

"We believe that by 2025, we will be able to fully operate Great Britain's electricity system with zero carbon." ■

Newsinbrief

Horizontal launch funds

The government has committed £2m to support plans for satellite launches and sub-orbital flights from a spaceplane-oriented spaceport.

The UK Space Agency has opened the fund to enable research into market opportunities offered by horizontal space flight technologies. Organisations can use the research to develop a business case for offering horizontal launch services in the early 2020s.

New battery tech hub

Coventry is to host a new national centre of excellence in battery technologies, aimed at electric car energy storage.

The UK Battery Industrialisation Centre will develop battery chemistry, electrodes, cell design, modules and battery packs, and is aimed to open in 2020. It will create around 100 jobs but hopes to launch 10,000 new jobs in the supply chain and related technologies.

British Steel jobs at risk

About 5,000 jobs and thousands more in the supply chain are at risk after the High Court's decision to wind up British Steel.

The firm, which employs 3,000 staff at its Scunthorpe plant, has been placed into receivership after rescue talks collapsed between the government and Greybull Capital, which bought Tata Steel's long products business in 2016 and rebranded it as British Steel.

Sellafield service boost

Wood has secured a new contract worth up to $1bn (£0.8bn) to provide engineering design services to Sellafield Ltd over the next 20 years. The company has been selected as part of the new Programme and Project Partners procurement model.

Wood will provide the front-end design and engineering capability and services required to deliver major projects.

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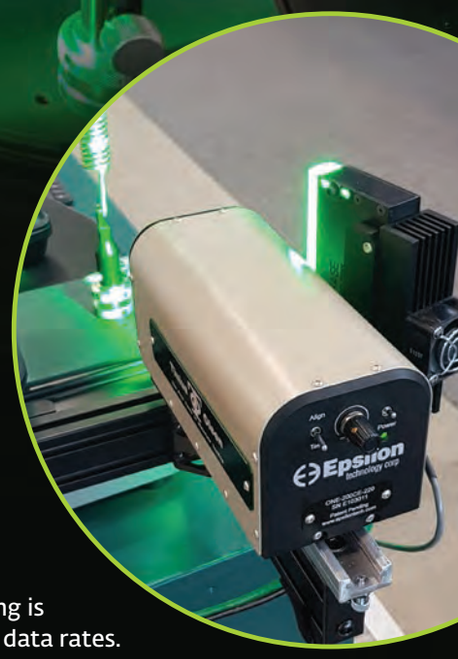

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RAIL

New framework to support light rail

Design will allow services to carry extra passengers and reduce energy HELEN KNIGHT REPORTS

A recyclable and extremely lightweight vehicle frame for very light rail (VLR) has been developed in the UK.

The frame, which is weaved, or braided, from carbon fibre composites into a series of tubes that can be easily fitted together, has been designed by researchers at WMG at the University of Warwick, alongside composite components company Far and Stratford-upon-Avon-based Transport Design International.

The prototype, which can be easily assembled using adhesive and simple welding, will allow VLR services to carry more passengers, while reducing the amount of energy needed to propel the vehicle.

The design will also reduce the weight stress the vehicle places on its rails and road surface.

The demonstrator consists of an underlying tubular space frame chassis.

If any one of the tubes, or beams, used to construct the frame is damaged through accidental impact, it can simply be removed and replaced with a new one.

What's more, the thermoplastic material used to build the beams is recyclable, according to David Goodwin, engineering manager at Far.

"With composites you can save a lot of weight, which is obviously appealing for the operation of the car, but with traditional composites at the end of the car's life, it is simply placed in landfill, which is not ideal," said Goodwin.

"With this [design] there is a route to recycle the car body when it eventually goes out of service, or if alternatively it suffers an impact and part of it has to be repaired and replaced."

Although each beam used to build the demonstrator has the same diameter outside, the wall thickness varies depending on where on the chassis it will be placed, in order to meet the specific performance needs of that particular section of the frame.

As well as keeping tooling costs low, this means that all of the joins can be standardised.

The braiding process used to produce the beams is highly automated, with rates of more than a mile a day of braided tubing.

The process also allows a wide range of materials to be used, including fibres such as carbon, glass and aramid, and thermoplastics such as polypropylene and polyether ether ketone. ■

A new frame has been developed for very light rail

AEROSPACE

RAF simulation to allow air crews to train in same environment

The Ministry of Defence has announced £36m for Gladiator, a new RAF simulation capability that will allow up to three pilots or crews to experience the same virtual environment.

Implemented by Boeing Defence UK, the system will allow US and UK aircrews to train together in scenarios that would be extremely difficult to replicate in real life, creating a virtual transatlantic bridge between the two air forces.

It is expected that pilots will be using the simulation capability by autumn 2021.

"The contract heralds a 21st century capability that will transform the ability of the RAF to undertake collective operations, tactics and procedures training in the synthetic environment that cannot be performed in the live environment," commented Russ Cole, who is the flight simulator and synthetic training portfolio team leader. AW

MARINE

Submarine visits deepest point on planet

Five Deeps Mission milestone JON EXCELL REPORTS

An advanced manned submarine has successfully completed a mission to the deepest point on the planet: Challenger Deep, within the Pacific Ocean's Mariana Trench.

Developed in Florida by Triton, but with much of the engineering work taking place in the UK, the vessel was piloted to a record-breaking depth of 10,928m by US financier and explorer Victor Vescovo.

"We feel like we have just created, validated, and opened a powerful door to discover and visit any place, any time, in the ocean – which is 90 per cent unexplored," he said.

The dive is part of the Five Deeps Mission, an effort to take a manned submersible to the deepest points of the world's five oceans, which has been hailed as an unprecedented opportunity to study the trenches of the 6,000m-11,000m hadal zone.

During the visit to the Mariana Trench, the team reportedly discovered new species. It also detected evidence of the scale of the oceans' plastic pollution problem.

The project has already visited the Puerto Rico Trench in the Southern Ocean (8,376m), the Atlantic's South Sandwich Trench (7,433m) and the deepest part of the Java Trench in the Indian Ocean (7,192m).

The latest dive reached a greater depth than either of the previous manned visits to the trench.

Unlike these earlier efforts, which descended Challenger Deep once, Vescovo's vessel completed four dives to the bottom of Challenger Deep and one final dive on 7 May 2019, to the Sirena Deep which is also in the Mariana Trench, approximately 128 miles to the northeast. ■

START-UP TO SCALE UP

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ELECTRONICS

Electronic skin has the human touch

Wootzkin will give robots greater dexterity to complete tougher tasks HELEN KNIGHT REPORTS

An electronic skin designed to give robots the same sense of touch as that of humans has been developed in the UK.

Known as Wootzkin, the electronic skin is designed to allow robots to complete tasks requiring greater dexterity, such as handling soft fruit.

The skin, which was developed by Edinburgh and Sedgefield-based Wootzano, was presented at the annual showcase of the Royal Academy of Engineering's Enterprise Hub in May.

The Wootzkin, which is made of a specially-modified elastomer with metal electrodes deposited on top using photolithography, can be bent, stretched and twisted without causing any damage to the sensor.

The skin has piezoelectric and piezoresistive sensing capabilities, meaning it can be used to measure force and pressure, and is also embedded with temperature sensors, according to its developer Dr Atif Syed, founder and CEO of Wootzano.

"We're trying to make something that is akin to human skin, so it can give the robot feedback on force, pressure, temperature, and humidity," he said.

"And it can also go beyond human evolution and smell when it is touching a particular object."

Syed began developing the technology in 2013 while undertaking his PhD at the University of Edinburgh, for use in targeted drug delivery. However, he soon realised the skin could be used to solve many of the problems facing roboticists trying to develop robots capable of performing dexterous tasks like grasping objects.

As well as the skin itself, the company has also developed machine-learning algorithms that allow the robot to learn how to handle items through reinforcement.

The electronic skin can be used in agritech, to allow robots to safely pick and pack delicate fruits and vegetables without damaging them.

The company is also investigating the use of the skin in prosthetic limbs, to allow wearers to feel objects and surfaces that their robotic arm is touching.

"And as well as making sensors for hands, we also make them for feet, because they also come into contact with the environment," said Syed. "Sensors for robotic feet will allow robots to walk on difficult surfaces, by allowing the robot to control itself as it is walking."

It is suitable for scaling up to mass production, Syed added. ■

Wootzkin will give robots a similar sense of touch to that of humans

ROBOTICS

Robots to boost productivity in farming and food sector

Engineers at the Manufacturing Technology Centre (MTC) in Coventry are collaborating with a Hampshire robotics firm on the development of robots and AI solutions for the farming and food production sectors.

MTC will work with the Small Robot Company on the development of a new generation of digitally controlled robots that plant seeds, apply fertiliser and herbicides, as well as weed crops with the precision.

The team claims that the farmbots could improve the way food is produced, minimise chemical use, and help increase yield and efficiency.

Prototypes have been produced and are carrying out field trials on 20 farms in the UK, including the Waitrose Leckford Estate Farm and the National Trust's Wimpole Estate. Funding for the project has come from Innovate UK and the MTC, boosted by £1.2m in crowdfunding.

Jeremy Hadall, chief engineer for intelligent automation at the MTC, said the technology had the potential to make significant improvements in farm productivity and profitability. **AW**

MARINE

Ultrasound's new depths

Device scans pregnant manta ray JASON FORD REPORTS

The world's first contactless underwater ultrasound device has been used to scan a pregnant reef manta ray in the wild to obtain clear images of its foetus.

Designed, developed and manufactured by IMV imaging and field-tested on wild reef manta rays by scientists from the Manta Trust and the University of Cambridge's veterinary school, the Duo-Scan:Go Oceanic can be taken to water depths of up to 30m for real-time scanning.

Debra Malcolm, UK & international marketing manager at IMV imaging, told *The Engineer* that viable imagery can be obtained by getting within 10cm-20cm of a target object. Once in position, ultrasound can penetrate to a depth of 24cm.

IMV imaging's SoundLink wireless technology relays imagery between the transducer and viewing screen on a smartphone contained in waterproof housing. Malcolm added that the system can be used for 2.5 hours or longer, depending on scanning conditions.

Previous attempts to use ultrasonography on wild animals in water required scuba divers to take conventional scanners underwater in waterproof housing, often trailing cables attached to bulky viewing screens.

"Our team of engineers had to ensure the device was durable enough to be taken to the same depths as recreational scuba divers, manoeuvrable enough to aid the diver in scanning but not so flexible that strong ocean currents would inhibit is functionality," said Alan Picken, chief executive of IMV imaging. "It was a delicate balance and a great feat of engineering." ■

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MATERIALS

Microrobots key to medical sensing

Shape memory alloys can be deformed in response to temperature change HELEN KNIGHT REPORTS

Microrobots that carry out very precise tissue incision and sensing for medical procedures could be built using controllable shape memory alloys being made in the UK.

Shape memory alloys "remember" their shape, meaning they can be deformed and then returned to their previous form when heated.

However, existing shape memory alloys are typically only able to change from one shape to another, or in response to one particular temperature change.

By developing functionally graded shape memory alloys, a team of UK researchers are hoping to modify these properties at different points in the material. In this way the material could change its shape in response to different temperatures at various points on the device, for example.

This would allow much more complex and controllable microrobots to be built, according to Prof Duncan Hand at Heriot-Watt University, who is developing the alloys in an EPSRC-funded project alongside his colleague Prof Bob Reuben.

To produce the tailored materials, the researchers are developing a new technique known as functionally graded laser induced forward transfer.

Thin films of metal, such as nickel, titanium or copper, layered on a transparent polymer, are deposited onto a substrate using a pulse laser, said Hand.

"So you have a ribbon of transparent polymer with these thin metal films parallel on it, and then like an old-fashioned typewriter ribbon, you transfer bits of this ribbon over on to the [receiver] substrate," he said.

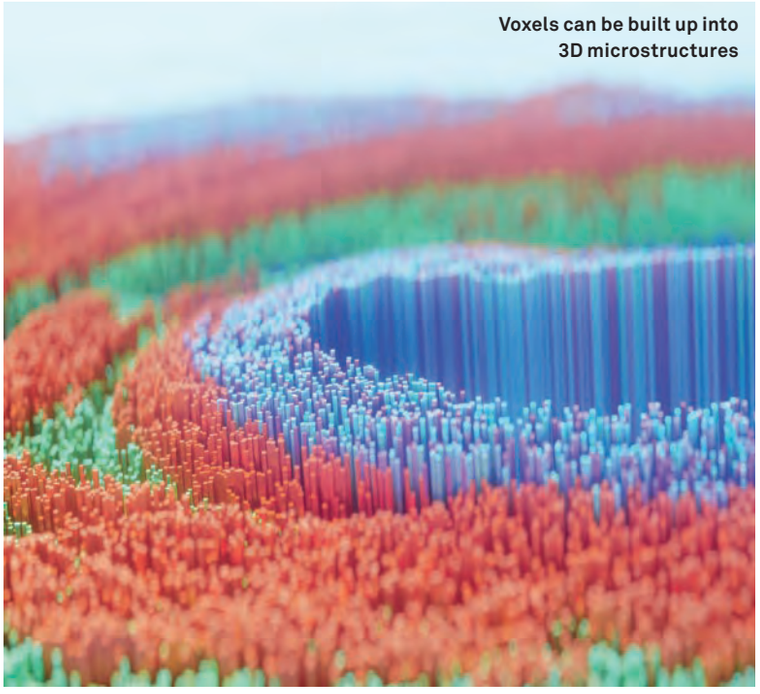
"So you might put down three layers of titanium, four layers of nickel and a layer of copper."

In this way the process can build up 3D elements, which the team describe as voxels, consisting of layers of different metals.

The material can then be heat-treated to carefully control a process of diffusion between the metal layers in each voxel, allowing the researchers to precisely control the composition of the material.

By adding voxels together, the researchers can then build up 3D microstructures with properties that differ at particular points across the material.

"Some parts of the device might be a shape memory alloy, some parts will not have that effect, and some will have a shape memory alloy that operates at a different temperature," said Hand. ■



Voxels can be built up into 3D microstructures

ENVIRONMENT

Recycling plant to turn plastic waste into saleable products

East Timor plans to become the world's first 'plastics-neutral' economy following a $40m (£32m) agreement for the development a recycling plant that turns plastic waste into saleable products.

The memorandum of understanding was signed at the University of Sydney by the government of East Timor and Mura Technology Limited, a joint venture between Australia's Licella Holdings and the UK's Armstrong Energy.

The plant will deploy a catalytic hydrothermal reactor (Cat-HTR), a chemical recycling technology invented by the university's Prof Thomas Maschmeyer, who founded Licella Holdings to commercialise the technology.

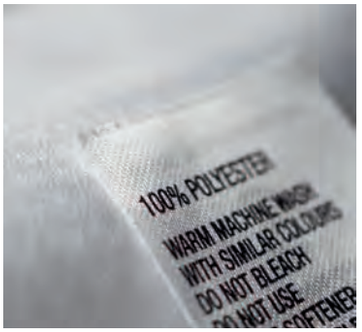
Cat-HTR uses water under high temperature and pressure to chemically recycle waste plastic (including plastic currently deemed non-recyclable) back into oil that can be used to produce new plastic, fuels and chemicals. **JF**

MATERIALS

Washable power source

Electronic components to be used in textiles

STUART NATHAN REPORTS



Wearable electronic devices could be developed from capacitors and other charge storage components formed from fabric into which graphene and related materials are directly incorporated.

This is the claim of the Cambridge Graphene Centre which has collaborated with colleagues at Jiangnan University in China on the washable electricity source.

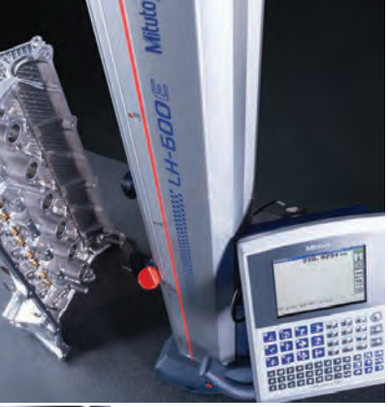
In a paper in the journal Nanoscale, Felice Torrisi of the graphene centre and colleagues explain that while other techniques to incorporate electronic components into textiles depend on components mounted on plastics that cannot be washed and are uncomfortable to wear, the new technique creates electric circuits by "simply overlaying different fabrics made of 2D materials" on to polyester.

The researchers suspended graphene sheets in a low boiling point solvent to make the ink, which can be dyed onto polyester.

Overlaying this fabric with fabric similarly dyed with hexagonal boron nitride, another 2D conductive material, creates an active region that works as a capacitor, enabling charge storage.

The fabric remains bendable, breathable, and can withstand cycles in a normal washing machine.

"Turning textiles into functional energy storage elements can open up an entirely new set of applications, from body energy harvesting and storage to the internet of things," said Torrisi. ■



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MATERIALS

Industrial diamond composite in 3D

New process will allow diamonds to be made in highly complex shapes JON EXCELL REPORTS

Engineers at Sandvik have created what is claimed to be the world's first ever 3D-printed industrial diamond composite.

Synthetic diamond is 58 times harder than anything else in nature and a key component in a range of drilling and machining tools.

But while it has been possible to produce the industrial diamonds since the 1950s, it has been impossible to form anything other than geometric shapes from the super-hard material.

The new process, which enables diamonds to be produced in highly complex shapes, could revolutionise the way industry uses the material.

Unlike natural or existing synthetic diamonds, the material produced using Sandvik's process is a composite. Most of the material is diamond, but to make it printable and dense, it needs to be cemented in a very hard matrix material.

Mikael Schuisky, head of research and development and operations at Sandvik Additive Manufacturing, explained that the process prints a slurry consisting of diamond powder and polymer using stereolithography, where complex parts are produced, layer by layer, using ultraviolet light.

This is followed by a proprietary post-processing method, optimised to produce the exact properties of a dense super-hard diamond composite.

According to Sandvik, tests on the resulting material have shown it to have extremely high hardness, exceptional heat conductivity, while also possessing low density, very good thermal expansion and excellent corrosion resistance.

"Even now, we are just starting to grasp the possibilities and applications that this breakthrough could have," said Anders Ohlsson, delivery manager at Sandvik Additive Manufacturing.

"On seeing its potential, we began to wonder what else would be possible from 3D-printing complex shapes in a material that is three times stiffer than steel, with heat conductivity higher than copper, the thermal expansion close to Invar – and with a density close to aluminium.

"These benefits make us believe that you will see this diamond composite in new advanced industrial applications ranging from wear parts to space programmes, in just a few years from now."

"Sandvik's 3D-printed diamond composite is a true innovation. It means that we can begin to use diamond in applications and shapes never conceived possible before," added Susanne Norgren, adjunct professor in applied materials science at Sweden's Uppsala University. ■

The 3D-printed industrial composite diamond can be produced in complex shapes

ENERGY

Scientists discover efficient way of storing hydrogen with new material

An international team of scientists has discovered a new material that allows hydrogen to be stored four times more efficiently, at a fraction of current costs.

Kubas Manganese Hydride-1 (KMH-1) exploits Kubas binding, a process that distances hydrogen atoms within an H2 molecule without the need to split the molecule.

The process works at room temperature and around 120 bar compared to current systems typically operating at around 700 bar.

KMH-1 would be used to make molecular sieves within hydrogen fuel tanks, which would feed hydrogen cells when the pressure was released.

The material also absorbs and stores excess energy so external heat and cooling is not required.

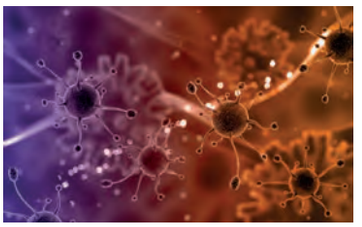
This could result in hydrogen-powered vehicles that are significantly lighter and more efficient than existing designs. **AW**

MEDICAL

£30m project to test drugs

3D images to be made at cellular level

HELEN KNIGHT REPORTS



A new £30m electron microscopy project is aiming to allow researchers to see how a particular drug works within a patient at a cellular level, before it reaches clinical trials.

The project, led by the Rosalind Franklin Institute and including Thermo Fisher Scientific, will develop technology designed to create 3D cell images at very high resolution.

The technology is based on cryogenic electron tomography (cryo-ET), which builds up a 3D image by stitching together multiple 2D images of samples that have been flash-frozen at less than -180C, according to Prof James Naismith, Rosalind Franklin Institute director.

"In this large volume technique, we can go further than current technology allows – creating images of whole cells, and cells in tissues," he said. "These cell-to-cell interfaces are where a lot of incredibly important biology happens – where drugs are taken into cells, and where cells communicate, sending and receiving signals."

Existing cryo-ET systems can only handle very small samples, such as parts of cells. In contrast, the five-year project is aiming to speed up the technique to allow it to process much larger samples, including patient biopsies.

"The large volume allows us the potential to use patients' samples, and see for the first time the molecular effect of a drug in a cell, patient by patient," said Naismith.

"This could be really important for patients whose diseases are caused by misfolded proteins – there are drugs called chaperones which can help them fold correctly, and this technique would allow a doctor to check the protein was being fixed." ■

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Why UK plc must go all out for Industry 4.0

With many British manufacturers having a low robot to human ratio, businesses need to become true leaders in automation and avoid the risk of being left behind

"Pretty rubbish". That's how Bank of England economist Will Abel described the UK's record on automation in a speech last year. This is the age of the Fourth Industrial Revolution. Or at least it is if your business is headquartered in Seoul or Singapore. In the UK there are some 74 robots for every 10,000 people employed in the manufacturing sector. Singapore has close to 500 robots for every 10,000 employees, while South Korea has more than 600.

Even by European standards, the UK has been slow on the uptake when it comes to embracing technology in manufacturing. British firms have a lower robot to human ratio than countries across Europe from Sweden in the north to Italy in the south. Germany invests 6.6 times more than the UK in automation, although its manufacturing sector is only 2.7 times larger. Indeed, Dell Technologies revealed in 2018 that across the economy, just 16 per cent of UK businesses are actively investing in advanced artificial intelligence, compared to 26 per cent in Germany, and almost a third in France.

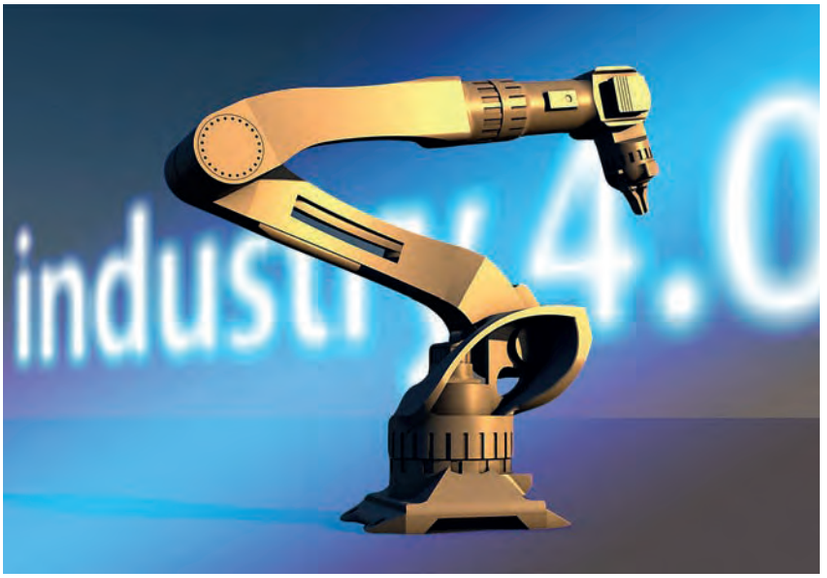
Automation is good for business

As a result, Britain is one of the world's least productive major economies, with it taking five hours for British workers to produce what their German equivalents can produce in four.

Doomsday predictions linking investment in technology to mass job losses have become a regular fixture in the debate on automation. Indeed, a study by the Fabian Society commission on workers and technology reported last year that some 37 per cent of workers are worried their job may be at risk due to increasing mechanisation. But it doesn't have to be this way.

Across manufacturing, automation will boost margins, ensuring companies are better equipped to deliver meaningful growth into the future. When well-run businesses grow their revenues and become more profitable, they will inevitably want to expand their capacity – both human and robot.

While robots can run 24 hours a day free of repetitive strain injury in the kind of environment that would make a health and safety inspector wince, they're not so good at business strategy, quality control and keeping clients happy. I've never seen a robot seal the deal with an inspiring pitch, or mount a compelling marketing campaign.



Automation can boost margins, meaning businesses can flourish

"The secret to avoiding job losses is early adoption"

The secret to avoiding job losses is early adoption. The sooner a company starts using robots (or AI), the sooner it can learn to adapt and retrain if necessary.

Late adopters will have continued to employ more and more people and then may well have to deal with a sudden and dramatic change in their employment requirements, raising the possibility of redundancies.

Being smart in manufacturing

Creating the smart factories of the future will be key to ensuring British manufacturers can be the productive wealth creators the UK economy so badly needs.

Smart factories will use automation to free human time for logistical oversight and strategy. They will be connected, providing real-time data to allow for better demand planning.

They will slash order-to-despatch times, enabling companies to produce more in less time for less money. Smart factories will be more productive, generating high-quality jobs and boosting the UK's balance of payments.

Running a business that manufactures fluid control equipment for both domestic and export markets, we are increasingly seeing technology transform the way we run our business. Optical character recognition software is streamlining the way we process customer orders, while we're using augmented reality software and 3D printing to give customers an interactive impression of our valves.

The 2020s belong to those manufacturers that put technology at the heart of everything they do. Now more than ever before must UK plc go all out to become a leader in the Fourth Industrial Revolution. ■

David Millar is managing director of Heap & Partners. Founded in 1866, the firm is one of the UK's leading manufacturers and distributors of fluid control equipment

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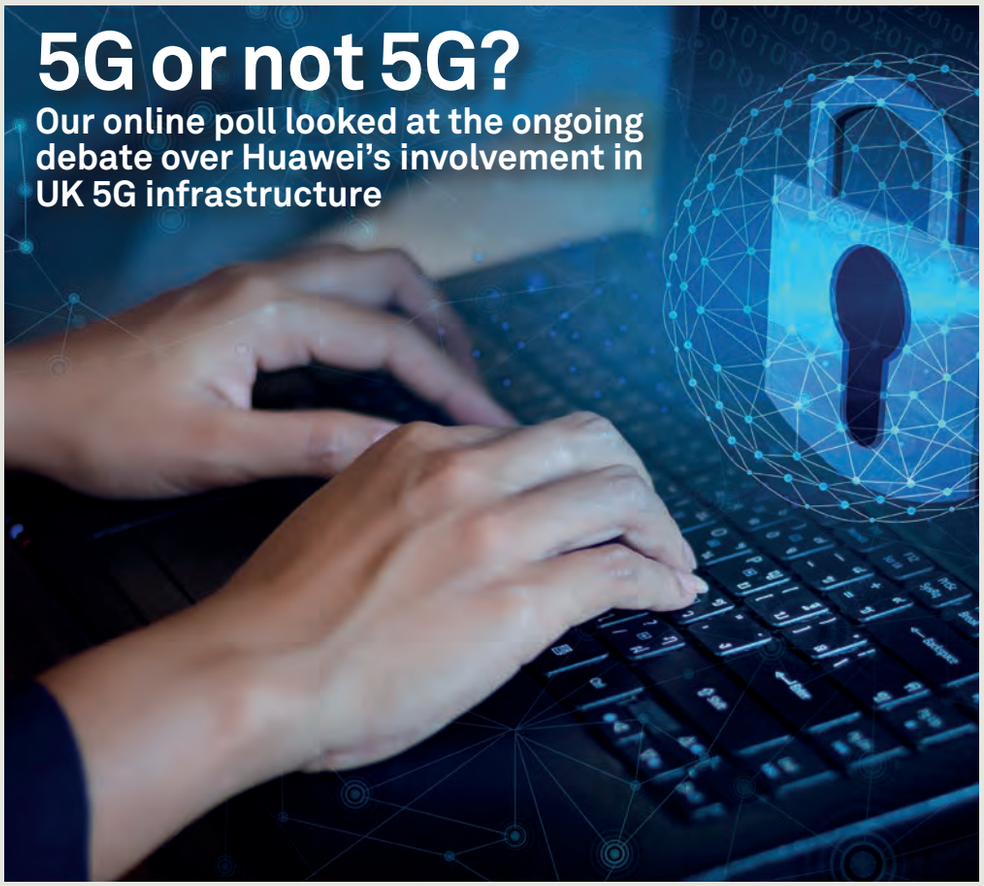


5G or not 5G?

Our online poll looked at the ongoing debate over Huawei's involvement in UK 5G infrastructure

The attacks on Huawei are purely politically motivated by our 'friends' in the good old USA. There is no reason why we should fixate on the risks of Chinese technology over and above the well-documented risks of American and Israeli technology, for example. Let's have a level playing field, independent of the machinations of protectionist politicians.

Technically, this is a non-problem. If the managers and technical teams are doing their jobs correctly (which on the whole they will be) then all risks will be assessed and mitigated. Let's select the best technology.

Another Steve

Is there no other supplier of this equipment? If not, why not? What has happened to American technological superiority? Huawei has clearly not 'stolen' the technology.

Adrian Tawse

All single-sourced electronic networking structures can form a security risk. Use the best manufactures and take steps to ensure the operators have complete control access to all products used and block any unrecognised data. Use software-defined networks in sections to strip out unwanted protocols.

Chris Chambers

Our relationship with America leads us into American wars of choice. It makes us a secondary target. Measured in lives lost and saved, it may even be a minus.

Huawei seems to have the technological edge in delivering 5G. We need to have this as a matter of urgency. The added value in 5G will be the services that can be developed to use it. If we have it second, after China, we will be in second place as a service developer ahead of the US. We need installations in our chief software development centres, such as central London and Manchester, sooner rather than later. The US has Cisco. They had all the cards. They managed to throw them away.

In the EU, we have Nokia using quite a lot of British IP as I understand it. When Nokia is ready, we can scrap Huawei. Getting started on the added value applications is the priority.

Philip Owen

As with so many issues about technology infrastructure, we have the know-how but not the hardware – In Britain, as in the US, there is virtually no one left who manufactures the components needed to assemble infrastructure like this autonomously.

One day we'll all wake up to the fact that most of the hi-tech industry in the UK (including the car industry of course) is foreign-owned – our high-value manufacturing capability and capacity is wholly dependent on the patronage of others and the vagaries of the global market. In no way do I support isolationism or nationalism – but we do need to start investing again in local capability.

Bruce Renfrew

If, after Brexit, we are to make trade deals with the rest of the world, then deals with China appear to be necessary, if unpalatable.

Since the US only want to trade on its terms, it is probably not a good partner. However, China also seems to be parochial regarding balancing trade. So, where else do we go if we want to be in the vanguard of IR 4.0 as no one else seems to be capable of designing and building 5G kit?

Sandy

Forget 5G. It should not be subsidised by government. It has hopeless range, needs a ridiculous number of transponders and is over-hyped to a public who are not equipped to push back.

More work is required to give bulletproof 4G everywhere, or fibre. Self-driving cars are not reason enough for 5G. This pit for public funding should be closed and diverted to better return on investment areas not currently served by the private sector, such as health or education.

Andrew C

America is scared of Huawei, not because it may or may not be part of the Chinese 'party', but because Apple is scared of it – and rightly so when it can make a better and cheaper products.

How better to topple Huawei's empire than to get the US government on Apple's side. If China retaliated and banned Apple products in China, I wonder how well Apple would do.

Chris Oates-Miller

Thesecretengineer

A call for diversity in a profession dominated by white, straight males

I was recently talking to friends about the new 'W Series' motor sport championship where all the drivers are female. The discussion regarding whether there is a need for this and what it might – or might not – achieve soon turned to the lack of women in engineering and science.

Thinking about that was probably down to me, but the current dearth of female competitors in motor sport in general, and F1 in particular, can be used as a parable for industry in the wider sense. There are some women, but not very many at all. Although there will always be those with antediluvian views, I cannot think of anyone I've recently worked with who would openly object to more women working within engineering.

Some may mutter darkly behind closed doors or patronisingly mock in private but so long as they keep it to themselves and don't adversely influence a woman's career path, then who cares? In addition there has been much effort put into getting girls at school interested in science and engineering. So, given that there appears to be no real resistance from the workforce, backed up by a programme of active encouragement generally, how come I've only worked with a couple of female engineers in the past decade or so?

So far, so familiarly perplexing. What made this particular conversation more interesting was the input from a friend who happens to be transgender. She highlighted a slightly different view that I had sort of been aware of but which I

hadn't yet fully formed as a coherent thought. The problem isn't so much that there are not enough women, but that engineering has a very high percentage of white, straight and male people working in it. Again, not exclusively so, but enough for it to be noticeable. To give some context, although the brevity of these pieces means that I can only give pointers, women account for just under half of the UK workforce in total and one in five staff in the NHS are 'non-white'.

Why is this a problem? For a start there is no section of society that holds a cast iron monopoly on engineering excellence and we are therefore failing to tap into a valuable resource. Solving the problem of a Spitfire's engine cutting during 'negative g' manoeuvres? A woman did that. The founder of computer science as we know it? A homosexual. The BBC computer that was pivotal in making Britain computer-literate? You can thank a transsexual for that one. So it goes on, with many examples from just about any group other than white, male and straight. By pushing out from the standard pattern of 'the engineer' you also gain a positive in that you open up the chance of insight and opinion informed by experience and culture outside of the current norm. Those of us who correspond to the stereotype of the engineer generally work as part of an organisation to produce items for everyone. However, we cannot be helped but have our decisions and interactions predominantly informed by our own viewpoint. This is a distinct limitation.

We have been wringing our hands over a lack of women within our profession for so long that I fear we've lost sight of the real issue. What is perceived as a specific failing regarding resource is in itself, and by its definition, limiting in the scope offered by the 21st century society we inhabit. What is needed isn't the target of pulling people in from a second group but rather the move away from a single group. I'll freely admit that, given how it should be through actively spreading the net wider rather than discouraging those already most likely to join our ranks, I've no idea how to achieve this. What I do know is that simply saying "more women should be in engineering and science" wilfully ignores the reality of the world we are living in. ■

Inyouropinion

First coal-free week since 1882

Renewables have serious limitations (no wind, excessively high wind speeds, hours of darkness limiting solar). Batteries and fuel cells are proposed as storage options but have yet to make any economic sense. Perhaps those advocating total dependence on renewables would like to live their lives without any grid connections, lighting (no candles or oil lamps as these produce CO_2), pumped water and sewage and no transport as an example of how truly awful this would be.
Phil Mortimer

I'm a keen watcher of http://gridwatch.co.uk and it shows that no coal fired sources were on the grid 1-8 May, but the charts also show we were heavily reliant on open-cycle gas turbines, which are hardly carbon-free. I also think bulk battery storage systems are themselves a seriously toxic danger to the planet. Why is no one developing grain-silo-sized high inertia, low RPM flywheel storage systems of perhaps 10GJ capacity optimised to return the power over several hours? I have the designs on my desk.
Richard Masters

My understanding was much of the base load (and the competition for nuclear) is to do with gas and biomass-fuelled generation – which have a net CO_2 contribution. So the crowing about 'zero carbon' by 2025 sounds somewhat disingenuous. A better, though still somewhat misleading, comparison might have been comparing solar power energy with CO_2-producing energy.
Peter Spence

And not a moment too soon, as CO_2 concentration in the atmosphere just reached a record 414.32ppm. What is the price of life, for those who think that money is the ultimate measure? Infinite, that's the price.
Silvia Leahu-Aluas

The first country to make renewable energy viable will sell the technology to the laggards as it becomes more and more apparent that it is necessary. So invest in the expensive stuff now and be a leader in it.
Timothy Murphy

Join the debate theengineer.co.uk

Carbon capture gears

Image: Arni Saeberg

Geothermal power is used to drive the DAC process in Iceland, with captured CO_2 stored in the underlying bedrock

Removing vast quantities of CO_2 from the air is necessary to avoid the worst effects of climate change. Andrew Wade **reports on the companies taking on the task**

When humans first started burning fossil fuels on an industrial scale in the late 19th century, Earth's atmosphere contained about 280ppm of CO_2. The intervening years have seen that concentration rise above 410ppm, alongside a corresponding global average temperature increase of more than 1°C. There is virtually blanket scientific consensus that atmospheric CO_2 is the root cause of this rapid warming, and that humanity must stop burning fossil fuels to halt it. Recently, however, there has also been growing consensus that decarbonisation on its own will not be enough.

If the goals set out in the 2016 Paris Agreement are to be met, many scientists – including those at the Intergovernmental Panel on Climate Change (IPCC) – believe that CO_2 must be actively removed from the atmosphere. There are numerous ways this might be achieved using quasi-natural methods such as large-scale reforestation, rock weathering, and instigating massive ocean algae blooms that act as carbon sinks. Less natural – but no less interesting – is the method of direct air capture (DAC), whereby CO_2 is extracted from the atmosphere using man-made technology.

DAC has seen a handful of companies making waves over the past decade, including Canada's Carbon Engineering, the US's Global Thermostat and Climeworks of Switzerland. Broadly speaking, they rely on similar technologies, using amine-based sorbents to scrub CO_2 from the air. The sorbents are then heated to release pure CO_2 which can either be sequestered or repurposed for a variety of industrial and agricultural applications.

up for climate battle

Climeworks' DAC technology is based on a cyclic capture-regeneration process using a filter made of porous granulates modified with amines. Fans suck in atmospheric CO_2 that chemically binds to the filter's surface. Once saturated, the filter is then heated to around 100°C, releasing high-purity gaseous CO_2. According to Climeworks, the filters can operate for several thousand cycles before needing to be replaced. Like most other DAC operators, the Swiss company relies on a source of waste heat to maximise the efficiency of its release process.

"We need energy to power our CO_2 collectors," Louise Charles, communications manager at Climeworks, told *The Engineer*. "We use only waste energy and renewable energy for this."

The company's first commercial plant in Hinwil, near Zurich, captures around 900 tonnes of CO_2 per year using 2,000kWh of heat and around 600kWh of electricity per tonne. This is a drop in the ocean of total global emissions, but other plants have been coming online and Climeworks has ambitious plans of capturing 1 per cent of annual CO_2 emissions by 2025.

"The world currently emits 40 gigatons of CO_2 every year – this is 12,688 tonnes per second," Charles continued. "To capture 1 per cent of that would require 250,000 (Climeworks) plants, equivalent to 750,000 shipping containers full of collectors. This might sound like a lot – but in comparison, this is the same number of shipping containers that pass through Shanghai harbour in two weeks. This is something that the global economy can handle."

While the global economy may well be able to handle it, it remains to be seen if it will be incentivised to fund it. Climeworks is currently capturing CO_2 at $600-$800 (£474-£633) per tonne. Some of this cost is offset by selling the purified gas to customers in the beverage industry and for use in greenhouses to promote plant growth. This falls a long way short of covering the costs of capture, however.

What's more, much of the gas sold on to customers ends up back in the atmosphere, diminishing the overall climate benefit.

In 2017, Climeworks teamed up with Iceland's Reykjavik Energy on a pilot project to harness geothermal heat for its DAC process. The captured CO_2 is then sequestered by pumping it 700m underground to react with the basalt bedrock, locking it away permanently in geological storage.

Known as DACCS (direct air capture with carbon storage), this type of long-term sequestration is what will be required if humanity is to eventually reduce the concentration of atmospheric CO_2 back to 19th century levels.

01 Prof Klaus Lackner has been working on DAC since the 1990s

02 A prototype mechanical tree on the ASU campus

> "Removing CO_2 from the atmosphere is a crucial condition to achieve climate goals: to hit the 2C target, we would have to remove 10 billion tonnes of CO_2 every year from 2050 onwards"
>
> Louise Charles, Climeworks

Locking away the CO_2 means that there is no product to sell and, as a result, a substantial market for DACCS is yet to emerge. Carbon taxing could change this, as DACCS would allow organisations to offset unavoidable emissions, but the price of capture would still have to fall dramatically for DACCS to be commercially viable.

According to Climeworks, a target of $100 per tonne is achievable, and is also likely to intersect with carbon pricing in the near future.

"We have a clear cost-reduction road map for the future to bring down the cost of CO_2/tonne to $100," said Charles. "Regulations that reflect the real cost of CO_2 emissions need to be in place. We consider a price on carbon of $100-$150 per tonne by 2030 a realistic target.

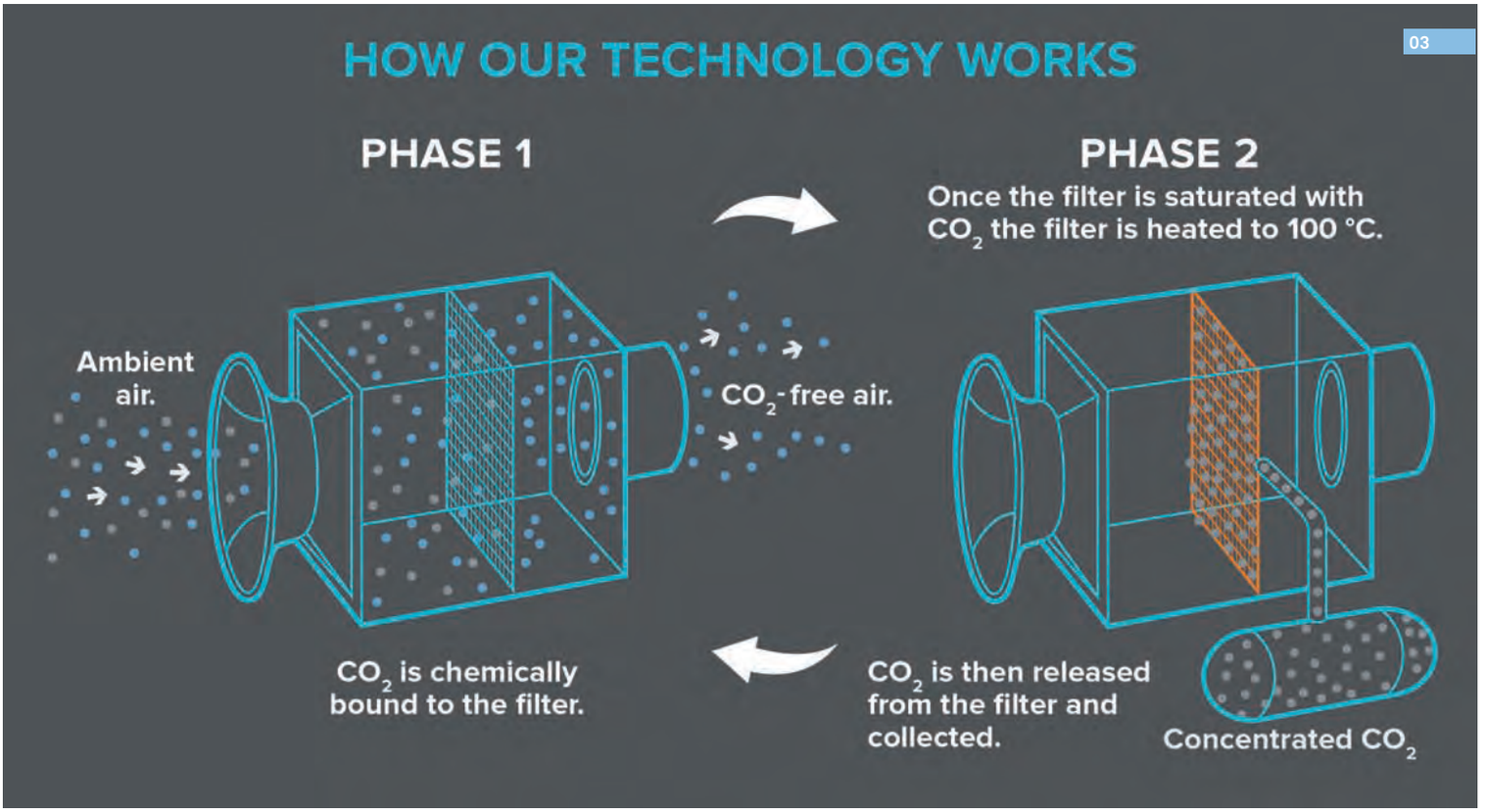
"Removing CO_2 from the atmosphere is a crucial condition to achieve climate goals: to hit the 2°C target, we would have to remove 10 billion tonnes of CO_2 every year from 2050 onwards."

Climeworks may have a road map to $100, but there is a new start-up in the space that claims to already be there. Dublin-based Silicon Kingdom Holdings (SKH) says its 'mechanical trees', which passively capture CO_2 using stacked discs of sorbent, will deliver DAC at $100 per tonne once at scale. The man behind the technology is Prof Klaus Lackner, director of Arizona State University's (ASU) Center for Negative Carbon Emissions. Lackner, who will act as chief scientific adviser to SKH, is a pioneer in the DAC space, according to company CEO Pól Ó Móráin.

"If you look at Climeworks, Carbon Engineering, Global Thermostat – all those companies have actually based their start-ups and their technological approach on the early work of Klaus, and they'll publicly acknowledge that," Ó Móráin told *The Engineer*. "Klaus has been working on this going back to 1992 and in 1999 he was the first, globally, to say we need to take carbon out of the air to deal with climate change, and nobody listened for a long time."

Four years ago, Lackner moved to ASU with a view to finally commercialising his decades of research. Other DAC companies were springing up all over the world, but Lackner anticipated that rushing to market would lead to a high cost of capture. It was better, he reasoned, to optimise the technology and bring a product to market that could achieve $100 per tonne straight out of the blocks, leapfrogging any competitors that had a head start. After Lackner crossed paths with venture capitalist Ó Móráin about a year ago, SKH was established in the latter's native Ireland.

"Klaus's focus was making it commercial, reducing the cost of capture and enhancing it, and looking at novel aspects in terms of design and the



03 Climeworks' DAC technology uses a solid sorbent to capture CO_2

geometry," said Ó Móráin. "So in some ways he's fallen behind where people are at in terms of roll-out and testing, but having taken that slower and more considered approach, he's ended up with a design that's very novel. It's a shift to passive capture, so we don't actually spend energy on the capture part."

SKH's column-shaped mechanical trees use an ion-exchange material to harvest CO_2 passively, without the need for fans or even the wind to draw air into them. The devices are 2.5m high when closed, but grow to around 10m when open, exposing 150 sorbent-filled discs, each with a diameter of about 1.5m. A cluster of 12 of these columns will be capable of capturing a tonne of CO_2 per day, according to SKH.

"Those discs are coated in an ion-exchange material, so they basically attract CO_2 when they're dry," said Ó Móráin. "We're not reliant on kinetic energy, so it's not like a wind farm. It's literally just the contact of air to the surface of the discs."

After 20 minutes of exposure to air, the discs become saturated and return back into the base of the column, which is then sealed airtight. At this point, either heat or a change in humidity can be used to release the CO_2, and the method can vary depending on local climate.

"We end up with 5 to 10 per cent (CO_2) concentration at that stage on the offtake," Ó Móráin explained. "If you want to get it up to 95 per cent for food grade or beverage grade, that's a fairly standard process and our method would be no different to what anyone else would use."

Lackner's prototype device has been put through its paces in Arizona's harsh conditions for more than a year, with no degradation of performance, according to Ó Móráin. The next stage will be a pilot project capable of capturing 100 metric tonnes a day. This will require around 1,200 of the mechanical trees, with a footprint roughly equivalent to 200 standard 40ft shipping containers. SKH is looking at locations in Arizona and California but is yet to make a final decision.

As with Climeworks, the question of economics looms large for SKH. Currently, the biggest market for CO_2 is the energy industry, where it is used for a process called enhanced oil recovery (EOR). This involves pumping the gas into wells to extract crude oil that would otherwise be unobtainable.

Harvesting atmospheric CO_2 to extract oil seems a counterintuitive way to mitigate climate change, and Climeworks has said it will not supply CO_2 for this purpose. Ó Móráin, formally of BP, has a different view. He believes the EOR revenue stream is necessary to support DAC in its nascent stages and that the inevitable introduction of carbon pricing will ultimately allow the technology to fulfil a climate-friendly role.

"We don't think the environmental market is there just yet," the SKH CEO said. "We're basically taking a gamble that the price of carbon is going to go to $100 per tonne.

"We don't want to be a white elephant, so our focus is to build something now that's profitable.

> "We're taking a gamble that the price of carbon is going to go to $100 per tonne. We don't want to be a white elephant, so our focus is to build something profitable"
>
> Pól Ó Móráin, Silicon Kingdom Holdings

"We can satisfy the actual use cases of CO_2 while the market prepares and flips for the more environmental capture and dispose."

While EOR may divide opinion, synthetic fuel is an area that virtually everyone in the DAC space is embracing.

Captured CO_2 can be combined with other chemicals to create fuels that are theoretically carbon neutral, so long as the process is powered by waste heat and renewable energy. The end product is pricey in comparison with fossil fuels but could allow industries such as aviation and shipping to decarbonise in the absence of realistic pathways to electrification.

"The industrial sector and the transport sector will need in the future some chemical energy carriers. It will not be possible to do everything with electricity directly," said Prof Roland Dittmeyer of Germany's Karlsruhe Institute of Technology.

Dittmeyer and colleagues recently published a paper in *Nature Communications* outlining how air conditioning units could be used for DAC in buildings around the world, with the captured CO_2 then processed locally into synthetic fuels.

The 'crowd oil' produced by this decentralised capture and refining could then be used to power local transport or fed into a 'renewable oil grid'. It could even act as a long-term storage medium with the option of utilising it at some point in the future.

"Taking air, conceptually, leads to a circular approach," Dittmeyer told *The Engineer*. "You take the CO_2 from the air, put in renewable energy – or CO_2-free power, I should say, because it could also be nuclear – and then you generate a hydrocarbon which releases the CO_2 again during use.

"Why combine it with ventilation systems? Because there you already contact a huge amount of air. You pay already for the electricity for making this contact.

"So if you can put this together, you eliminate one of the disadvantages of direct air capture. That was my motivation."

Dittmeyer's paper describes three potential scenarios for the technology: the Frankfurt Fair Tower office building, a typical supermarket and a collection of low-energy houses.

As one of the EU's tallest skyscrapers, the Frankfurt Fair Tower has a HVAC system that contacts huge volumes of air, and the research claims enough CO_2 could be harvested there to produce 2,000-4,000 metric tonnes of synthetic fuel per year. If applied to all big office buildings across Germany's five biggest cities, 2.4-4.8 million metric tonnes of synthetic fuel could be produced.

"You have to sacrifice probably one or two floors of a skyscraper for this kind of technology," Dittmeyer explained. "The way that I would say is state-of-the-art is that you produce hydrogen. So you need an electrolyser. There are several companies offering this, typically in a modular format or container-based plants. It could be in the basement or on top, where you already have the big ventilation machines."

At least two further reactor stages are required; one to convert the hydrogen and CO_2 into a reactive gas, or syngas, and a second to convert that syngas into a hydrocarbon.

Ineratec, a spin-out from the Karlsruhe Institute of Technology, has already developed container-based plants capable of the conversion process, and Dittmeyer believes these could be slotted into existing large buildings.

"A household air conditioner, quite evidently, that's not the target here," he said. "But say a large ventilation plant, in my opinion, can be retrofitted with these conversion steps."

Questions remain about storage and transport. Large stockpiles of fuel within tall buildings or supermarkets pose an obvious risk, as would transferring it to roadside tankers.

Dittmeyer is involved with a pilot project that's currently producing 10 litres of synthetic fuel a day and there are plans to scale this up significantly over the coming years, with Climeworks one potential partner.

Within five to 10 years, the professor believes that the technology could be commercialised and play a key role in the climate battle.

"I hope that we see many of these systems in practice," said Dittmeyer. "Because we have to do that. We have to achieve that, because time is running out." ■

> "The industrial sector and the transport sector will need in the future some chemical energy carriers. It will not be possible to do everything with electricity directly"
>
> Prof Roland Dittmeyer, Karlsruhe Institute of Technology

Image: Julia Dunlop

04 Most DAC systems use fans to drive airflow

Image: Julia Dunlop

05 Captured CO_2 can be sold to farmers to promote greenhouse growth

Battery tech breakthrough?

As more systems look towards better electricity storage, a harmless, durable and non-flammable battery could be the way forward Stuart Nathan reports

We are living in an electric age. Our energy carrier of choice is the zipping electron in a conductor. And this trend is increasing. As we develop more and more systems which rely on both electricity and mobility – electric cars, electrically powered shipping and, in the coming decades, electric aircraft, we are faced with two pressing problems. The first is how to generate the electricity we need to power our devices without adversely affecting the environment, and the second is how to store it in such a way that it can be delivered in the amounts and for the duration necessary. Both problems are difficult and pressing, but a breakthrough in the second – battery systems – may be on its way.

For decades, the battery technology of choice for storing and delivering relatively large amounts of electricity over a long period has been the lithium ion battery. But these have well-known drawbacks. One is that their energy density is simply not as big as that of the liquid hydrocarbon fuels they typically replace in vehicles, meaning that it is difficult to pack enough batteries into a car to power it over the distances that drivers are typically used to from a tank of petrol. It also limits the usefulness in aircraft, because the power to weight ratio for a long flight is not favourable.

> "The batteries have an inorganic, non-flammable electrolyte system"

The other problem is safety – lithium ion batteries have an unfortunate tendency to catch fire and explode, which is obviously not favourable if they are in a car or an aircraft.

Swiss start-up Innolith is claiming to have made major advances towards solving both problems with a world-first battery with energy density of 1kWh per kilogram. Rather than the organic electrolyte that most lithium ion batteries contain, which is flammable, these batteries have an entirely inorganic, non-flammable electrolyte system and they do not contain toxic materials, rare-earth metals or minerals from conflict zones. The company claims these batteries are stable over many thousands of charge-discharge cycles and cannot fail in a harmful or dangerous way.

Innolith's underlying technology has been covered in *The Engineer* before. In 2015, a Norwegian-based company called Alevo attempted to start up as the world's first industrial-scale producer of grid-connected batteries in a former William Morris cigarette factory in Concord, North Carolina.

However, this was an expansion too far, too soon, and the challenges of building modern manufacturing technology into an enormous 1950s building proved too much, and the company went bankrupt in 2017. Former chief technology officer Alan Greenshields and chief operating officer Sergey Buchin bought the company's intellectual property and its R&D facility in Bruchsal, Germany in 2018 to launch Innolith, focusing on R&D rather than manufacturing. *The Engineer* visited the Bruchsal laboratories in March to see how work was coming along and spoke to several of the management team.


01

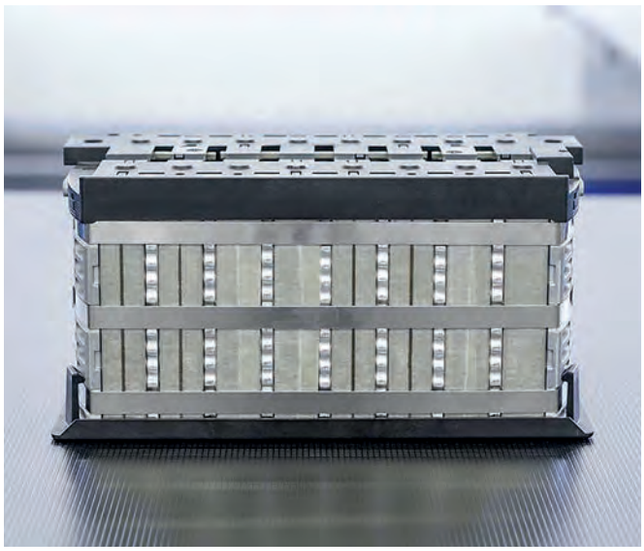

02

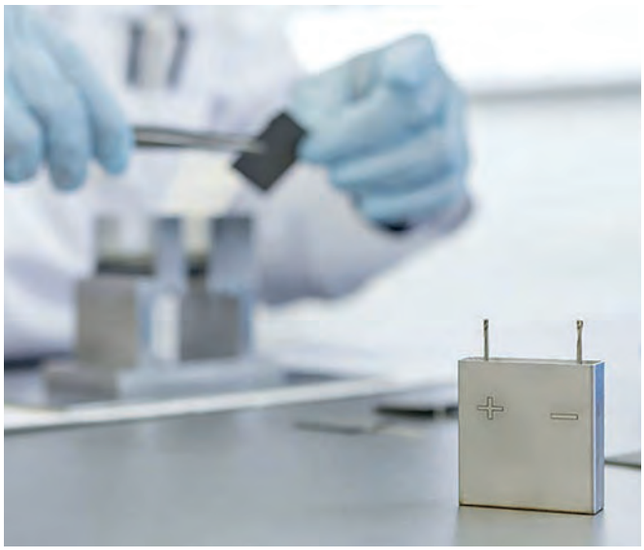
The battery is based on lithium chemistry, but is not a lithium ion battery. According to chief engineer Markus Borck, co-inventor of many of the technological details of the battery with Laurent Zinck, who has the role of chief scientist for the company, lithium itself may be replaceable with a similar but more abundant metal (he did not specifically say which metal this might be, but sodium would be an obvious candidate).

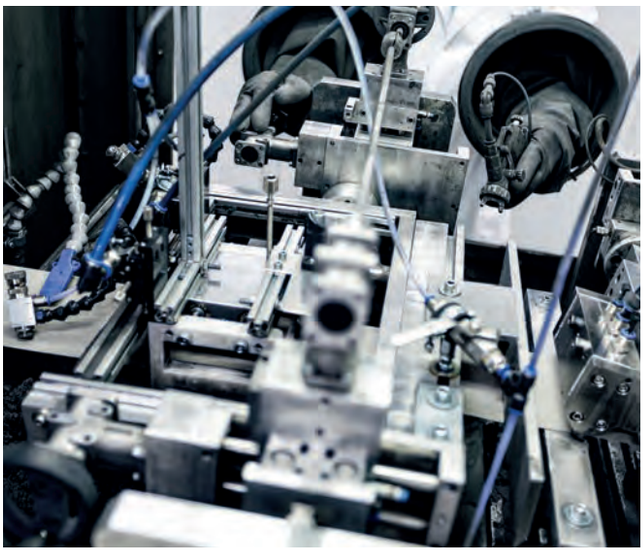
The key difference is that while lithium ion batteries work by moving lithium ions through the electrolyte from one electrode to the other, and lithium ions slip between the layered structure of the electrode (hence they are known as intercalation batteries, this being the term for particles introducing themselves into a regular lattice structure without disturbing it), the Innolith battery works by transferring electrons between electrodes and lithium atoms at the electrode, and hence it is a type known as a conversion battery (most of the batteries we are familiar with, from lead-acid batteries batteries in cars to the cylindrical batteries in corner shops, are conversion-type).

The electrolyte in the Innolith battery is a strange substance. It has two components: a conducting salt, lithium tetrachloroaluminate ($LiAlCl_4$), and sulphur dioxide as a solvent. The salt is solid and the SO_2 is a gas, but when combined, they form a clear, pale-yellow liquid with a viscosity similar to water.

This looks like a solution, but is actually technically a solvate: the SO_2 molecules surround and bind to the salt, producing a liquid which behaves







01 Markus Borck

02 Alan Greenshields

03 The electrodes for the cell are coated in a film of nickel foam

more like a molten salt than a conventional aqueous solution – it is more concentrated in charge carriers. This means that the electrolyte has electrical conductivity of 60 to 100 million Siemens per cm at room temperature, compared with around 10 million Siemens per cm for organic electrolytes. This allows the cells to be built with intrinsically higher power than an organic electrolyte cell, Borck explained. The electrodes for the cell are coated in a film of nickel foam which is three to five times thicker and therefore more durable than the thin-film coatings needed for lithium ion battery electrodes.

It is also much easier to manufacture thick films than thin films. Less precision is needed in the manufacturing process, explained Greenshields, the thick films are more tolerant to contaminants and are simpler to package in the cell assembly, requiring fewer connections and a less complex battery pack construction.

The Innolith cells have been tested over 55,000 complete charge-discharge cycles, equating to 10 to 100 times the lifetime of conventional lithium ion cells. One reason for the lifetime is that unlike lithium ion cells, the use of the cell does not result in a deposit on the surface of the electrode, which is one of the life-limiting factors of lithium ion technology, as it reduces the battery power over time. There are also fewer ways for the cell to fail, unlike lithium ion cells which have many failure modes as the organic chemistry of the electrolyte changes over time in unpredictable ways.

Electrical aircraft developer Richard Glassock of the University of Nottingham, who is developing racing aircraft in collaboration with engineers from Airbus who are working on hybrid passenger aircraft, told *The Engineer* that the development was potentially extremely significant.

"If they really have cracked the energy and power density trade-off to get 1kWh/kg, then we will be looking forward to a major advance in electric transport utility," he said. "Many of the concepts currently in development, including the Air Race E types, are viable with around 200Wh/kg, so five times this will equate to much extra payload, endurance or range.

"The economics of battery life cycle is the other big issue. I look forward to seeing how it goes in the real market. I guess this is the sort of thing we are all expecting to happen sometime. Maybe this is the next increment?" ■

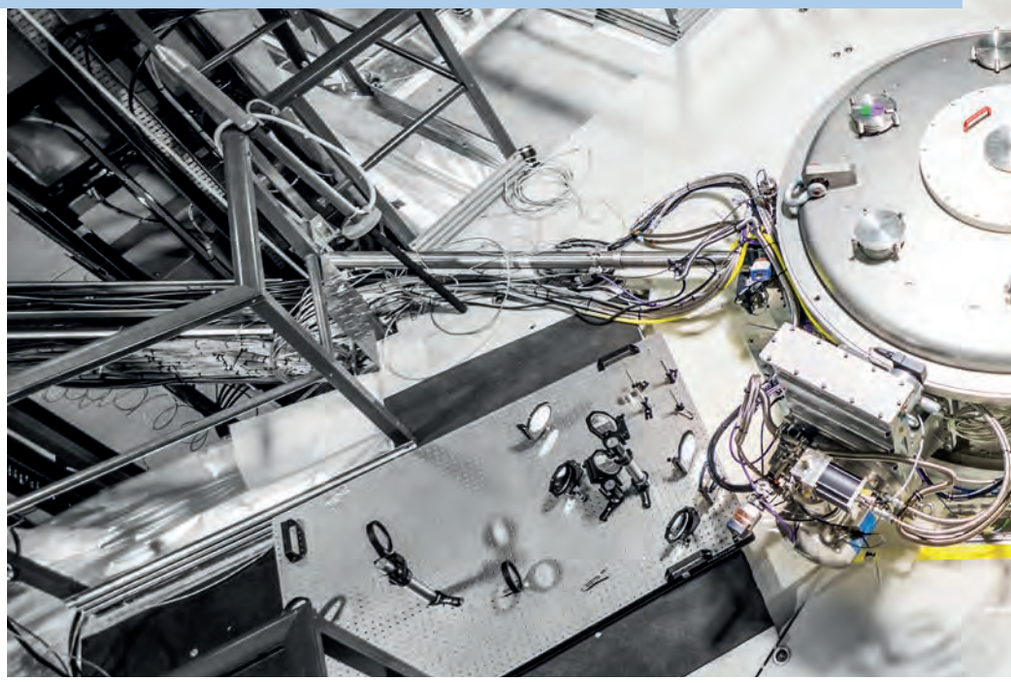
Tracing the sources of nuclear fusion

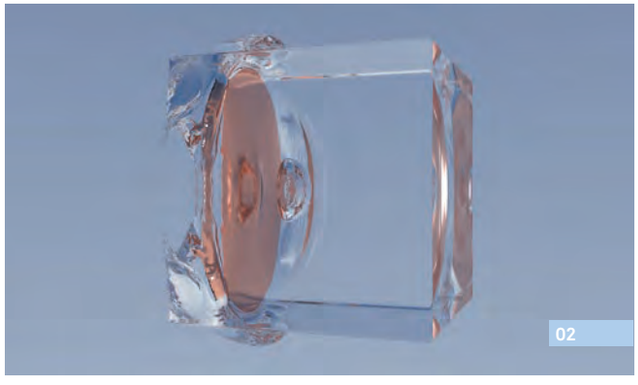
First Light Fusion's CEO talks to Stuart Nathan **about the aim to tackle nuclear fusion with his own theory – a variant of natural inertial confinement – and explains the factors involved**

When engineering takes inspiration from small animals, the word 'humble' is certain to turn up any descriptions of the technology. But there's nothing humble about the pistol shrimp, apart from its size. Only millimetres in length, these crustacea are fearsome hunters, marvels of evolution and possessed of the nearest thing we know to superpowers. They are the only creatures apart from humans that kill their prey from a distance, but they don't need to rely on weapons. Instead, the pistol shrimp sports one outsize claw which it can snap (almost exactly like snapping fingers) to generate a shockwave that can stun or kill even much larger animals, including fish.

This unlikely ability makes this tiny animal the loudest creature on the planet, louder even than sperm whales (whose entire cranial anatomy has evolved to produce high energy sonar clicks) and beluga whales, the opera singers of the seas. Pistol shrimp are so loud that they interfere with submarine navigation.

Studying pistol shrimp led Dr Nick Hawker, a speaker at the upcoming *The Engineer* conference, which runs alongside the Subcon exhibition at the National Exhibition Centre in June, to what might seem to be the unintuitive conclusion that this marvellous oddity might be the answer to humanity's biggest current challenge: ensuring the supply of the electricity on which our lifestyles depend without further damaging the planet's ability to support human life. Hawker is developing a technological theory that might be the key to nuclear fusion: the time-worn but keenly chased goal of near unlimited energy with little to no pollution drawbacks by recreating the process that powers the sun.





01 First Light's fusion experiment, with the reaction chamber surrounded by capacitors which store and release energy to shoot the projectile into the target

02 As the shockwave hits the target, it begins to deform, collapsing the bubble of fusion fuel

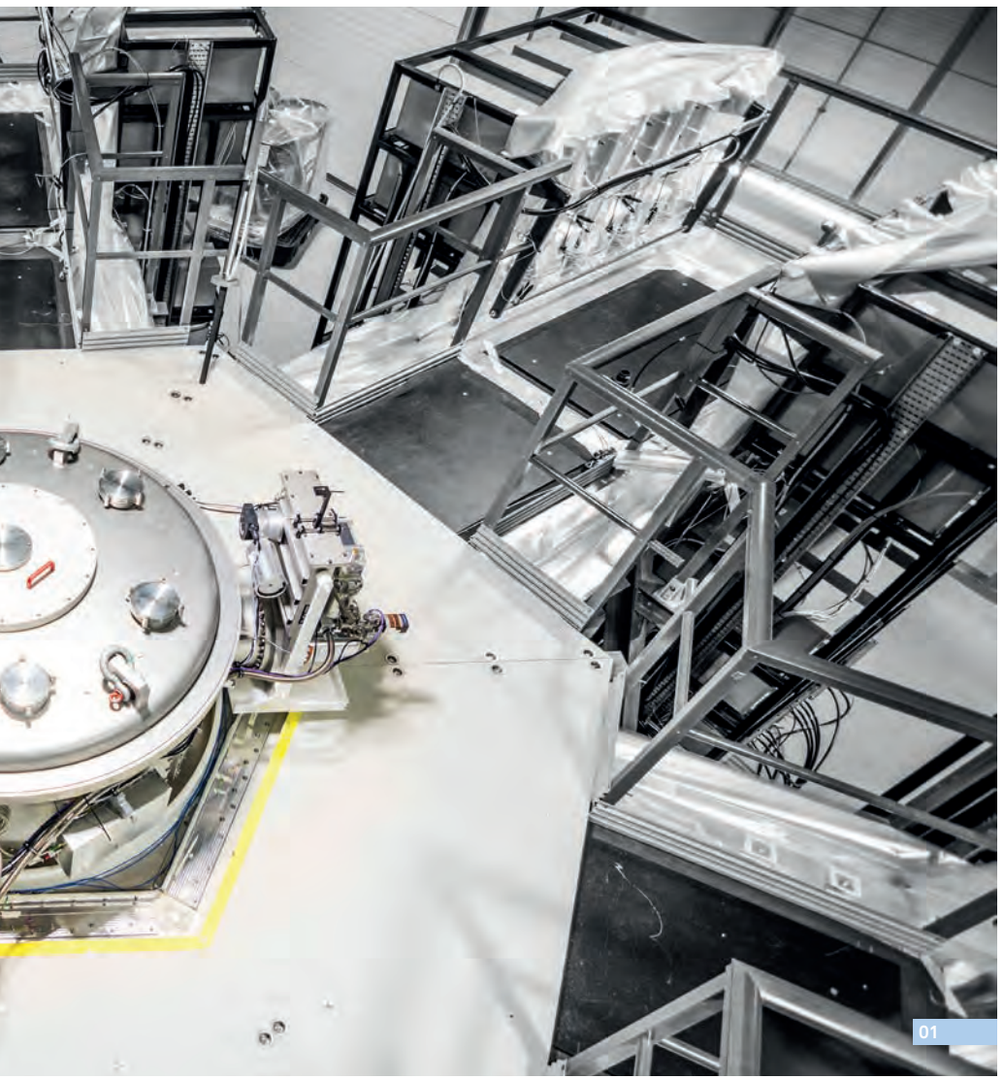
Energy on a big scale

There are many routes to fusion, but the most studied revolve around creating almost inconceivably high temperatures in volumes of electrically charged gas (plasma) and squeezing them in titanic magnetic fields inside enormous machines – this is known as magnetic confinement fusion. *The Engineer* has covered this in detail in several features about the France-based project ITER, in which 35 countries are collaborating to build the largest ever magnetic confinement fusion reactor.

Although significant progress has been made towards producing fusion by magnetic confinement, it has not yet succeeded in demonstrating gain – that is, producing more energy than it takes to trigger fusion.

Hawker is taking a completely different route, known as inertial confinement. This centres around triggering fusion by physically crushing a bubble of plasma. And this is where the pistol shrimp comes in. The shockwave with which it hunts is accompanied by collapsing bubbles: when it clicks its claw, the moving digit rips through the water so quickly that it causes a pressure drop in its wake that vaporises water, creating bubbles – a process known as cavitation, which also occurs in the wake of rotating propeller blades. The surrounding water pressure causes the bubbles to implode, raising their internal temperature so high that they generate light. This is the only known example of inertial confinement in the universe, apart from in stars as they collapse into a supernova.

Collapsing bubbles has been a known possible source of nuclear fusion for some time. In the early 2000s, an engineer at Purdue University in the US claims to have generated fusion by collapsing bubbles in liquid through bombarding them with ultrasound: a technique that became known as sonofusion. However, the results of experiments could not be replicated and he was charged with misconduct.



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Sonofusion is not the path pursued by Hawker's company, Oxford-based First Light Fusion, he told *The Engineer*. "Sonofusion is complex – the ultrasound that vibrates the bubble to make it implode and that's not a stable or predictable process," he explained. "The conditions that could cause it have been mapped pretty well and there is only a very small set of conditions where fusion is possible." Rather than using ultrasound, First Light follows the pistol shrimp example, creating a powerful shockwave to force a bubble to implode. That shockwave is produced by firing a projectile into a target that contains a small void or voids filled with fusion fuel; the impact mimics the shrimp's clicking of one part of its claw against the other.

The crucial condition to raise the pressure (and hence the temperature) inside the void high enough to initiate fusion is the velocity of the projectile when it hits the target, Hawker said. "To be honest, we're talking about brute force."

The velocity of the projectile directly maps to the speed of the implosion, which controls whether the contents of the bubble reach fusion temperatures (around 50 million°C).

For example, the National Ignition Facility (NIF) in California, the largest experiment into inertial confinement fusion in the world, is using powerful lasers to trigger an explosive implosion of a capsule of fusion fuel at around 350km/s – compared with around 5km/s for most sonofusion experiments. "If you keep turning up the shock strength, which correlates to both the internal pressure of the bubble and the velocity of implosion, can you eventually get the same conditions present at NIF? And the answer in my research was yes, you can," Hawker explained.

One complicating factor is that with projectile-triggered implosion, the shockwave hits the bubble on one side and the collapse is planar, which is very different from the situation at NIF, where lasers hit capsules from all sides simultaneously and the implosion is symmetrical. One way to tackle this problem, Hawker said, is with the arrangement of voids inside the target.

The display target model that Hawker shows when explaining his process is a transparent Perspex cube with a single bubble in its centre, with inlet tubes on either side through which fuel would be introduced. "But the actual thing won't be one spherical cavity by itself, it'll be something more complicated," Hawker said.

One demonstration that Hawker shows features two spherical bubbles side-by-side. Tucked into the space where two edges approach each other is a single, much smaller spherical bubble. In this simulation, when the planar shockwave approaches from the opposite side of the two bubbles from where the small bubble is located, the large bubbles collapse and turn inside out and this collapse envelops the small bubble.

"We call this convergence, and it's crucial to getting the correct geometry of implosion," Hawker said. "The target itself could be made from any solid material, in theory. You hit it so hard with the projectile that it behaves like liquid."

The projectile is accelerated using an electrostatic device which makes up the bulk of the fusion machine. If magnetic confinement is characterised by enormous magnets, and the NIF's inertial fusion by enormous lasers, then First Light is characterised by banks of capacitors which act like a camera flash, storing a huge amount of electric charge released in an instant to generate a magnetic field of 500 to 1,000 tesla, which launches the projectile at around twice the escape velocity (some 22km/s, which is about mach 66). This is still nowhere near the implosion velocities achieved at NIF, which is why the target design is so crucial, Hawker explained.

High-velocity implosion

Although the shockwave travels inside the target material faster than the projectile velocity, the geometry and arrangement of the fusion fuel containing bubbles inside the target acts to concentrate the force and increase the velocity of implosion. "If you can get the target bubbles up to about 5keV, you start to trigger fusion and it self-heats, it's an incredibly non-linear process and will rocket up to millions of keV in a few picoseconds. That will burn a much larger fraction of the fusion fuel than a magnetic confinement reactor will," Hawker said.

First Light plans to prove it can achieve fusion with its existing machine using deuterium fuel alone. Its next stage, for which it will need to raise a substantial amount of money, will involve building a machine some 40 times larger to demonstrate energy gain. This machine will also include features designed to capture the energy of fusion.

Hawker explained that the current idea is to use a liquid lithium coolant in a pool below the target with a cascading cylindrical curtain of liquid lithium falling around the sides, so all the energy emitted apart from that which is going straight upwards will be intercepted by the liquid metal. Fast neutrons emitted by the fusion reaction will collide with lithium atoms in the coolant to generate tritium, the heavier isotope of hydrogen which is the other component of "standard" fusion fuel.

"Liquid metal coolant has been used extensively in fast breeder reactors, notably at Dounreay in Scotland," Hawker said. "They tend to use sodium or an alloy of sodium and potassium, and liquid lithium is slightly different chemically but behaves in the same way physically, so we can use the expertise gained in these reactors to design our system. We can also put the coolant through a similar type of heat exchange system that the breeder reactors used to use the fusion energy to raise steam and generate electricity.

"In essence, what we are talking about is a plant that could be built by any company with experience of fabricating large components. If you can make a nuclear reactor, you can make one of our plants. In fact, if you can make a gas-fired power station, you would be able to make one of ours as well." ■

Mitsubishi Outlander PHEV

Combining a meaningful electric-only range with the convenience of a combustion engine, the Mitsubishi Outlander PHEV might offer the best of both worlds, writes Chris Pickering

Growing interest in electric cars has brought with it a new phrase: 'range anxiety'. Despite rapidly increasing battery capacities and significant improvements to the charging infrastructure, electric vehicles (EVs) still aren't ideal if you want to travel from, say, London to Cornwall. That's not something that most of us do very often, yet that nagging concern about battery range is still a major obstacle to EV adoption, at least in psychological terms.

A plug-in hybrid electric vehicle (PHEV) might just be the best solution to that problem. The theory goes that a PHEV should be able to cover a substantial portion of its day-to-day mileage on electricity alone, while also offering the convenience of a combustion engine for those times when you need to go further afield.

Mitsubishi has championed this approach with the Outlander PHEV. First launched in 2014, it has been the best-selling plug-in vehicle in Europe for the past four consecutive years (and that includes full EVs). During that time, the Outlander PHEV has benefited from a series of significant revisions, the most recent of which came in the summer of 2018. This included a new 2.4-litre four-cylinder petrol engine, which uses a variable cam timing system to switch between the Otto and Atkinson cycles. At medium-to-high loads, the Otto cycle is used, offering peak outputs of 135PS and 211Nm. Meanwhile, at light loads, the engine switches to the Atkinson cycle, offering higher thermal efficiency in return for a lower peak output.

> "It has been the best-selling plug-in vehicle in Europe"

The petrol engine is connected to a 77kW generator, but it can also be used to drive the front wheels direct. Alongside sits a 60kW AC synchronous permanent magnet electric motor, which provides additional power to the front wheels, while the rear axle has a similar unit, now upgraded to 70kW for the latest model. New cells in the 300-volt lithium ion battery pack – mounted under the floor of the cabin – have seen its capacity rise by 10 per cent to 13.8kWh.

In EV mode, the two motors draw direct from the battery, giving a claimed electric-only range of 28 miles. Once the battery becomes depleted or when additional power is required, the Outlander PHEV switches to Series Hybrid mode. Here, the motors remain the sole source of propulsion, but the engine is engaged to drive the generator. At high speeds, the Outlander PHEV automatically switches to Parallel Hybrid mode, with the engine driving the front wheels direct.

There's also a Charge mode, which replenishes the battery as quickly as possible and a Save mode that stores energy to use later – handy if you're approaching a zero emissions zone, such as those planned for London and Oxford.

01 The PHEV was improved and relaunched in 2018

02 The driving experience is very refined

A good compromise: the Mitsubishi Outlander PHEV offers EV savings without the range anxiety

A refined driving experience

Around town, the Outlander PHEV delivers the same impeccable levels of refinement that you'd expect from an EV. The switchover to the internal combustion engine is very smooth – with the radio on you'd be hard pushed to notice it at all. Things do get a bit more vocal if you accelerate hard, and there's also a touch of wind and road noise at higher speeds. Overall, though, the Outlander PHEV offers a useful step up in refinement compared to its petrol and diesel counterparts.

Performance is fairly sedate in EV mode, but it's enough to keep up with normal traffic. More importantly, the real-world range figures are pretty close to Mitsubishi's claims; we managed 23.3 miles on a mixture of town and country roads without driving too studiously. That's around twice the length of the average UK commute, so it means that some people could feasibly carry out the majority of their day-to-day driving without ever using a drop of fuel. That said, the car will still insist on using the combustion engine once every 90 days in order to preserve the catalytic converter and the fuel injection system.

With household electricity rates hovering at around 12.9 pence per kWh, a full charge will cost you somewhere in the region £1.78. That takes around 5.5 hours from a standard 13-amp plug, although the Outlander PHEV's onboard charger also allows you to tap into high-power charging points that can bring the time down to as little as 25 minutes. A petrol-only vehicle covering the same 23.3-mile journey at 35mpg would set you back around twice as much in fuel at £3.89.

Quantifying the fuel economy in the hybrid modes is harder, because it covers such a broad spectrum. Driving short distances at low speeds and with a full battery, it is possible to replicate the 100+mpg figures that you hear talked about. And even setting off with the battery depleted we saw upwards of 43mpg on rural roads, which is more than you'd expect from a conventional petrol or diesel car. On the other hand, we found that driving on the motorway would rapidly drain the battery, whereupon that figure could tumble to the mid-30s.

Fuel and tax savings

In short, then, it all depends on the type of driving that you do. For those largely covering short trips and rarely venturing on to motorways, the Outlander PHEV can offer a compelling reduction in running costs, not to mention a more refined driving experience. There are also benefits when it comes to taxation, particularly where company car drivers are concerned.

However, these advantages have to be balanced against the purchase price of a plug-in hybrid. At £39,500, the mid-spec Outlander PHEV 4H retails for over £9,000 more than its petrol equivalent and around £4,750 more than the diesel. Private buyers are going to struggle to recoup that deficit on fuel savings alone.

On the other hand, you could argue that the Outlander PHEV constitutes something of a bargain, offering what is essentially an EV driving experience for a fraction of the cost of most of the electric SUVs on the market.

Many automotive experts predict that plug-in hybrids will be a flash in the pan. Once battery technology becomes cheaper, they argue, it will become unnecessary to lug around what is essentially a whole other powertrain. For now, though, cars like the Outlander PHEV seem to strike a pretty attractive compromise between the convenience of a combustion engine and the benefits of a pure EV. ■

Balancing the scales between pay and gender

The Engineer's 2019 survey shows a moderate increase in salary, regional consistency and an urgent need to address gender imbalance across the industry

This year has seen the date of our planned departure from the European Union come and go, without offering any greater clarity on the future of the UK's trading relationship with Europe and the rest of the world. Despite a series of meaningful and indicative votes in Parliament, online petitions and demonstrations on the streets, we are still no closer to untangling the mess that Brexit has become.

The past 12 months have also seen a much greater willingness among manufacturers such as Airbus and Ford to place their heads above the parapet and express their considerable concerns about the impact of the UK leaving the EU without a deal.

And the industry has also been hit by the announcement that Honda will close its manufacturing plant in Swindon in 2021, with the loss of 3,500 jobs.

But how has the turmoil and indecision in Westminster affected the UK's engineering industry? How have salaries fared across the engineering sectors as a result?

This year, 1,568 engineers took part in the survey, from 11 different sectors

Every year, *The Engineer* surveys professionals from across the industry to ask how much they are earning, where in the UK they are based, and in which sector they work, as well as how they feel about their chosen career.

This year, 1,568 engineers took part in the survey, from 11 different sectors.

We have analysed the results to find out which sectors award the highest salaries, how large the gender and racial imbalances are within the profession, and how engineers really feel about Brexit.

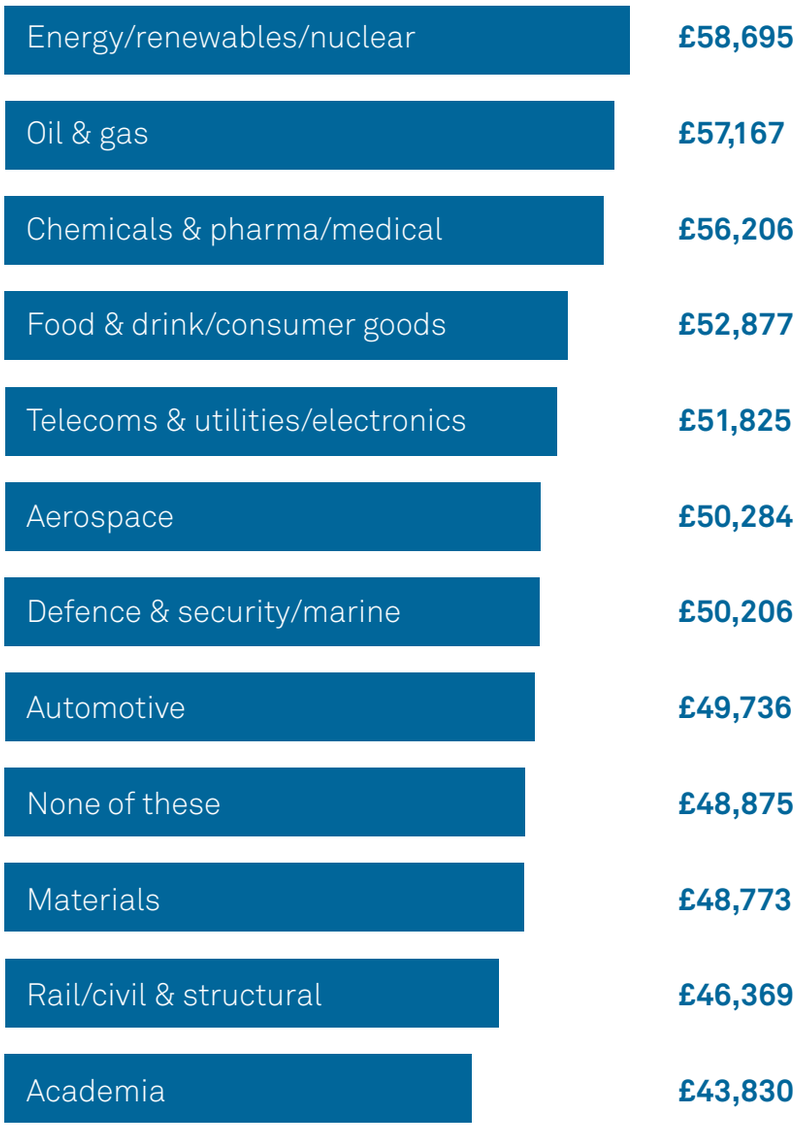
The average salary for engineers in 2019 is £51,253, an increase on last year's average of £47,896, although this may be partly the result of a smaller survey size this year.

Among those surveyed, the proportion of engineers concerned or very concerned about the potential impact of Brexit on the industry has risen from 61.2 per cent last year to 70.2 per cent in 2019.

Concerns about Brexit's impact on their own job security have also risen slightly among engineers this year, up from 37.1 per cent in 2018 to 44 per cent this year.

£43.8k-£58.7k

Average salary by sector



RobHarper Director, CBSbutler

CBSbutler is privileged to be associated with *The Engineer* Salary Survey 2019. We have seen an even spread of respondents from different sectors, career levels and UK locations from across the industry. As always, the findings provide for interesting reading, and especially the percentage of BAME coming into the industry and the gender imbalance, which shows small signs of improvement.

Last year was a fairly turbulent year; the uncertainty of Brexit has impacted the UK industries negatively with spending plans being cut, expansion in certain developments halted, mass job losses and several businesses going into administration. The potential warnings over leaving the customs union and European single market have never been so clear. Although there remains concern about the impact of Brexit on UK investment, employers are still seeking out talent to fill the ever-growing skills gap within the industry. With unemployment at an all-time low, the changing technological needs, AI and automation trends as well as the ever-present skills shortage means that we are still seeing healthy demand for talent within the engineering sector.

Average salaries have seen a healthy increase and it is pleasing to see that this trend is consistent across all of the separate sectors covered in the survey. Clearly, with all the external challenges and the shortages of skills within the sector, it is vital that the workforce is being rewarded. Job satisfaction is not always about pay considerations, but work-life balance, benefits, career progression, learning and development, corporate social responsibility as well as the working day itself. These have all become essential propositions to retain and attract talent.

We have seen an increase in those saying they are happy in their roles with a very healthy proportion indicating they are content to stay in the engineering industry in the next five years. That said, the numbers of people considering a job change has increased. This emphasises the need for businesses to ensure they have appealing and attractive employee value propositions as well as positioning themselves as true employers of choice. We are also seeing the possible impact of Brexit with mobility options, with a big increase in those now considering relocation overseas.

Other key findings were the significant hardening in attitudes toward Brexit; reports showing the concerns around job security as well as increasing concern about the overall impact of Brexit on the industry. This is no real surprise given what we have seen across the past year or so in the news as well as the hearsay across networks and communities. This trend is likely to continue as uncertainty grows. CBSbutler will continue to consult and engage with clients to understand their internal challenges and pressures arising from this and, in addition, wherever possible look to offer advice and expertise around the market trends.

With International Women in Engineering Day (23 June 2019) celebrating its 100th year, it reminds us that we still have a lot to do. Once again, diversity plays a very strong part in the survey this year. The number of female survey respondents has increased slightly in 2019. We have seen a marked narrowing of the gender pay gap for women at junior levels, perhaps a sign that action is being taken to reduce discrepancies. It really is an ongoing challenge. However, we have seen many good examples of attraction and hiring practices, leadership programmes for women and succession plans around inclusion. As an example, one client we partner with offers 'concierge calls' prior to later-stage interviews with an influential female within the organisation. It is also pleasing to see schools offering tasters and learning around engineering. Weekly Stem clubs and lessons are a great way of introducing this area at a grass-roots level.

Thanks once again to all the participants; these surveys are a fantastic pulse check to gauge what is happening in the market we operate within. The UK engineering market is worth trillions to the UK economy and as recruiters, hiring managers, candidates and all interested parties it is crucial we share information and knowledge around what we are all doing to continually support this amazing sector.

Among the different sectors, engineers in the oil and gas, energy, renewables and nuclear sectors continue to command the highest salaries. However, this year their ranking has flipped, with energy, renewables and nuclear engineers earning the highest salaries, with an average of £58,695, up from £52,653 last year.

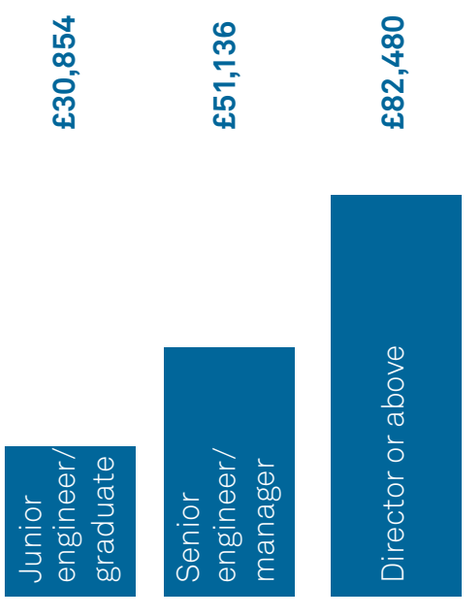
Meanwhile, engineers in the oil and gas industry earn the second highest salaries, with an average of £57,167. This is an increase on last year's average salary in the sector, of £53,193.

Like last year, just under a quarter of engineers surveyed are employed directly in the automotive and aerospace sectors, and three-quarters describe themselves as senior engineers and managers.

£51,253

Average salary for engineers in 2019

Average salary by seniority



Once again, the manufacturing heartland of the Midlands and East Anglia employs the greatest proportion of engineers, with a quarter of respondents working in the region. This is again followed by London and the South East, where 21.4 per cent of engineers say they work.

When it comes to the industry's progress on inclusivity, very little seems to have changed, as once again over 90 per cent of respondents are male, and just under 90 per cent are white. Of those surveyed, 81.2 per cent expect to remain in the profession for at least the next five years, a similar percentage to previous years.

Over the following pages we have analysed in more detail what the results of our survey tell us about the engineering profession in 2019.

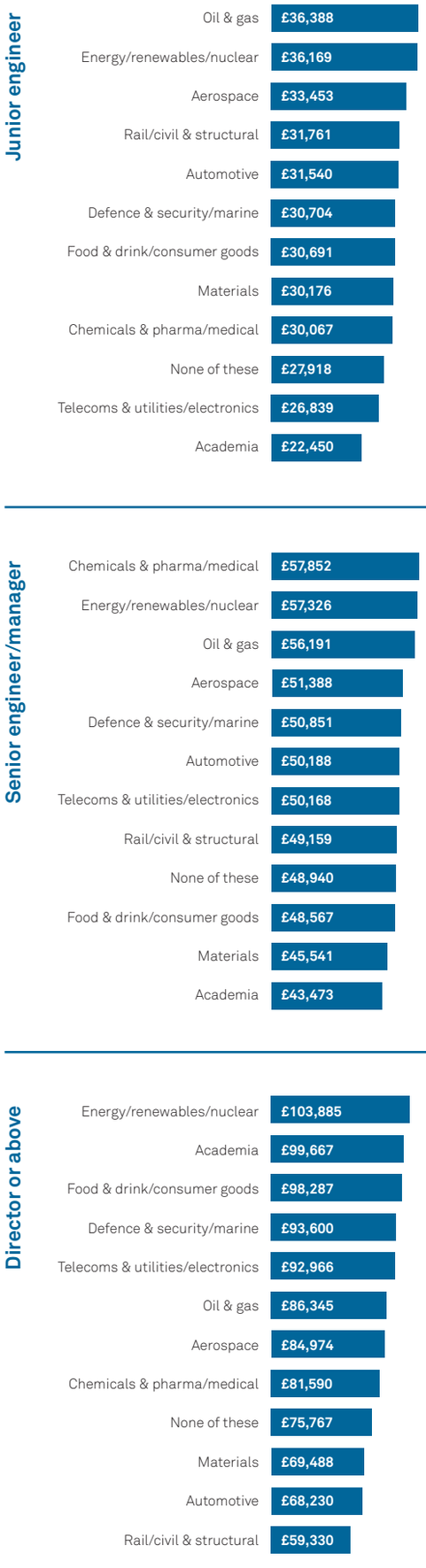
£43,830

Lowest average salary, which is in the academia sector

Average salary by industry

Average salary for a director or above in the energy, renewables and nuclear sector

£103,885



1. seniority

As in previous surveys, the overwhelming majority of respondents – 85.4 per cent – describe themselves as senior engineers or above, reflecting the seniority of *The Engineer* readership.

Senior engineers are once again the largest group of respondents, at 46.6 per cent, a slight increase on last year's figure. Managers are again the second largest group, at 29 per cent, followed by junior engineers at 11.9 per cent, a strikingly similar figure to 2018. Directors make up 6.6 per cent of respondents, with chief executives on 3.3 per cent, and graduate trainees and apprentices on 2.7 per cent.

The majority of engineers responding to the survey have seen a moderate year-on-year increase in their salaries in 2019. Senior engineers and managers, for example, have seen their average salaries increase from £47,971 in 2018 to £51,136 in 2019.

Those describing themselves as director or above have also seen a significant increase in their pay this year, from an average of £72,071 in 2018 to £82,480 in 2019.

Among junior engineers and graduate trainees, pay has remained fairly static this year, however, rising only a fraction from £30,557 in 2018 to £30,854 in 2019.

The average age among engineers responding to our survey is 47.6

Junior engineers and graduate trainees earning the highest salaries can be found in the oil and gas sector, on £36,388, and the energy, renewables and nuclear sector, on £36,169. This is over £10,000 more than the lowest-earning junior engineers and graduate trainees, in academia, on £22,450. However, these results are possibly affected by the small sample size.

The highest-earning directors are those working in the energy, renewables and nuclear sector, with an average salary of £103,885, up from £76,226 last year. This is followed by those in academia, on £99,667, but again, these results may be affected by the small sample size.

Average earnings among senior engineers and managers have risen across all sectors apart from the materials industry this year. In the materials sector, pay has dropped from £47,107 in 2018 to £45,541 in 2019.

In contrast, senior engineers and managers in the chemical, pharmaceutical and medical sector are commanding the highest wages this year, with an average salary of £57,852. This is closely followed by those in the energy, renewables and nuclear industry, on £57,326, and the oil and gas sector, on £56,191.

The average age among engineers responding to our survey is 47.6, two years older than the average in 2018. But like previous surveys, almost half are 50 or above.

The percentage of female directors, managers and senior engineers is slightly higher than in 2018, rising from 5 per cent last year to 6.8 per cent this year. However, this is slightly below the overall picture for the profession this year, in which 7.4 per cent of respondents are female.

2. regions

Our survey has consistently shown that engineers can be found working in all four corners of the UK and beyond, and this year is no exception.

The largest group of engineers, around one quarter, are working in the engineering heartland of the Midlands and East Anglia, a similar percentage to that of last year.

Close behind them, the proportion of engineers working in London and the South East, the second largest group, has held steady, at 21.4 per cent, compared to 21.8 per cent last year. This is followed by engineers in the north of England, at 17.9 per cent, the South West, on 13.4 per cent, outside the UK, on 12.8 per cent, and Scotland, Wales and Northern Ireland, on 9.6 per cent.

This year, engineers based abroad have the highest average salary, at £57,691.

Among the high-earning overseas engineers, those with the biggest salaries on average can be found in the defence, security and marine industry, at £76,632, although this is a very small sample size.

Where are the UK's engineers?	
Midlands or East Anglia	24.9%
London or South East	21.4%
North	17.9%
Outside UK	12.8%
South West	13.4%
Scotland, Wales or NI	9.6%

The second highest earnings overseas can be found among aerospace engineers, on £69,414.

In London and the South East, engineers working in the energy, renewables and nuclear industry have the highest salaries, on £68,222. This is followed by those in the automotive industry, on £63,714.

In contrast, the lowest earners, for the second year running, are those working in Scotland, Wales and Northern Ireland, with an average salary of £46,141. This, however, is a slight increase on their average salary from 2018, which was £44,404.

Their low earnings may well explain why engineers in Scotland, Wales and Northern Ireland are the least likely in all of the regions to be happy with pay, at 38 per cent.

Engineers in the Midlands and East Anglia are the most likely to be happy with their pay, with 46.8 per cent describing themselves as satisfied with their earnings.

Engineers in London and the South East are the most likely to be happy with their job overall, at 62.5 per cent. This is closely followed by engineers in the South West, of whom 62.38 per cent are happy. Engineers in the South West are also the most likely to expect to stay in working in the industry for at least the next five years, with 84.7 per cent declaring they are likely or very likely to remain.

Those unhappy engineers in Scotland, Wales and Northern Ireland are least likely to say they will remain in the industry for the next five years, on 78 per cent.

Midlands or East Anglia

Materials	£59,952
Telecoms & utilities/electronics	£59,346
Oil & gas	£58,214
Energy/renewables/nuclear	£57,600
Food & drink/consumer goods	£54,769
Academia	£53,867
Automotive	£49,642
None of these	£49,317
Aerospace	£49,255
Chemicals & pharma/medical	£47,700
Defence & security/marine	£39,421
Rail/civil & structural	£39,292

North (England)

Energy/renewables/nuclear	£58,654
Chemicals & pharma/medical	£56,739
Oil & gas	£52,966
Defence & security/marine	£52,929
Automotive	£45,538
None of these	£44,511
Rail/civil & structural	£43,842
Aerospace	£41,733
Food & drink/consumer goods	£40,722
Materials	£40,273
Academia	£38,750
Telecoms & utilities/electronics	£34,556

Outside UK

Defence & security/marine	£76,632
Aerospace	£69,414
Chemicals & pharma/medical	£69,204
Energy/renewables/nuclear	£64,240
Telecoms & utilities/electronics	£63,837
Oil & gas	£60,893
Food & drink/consumer goods	£59,419
None of these	£58,601
Automotive	£45,891
Rail/civil & structural	£35,354
Materials	£34,767
Academia	£31,044

Scotland, Wales or Northern Ireland

Oil & gas	£65,571
Materials	£61,500
Defence & security/marine	£53,750
Food & drink/consumer goods	£49,833
Academia	£46,400
Chemicals & pharma/medical	£46,333
Automotive	£45,500
Energy/renewables/nuclear	£44,941
Aerospace	£43,667
Rail/civil & structural	£40,333
None of these	£37,658
Telecoms & Utilities/electronics	£36,267

South West (England)

Chemicals & pharma/medical	£63,500
Rail/civil & structural	£56,833
Energy/renewables/nuclear	£55,133
Oil & gas	£53,889
Telecoms & utilities/electronics	£52,500
Defence & security/marine	£51,769
Materials	£50,000
Food & drink/consumer goods	£49,214
Aerospace	£48,083
None of these	£44,400
Automotive	£41,200
Academia	£38,600

London or South East

Energy/renewables/nuclear	£68,222
Automotive	£63,714
Food & drink/consumer goods	£62,889
None of these	£55,254
Chemicals & pharma/medical	£54,429
Oil & gas	£54,053
Rail/civil & structural	£52,889
Telecoms & utilities/electronics	£52,833
Aerospace	£51,516
Materials	£50,818
Academia	£47,797
Defence & security/marine	£47,775

Sector	Average Salary (£)	Average Age	% content with salary	% happy in current job	% considering change of job	% likely to stay in the industry for five years
Academia	43,830	51.8	25	66.67	30	83
Aerospace	50,284	47.2	43.8	59.8	39.7	84
Automotive	49,736	46.2	42.7	57.8	39.1	86.4
Chemicals & pharma/medical	56,206	47.3	45	56.8	44.04	84.8
Defence & security/marine	50,206	47.1	36.5	52.5	46.7	80.1
Energy/renwables/nuclear	58,695	47.8	49.6	53.4	45.1	72.2
Food & drink/consumer goods	52,877	47.7	41.7	62.6	42.8	74.7
Materials	48,773	49.06	50.7	56.34	46.5	80.9
Oil & gas	57,167	45.9	42.45	57.55	46.2	78.2
Rail/civil & structural	46,369	43.3	38.89	52.7	46.3	79.6
Telecoms & utilities/electronics	51,825	47	35.4	57.5	46.8	82.5

3. sectors

Engineers working across the industry have seen an increase in their average salary this year, from £47,896 in 2018 to £51,253 in 2019.

As in previous years, the highest salaries can be found in those sectors producing the country's energy and fuel. However, this year, engineers in the energy, renewables and nuclear sector have overtaken their counterparts in oil and gas, with an average salary of £58,695. This compares to an average of £52,653 in 2018.

In the oil and gas industry, engineers earned an average of £57,167 in 2019, compared with £53,913 in 2018.

At the other end of the pay scale, engineers in academia received the smallest pay packets on average, earning £43,830. This is a reduction on their 2018 salary, of £44,774, making them the only sector not to see an overall pay rise this year.

Engineers in the rail, civil and structural engineering sector were the second-lowest earners, with an average salary of £46,369.

But proving once again that money does not buy happiness, engineers in academia are the most content in their jobs. For the third year in a row, they top the poll of those describing themselves as happy in their job, at 66.7 per cent, an increase from 56.5 per cent in 2018, and 61 per cent in 2017.

Meanwhile, engineers in the materials industry are happiest with their salary, with 50.7 per cent describing themselves as content with their level of remuneration, compared to just 29.2 per cent in 2018. Engineers in the sector have seen their average pay rise from £47,130 in 2018 to £50,818.

The high earners in the energy, renewables and nuclear industry are the second happiest with their salary, with 49.6 per cent describing themselves as satisfied with their pay. Engineers in the energy, renewables and nuclear industry were also the most likely to feel valued, at 55.6 per cent, followed by those in the chemicals and pharmaceuticals and medical sector, at 55.1 per cent.

Once again, engineers in the automotive sector were the most likely to see themselves staying in the industry for the next five years, with 86.4 per cent expecting to remain in the sector for at least that period. Engineering professionals in academia, meanwhile, are the least likely to be considering a change of job (30 per cent).

Sadly, not everyone is as content with their lot. Engineers in the defence and security and marine industry are the least likely to say they are happy in their job (52.6 per cent). This is followed closely by last years' least happy engineers in the rail, civil and structural industry (52.8 per cent).

£57,167

Average salary engineers earned in the oil and gas sector

50.7%

The proportion of engineers in the materials sector who are happiest with their salary

86.4%

Engineers in the automotive sector who see themselves staying for the next five years

	% that feel valued in their current role	% that do not feel valued
	45	21.67
	49.11	22.49
	45.8	25
	55.1	24.8
	37.2	24.1
	55.6	18.8
	20.8	45
	50.7	19.7
	44.3	23.5
	42.5	15.7
	54.3	18.9

Perhaps unsurprisingly, engineers in academia, consistently among the lowest-paying industries for all but directors and above, are the least satisfied with their salary.

Indeed, just a quarter of engineers in academia say they are happy with their pay this year, down from 34.1 per cent in 2018.

A quarter of engineers in the chemicals and pharmaceuticals and medical industry (24.8 per cent) do not feel valued in their current role, followed by those in the defence and security and marine sector (24.1 per cent).

Despite being the highest-paid industry this year, engineers in the energy, renewables and nuclear sector are the least likely to see themselves staying in the industry for the next five years (72.2 per cent), and among the most likely to be considering a change of job (45.1 per cent).

4. gender and diversity

The gap between male and female pay in the UK workforce has continued to make headlines.

However, in engineering at least, our survey suggests the pay gap is finally shrinking slightly.

The average salary for female engineers responding to our survey in 2019 is £42,913, up from £35,801 in 2018. This is based on a similar spread of seniority to our 2018 survey, although the smaller sample size this year may have had an impact on the results.

In contrast, the average salary among male engineers in 2019 is £51,848, compared to £48,724 in 2018. While this demonstrates that there is still a pay gap between male and female engineers, this has shrunk from approximately £13,000 in 2018, to just under £9,000 in 2019.

As in previous years, this gap can be partly explained by the difference in seniority among male and female engineers responding to the survey. Just 2.3 per cent and 11.3 per cent of male respondents describe themselves as graduates and junior engineers respectively compared to 7.8 per cent and 19 per cent of females.

Similarly, 47.2 per cent of male engineers describe themselves as senior engineers, compared to 38.8 per cent of females, although this gap has narrowed from 2018, when the figures were 45.8 per cent and 30.5 per cent respectively.

Once again, the proportion of male and female managers is very similar, at 29 per cent and 30.2 per cent respectively. These figures are very similar to 2018, although female engineers have overtaken their male counterparts this year.

The pay gap within the different levels of seniority also appears to be narrowing. This is particularly the case among graduates and junior engineers, of whom females are earning an average of £30,700, compared to £30,878 for males.

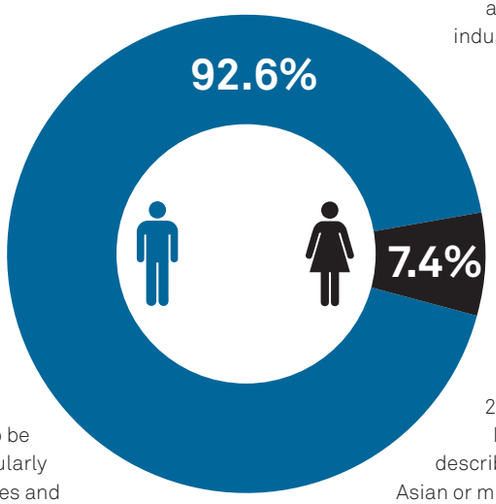
The gap increases to around £6,000 among senior engineers and managers, of whom women earn £45,458 and men £51,548. However, it narrows again to just over £4,000 at director level and above, where women earn £77,900 and men £82,145. This compares to a huge pay gap of £27,542 among male and female directors in 2018, although once again, the smaller sample size this year may have had an impact.

Despite some good news on pay differences, the overall gender imbalance in engineering continues to be a cause for concern. The percentage of female engineers responding to our survey in 2019 is just 7.4 per cent. This has barely increased in the past two years, rising slightly from 7 per cent in 2017 and 7.2 per cent in 2018.

The individual sector with the highest percentage of female engineers is yet again academia, where 16.7 per cent of respondents are women. This is followed by the rail, civil and structural industry, on 11.1 per cent.

But worryingly, this year, just 1.1 per cent of engineers responding to our survey from the food and drink and consumer goods sector are women, compared to an already very low 2.6 per cent in 2018. This is the second year running the sector has had the worst gender imbalance throughout engineering, suggesting more needs to be done to attract women to the industry.

The gender balance continues to be a cause for concern



The diversity gap in engineering, meanwhile, is continuing to narrow only marginally each year, with 87.9 per cent of respondents describing themselves as white in 2019, compared to 88.6 per cent in 2018, 89.3 per cent in 2017 and 92.1 per cent in 2016.

In 2019, 9.5 per cent described themselves as black, Asian or minority ethnic, compared to 8.1 per cent in 2018.

This year, the sector with the highest percentage of non-white engineers is academia, with 15 per cent, followed by materials, with 12.7 per cent.

In contrast, just 5.1 per cent of respondents from the defence and security and marine sector described themselves as non-white.

Engineers describing themselves as non-white are earning an average of £42,580 in 2019, compared to an average of £51,963 among white engineers.

Average salary by gender by seniority

	Junior	Senior	Director
Male	£30,878	£51,548	£82,145
Female	£30,700	£45,458	£77,900

Upskilling for Industry 4.0

An expert panel discusses how UK manufacturing can ensure it has the right skills to make the most of the new technology

A critical consideration for any company looking to go down the Industry 4.0 route is ensuring that it has the right skills to fully understand and exploit this rapidly evolving area of technology.

In this Q&A feature, we asked some of the UK's key Industry 4.0 stakeholders how the concept is changing UK manufacturing's skills requirements and what measures employers can take to ensure that they have the right skills on board.

How is Industry 4.0 shaping the manufacturing sector's skills requirements?

NJ: Industry 4.0 is demanding a much more diverse skill set within manufacturers. A requirement to understand data flows, and the potential value of data, while retaining expert knowledge, means we are now developing the need for more digitally enabled engineers.

The skills required include a knowledge of what data could be useful to capture – this allows the identification of the right sensors to capture the required data; of data flows and the interoperability of data; of the use of artificial intelligence and analytic tools to convert this data into information; of the application of expertise in the interpretation of this information; and the use of augmented reality/virtual reality and digital twins to deliver knowledge to the engineer.

BH: First, we're going to need the domain and process skills of people who work in our factories today. Industry 4.0 will augment human effort, rather than replace it, but there are also many new roles emerging in app development, sensing, robotics, data analytics and virtualisation. This means today's employees will need to develop new capabilities and embrace new tools and digital methods.

Overall, we will need more automation and software engineers, people who can operate between the virtual and real worlds as we adopt increasingly sophisticated digital twins of products and production processes. New entrants to the industry will need to be agile, digitally competent, creative, collaborative and practical. It's really important we work together as an industry and academia to develop the right applied learning and training pathways to help achieve these outcomes.

DE: The government review which led to Made Smarter identified that UK manufacturers will increasingly need to compete by creating value through the smart use of industrial digital technologies (IDT).

One of the biggest barriers to IDT adoption is lack of skills. The skills shortage is particularly acute in the industry, where there are shortages of engineers and product designers, and within other key manufacturing trades, especially at the higher technical levels (for example, Level 4/Foundation Degree equivalent). If the UK is going to lead the way in digitalising manufacturing, it needs enough people with the skills to support them, either within current businesses or as pioneers at start-ups.

What is your organisation doing to address this skills gap?

NJ: Our strategy for the training centre is to grow our engineering apprenticeships and to work closely with industry partners to develop a curriculum that meets the changing needs of manufacturing businesses.

We work hand-in-hand with our industry board and wider employer base to ensure our curriculum is aligned to LEP priorities, including digitalisation in manufacturing. We have moved away from frameworks in apprenticeships and now deliver the new standards that incorporate

Meet the panel

Nikki Jones (NJ), director of the University of Sheffield AMRC Training Centre. Based in Sheffield, the AMRC Training Centre works with employers to identify and provide the skills that manufacturing companies need to compete globally, from apprenticeship through to doctorate and MBA level.

Donna Edwards (DE), programme director for the Made Smarter North West Pilot. The Made Smarter North West Pilot is testing the most effective ways to engage with manufacturers and encourage them to adopt technologies.

Brian Holliday (BH), managing director for Siemens Digital Factory. Siemens is at the forefront of driving Industry 4.0 adoption in the UK and its digital factory division offers a portfolio of technologies to help manufacturers embrace the vision.

the drive to Industry 4.0. We have also developed degree provision to meet the higher and diverse needs of the industry.

BH: We're trying to embed the excitement of Industry 4.0 into the DNA of the education system and across the vocational skills agenda. We already create Key Stage 2 content for teachers and support applied learning opportunities such as hackathons. Another initiative we actively support is Greenpower which enables school children to apply learning through competition in designing, building and racing electric carts.

Post-16, we are currently training around 560 apprentices and 120 graduates across our UK businesses and are actively working with colleges and universities to develop up-to-date content aligned to the needs of Industry 4.0.

DE: Via the Made Smarter North West Pilot, businesses can attend workshops and utilise specialists who will help enhance SME workforce skills. Businesses can also access student placements to support the implementation of digital technology projects and skills development. Strong leadership skills are essential to drive this change.

The Made Smarter leadership development programme delivered by Lancaster University Management School will equip business leaders with the vision, the skills and an approach to pursue smarter manufacturing.

The Made Smarter national skills group is working across engineering and manufacturing sectors to identify the future skills needs of employers. The results will be shared with BEIS and DfE to inform and develop the required technical infrastructure.

What impact are these measures having?

NJ: We have growth in apprenticeship numbers and those progressing to higher level study. We are also experiencing growth in programmes such as technical support, robotics, CNC/CAD and design, along with improved and increased engagement with large multinational organisations. We have excellent case studies from companies with increased productivity and technical/digital abilities of their apprentices, who are positively impacting on their business.

BH: By focusing on the skills gap we are developing capabilities and recruiting talent for the future now. New recruits are influencing the future of our organisation, actively shaping our business, our culture and our approach to problem solving and technology adoption.

To offer a concrete example, our 'junior factory' operating in Congleton, Cheshire, is a factory within a factory – run entirely by apprentices. It has its own management team; a managing director, a finance director and other roles too. It reshored the assembly of fans used inside our variable speed drives that are sold across the world. That's an applied learning opportunity that delivers impact in a real production environment.

02

03

01 Apprenticeship growth could address the skills shortage

02 Training centres are meeting industry needs

03 Young people can learn essential industry skills

DE: The immediate priority is for the industry and government to increase IDT skills in the existing workforce. This will be achieved in conjunction with employers who can seize the opportunity to upskill the workforce through development of their employees. Young people will acquire basic digital skills by default, but to be truly employable, more advanced skills are required. Made Smarter has set an ambitious goal to reskill and upskill one million workers over the next five years. Its focus, although not exclusively, will be on SME workers (who represent a third of industrial sector employees). This will be achieved by the increased coordination of IDT-related skills initiatives through the Institute of Coding, the upcoming Institutes of Technology, the national college programme, the National Retraining Scheme, apprenticeship programmes, and the wider further and higher education system.

What advice would you give to other organisations looking to build their in-house Industry 4.0 expertise?

NJ: Understand the challenge you are trying to solve, deliver solutions through 'agile sprints' that come together as larger solutions, embrace failure (experiments) but learn from your experiments – and be prepared to ask others for help starting on your digital transformation.

BH: By 2022, UK industry needs to recruit 1.8 million engineers. We need to increase the numbers we are training and ensure that we have are multi-skilled people who understand Industry 4.0 trends such as virtualisation, mass-customisation, data analytics and servitisation.

We won't build factories in the future without digital simulation and will be increasingly reliant on data for decisions. Today's trends will increasingly impact companies, which is why it's worth investing in skills and pilot adoption activity today to help start a productivity journey anchored in emerging digital technologies.

Many workforces also feature mature talent at one end, apprentices and graduates at the other, with a gap in the middle. To fill that gap we need to tap into the experience of the 'valve whisperers' before they leave the industry and get them to download their knowledge to the next generation.

DE: Develop a road map for digital transformation within your business. Ask yourself where your business will be in two, five or even 10 years and what skill sets you will need.

Industrial digital technology adoption is not all about 'techies' – there are a variety of skill sets required, from analytical thinking, information management, problem solving, understanding and interpreting data. Think broadly about the skills most useful for your business and transferable skills which will play a key part.

Utilise the specialist support Made Smarter offers by registering at www.madesmarter.uk and review the skills matrix to identify new or emerging skills which your business may need in the future. ■

Industry 4.0 offers a Brexit lifeline

Amid the political turmoil, there has never been a more important time for UK manufacturers to invest in technologies that can boost productivity, writes Make UK CEO Stephen Phipson

A costly divorce. A chocolate orange. A cake. A cliff edge. These are just a few of the metaphors that have been used to make sense of what is happening in the UK's departure from the European Union.

Whatever people choose to refer to it as, we can all agree that Brexit is complicated, and, as we have seen from the negotiating process, time-consuming, taking up the majority of discussions regarding business, policymaking and daily life. The all-encompassing nature of Brexit, however, means that other issues pressing to the current and future UK economy, such as the advancement of UK industry into the Fourth Industrial Revolution (4IR) which is rapidly gaining momentum elsewhere, are falling by the wayside.

Boosting productivity

The primary benefit of the technologies of the 4IR to UK industry is that they can help to improve productivity in firms, an issue that is of utmost importance given the stagnating performance of UK productivity over the past decade.

Many manufacturers have been engaging in the technological advancements associated with 4IR for quite some time, although often not under the label of 4IR, as a means of engaging in business improvements through technology.

However, despite initiatives in the past few years, such as the Government's Made Smarter review and subsequent funding programmes to increase the adoption of industrial digital technologies within manufacturing, the UK is still behind several international counterparts in metrics for adoption of, and readiness for, 4IR.

The Economist's 2018 Automation Readiness Index ranked the UK eighth, behind countries such as South Korea, Germany, and Singapore. The report noted the priorities of the Industrial Strategy and digital strategies such as AI and robotics R&D were a strong point for the UK, but also highlighted weaknesses in areas such as education policy and the need to support lifelong learning.

With Brexit taking up so much of UK policy-making time, it is important that the UK takes steps to improve adoption, and even aims to become a global leader of 4IR technologies and techniques, to raise productivity levels and avoid falling further behind competitors.

The truth is, there has never been a more important time for manufacturers to engage in the Fourth Industrial Revolution. The UK economy is globalised in nature and there will be an inevitable shift in the way that our economy interacts with others. As such, it is vitally important to continue to improve all component parts of our economy – manufacturing being one of the most important – to ensure that it remains competitive post-Brexit.

Many aspects of 4IR can even offer a lifeline to mitigate concerns brought about by Brexit. The manufacturing sector has been dealing with labour and skills shortages for some time now, and the potential loss of the EU workforce has the possibility to worsen this skills gap.

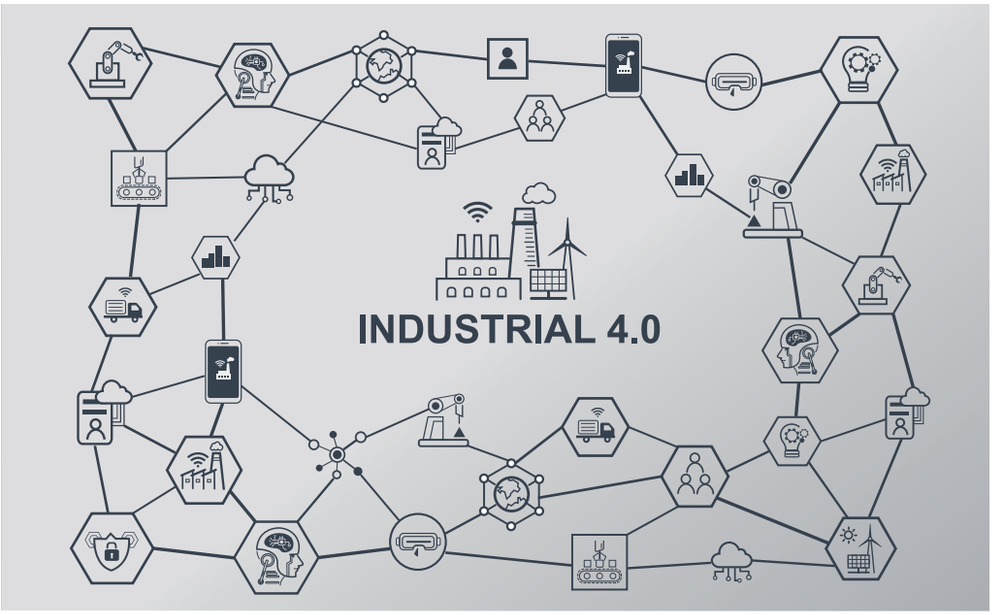
The technologies of 4IR, such as collaborative robots (cobots), automation and AI, can help to supplement existing workforces, allowing workers to work collaboratively with technology, particularly on repetitive and low-skilled tasks, freeing up time to focus on the more knowledge-based elements of their roles.

Information gained from sensors in the Internet of Things (IoT) can provide 'big data', allowing manufacturers to gain further insight into what the most efficient equipment is, increase machine utilisation, and give full traceability to component parts and finished products. This allows manufacturers the possibility of improving their processes and supply chains, and the ability to keep their customers better informed.

A chance to lead

Whatever metaphor is most apt for the ongoing developments in Brexit, the UK has the opportunity now more than ever to take full advantage of the opportunities that 4IR offers. Rather than getting through the global race by focusing solely on trying to jump the Brexit-shaped hurdle, it can find its way to the top of the group in 4IR and become the leader of the pack.

Either that or a mix of other metaphors that represent a risk to global competitiveness in manufacturing, a continuation of flatlining productivity levels and the chance of being left behind in the current industrial revolution after being a world leader in the previous three. It's possible that if we get too distracted by the 'B-word', we may have missed an important opportunity to improve productivity and the economy. ■



UK to use robots and AI to tackle nuclear waste

The UK's National Centre for Nuclear Robotics is developing machine vision, artificial intelligence and advanced robots to decommission 4.9 million tonnes of material, as Andrew Wade reports

Launched in 2018, the National Centre for Nuclear Robotics (NCNR) is a consortium of eight universities led by the University of Birmingham and backed by £42m of funding. Its primary mission is to develop robotic solutions that can characterise, handle and decommission the huge amounts of waste generated by the nuclear industry since the early 1950s.

Using current technology, the clean-up would take 120 years and an estimated one million human entries into contaminated zones, at a cost of approximately £234bn.

According to the NCNR, developing robots capable of taking up the task is a necessity for a number of reasons.

"There's a large amount of radioactive waste that humans can't go near at all," Prof Rustam Stolkin, co-director of the NCNR, told a press event at the Royal Institution. "And where we have technology that's now becoming capable to do the complex things that human workers do, we have an ethical and moral obligation to stop using humans in those roles. We don't send Victorian children up chimneys any more. It's not socially acceptable."

Where humans can deal with nuclear waste, they must be kitted out in air-fed plastic suits, usually wearing multiple layers and gloves for protection. But they must often also operate heavy tools, such as disc grinders, for dismantling the metal piping and containers that make up much of the legacy waste. It's tiring and dangerous work, limited to just a couple of hours at a time. And for every barrel of high-level waste that is decommissioned, 11 further barrels of secondary waste – such as contaminated suits and gloves – are created. Using machines would help cut down on this secondary waste, but the sector has largely proved resistant to the adoption of robotics.

"Nuclear is a profoundly un-roboticised industry," said Stolkin, head of Birmingham's Extreme Robotics Lab, which is at the vanguard of NCNR's research. "The reason that you've been able to have this (robotics) revolution in manufacturing is because manufacturing is a very structured, constrained, precise environment."

> "We have an ethical and moral obligation to stop using humans in these roles"
>
> Prof Rustam Stolkin, NCNR

Conversely, nuclear waste is completely unstructured, and therein lies the challenge. What is required is machine vision and AI that can characterise waste objects with no prior knowledge, enabling robots to deal with the waste autonomously. While this is a relatively simple task for a human – radiation levels notwithstanding – it is incredibly complex for a machine and represents the bleeding edge of current AI research.

"Autonomous robotic grasping is the current forefront frontier in international robotics and AI research," Stolkin explained. "You can't buy a robot from an industrial robot manufacturer that can do that stuff. Well, we buy the robots, but we make them behave in clever ways."

On top of this, the robots obviously need to be resilient to high levels of radiation, as well as capable of mapping and navigating areas where no human has set foot in 70 years. And it is not just grasping that the robots will be required to do. NCNR has already used a robot to cut contaminated steel with a laser, the first time a robot has been allowed to act autonomously inside a radioactive zone.

NCNR has been involved in operations at Chernobyl, using drones to map radiation levels in the infamous 'Red Forest', the most highly contaminated area following the 1986 nuclear disaster at the plant.

Under the lead of NCNR co-director Prof Tom Scott, and working alongside Ukrainian authorities, the team successfully identified a previously unknown radiation hotspot within the forest. It is hoped the drone mapping system, along with other NCNR advances, can be spun out to commercial applications beyond the nuclear industry. ■

Inspection system retains accuracy on non-reflective surfaces Supplier: Micro-Epsilon

Non-contact surface inspection system uses deflectometry and fringe projection

The surfaceCONTROL system complements the company's existing reflectCONTROL system, which is designed for shiny, reflective and painted surfaces and is used by automotive manufacturers including Daimler, BMW and Honda.

By contrast, the new system is designed for diffuse surfaces such as uncoated metal, plastics and ceramics.

Comprising a 3D smart sensor and two optional software packages, surfaceCONTROL scans the surface of the component it is inspecting and generates a 3D point cloud. This is then analysed using specifically developed software to recognise defects and discontinuities.

Deviations of from 5µm in height can be detected reliably on measurement areas from 290 to 210mm² up to 570 x 430mm². The

achievable lateral resolution between 0.25mm for small areas and .5mm for the largest area. Strong curvatures can also be detected, and by using planning software based on CAD data larger test subjects are separate in several measuring positions that are approached one after the other. The system is designed so that several robots can operate within one cell on the same test object so that inspection times can be adapted to suit production cycle times.

surfaceCONTROL is available in three different versions: surfaceCONTROL Robotic for inspection of large components designed to use a sensor mounted to robot arm; surfaceCONTROL Mobile, comprising a laptop and a sensor mounted on a tripod which can be transported to different locations in a carrying case to measure services approximately 410m x 300mm; and surfaceCONTROL Compact, designed to measure pieces approximately 200m x 300mm, with the sensor integrated into better enclosure or cabinet. Micro-Epsilon suggests that this system is ideal for in-line inspection of injection moulded or die cast components. ■

Latest non-contact tool setting product to be launched in Hannover Supplier: Renishaw

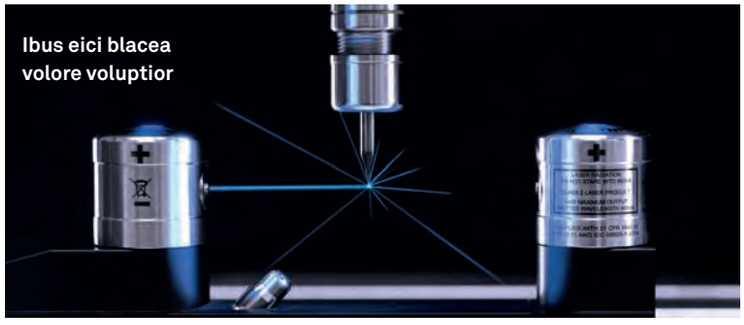
A real step-change in tool measurement accuracy, say manufacturers

Renishaw has earmarked EMO Hannover 2019 for the launch of its NC4+ Blue system, the latest in the company's non-contact tool setting products.

Building on the enhanced NC4 range of tool setters, the NC4+ Blue is Renishaw's latest evolution of the non-contact tool setter, delivering what is claimed to be a step-change in tool measurement accuracy, with tool-to-tool performance proven to ISO230-10 standards.

Featuring industry-first, blue laser technology (patent pending) and improved optics, Renishaw's NC4+ Blue systems deliver significant improvements in tool measurement accuracy, ensuring components can be machined more accurately and efficiently.

Compared to red laser sources found in conventional non-contact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tool setters, blue laser technology has a shorter wavelength, resulting in improved diffraction effects and optimised laser beam geometry. This enables the measurement of very small tools, whilst minimising tool-to-tool measurement errors.

NC4+ Blue systems also use Renishaw's latest non-contact tool setting software packages, which include a new dual measurement mode with auto optimisation technology. Combined, these features ensure fast and reliable tool measurement, even in wet conditions.

NC4+ Blue support is now embedded into Renishaw's range of graphical user interfaces, including on-machine and mobile apps such as Renishaw Set and Inspect and GoProbe. These programming platforms are said to be ideal for users who are new to probing or have little machine code knowledge, whilst still offering operational benefits to more experienced users.

Renishaw further adds that its technologies provide the data that enables intelligent decision-making for Industry 4.0. On-machine tool measurement allows manufacturers to automate and optimise their processes and minimise quality problems and CNC machine stoppages.

With the latest version of Renishaw's on-machine Reporter app, users can view historical tool data captured by the NC4+ Blue and export the results for use in their chosen software and control systems.

Renishaw will be in Hall 6, stand D48 during EMO Hannover 2019, which runs between 16th – 21st September. ■

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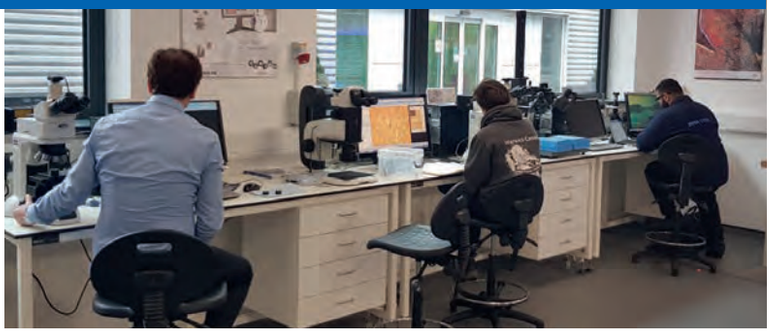

New **Buehler** Solutions Centre

Materials Engineering Centre, Warwick Manufacturing Group (WMG) Available for Metallography & Hardness Testing Training, Process Improvement, Consultations

Buehler, ITW Test & Measurement GmbH announces a new location - Buehler is pleased to announce a new location move for its United Kingdom Solutions Centre to a brand-new facility within Warwick Manufacturing Group (WMG), an academic department of the University of Warwick, with over 600 staff, and a strong relationship with over 1000 global companies and offering support to over 1800 SMEs through dedicated programmes. The Buehler Solutions Centre is a collaborative venture between WMG and Buehler to better support academic and industrial research on various technologies ranging from additive manufacturing, energy storage and system characterisation, machining of metallic and composite materials, material processing and joining technologies among others.

The new laboratory is housed within the Materials Engineering Centre and is equipped with the latest metallographic sample preparation equipment ranging from abrasive and precision sectioning equipment, high end grinder-polishers for sample preparation and a wet characterisation unit for chemical characterisation of materials.

The centre also houses a microscopy and hardness suite that is equipped with a range of latest Buehler hardness testers with various degree of automation and testing capabilities, and Nikon optical microscopes interfaced with image analysis software ideal for metallographic analysis.

Paul Johnson, WMGs technical services manager notes, "This well-equipped and well-appointed microscopy, metallographic and materials preparation laboratory housed with our new Materials Engineering Centre provides a valuable resource for the entire group. WMG's continued success in the wide variety of research fields, in which we operate is built on having the ability to utilize the very latest equipment - which is always well maintained and highly accurate. The opportunity to work side by side with a leading developer, producer and supplier of the latest metallographic preparation and characterization equipment is a mutually beneficial relationship where Buehler can gain knowledge to develop their product range whilst working with the very latest materials that we are developing and we, can further develop and manufacture these material products. The great relationship that we have built here continues to facilitate that goal."

Metallography Classes are held at the centre throughout the year by Buehler. The next class will be held July 16-18, 2019. For further information or to make arrangements for a visit or tour please contact Dr E Mogire at evans.mogire@buehler.com.

Dr. Mogire and the recent graduates of the metallography class.

Dr. Evans Mogire, Buehler European Technical and laboratory manager explains, "The new Buehler Solutions Centre allows us to better address complex customer application and/or technical requests relating to metallography, as well as offering exceptional facilities for conducting and hosting seminars and training in an ever-changing materials world". He also stresses, "The collaborative relationship with WMG is one of a win-win relationship, and as a resident material scientist within this facility, the synergetic relationship with WMG offers Buehler and its stakeholders' exceptional exposure to cutting edge characterization technologies to address metallic, polymeric, ceramic, and composite materials solutions".

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June 1960

Floating a new idea

The Engineer assessed Ford's air-cushioned vehicle concept

In the late 1950s, public transport in the US was a multi-billion-dollar industry being eclipsed by a rise in private car ownership that saw a fifth of all households owning more than one car.

By 1960, the US automotive market – excluding business and government fleets – was estimated to be worth $36bn, a figure broken down into $16bn on car purchases and $20bn on maintenance and operation.

By comparison, the market for public transport – incorporating airlines and taxis as well as buses and trains – was worth $3bn and Ford Motor Company was working on a project designed to take a share of the spoils by connecting cities at speed.

The idea was, in fact, 30 years-old when it was presented to an audience at the Institution of Mechanical Engineers by a certain Mr VG Raviolo, Ford's executive director of engineering staff. By that time, the concept of the Ford Levacar – a wheel-less vehicle supported on a thin film of air – was out of the lab and operating as a single-passenger vehicle on a circular track that was 28ft in diameter.

According to our correspondent, Levacar was envisioned as a 40 to 60 passenger vehicle operating at speeds of about 300mph.

"In this form it would provide a high-speed public transport system which would fill the gap between wheeled vehicles and high-speed aircraft, operating directly between city centres at intermediate distances of up to 1,000 miles," said *The Engineer*.

In his presentation, Raviolo told IMechE that a working system would likely consist of two rails supported several feet off the ground and that commercially available degrees of finish and tolerances were up to the job. The supporting cushion of air – between the faces of the 'levapads' and track surfaces – was estimated to be between 0.02 and 0.05 inches.

930 June 3, 1960 THE ENGINEER

Locomotion

The trend for sources of power to become cheaper and lighter has allowed vehicle performances to increase rapidly, and the wheel, once established on all high-speed vehicles, is now pressed by other systems of motion ; on the fastest earth-borne vehicles, used for imposing high accelerations on aircraft and rocket equipment, the wheel is invariably displaced by steel runners on highly accurate brakes. For many more mundane purposes the tolerance of the wheel to irregularities is invaluable and the stability it provides is indispensable, and the Goodyear Tire and Rubber Company has installed at Akron, Ohio, a tyre testing dynamometer able to impose speeds of over 500 m.p.h.

The machine, built by the Adamson-United Company of Akron, has two modes of operation ; tyre-on-rim for the highest speeds, and tyre-on-drum for speeds up to 320 m.p.h. The 10ft drum is used primarily for aircraft tyres, since it can simulate take-offs and landings ; a stationary tyre can be loaded on to the drum at full speed with a force of 30,000 lb. The tyre-on-tyre unit has tested at 510 m.p.h. the tyres used on the Thompson "Challenger", the four-engined car which holds the American national land speed record of 372.8 m.p.h. A batch of Goodyear passenger car tyres were tested to destruction by increasing speed under simulated service load, failing at between 297 m.p.h. and 305 m.p.h. ; a failure can be seen RIGHT, the bead of the left-hand tyre having left the wheel rim.

More than thirty years ago Andrew A. Kucher, now Vice President, Engineering and Research, Ford Motor Company, conceived the air-bearing vehicle, supported clear of its tracks by "levitation" on a thin film of air. The passage of a "Levacar" would be virtually frictionless, and while propulsion can be achieved with moderate efficiency at speeds of, say, 300 m.p.h. steering is not easily achieved to the standards of surface vehicles ; hence it is anticipated that such vehicles would be run-bound.

Two possible forms of "Levacar," propeller-driven and jet-propelled, are seen here in model form with Mr. Victor G. Raviolo, executive director of engineering staff, F.M.C., who discussed these and other developments at the Institution of Mechanical Engineers last month. (See page 931).

For applications where a prepared track cannot be provided, an air cushion vehicle or ground effect machine may prove valuable. Many of these machines float on a low-pressure air cushion contained by a curtain that deflects when irregularities are encountered. But the patents of Mr. C. S. Cockerell are based on both containing and supplying the air cushion with a jet wheel ; the force needed to deflect unit length of the jet to flow parallel to the ground divided by the ground clearance is the pressure differential available. A vehicle with a long perimeter can attain large ground clearances without excessive energy consumption, and could pass over open areas or even hedgerows and rough ground. The prototype "Hovercraft" was built by Saunders-Roe, Ltd., and fitted with an Alvis "Leonides" jet wheel and the control jets and, later, a Blackburn-Turbomeca "Herbert" 330 turbine providing forward thrust ; it is seen, RIGHT, in London last week, "hovering" above the River Thames. Notice the sheer forward to keep spray from obscuring forward vision, and the bellowed-turned intake for the turbine, also the result of the intense spray created when the high-momentum jet passes over the water surface.

In experiments, air was supplied at 50 to 60lb per square inch to a 450lb Levacar that required 15hp for levitation and 2.5hp to propel it at 20mph. *The Engineer* recorded that in the case of a larger vehicle, 25hp would be required per 1,000lb of gross vehicle weight "so that a 40-passenger model with an estimated gross weight of 28,000lb would require 700hp for levitation".

"The energy required for levitation remains substantially constant while the forward speed of the vehicle increases, but the air drag rises rapidly, of course," said our correspondent. "Thus, to move the same 40-passenger vehicle at 200mph would require an additional 320hp and at 400mph, 2560hp. Consequently, the proportion of energy absorbed in levitation decreases substantially with speed, and the Levacar is seen to be most efficient at high speeds."

Certain elements of Levacar were still in development and Raviolo couldn't reveal too much about the vehicle's aerodynamics, except to say that drag and side winds would be countered by "selective air feed to the multiple levapads". Propulsion, however, would be delivered by a shrouded propeller with a low tip speed to reduce noise.

"The question of noise is particularly important if such vehicles are intended to operate to and from the centres of cities: according to the speaker, the noise level of a Levacar would be comparable to that of an express train at 80mph," *The Engineer* said.

It was further added that to be economical, Levacars would have to operate above 125mph – preferably between 200 to 500mph – leading to questions about braking safely at speed. According to Raviolo, the Levacar would be brought to rest by a combination of reversed propeller thrust and air brakes or flaps, followed from 30 or 40mph by the application of bellows-actuated pads lined with brake material.

"In the event of engine failure, the vehicle would have to rely on the brake pads, which were thought to be adequate dealing with such emergencies, but this still had to be proved in full scale tests," *The Engineer* said.

History has told us that Levacar failed to come to fruition, although in 1960 Raviolo was confident that the cost of the system – including land clearance but not acquisition of rights of way – would be approximately $75,000 per mile.

"The possibility of direct high-speed travel between the centres of cities is attractive but the economics of the proposed system call for further, more detailed examination," concluded *The Engineer*. ■ JF

Word of the issue

Anthony Poulton-Smith explores origins of the word 'pin'

One of the earliest forms for a fastener must have been the pin. Effectively a nail of finer design and with a sharper point, it is only the usage of a pin which makes the basic design any different.

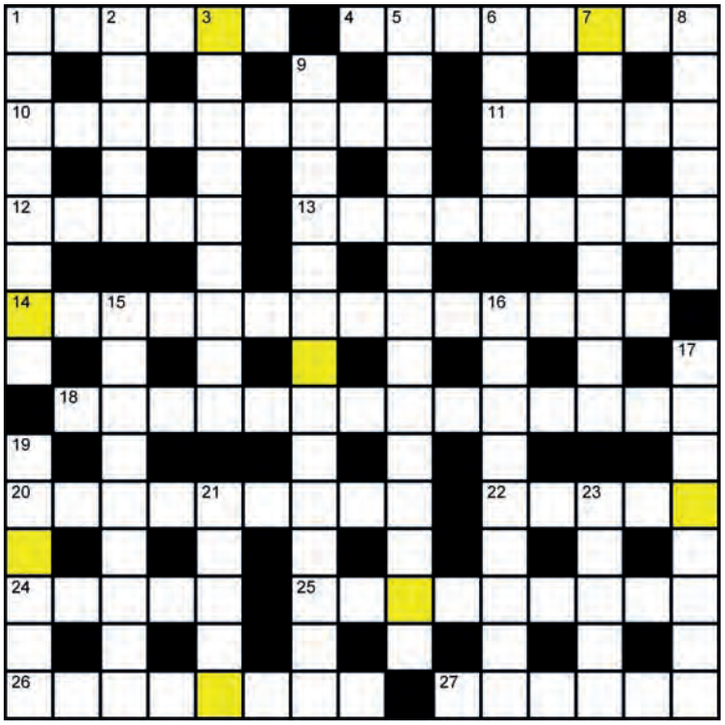
Pins come in many forms – everything from safety pins to cotter pins, and others too numerous to mention.

Etymologically, all 'pins' are derived from the same source as 'peg'. Again, each has the same use but, in general terms, a peg is wooden while a pin is metal. All are from Proto-Germanic 'penn' which has given several words, most notably unchanged in referring to a hill or mountain peak, particularly a sharp peak.

Ultimately this comes from the same source as Latin 'pinna', meaning a wing as a plural and feather when singular, and taking it back to the Proto-Indo-European root some 8,000 to 12,000 years ago is from 'pet' (to rush and latterly to fly). Other modern words to come from this ancient root of 'pet' include spike, pinnacle, plume, and fin.

Bigpicture

German start-up Lilium has completed the maiden flight of its all-electric air-taxi, a five-seater VTOL tilt-jet capable of covering 300km in 60 minutes. Known as the Lilium Jet, the prototype aircraft is powered by 36 electric jet engines. The main wings house 24 engines, while a smaller wing bank at the front of the plane is home to the remaining 12.



Prizecrossword

When completed rearrange the highlighted squares to spell out a word for waste mining materials. The first correct answer received will win a £20 Amazon voucher. Email your answer to **jon.excell@centaurmedia.com**

Across

1 Expresses contempt or lack of interest (2,4)
4 Amassing so as to keep for future use (6,2)
10 Common people generally (3,6)
11 To cut open (5)
12 Restoration of someone to a useful place in society (5)
13 Site of a major nuclear disaster in 1986 (9)
14 Incapable of being pressed together (14)
18 Frames of a human being (8,6)
20 Set of pieces of creative work (9)
22 Obtain by seizing forcibly (5)
24 Located closer to a centre (5)
25 Act of having and controlling property (9)
26 Something of sentimental value (8)
27 Seize and takes control by force (6)

Down

1 Shape that is generated by rotating an ellipse (8)
2 Measure the force exerted by a mass (5)
3 Powerful nuclear weapons (4,5)
5 Coupling that allows movement in all directions (9,5)
6 To bury or entomb (5)
7 Loose high-necked blouse with long sleeves (9)
8 Petrol jelled with aluminium soaps (6)
9 Activity undertaken by a sparky (10,4)
15 Logical and orderly relation of parts (9)
16 Factory making rails, gratings etc. (9)
17 Forms of the same element (8)
19 Transmission from Earth to a spacecraft (6)
21 Business organisations (5)
23 Compound with two hydrocarbon groups linked by an oxygen atom (5)

May's highlighted solution was: **METALLURGY**. The winner was: **Robert Burns**

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