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THE ENGINEER

JULY 2021

Going underground

How DARPA's subterranean robotics challenge is pushing autonomous technology to its limits

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COVER IMAGE: *Team Explorer*

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SCAN ME

JON EXCELL

Why low carbon innovation is a win win for UK industry

Despite plenty of evidence to the contrary it's still often - and usually erroneously - claimed that the push for net zero inevitably entails some sort of trade-off or compromise: that energy sustainability and improved performance are incompatible aims.

Some net zero sceptics, including occasional visitors to The Engineer's website, even argue that the UK's low carbon ambitions represent some kind of existential threat to its broader industrial competitiveness, claiming that an obsession with green technologies will hamper UK's engineering's ability to hold its own on the world stage.

This issue's special report on energy sustainability in the defence sector (page 28) puts forward some compelling arguments for why that isn't the case, and - with the help of a panel of leading experts - explains how embracing the green technology revolution isn't just good for the planet, but absolutely key to future competitiveness.

One might imagine that in the world of defence concerns over climate change would take a back seat to issues of global security. But as our panel explains, as well as minimising the sector's impact on the environment low carbon innovation will also deliver some significant operational advantages: whether it's through the development of more agile, lightweight and stealthier vehicles, or the adoption of methods of energy production that free us from the volatilities of global energy markets.

The key point made by our panelists - though focused on defence - is arguably relevant to all sectors of the engineering economy: sustainable solutions are often simply the best solutions, regardless of their positive environmental credentials. Indeed, as one of our panelists - retired general and MOD climate change lead Richard Nugee - reminded us, defence simply wouldn't be investing in low carbon if it presented a risk to military effectiveness. "Let's be in no doubt," he told us, "we're not going to sacrifice our capability for just being green, because if you come second in a war but you're the greenest military you've still come second in the war."

Finally, a reminder that that The Engineer's annual celebration of engineering collaboration, the Collaborate to Innovate awards, is now open for entries. So if you're involved in an innovative engineering collaboration, which you believe could have a significant impact in its eventual application area, then we'd love to hear from you. You can find out more including how to enter at **https://awards.theengineer.co.uk**

Jon Excell

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Digital twins, hydrogen trains and the semiconductor shortage

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SCAN ME

MISSION STATEMENT

The aim of The Engineer is to champion and promote engineering innovation and technology development across all of the UK's key engineering sectors.

5 THINGS WE'VE LEARNT THIS ISSUE

1. Underground tunnels and caves represent one of the most challenging environments for autonomous robots
2. Graphene additives can reduce the weight of concrete by up to 20 per cent
3. BAE Systems aims to achieve net zero emissions across all operations by 2030
4. The civil aviation sector will require 500 million tonnes of SAF by 2050
5. Millbrook has over 70km of physical test tracks

Electronic Digital Position Indicators

DD52R-E-RF
New system with radio frequency transmissions (RF)

In addition to the vast Elesa range of position indicators, comes the new DD52R-E-RF indicators (Elesa Patent). This system allows for faster, more reliable machine set up by use of a wireless connected control unit (UC-RF), which handles up to 36 position indicators.

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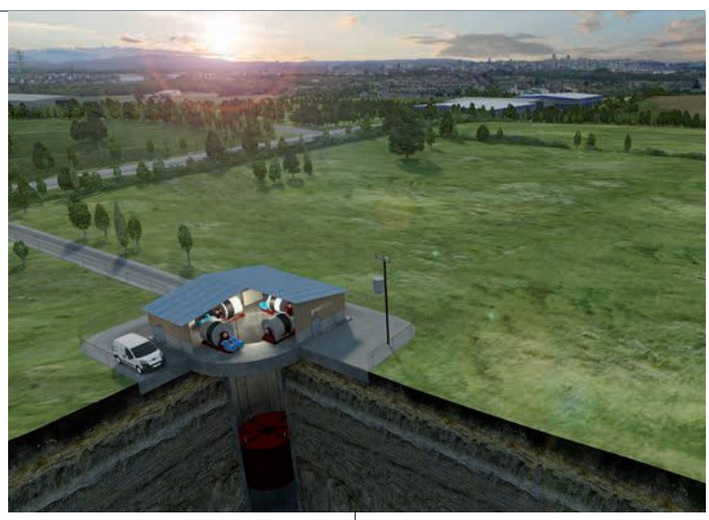
High hopes for underground hydrogen storage

Scottish energy company identifies new deep shaft solutions for energy storage

MELISSA BRADSHAW REPORTS



Gravitricity is to add hydrogen and heat storage to its underground gravity energy system.

The Edinburgh-based company's patented power storage technology uses a multi-weight system to store and release energy. This is done by suspending the weights by cables within a deep shaft, with electrical power able to be absorbed or generated by raising and lowering the weights.

Managing director Charlie Blair said the long shelf and cycle life of the technology is core to the company's proposition. "The USP for the power storage is definitely longevity, and longevity is something that's not going away — we're building something that lasts for 25 to 50 years," Blair said.

In response to the accelerating demand for renewable energy solutions and the need for safe, economic storage of hydrogen, Gravitricity has now submitted a global patent to turn purpose-built shafts into pressurised energy stores for this added purpose.

Company founder Martin Wright said: "We envision building single or multiple shafts which, when co-located with a green hydrogen electrolysis plant, would have a very clear dual function: to store excess electricity for use by the electrolysers when needed, and to store the plant's output as a buffer into the gas grid."

This would aim to smooth the input and output of the green hydrogen plant and improve the economics, bringing down the cost of green H2, he added.

"Storing explosive gas is a big challenge, so we've realised that we can actually use our underground infrastructure - which is pressurised because the geology of the Earth is holding it in and maintaining the pressure, and no oxygen can get down there so it'll be non-explosive once it's in as long as we do our engineering job right," said Blair.

The company is also looking at building inter-seasonal heat storage into the system on a long-term basis, increasing its versatility and economic value by maximising utilisation of the infrastructure.

"In the decade ahead, we believe that the capacity to sink single or multiple shafts exactly where required could result in the rapid scale-up of our technology, not just in the UK but around the world," said Blair. "Building below-ground hydrogen storage into our system will become another extremely valuable revenue stream for Gravitricity projects."

A pilot hydrogen storage system could be in place within three-to-five years, and could also be used as a fuelling point to provide low carbon hydrogen fuel for HGVs, ships or trains.

Whilst the first project will be costly at the outset, Blair said, Gravitricity believes that in the medium and longer-term it will allow for a significant decrease in cost per energy unit stored due to the technology being utilised across the three different scales.

Read more at www.theengineer.co.uk

Surrey team to improve torque vectoring in EVs

EV manoeuvrability – and wider acceptability – likely outcomes of EU project

MELISSA BRADSHAW REPORTS

Researchers at Surrey University have created a new method of torque vectoring aiming to improve electric vehicle (EV) safety and range.

Developed as part of the EU's € 9.5m STEVE project to deliver new concepts in urban mobility, the Surrey team's method is suitable for implementation in everyday consumer EVs and aims to solve impracticalities in traditional torque vectoring approaches.

Torque vectoring allows different amounts of drive power to be delivered to each wheel, improving the vehicle's power consumption, safety and control.

Professor Aldo Sorniotti, head of the Centre for Automotive Engineering at Surrey University explained how multiple drive motors and torque vectoring techniques can allow for 'always-on' stability control systems, as opposed to a conventional stability system which only becomes activated when a vehicle is braking hard.

"As a consequence, you can use these new drive controls not just for emergency conditions but to support a wider range of objectives such as driveability, active safety measures, reduction in energy usage and so on," Sorniotti said. "The problem is, delivering this capability is very complex, requiring significant computer power and sophisticated algorithms that can balance all these competing factors in a way that keeps the car safe and fun to drive."

Surrey's work, published in *Vehicle System Dynamics*, combines a predictive control model with fuzzy logic to adaptively prioritise vehicle dynamics of energy efficiency. The team's stability control system can anticipate the curvature of the road ahead, allowing the car to pre-emptively break when approaching a bend too fast.

"Because the system is always on, it can react in a split second to something that might otherwise lead to loss of control," said Patrick Gruber, professor in Advanced Vehicle Systems Engineering at Surrey University.

The torque vectoring technique can create improved overall vehicle dynamics when driving at the edge of controllability, he added, for example when turning sharply, driving at a high speed or manoeuvring in poor weather conditions.

Whilst the use of torque vectoring techniques is expected to lead to a significant improvement in road safety, Sorniotti explained, the main barrier to widespread adoption is cost, which is expected to drop as adoption increases.

AIRBUS AIRTEC OPENS FOR TESTING AND COLLABORATION

JASON FORD REPORTS

Airbus has formally launched AIRTeC, a £40m research and testing facility designed to undertake structural testing of large-scale aircraft assemblies.

Located in Filton, Bristol and funded jointly by the government's ATI programme and Airbus, AIRTeC (Aerospace Integrated Research and Test Centre) will allow structural testing of full-size wings and individual components and materials used in aircraft design.

The facility includes 6 a 40x18m strong floor and a 14x10m strong wall capable of testing full-size wings using a 25MN high-capacity loading test machine (HCTM) that performs high-force static and dynamic testing.

Speaking at the launch, Pete Smith, head of laboratories and test centres, Airbus, said the high-capacity test machine can hold a 9m test specimen and full load can be applied in a second.

"It combines a number of test capabilities," he said. "That means we can really speed through the test process that has been part of the critical path for technology and aircraft development."

The strong wall is a reconfigurable testing capability that removes the need for the design and build of custom test rigs. Strong wall tests validate the predicted behaviour of structures and simulate the stresses that a wing goes through during its lifespan. The wall is supported by a strong floor, which is a 2m thick concrete floor incorporating over 1,000 high strength anchor bolts that connect multiple high force actuators to simulate complex load scenarios on the test specimens.

As well as its own projects, Airbus anticipates universities and companies in other sectors utilising AIRTeC.

NEWS IN BRIEF

FEASIBLE FUSION

An exhaust system that increases the viability of nuclear fusion has undergone a series of successful tests. Initial results from UKAEA's new 'MAST Upgrade' experiment at Culham have demonstrated the effectiveness of the Super-X divertor, an exhaust system that will allow components in future commercial tokamaks to last longer and bring costs down. Tests have shown at least a tenfold reduction in the heat on materials with the Super-X system.

UAV REFUELS FIGHTER

The US Navy and Boeing have made aviation history with the first air-to-air refuelling using an unmanned aircraft. During a test flight on June 4, 2021 a Boeing MQ-25 T1 successfully extended the hose and drogue from its navy-issued aerial refuelling store (ARS) and transferred jet fuel to a US Navy F/A-18 Super Hornet, demonstrating the MQ-25 Stingray's ability to carry out its primary aerial refuelling mission.

SET FAIR

SME manufacturers are at their most confident for two years with over half expecting to recruit to meet an anticipated rise in sales. The Manufacturing Barometer quarterly survey found two thirds of firms expecting to increase sales to October, with 58 per cent indicating increased investment over the next six months. Out of nearly 300 firms questioned, 54 per cent highlighted the need to recruit staff over the coming months.

Read more at www.theengineer.co.uk

UEA technology to detect endangered right whales

Endangered whale species to benefit from convolutional neural network

MELISSA BRAWSHAW REPORTS

Researchers at the University of East Anglia (UEA) have developed machine learning technology to protect endangered North Atlantic right whales from threats posed by human marine activity.

The machine learning techniques can be used to detect the whales' presence by listening to their submarine sounds. By locating the whales before they approach potentially harmful situations, the technology aims to protect the animals and avoid costly shutdowns at offshore operations.

Lead researcher Dr Ben Milner explained that the technique utilises a deep convolutional neural network (CNN). "To train the CNN, we begin by taking around 2,000 examples of right whale upcall and gunshot sounds and a further 1,000 examples of just background noise, all collected through passive acoustic monitoring (PAM) devices," he said.

Upcall tones and gunshot sounds are common vocalisations emitted from whales and can be detected by the technology.

"We convert these to a spectrogram representation which is a two-dimensional representation with time along one axis and frequency along the other. The colour or greyscale shows the energy of the signal at that time-frequency point. This essentially converts all of the time-domain samples into a 2D image – which CNNs are known to process very effectively."

The CNN is trained to be able to distinguish between the three classes (upcall, gunshot and no whale) from the set of spectrograms.

Recordings can often be interrupted by unwanted sounds such as from shipping, drilling, piling, seismic noise and noises from other animals, resulting in false detections.

"To address these problems we also developed a method of noise reduction that is applied to the spectrogram representations," said Dr Milner. "This is based on methods applied to image filtering and uses another CNN but this time not trained for classification, instead it learns the relationship between clean spectrograms and noisy spectrograms. Knowing this, the CNN is able to transform a noisy spectrogram into a clean spectrogram which can then be classified."

Dr Milner envisions the technology implemented on buoys, autonomous surface vehicles (ASVs) or gliders to achieve high levels of real-time detection. The system was developed with the Scottish Association for Marine Science and Gardline Geosurvey.

C-ALPS JOINS HYDROGEN-POWER COACH PROJECT

An EU-funded project developing hydrogen-powered passenger coaches has selected Coventry University's Centre for Advance Low Carbon Propulsion Systems (C-ALPS) to join its 14-strong CoacHyfied consortium.

The €7m CoacHyfied project includes partners from higher education and engineering who are developing technology that in Britain alone could remove up to 1.4million tonnes of CO_2 generated by diesel-fuelled coaches.

C-ALPS is responsible for the advanced thermal management system that will look to increase fuel efficiency in novel ways, including harnessing waste heat from the hydrogen fuel cell to power air conditioning in cabins.

Led by engineering consultants and founding C-ALPS partner FEV, CoacHyfied is to present solutions for challenges in the medium range regional and long-distance public and commercial transport sector. It will do this by developing and operating six fuel cell coaches at two regions in Latvia and France in two-to-three-year demonstration phases. ***JF***

Read more at www.theengineer.co.uk

DEFUELLING AT DUNGENESS B

JASON FORD REPORTS

EDF's Dungeness B nuclear power station in Kent has been placed into the defuelling phase of decommissioning with immediate effect.

The power station has been in extended outage since September 2018 and during this time EDF has managed 'a range of unique, significant and ongoing technical challenges.'

A number of those challenges were overcome but faults remained within some key components, including parts within the fuel assemblies, the company said.

Consequently, EDF has cancelled restart of the plant and moved it into defueling, which is the first stage of decommissioning a nuclear power station.

Dungeness B came online in 1983 and final generation of electricity in 2018 means the plant ran for 10 years longer than its original design life.

Commenting on EDF's announcement Tom Greatrex, chief executive of the Nuclear Industry Association said: "Despite its difficulties, the plant has been of one of the ten most productive low-carbon assets in UK history.

"Its retirement underscores the urgency of investing in new nuclear capacity to hit net zero: in less than three years, more than half of our nuclear fleet will be gone. If this base of firm power is not replaced, we will have to rely on gas to stabilise the grid. This fossil fuel dependence will cause higher emissions and higher prices and push our climate goals further from our grasp."

Satellite Vu raises £3.6m for thermal imaging satellites

MELISSA BRADSHAW REPORTS

London-based start-up Satellite Vu has raised £3.6m to support the launch of seven infrared thermal imaging satellites, aiming to provide the 'Earth's Smart Energy Meter in Space'.

The satellite constellation will be equipped with infrared sensors capable of detecting heat emissions from any building on the planet, said Satellite Vu CEO Anthony Baker.

They will be able to collect real-time temperature data about the Earth's built environment several times a day, allowing for key insights around energy efficiency and how buildings are being used.

"We're finding two major applications for it: one is in economic activity, so we can determine whether a building is operating, outflows, or how active it is over time," said Baker. "The other thing is, where in the world are we wasting all our energy?

"This is particularly pertinent in everyone declaring net zero — thousands of companies and many countries ... don't really know what their carbon footprint is today, or where their energy is being used, and they don't know where the worst sites are."

Baker explained how the mid-wave infrared video cameras can take multiple frames of the same site, which can be viewed from various angles to allow for further data sets.

"Just like your iPhone, we can stack these images to get a better resolution than you can normally anticipate for a small satellite," he added. "This is a completely new data set of this resolution and at this frequency with a video camera."

He describes the satellites, around 150kg in mass, as being on a medium size scale for a new space satellite — slightly larger than recently developed shoebox-sized satellites, with a high resolution of three and a half metres. Their lifespan will be around five years, Baker said, and the entire constellation is planned for launch within the next two years.

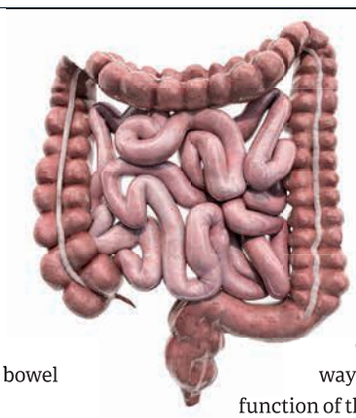
The seed funding round, led by Seraphim Capital, was also supported by A/O PropTech amongst other specialist investors. The newly announced funding round will enable construction of the first satellite, due for launch in October 2022.

BOWEL SENSOR COULD HELP TACKLE INCONTINENCE

MELISSA BRADSHAW REPORTS

A team of engineers led by Heriot-Watt University is developing a bowel sensor that aims to tackle incontinence by alerting people when they need to go to the toilet.

Leader of the project team, Herriot-Watt's Dr Michael Crichton, explained that the flexible sensor could be mounted on the large intestine in order to measure how the tissue moves and strains during bowel movements.



"The sensor will track the stool as it moves through the body, and turn the data into an early warning system for the user," he said. "People's lives are badly affected by faecal incontinence, and it's compounded by the fact that few people feel comfortable or confident to talk about the issue.

"Discreet digital technologies could help people monitor and manage their bowel condition and have more active, confident lives."

Dr Crichton said that the sensor's design makes use of flexible electronics and flexible strain measurements in addition to audio measurements, allowing for identification of motion. The behaviour is then transmitted to an app for interpretation.

"Developing a technology that can be delivered in minimally invasive way and not interfere with the normal function of the organs is a big challenge," he added. "By understanding the attachment surfaces and its movement, we can tailor the technology to minimise any risk of failure or adverse patient impact."

The team comprises researchers from Heriot-Watt, Manchester, Stirling and Sheffield Hallam Universities and the Glasgow School of Art.

The 18-month project has received £500,000 funding from the EPSRC and the Medical Research Council.

BOOM TIME FOR UNITED AIRLINES

United Airlines looks set to introduce supersonic aircraft to its fleet following the conditional order for 15 Overture airliners from Boom Supersonic.

The 15 Overture aircraft will be purchased once they fulfil United's safety, operating and sustainability requirements. The terms of the agreement include an option for an additional 35 aircraft from the Denver-based aircraft company.

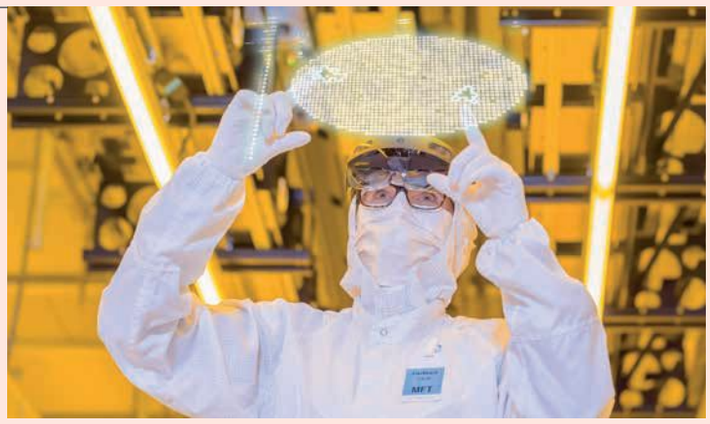
Once operational, the Mach 1.7 Overture aircraft is expected to be the first large commercial aircraft to be net-zero carbon as it will be optimised to run on 100 per cent sustainable aviation fuel (SAF). It is slated to roll out in 2025, fly in 2026 and expected to carry passengers by 2029. ***JF***

Read more at www.theengineer.co.uk

Bosch opens €1bn semiconductor plant

New plant in Silicon Saxony heralded as wafer fab of the future

JASON FORD REPORTS



Production will begin ahead of schedule at Bosch's new semiconductor manufacturing plant, which was opened in Dresden, Germany on June 7, 2021.

The €1bn plant will start producing chips for Bosch power tools in July, six months ahead of schedule, followed by chips for the automotive sector in September, 2021.

Dr. Volkmar Denner, chairman of the board of management, Robert Bosch GmbH, said the new AIoT factory (combining internet of things with artificial intelligence) provides Bosch with a fully connected, data-driven, self-optimising manufacturing facility.

"With AI, we are taking production to the next level," Dr Denner said during the opening ceremony. "In our Dresden plant, we will in the future be relying on solutions provided by the Bosch Center for Artificial Intelligence: at an early stage, our AI-based systems can detect anomalies and malfunctions in the manufacturing process, make learning curves faster, and constantly enhance quality. AI is also used in production scheduling, where it saves time and money as it guides the wafers through as many as 700 process steps at some 100 machines."

He continued: "In our plant, we are permanently collecting and examining data – this data comes to the equivalent of 500 pages of text a second, or 42 million pages a day. Smart algorithms are used to evaluate this data in real time. This too is a key to the rapid rollout of semiconductor production in our new factory."

Maintenance at the site will benefit also from AI with algorithms predicting whether and when a piece of manufacturing machinery or a robot needs maintenance or adjustment. The use of data glasses and augmented reality will allow maintenance work on machinery to be carried out remotely, a factor that helped during commissioning despite coronavirus-related travel restrictions.

A total of 250 staff are working at the Dresden plant but this is expected to rise to around 700 in the years ahead.

BP ACQUIRES 9GW SOLAR PROJECTS

bp is to acquire 9GW of solar development projects in the US from 7X Energy for $220m.

The acquisition is said to represent 'a significant step' towards bp's target of growing its net developed renewable generating capacity to 20GW by 2025, increasing to 50GW by 2030.

The assets will be developed through bp's 50-50 solar joint venture Lightsource bp and are expected to generate returns of at least 8-10 per cent.

Dave Lawler, bp America chairman and president said the projects will be integrated into the company's existing onshore and offshore wind, natural gas, and trading and shipping businesses to 'give customers what they want: reliable, affordable and clean energy.'

Solar energy is the fastest growing power source in the US and is expected to quadruple over the next 10 years. It currently accounts for over 40 per cent of all new electricity generating capacity added in the US. ***JF***

Read more at www.theengineer.co.uk

AIRBUS SENDS SIGNAL TO SUPPLIERS

JASON FORD REPORTS

Airbus has told suppliers to prepare for a ramp up in production as the commercial aircraft market recovers to pre-COVID levels between 2023 and 2025.

According to Airbus, suppliers are being advised to 'schedule necessary investments and secure long-term capacity and production rate readiness' in line with the expected recovery, which is being driven by single-aisle aircraft. For its part, Airbus is modernising its A320 production facilities.

Production of A320s will average 45 aircraft per month in the fourth quarter of 2021, rising to a firm rate of 64 by the second quarter of 2023. Suppliers are being asked to anticipate a scenario of rate 70 by the first quarter of 2024 and as many as 75 by 2025.

Airbus further anticipates a monthly production rate of 14 A220s by the middle of the decade, and six A350s per month by autumn 2022. Production of A330s will remain at an average rate of two per month, with Airbus stating it 'is protecting its ability to further adapt as the market evolves.'

Commenting on the announcement, Paul Adams, partner and aerospace & defence sector specialist at Vendigital, said: "There is still a risk of supply chain disruption, as some Tier 2 and 3 manufacturers may have only just made it through the pandemic and lack the cash to pay for raw materials.

"The ramp-up mainly affects the A320 and to a lesser extent the A350, which means demand for wide-body aircraft remains well down on pre-pandemic levels. So while the announcement is good news for the sector, some manufacturers may not feel the benefit."

DEEP THINKING

The DARPA SubT Challenge is pushing robotics and autonomous technologies to their limits. Andrew Wade reports.

This September, eight teams will converge on the US state of Kentucky for a unique competition. At the Louisville Mega Cavern, several metres below the Earth's surface, an army of machines developed by some of the world's leading roboticists will search for backpacks, phones, gas leaks and trapped survivors – all the paraphernalia you might associate with an underground disaster. When the dust settles, the winners will walk away with a million dollars in prize money.

The SubT Challenge is the latest in a long line of flagship competitions run by the US government agency DARPA (Defense Advanced Research Projects Agency), a storied organisation founded by Eisenhower in response to Russia's success with Sputnik. Central to the development of both the Internet and GPS, DARPA is by no means confined to military applications, something reflected in the fact that its 'D' has been axed and reinstated multiple times.

Its latest venture, running since 2018, has seen teams developing both real and virtual robotic systems to navigate different underground worlds, including caves, tunnels and subways. Competition courses have been intentionally designed to replicate the dangers of rescue efforts in collapsed mines, post-earthquake search and rescue in urban underground settings, and cave rescue operations for injured or lost spelunkers.

"I had the great pleasure of conceptualising, envisioning what such a challenge would look like, working with a team to craft everything from the structure to the end goals, the scoring function, all of those things," Dr Timothy Chung, programme manager at DARPA's Tactical Technology Office (TTO), told The Engineer.

"DARPA's really interested in identifying and discovering those breakthrough technologies, and one of the places where robotics could really accelerate and have deep impact is in complex, real-world environments... it's really great to see the concept for this vision continually evolve and grow and materialise in the form of the SubT Challenge we have today."

The variety of different underground settings, combined with obstacles to simulate the chaos of search and rescue, means that teams involved in the competition rarely rely on a single platform. Instead, most have an assortment of robotic technologies to select from, depending on the setting and the task in hand.

"We have three conventional ground vehicles," explained Carnegie Mellon University's Matt Travers, a leader of the Explorer team, which has been one of the top performers in the two 'Circuit' events held in the lead up to September's final.

"Then we have one legged robot, six drones - four of which are homogeneous – and that's pretty much the overall system. So nominally about 10 platforms, aerial and ground, and some combination thereof goes out and tries to compete in the competition."

Operating robots underground comes with significant technical challenges, including an absence of GPS, restricted vision, and networking difficulties. While these issues aren't exclusive to →

the subterranean world, it brings all of them together in one place, making it the ultimate proving ground for rugged, adaptable robotics.

"The underground is just one example of the types of really complex environments that robots in the future will have to work in, and the SubT environment really lends itself to seeing how we can employ robots while advancing the technology and allowing them to be the first ones in to save human lives," said Chung.

Drones and robotics have also been advancing at a rapid rate since the competition kicked off back in 2018, and the rules don't dictate that teams have to stick with the original platforms they proposed at the outset. Rather, in true DARPA spirit, the only real limitations are imagination and engineering capability.

"There's no rules," said Travers. "You can do whatever you want. You can restart every year. DARPA doesn't specify rules in terms of the platform, the strategy, whatever, it's just 'here is the playing field, go out and figure out how to do it'."

According to Chung, the competition setup encourages four particular areas of technology focus: autonomy, networking, perception and mobility. What became clear after speaking to those involved in the SubT Challenge, was that none of these things operates in a silo, and a holistic engineering approach that pays heed to all four is pivotal to solving the problems the competition throws up.

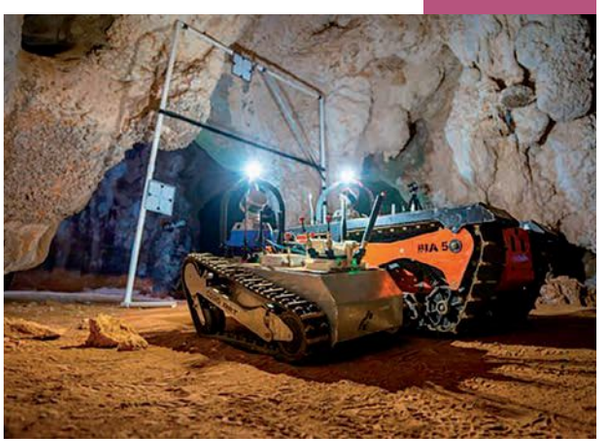
"It's a fine balancing act," said Chung. "You can't have autonomy when you don't have the ability to share the information that you've obtained. You can't obtain that information without good perception or sensor systems. And of course, if you can't get there with your mobility solution, there's nothing to go see.

"Sometimes it's a trade-off. Sometimes you've got to give a little on the networking side and compensate with more autonomous solutions... it's a really fascinating optimisation problem."

Travers echoed these sentiments. For the Explorer team - a collaboration between Carnegie Mellon and Oregon State University - that balance between comms and autonomy has been at the crux of the entire SubT Challenge.

"Within this competition in particular, what's very acutely apparent- at least to me – is that you can't solve anything in isolation," said Travers. "You put a perception system together with SLAM (simultaneous localisation and mapping), together with planning, together with control, they all...depend on each other in these complicated and intertwined ways. So the comms problem is hard, but the more complicated problem is the confluence of comms and autonomy, and what's the correct balance of those two things.

The Final Event will see teams tested in caves for the first



" THE UNDERGROUND IS JUST ONE EXAMPLE OF THE TYPES OF REALLY COMPLEX ENVIRONMENTS THAT ROBOTS IN THE FUTURE WILL HAVE TO WORK IN "

"And the jury's still out on that. For us, the biggest thing is that if a robot goes down-tunnel and is out of comms and gets stuck, we might as well have not sent it down the tunnel."

It's exactly these types of questions that the competition was designed to pose and, to some degree, answer. DARPA's role is to construct parameters that will encourage the type of research that can be applied in the real world, helping to save lives while advancing the overall state of robotics through collaboration and knowledge sharing.

As well as millions of dollars in prize money, DARPA is also providing funding to several teams in the competition, including Explorer and its close rival CoSTAR, a multi-partner team that includes members from MIT, Caltech and NASA's Jet Propulsion Laboratory (JPL). It's a model which dates all the way back to the first DARPA Grand Challenge in 2004 at the Mojave Desert, and which has been hugely successful, turbo charging the evolution of autonomous systems of all different stripes.

"The Grand Challenge model... is really about planting the seed and oftentimes rallying a community together," said Chung. "And that community benefits from the knowledge sharing that comes about. The SubT Challenge is no different.

"Many of the teams, whether they're DARPA-funded or not, are releasing a lot of their code, as well as their datasets, all open source, so that the community, everyone rises up with access to the latest and greatest. So even if they're competitors, you still find a lot of cooperation happening.

"Everyone wins in that scenario, and of course DARPA is keenly interested not only in that community, but also harnessing that advanced technology... so information sharing is integral to what DARPA Challenges bring to the table."

One might expect the DARPA programme director to exhibit that slightly rose-tinted, Corinthian attitude to the competition, but Chung is not alone in his views. Despite the close rivalry between his Explorer team and CoSTAR, among others, Travers also acknowledges that there is a bigger picture, that the SubT Challenge serves a higher purpose beyond the confines of the actual competition.

"From my understanding and perspective, it's not really about the winning team," said Travers. "DARPA is the wining team here. It's about bringing people together and getting a good understanding of the current state-of-the-art.

"Not any one system from this competition is going to be *the* optimised system...these technologies are pretty high on the TRL (Technology Readiness Level) already, it's just seeing what's going to work as you put them through their paces. At the end of the day, that's what it's about."

But with serious money at stake, not to mention professional pride, the

competition isn't all hugs and kisses and sharing of code. These are still engineers neck deep in a battle that's been running for three years, with two teams so far contesting the number one spot. Make no mistake, all eight teams turning up at the Mega Cavern in September want their technology to come out on top.

Of the two lead-in events that have taken place so far, Explorer took top honours at the 2019 Tunnel Circuit just ahead of CoSTAR, but the positions were flipped on the Urban Circuit which followed in February 2020, CoSTAR's legged Spot robot – of Boston Dynamics fame – proving the difference. A third event, the Cave Circuit, had to be abandoned due to COVID, leaving everything to play for this September. Although both Explorer and CoSTAR began the SubT Challenge with a wealth of robotic and underground experience, the task of building new robotic systems in a short space of time was still significant.

"Our system did really well in the Tunnel Circuit originally," said Travers. "That first competition was one year in. We built all our own robots and put them together from scratch and got them to work and go out and do something meaningful. Starting from zero, that would be very very difficult. JPL (CoSTAR), clearly they're not starting from zero either, so they also did well.

"Really it came down to platforms, our ground vehicles looked like they were the more beefy, more robust vehicles for the Tunnel Circuit. In the Urban Circuit, it was very clear to us that (CoSTAR) having the legged Spot robot that could go up and down stairs was the main differentiator…I'd say the biggest systematic error for us was that we did not have a legged robot."

Some of the innovations seen across the competition so far have been low-tech but high-value. One team attached 'comms breadcrumbs' to volleyballs and fired them down a tunnel in an effort to boost networking capability. Another team cleared out a local hardware store of all its powered lighting mid-competition in order to enhance the perception capabilities of its robots. These kind of on-the-fly solutions only come about when robots and their human masters are put to the test in the real world, informing decisions in a way that lab research simply can't replicate.

At the upcoming Final Event, that innovation and creativity will once again be tested, though prior success will count for little. Explorer and CoSTAR's earlier victories are consigned to history, with all eight teams starting from scratch. And with the inclusion of caves alongside the more familiar tunnel and urban landscapes, teams will face a combination of terrain that they won't have previously encountered, meaning any one of the finalists could potentially come out on top. If the Circuit events so far represent two legs of a triathlon, the Final Event is the full three legs together, where weaknesses in one discipline or environment will be exposed.

"What you want at the end of the day is the best all-round athlete who can overcome all three of these sub-domains at one go," said Chung. "And I think that's what the teams are preparing for. Certainly DARPA is raising the bar for the challenge at that Final Event."

Innovating on the fly has been a key factor for success so far

But when the last robot has emerged from the dark depths of the Louisville Mega Cavern, and the winners have departed with their million-dollar prize, the SubT journey will be far from over. Rather, it will simply mark the end of the beginning, a jumping off point for new government investment as well as commercialisation of successful technologies.

"We imagine that there's going to be quite a long runway for not only many of the technologies, but also the teams, as they continue advancing the technology," said Chung.

"Now that we know where the next plateau of technological difficulty is upon the conclusion of the SubT Challenge, we're just going to be setting up continued cycles of advancing and breaking through new barriers."

THE ENGINEER

Wheeled and tracked robots are put through their paces at SubT Circuit events

PAUL TAYLOR

Embedding an engineering mindest

The Engineering community has been key to addressing many of the challenges thrown up by the pandemic. It must now be at the heart of our plans for a more resilient future writes Paul Taylor

The Royal Academy of Engineering recently published a report, *Critical capabilities: Strengthening UK resilience*, which recommends steps the government should take to make the UK more resilient to new pandemics or other emergencies. One of the main recommendations is that it should embed an engineer's 'systems' approach in emergency planning and preparedness with the help of both public and private organisations.

But the report also calls for all organisations across the public, private and third sector to reach out and make connections beyond their immediate and familiar communities—to review and perhaps reassess where their interdependencies lie within the wider system, and how vulnerabilities can be reduced and resilience strengthened.

Emergency response

As the crisis caused by the COVID-19 pandemic was evolving, individuals, teams, organisations, collaborations and projects across all technical specialities, disciplines and career stages within the UK engineering community stepped up to maintain essential services, critical supply chains and infrastructure in unprecedented circumstances, using their training and skills to find innovative solutions to a host of problems and to help mitigate the impact of COVID-19. Engineering expertise and innovation has proved central to the fight to save lives and protect livelihoods not just nationally, but globally.

While dealing with the immediate challenges posed by the pandemic, engineers, like others, were also asking what the UK as a whole needed to do to be more resilient to address the emergencies of the future. What needs to be in place to ensure that we are better able to anticipate, resist, absorb, recover, and adapt to shocks and stresses in the system with agility, to enable continuity of delivery of critical needs?

Engineers see emergency responses and planning as a series of interdependent and interconnected systems of capabilities. An effective national response to an emergency or crisis is one that can rapidly call on the right capabilities to deliver the most effective response at the required pace. The Academy's report describes this in terms of 'critical capabilities' and focuses on the actions needed to identify and build these critical capabilities ready for future emergencies.

Cross sectoral transparency

Each emergency has a defined system boundary with the relevant capabilities that are most necessary to respond well. For most emergencies of scale, this will go far beyond the well-networked elements of the public sector and emergency services and will also need to draw on organisations, people and resources in the private and third sectors. Business and civil society are crucial to whole-society resilience.

My experience of working in both the public and private sector in defence and security has shown me time and again how crucial practice and a shared understanding of each other's capabilities and vulnerabilities are. Every crisis has specific characteristics and uncertainties that cannot be fully anticipated. There is a premium on understanding your system well in advance to quickly leverage the right capabilities for an effective emergency response. This requires identification and strengthening of the wider capabilities across the public, private and third sector which build greater resilience in the face of crisis; in particular, understanding what capabilities are available, how they interconnect and how to build them into the UK's emergency response, planning and preparedness by embedding a systems approach. Resilience can be mistaken for redundancy – instead, it is often a rich ecosystem which needs to be nurtured and ready to respond with agility when an emergency occurs.

More to be done

Looking at potential future emergencies, there are challenges to building the joined-up, principled and transparent governance and leadership systems necessary from local to national levels. The UK government has made building resilience a key part of its Integrated Review and Global Britain agenda. A resilient UK is a good place to do business and now is the time to think ahead, strategically and inclusively.

The day after *Critical Capabilities* was published, the UK government unveiled plans for an international surveillance network aimed at identifying and tracking new Covid variants and other emerging diseases. Expected to be up and running before the end of 2021, the Global Pandemic Radar will be led jointly by the UK and the World Health Organisation in collaboration with the Wellcome Trust and other partners with the aim of saving lives and protecting health systems by spotting diseases before they cause future pandemics. It will also seek to enable the rapid development of vaccines, treatments and tests. International coordination is a crucial capability to enable effective communication and access to expert advice necessary mobilise a rapid response. It is just one piece of the resilience puzzle. I strongly hope that a wider systems view will be applied and a broader consideration of all critical capabilities will support building a whole-society approach to resilience, without which we risk missing the mark.

Paul Taylor FREng is Director of Morgan Stanley International and Chair of the Royal Academy of Engineering's Critical Capabilities Working Group

THE ENGINEER

IN OUR OPINION

Heated debate

Low carbon heating will be key to reaching net zero, but it could prove to be hardest part of the energy transition to sell to the public. Jon Excell reports

For many, the realities of the battle against climate change remain an abstract, arms-length issue.

It makes little practical difference to the average consumer whether the electricity used to keep the lights on is generated by offshore renewables or coal fired power plant.

But recent tabloid talk of a "boiler ban" has bought the implications of the UK's net zero push firmly into the nation's living rooms, and perhaps also caused heating engineers and plumbers a few sleepless nights.

The outcry was prompted by the International Energy Agency and CBI's recent warnings that conventional gas boilers should be banned from sale by 2025. The UK government, which is making green issues a priority as it gears up to host the COP26 climate summit later this year, is widely expected to back the proposal in its soon to be unveiled heat and buildings strategy.

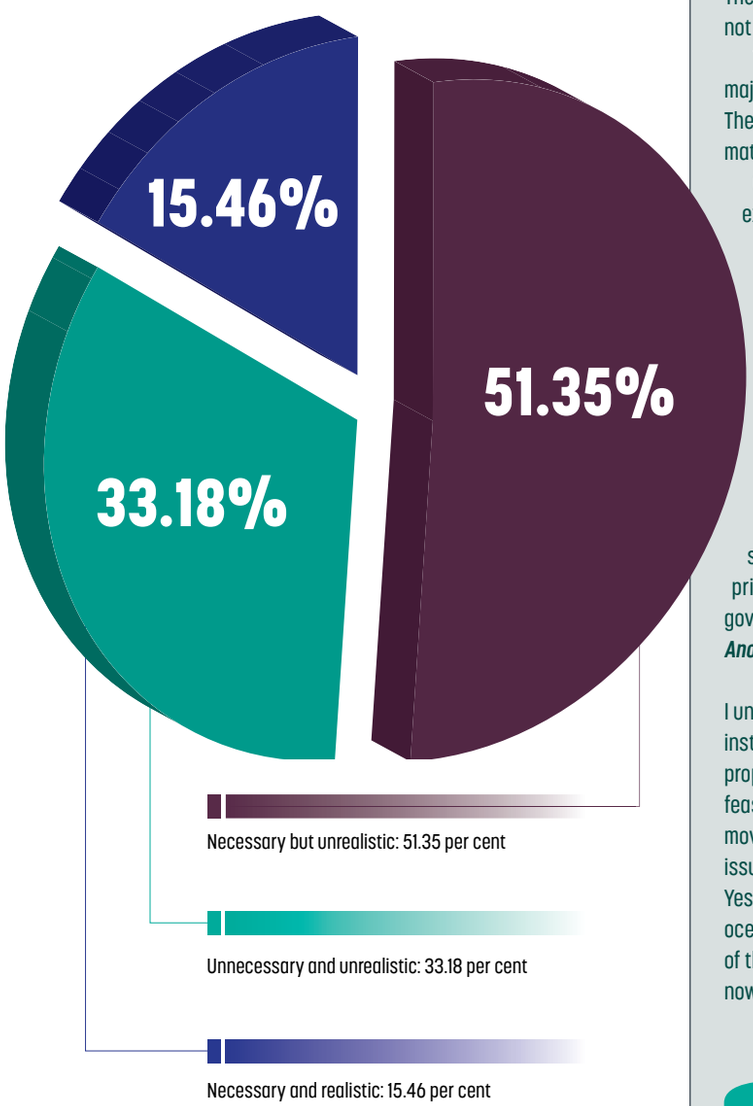
It is of course possible that Boris Johnson's famed populist tendencies could prompt a watering down of these ambitions but there's no escaping the fact that decarbonisation of heating – which accounts for as much as 17 per cent of the UK carbon emissions – will be key to delivering on the UK's accelerated net zero ambitions.

A switch to low carbon heating will require a range of different technologies from improved insulation through to district heating schemes, heat pumps, heat batteries and even – as previously reported by The Engineer – geothermal sources that tap into the heat trapped in flooded, abandoned mines. But it seems increasingly likely that one of the main elements will be a shift from natural gas to hydrogen fuelled boilers – a transition that will ultimately require most home owners to install new boilers.

As we reported in our June issue, achieving this presents a significant, but not insurmountable, technical challenge. Indeed, experts talk of a phased switchover akin to the UK's towns gas conversion of the 1960s and 70s. The biggest challenge, given the tone of recent newspaper headlines, might be persuading the general public that it's a good idea. THE ENGINEER

In a recent online poll about the proposed 2025 ban on conventional domestic heating boilers we asked readers whether they felt the idea was practical, desirable, or even necessary?

Interestingly, overall 67 per cent of our 886 respondents feel that a ban is required if we are to hit our net zero targets, however many of these also feel that it is an unrealistic aim. Indeed, 51.35 per cent of the overall sample group told us that a ban is necessary but unrealistic, whilst just 15.46 per cent believe it both essential and practical. Meanwhile, 294 respondents (33.18 per cent) argued that such a move would be both unnecessary and unrealistic.



HAVE YOUR SAY
Visit our website to take part in the continuing debate on this emotive topic

SCAN ME

IN YOUR OPINION

As is usual with government approaches to these issues, they are casting around for a "One size fits all solution" when a multi-mode approach is required.
Peter Thomas

The timescale's totally impractical, it will not happen by 2025, if at all.

The cost is out of reach for the great majority of people.

The proposed technology is not sufficiently mature.

Currently, most Hydrogen is 'Blue', ie. extracted from fossil fuels - not Green.

District Heating schemes tie the Public into one supplier, removes possibility of switching.

Current schemes don't provide sufficient heat for cold snaps and don't allow easy switching on and off and are impractical for flats and multiple occupancy accommodation.

In conclusion it's unrealistic and unnecessary (environmentally). More substance-less, badly thought out PR prior to COP26. Par for the course for this government.
Another Steve

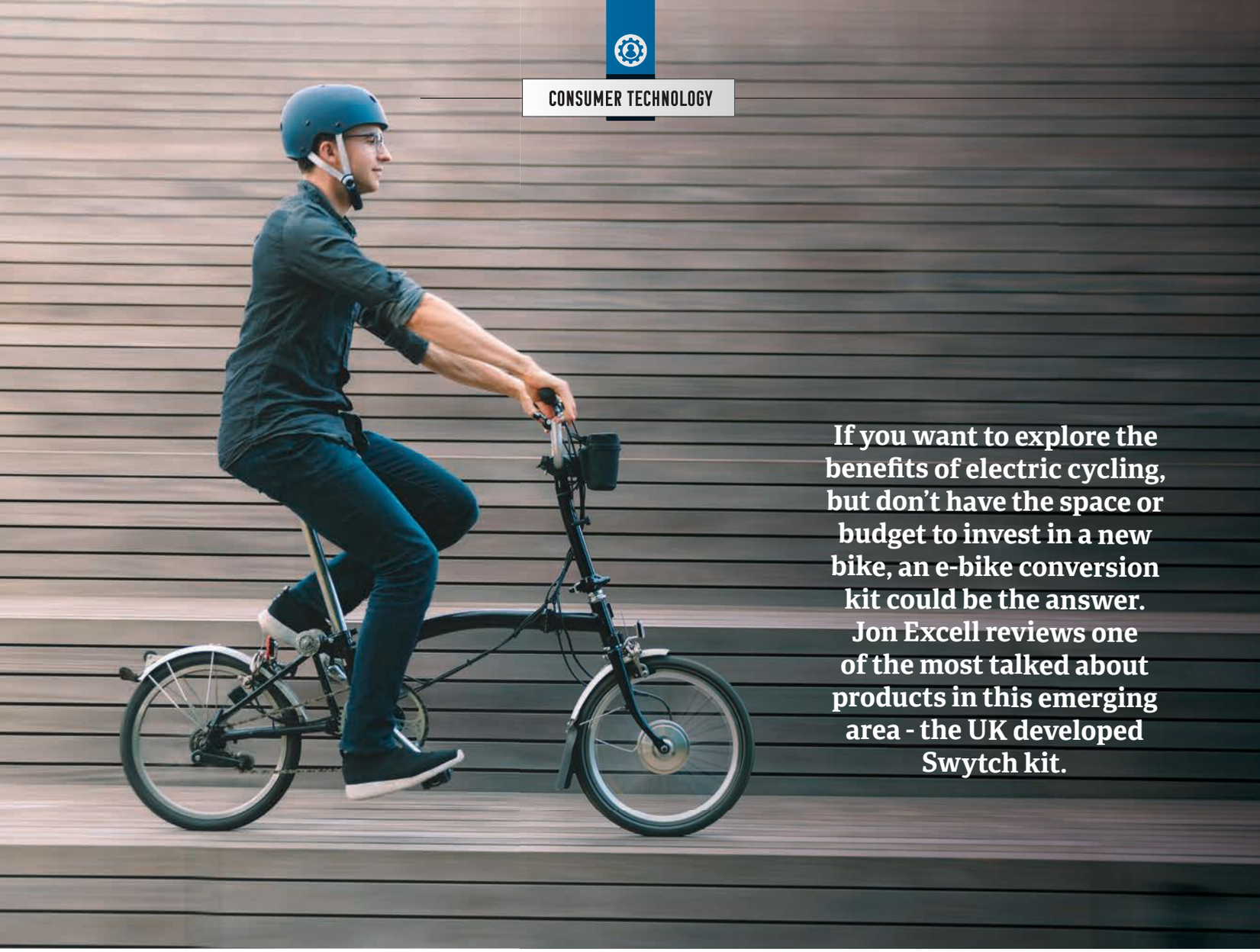
I understood that it applied to new installations only? i.e. new build properties? In which case it is entirely feasible and realistic. We need bolder moves from government to put right the issues we're facing with climate change. Yes it'll be tough and may be a drop in the ocean considering the size and population of the UK. However, making these moves now will allow the UK to become a market leader in greener domestic technologies. If this was supported by government grants and support for R&D in this area, I think we would be on to a winner.
Sam

I haven't quite worked out how you can have hydrogen and natural gas boilers connected to the same grid. Maybe as an electrical/electronics engineer the physics and chemistry is beyond me! But if my concern is right then this begs the question: how do you do co-ordinate it?
Brian M

One of the problems with hydrogen in an aged infrastructure will be leakage. Hydrogen is a very small molecule and is likely to leak a lot more than natural gas does. This could be a potential danger. Maybe it would be easier to make sustainable methane, even if not quite so simple as just producing hydrogen. This would not require any infrastructure changes.
Pat Symonds

Another pie in the sky proposal. Good on paper but completely devoid of any common-sense appreciation of what is actually involved. If the government was actually interested in pursuing this unrealistic timescale they would be investing in the infrastructure now.
Nick Cole

Wasn't town gas about 50% hydrogen? Converting appliances from burning town gas to natural gas didn't seem insuperable when it was done, quite smoothly, in the 1970s. Maybe we could convert to gas containing 50% hydrogen as in interim measure, with new boilers designed for 100% hydrogen introduced as the older boilers were retired. ***Julian Bassett***



If you want to explore the benefits of electric cycling, but don't have the space or budget to invest in a new bike, an e-bike conversion kit could be the answer. Jon Excell reviews one of the most talked about products in this emerging area - the UK developed Swytch kit.

E-MOBILITY CONVERT

Electric bikes have been on the market for a number of years now. But thanks to increasing affordability, a pandemic induced cycling boom, and a growing appetite for more sustainable modes of transport, sales have snowballed in recent months. Indeed, according to the Bicycle Association – the trade body for the UK cycle industry – e-bike sales grew by 67 per cent in 2020 and are expected to triple by 2023.

Scrambling to tap into this growing market, bike manufacturers have introduced a wide range of different products: from budget electric commuter models through to high end mountain and road bikes with car-sized price tags.

But the growing interest has also led to the emergence of a number of e-bike conversion kits that can be used to electrify much-loved existing bicycles and which potentially represent a more cost-effective and versatile solution than an entirely new machine.

The Engineer recently had an opportunity to try out one of the most talked about products in this emerging area: the Swytch kit, developed by London based e-mobility startup Swytch Technology ltd.

Consisting of a modified front wheel, pedal sensor system and handlebar mounted power pack – Swytch is claimed to be the smallest and lightest e-bike conversion kit on the market. What's more, according to its developers, it's compatible with any bike.

The product was invented in 2017 by electrical engineer Oliver Montague, who was inspired to develop his own system after having a crack at importing and selling off-the-shelf kits from China.

Frustrated by the variable quality of these devices and the non-existent customer service, Montague spotted a gap in the market for a well-designed, universal kit that could be backed up by a slick customer service operation and the concept for the Swytch kit was born.

Following a successful crowd funding campaign on Indiegogo, the product was launched in 2018 and sales have grown rapidly ever since. According to co-founder electrical engineer Dmitro Khroma the company - which now

employs 35 people at its HQ in Hackney, East London - sold 20,000 units last year, and is on track to hit similar numbers this year.

Swytch has four key components: a power pack (which contains the lithium ion battery, controller and display), a quick release handlebar bracket for attaching the power pack to the bike, a custom built front wheel with an integrated hub motor, and a magnetic pedal sensor kit (consisting of a magnet that fits on the centre of the pedal crank and a sensor that attaches to the bike frame.) The power pack and connector were developed entirely in house, whist the motors are sourced from an external supplier. These motor and battery add around 3.5kg to the weight of a bike.

During use, the magnetic pedal sensor detects when you're pedaling and sends a signal to the power pack which uses a bespoke control algorithm to determine how much power to supply based on factors including pedal cadence and acceleration. When you stop pedaling the motor stops spinning.

A simple display on the top of the power pack shows the battery level and allows the user to choose between five different power levels depending on how lazy or active you're feeling. If you turn the system off entirely you can pedal as you would normally.

The 250W brushless hub motor generates 40Nm of torque (claimed to be enough to drag the average adult up a 30 per cent incline with light pedaling) whilst the 250Wh power pack gives a range of 35 or 50km depending on how much work you're prepared to put in and which specification you go for (either the Eco or the higher capacity Pro). The system has a top speed of 15mph (24km/h) for UK customers and 20 mph for US customers.

Whilst Swytch isn't the only conversion kit out there, Khroma believes that the elegance of the design coupled with an emphasis on customer service (including video calls with technicians) sets the product apart. "The thing that separates us from a lot of companies is the level of service that we provide," he said, "there are challenges to converting your bike, but we'll be there every step of the way. We're trying to make the experience as seamless as possible."

Until now, the product's most enthusiastic adopters have been formerly active cyclists who - through old age, declining fitness or injury - are no longer able to conquer the hills of their glory days. But according to Khroma the customer demographic is becoming broader all of the time.

Indeed, because of the pandemic the firm hasn't yet had a serious chance to make an impact on the commuter market (where the technology has some major attractions) and the team is braced for a spike in this area as returning commuters seek out an alternative to crowded trains and buses.

Further into the future, Khroma said that the firm is eyeing up opportunities for other technologies and developments in what is becoming one of the mobility sector's fastest moving areas. "The e-bike industry is growing so rapidly," he said. "If you 're standing still you're falling behind. What I'm excited about is being able to provide more alternatives to cars and buses...so we're talking about new types of conversion kit, and even complete electric bikes."

Prices range from £999 for a universal Eco kit through to £1500 for the Brompton Pro, a configuration designed specifically for the Brompton folding bike (see box out). THE ENGINEER

SET UP AND RIDE

To put the technology to the test, Jon Excell fitted a Brompton Pro Swytch kit to his trusty folding bike.

Unless – like I did – you adopt the time-honoured approach of diving in without reading the instructions, assembling the Swytch kit (which requires you to fit a new front wheel, attach a power pack bracket, position the pedal sensor, and route an assortment of cables) is a relatively straightforward process, particularly if you take the firm up on the offer of a one-to-one video support call.

Even so, my more gung-ho approach was relatively hassle free, and the kit was up and running in just over an hour.

The trickiest part of the set-up is positioning the magnetic pedal sensor. Precise alignment between the frame mounted sensor and the pedal crank magnet array is key to ensuring that the system operates smoothly, and positioning the frame sensor required some judicious use of cable ties. In response to this relatively minor gripe, Swytch CTO Dmitro Khroma told The Engineer that the team is currently working on an alternative wireless, no fuss sensing method, akin to the Bluetooth cadence sensors already used by many serious cyclists.

With the bike up and running it was time to clip on the battery pack, select the highest power setting and put the technology to the test on the mean streets of Hertfordshire where – it has to be said – the Swytch kit didn't disappoint.

The boost provided by the kit's 250W motor – which kicks in after couple of seconds of pedaling – rapidly accelerates you up to a decent cycling speed without any effort at all. And once you're cruising, the ride is so smooth and quiet that you initially begin to wonder whether it's stopped working. Until - that is - you cruise past a lycra-clad road warrior without breaking a sweat.

The kit also performs admirably on reasonably steep hills where - although a little more pedaling effort is required - the 40Nm of torque helps you sail up ordinarily energy-sapping slopes.

What's more, the battery pack and power management system hold up well in various different scenarios. A five mile pedal across London on full power used up just one of the five bars on the battery monitor, so it's certainly a credible solution for a much longer ride (particularly if you're using it for the commute and able to charge it up again at the office).

The system does add some weight to the bike (around 3.5 kg including the battery pack and wheel motor) as well as a bit of extra cabling but – in the case of the Brompton – the folding mechanism still works well, and the bike can still be lugged on and off public transport reasonably comfortably.

In short, Swytch is a well-designed, easy to install, and nice to use system, developed by an engaging bunch of UK engineers who are clearly passionate about their technology. What's not to like?

The Swytch kit power pack clips onto a specially designed quick release handlebar mount

UNLOCKING THE POTENTIAL OF GRAPHENE

Dr Andrew Pollard, principal research scientist at the National Physical Laboratory (NPL) is helping to pave the way for the commercialisation of graphene. Melissa Bradshaw reports

Since its isolation and initial characterisation at Manchester University in 2004, graphene has become something of a hot topic. Classified as an advanced material, the single-atom thick carbon lattice carries a range of unique properties stirring up an eagerness in scientists, engineers and manufacturers globally to unlock its wide-ranging potential.

One of those excited by its potential is the National Physical Laboratory's Dr Andrew Pollard, who has been leading the lab's research into the standardisation and commercialisation of the nanomaterial. Pollard has been working with nanomaterials for around 15 years, having joined NPL 11 years ago where he explained that the focus has been around the metrology and measurement science around nanomaterials, particularly 2D materials such as graphene.

"The work we do at NPL as a metrology institute is focused on measurements — we're not necessarily making products, but we're helping companies in the UK and elsewhere to enable them to innovate," Pollard said.

As the UK's National Metrology Institute, NPL's work involves developing and maintaining a national measurement infrastructure for the UK through the National Measurement System (NMS). Based in Teddington, Middlesex, the laboratory is owned by the UK government's Department of Business, Energy and Industrial Strategy (BEIS) and its work provides vital support in measurement standards across industries ranging from healthcare through to IT and communications.

"The key science we've been [working on] is understanding the measurement of what is essentially quite a difficult material — it's nanoscale so it's actually an atom-thick layer of carbon," said Pollard in reference to NPL's graphene research. "Being able to measure it in ways that are not only accurate and precise, but also enabling ways of quality control for companies in the UK and in the world, is actually a very big challenge."

Notable for its thermal and electrical conductivity as well as its strength and flexibility, the addition of graphene into existing materials could lead to improved quality and efficiency of a huge variety of products, from batteries in wearable technologies through to composite materials in the aerospace and low carbon transport sectors.

"It becomes very exciting because you can get multiple improvements in products that you or I, or the general public, would use," said Pollard. "One of the real benefits of graphene is that there's a really broad array of very different applications of technologies, so we're looking at working with companies in many different areas to help them with not only the measurement understanding of the material but also the intermediates and the final product."

One example is its potential use within the construction industry, where the addition of tiny amounts of graphene to concrete can be used to improve strength and water resistance, and actually reduce the amount of concrete required by as much as 20 per cent. "Concrete is the most abundant manmade material on Earth and actually contributes to around 8 per cent of UK carbon emissions," he said. "If you can use 20 per cent less concrete, suddenly you're having a big hit on those CO2 emissions."

From a sustainability point of view, the wide-ranging →

The model structure of graphene sheets on a blue background 3d illustration

Transparent of graphene application

benefits of graphene across various industries is seen as a real game-changer by Pollard and his NPL team. And concrete is merely one example of how the material could play an important role in the fight against climate change.

Graphene could also prove key to the development of energy storage technologies, he added, with the addition of small amounts of the material being used to improve energy density in supercapacitors, as well as improving stability of new batteries such as lithium-sulfur as a sustainable solution for electric vehicles.

Yet another potential application area is the use of graphene additives to improve the environmental sustainability of car tyres.

Pollard explained that each year, billions of car tyres are burned or buried, whereas the addition of a small amount of graphene alongside virgin plastics could enhance recyclability and allow for these to be repurposed.

Meanwhile, in sectors such as aerospace where companies are grappling with the challenges required to develop new low-carbon technologies, graphene could play an important role in the kind of next generation lightweight composite materials that will be key to emerging technologies such as electric vertical take-off and landing) aircraft eVTOL.

Whilst we're already beginning to see an increase in the use of graphene in applications ranging from sporting gear to smartphones and even cars, Pollard stressed that there are still considerable challenges around commercialising the technology at a manageable cost. And one of the biggest obstacles to delivering on this potential, he said, is the ambiguity around standardisation and quality control of graphene. NPL's work in metrology and the characterisation of graphene will, he said, be key in giving confidence to companies wishing to utilise graphene in their products.

Pollard explained that a product labelled 'graphene' can come in many forms, be it a powder, a liquid dispersion or a slurry. "Knowing these properties, for example the size of the particles in the powders, both thickness and lateral size are going to have an impact on the final product and the performance of the product you're going to make, sell and use," he said. "If you don't know what those properties are, you're not going to be able to judge if it's the right material that you want to use."

"Some materials will, for example, be very good for a composite, but won't be for a battery, and vice versa, you might want very different properties there... that's where we've been coming in across the world developing international standards particularly. Showing that actually, we need to have a methodology that everyone can use and therefore everyone can measure it in the same way. That gives an accuracy and precision that we can define."

NPL's work, alongside Manchester University's National Graphene Institute (NGI) has been supporting this demand with research into the physical, structural and chemical characterisation of graphene. In March, the first international graphene measurement standard was published within the ISO (International Standards Organisation) to define the structural properties of graphene products. This followed terminology standards developed several years previously, allowing for precise definitions of types of graphene such as graphene oxide and few-layer graphene.

Further work being carried out by NPL includes developing a measurement standard for the chemistry of the material, looking at more specific in-depth standards for graphene oxide and establishing fast methods of quality control that can be done quickly and cost-effectively by companies that have scaled up the material. Pollard and his team have worked closely with producers, modifiers and users of graphene products such as First Graphene, Haydale, Cambridge Nanosystems and Thomas Swan amongst others.

Pollard believes that over the next 20 years, the full potential of graphene will begin to show in a wider ranging variety of products and applications.

"It'll be everywhere in our everyday lives and we won't notice," said Pollard. He gave examples ranging from our houses being built from sustainable graphene-based materials, through to sensors that could be used to develop greener, smarter cities and areas such as new materials for new modes of transport through to electronics.

"The UK is where it was first isolated and we've got world-leading expertise and academia and companies here, but it is very global so actually being able to trade and have those supply chains across these countries — it's the international standardisation that enables that," he concluded. THE ENGINEER

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Morgan's Plus Four applies modern engineering to a model originally launched in 1950

Back to The Future

The new Morgan Plus Four combines cutting edge hardware with traditional craftsmanship.

CHRIS PICKERING REPORTS

No other car manufacturer is quite as adept at blending old and new as the Morgan Motor Company. The original Plus 4 was the mainstay of the company's range for an incredible 70 years from 1950 to 2020. Its origins stretch back even further, with the steel ladder frame chassis and the coachbuilt aluminium body effectively an evolution of those on the 4/4 that was launched in 1936.

Now there's a new Plus Four (the subtle change to the name reflecting what Morgan describes as the biggest advancement in the model's history). Outwardly, it looks much the same as always. There's the same classic roadster styling and the famous handmade ash frame supporting the sleek aluminium panels. But underneath it's a car designed to take Morgan into the future.

"We recognised that we needed to ensure we had a strong future ahead of us in terms of emissions compliance, crashworthiness and the new GSR safety regulations," explains Morgan's head of design, Jon Wells. "That meant that we'd need a new vehicle platform, but a key requirement for us was to maintain the flexibility of coachbuilding with a separate body."

With this in mind, Morgan decided to switch to a bonded aluminium monocoque design for the chassis, while retaining the traditional coachbuilding techniques for the body. It's a tried and tested approach that the company has been using on its range-topping models since 2000.

Here, the majority of the structure is formed by folding sections out of sheet aluminium. The bonding surfaces are pre-treated with adhesive and then assembled on a jig before being baked at 180 deg C to create a single structure.

"It's a really good solution," notes Morgan's chief engineer, John Beech. "We've been using this method for 20-odd years and we've never had a failure. It results in a very rigid structure – we use a small number of rivets for location purposes, but it's the adhesive that does all the work."

New platform

Morgan's engineers refined this concept for the CX platform that would underpin the new Plus Four and Plus Six, Beech explains: "We managed to reduce the material thickness significantly – from 3 or 4mm down to 1.2mm in some places – which means the new chassis only weighs 97kg. At the same time, the stiffness has been doubled in comparison to the old Aero chassis."

One thing that was set in stone from the outset was that the new Plus Four had to occupy the same footprint as its predecessor, Wells recalls. This presented numerous challenges. For a start, the Plus Four's compact dimensions and low-slung running boards only left a narrow centre section for the main structure. And while the old Plus 4 used a live axle at the back and a sliding pillar arrangement on the front, the new car would use double wishbones all round.

Part of the design brief was that the car had to be capable of running wire wheels. This posed its own challenges, as wire wheels use spokes triangulated around a central hub, which leads to a larger offset than you'd find on an alloy wheel.

The direct injection turbocharged engines for both the Plus Four and Plus Six were supplied by BMW

"With a wire wheel, all the running gear has to be packaged well inboard of the centreline of the wheel. Getting the suspension geometry to perform – achieving a manageable scrub radius, for example, becomes a lot harder in that scenario," says Wells.

Morgan developed its own low-offset wire wheels in response to this, but it also necessitated extensive development work on the wishbones, uprights and brake components.

BMW partnership

Morgan was keen to futureproof the Plus Four against incoming emissions requirements – both to safeguard its position in existing markets and to open new opportunities where the previous car was unable to meet the legislation. A deal was struck with BMW, which had supplied the V8s used in the Aero 8 and the later versions of the Plus 8, to supply a new generation of direct injection turbocharged engines – an inline four for the Plus Four and an inline six for its bigger brother.

The majority of the powertrain electrical architecture is also shared with BMW, as are the transmission options. Much of the calibration work has been carried out at BMW's test facility in Aschheim, near Munich.

"The support and the hardware that we've received from BMW have been absolutely paramount to the programme. It's a relationship that goes back over 20 years and the engineers we work with there are very much part of the team," comments Wells.

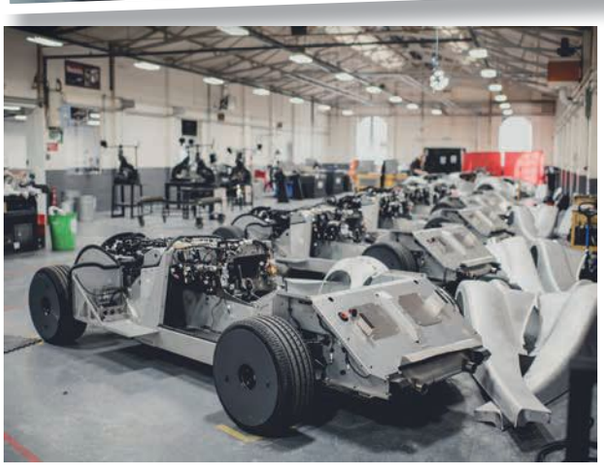
Packaging these powertrains would bring their own challenges. The six-cylinder engine in the Plus Six is the longest ever fitted to a Morgan, while both come with complex control and aftertreatment systems. This meant that there was a constant temptation to open up the packaging volume, but Wells dug his heals in.

"Power bulge is a phrase that's now banned from the Morgan Design Studio as it came up about once a day during the development," he jokes. "And once you've got everything in there – with the radiator and the cooling pack pushed up against the engine, the next challenge is keeping it cool. That required a lot of complex under-bonnet aerodynamics work. We've used external CFD for many years, but this was the first time we'd carried out a major study on internal aerodynamics."

Traditional techniques

Step into the Morgan factory on Pickersleigh Road and you're still greeted by the sound of panel beaters' hammers and the smell of fresh timber. In fact, there's more wood used in the body frame of the CX generation Plus Four than in its predecessor.

Traditional craftsmanship is still at the heart of Morgan's philosphy



Modern technology is used wherever it can offer an efficiency benefit without detracting from the traditional craftsmanship that lies at the heart of Morgan's production philosophy. Laser cutting, for instance, is now used to create the blanks that will later be hand-shaped into the Plus Four's elegantly-louvred bonnet. Likewise, 3D printing is used to create jigs and fixtures that are used in the wood shop.

One of the reasons for sticking with a traditional ash and aluminium coachbuilding process is that it provides plenty of flexibility for Morgan's small production runs (typically around 800 cars a year).

"We do everything for a reason – we really value the traditional skills that we have here, but as soon as we have a job justifying something then we don't force it," comments Wells. "For instance, Morgan is known for using wood, aluminium and leather, but when we did our electric 3 Wheeler concept we used a lot of carbon fibre. It's about choosing the right materials and processes for the job, not being too precious about doing things a certain way."

The wings are formed using the Superform process, which heats a sheet of aluminium to around 500 deg C and then blows it into a mould to create a complex 3D shape. But the remainder of the bodywork is sculpted by hand, just as it always has been.

The results are exquisite – particularly as other cars typically get bigger, heavier and more generic. Morgan has managed to retain the elegance of its original pre-war designs, despite bringing in a host of new technology.

There's undoubtedly more to come. Although the company says it has no specific plans for electric or hybrid models on this platform, it has been designed to provide sufficient flexibility should that be required. The last few years have also seen a significant period of expansion, with a team of 35 engineers and designers now occupying a dedicated 30,000-square foot engineering centre. Whatever challenges the future may have in store, you can be sure that Morgan will be well-placed to tackle them in its own inimitable style. THE ENGINEER

ENERGY SUSTAINABILITY IN DEFENCE

During a recent online panel session, experts from BAE Systems, the UK MOD, Supacat, Rolls-Royce and Williams Advanced Engineering explored the topic of energy sustainability in the defence sector. Jon Excell reports.

The push for net zero is fundamentally reshaping government agendas and many of our key industrial sectors. And that includes the world of defence, where energy sustainability is becoming an increasingly important focus both in terms of minimising the sector's impact on the environment and ensuring that it is resilient to current and future threats.

Earlier this year, in partnership with defence giant BAE Systems, The Engineer brought together leading voices from across industry to explore the importance of carbon reduction to the defence sector and examine some of the innovations that are helping it rise to this challenge.

The following report examines some of the key topics explored during this discussion, which was live-streamed to a registered audience.

Why sustainability matters to defence

Opening the session, Lieutenant General (Retd) Richard Nugee put forward a compelling case for why the defence sector must embrace "the green energy revolution".

Nugee - who has been key to shaping the MOD's strategy on climate change - told delegates that the adoption of green technologies will lead to significant improvements in military capability.

The ability to produce our own energy and adopt energy that's not reliant on imports will - he said – insulate our armed forces from the volatility of global energy markets and also help overcome some of the logistical challenges presented by getting fuel to bases or conflict zones overseas. Taking Adghanistan as an example Nugee said. "It costs in the region of £250 a gallon to get diesel to Helmand, and it costs in lives in terms of the logistics resupply - the most senior British officer killed in Afghanistan was killed on a logistics resupply patrol." The deployment of solar generators in Helmand would, he said, have vastly reduced the logistical and human costs of the operation.

The push for energy sustainability also creates the opportunity to significantly improve the performance of equipment, he added.

One example is the MOD's ongoing evaluation of a hybrid version of the Jackal high-mobility weapons platform which, he said, could have some compelling operational advantages over a conventionally powered vehicle. "You can sneak around the battlefield without emissions from the engine, without heat emissions and without noise emissions, it is just a better way of getting about the battlefield."

Whilst the push for net zero creates opportunities to introduce a host of new technologies – from lightweight, stealthy unmanned tanks and aircraft through to new ways of independently generating power on the battlefield - another key challenge for the defence sector will be finding ways to improve existing platforms, many of which will be in service for decades to come.

Here, said Nugee, the development of sustainable fuels will be critical. "I'm not a great fan of retrofitting....we're not going to change the engines on the aircraft carrier - it's due to last at least 40 years - so what we must do is look at new fuels and ways of capturing the carbon that comes off them without

MEET THE PANEL

- Cathy Davis- Head of Strategy, Sustainability, Simulation & Synthetics, BAE Systems
- Lieutenant General (Retd) Richard Nugee CB, CVO, CBE - Defence Non-Executive Director for Climate Change
- Paul McNamara - Technical Director, Williams Advanced Engineering
- Steve Austen- Engineering Director, SC Group & Supacat
- Dave Smith - Director of Technology, Rolls Royce

changing the engines."

There are clearly some key challenges ahead, but with the energy revolution in the wider world gathering pace doing nothing is not an option, he said. "If we don't move with this we will be left behind. If we insist on diesel engines in 2050, the net result will be that we will get either antiquated equipment or we'll get 2050 technology but it will be bespoke and unbelievably expensive. Neither of these are good for our military capability."

To meet these challenges, he said, the sector must work with other areas of industry, and become what he terms "a fast follower". "As soon as industry has come up with a solution that fits then we should jump on that and scale it as fast as possible." There are already positive signs that the sector has the appetite for the change that's required, he said. "I have been both surprised and delighted by industry's embracing of this in the defence sector".

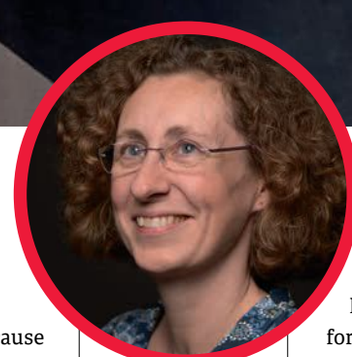
Nugee wrapped up by returning to his opening theme, stressing that the aims of military effectiveness and energy sustainability are complementary and not – as one viewer suggested - mutually exclusive. "Let's be in no doubt, we're not going to sacrifice our capability for just being green, because if you come second in a war but you're the greenest military you've still come second in the war. That doesn't work for us. We've got to do it in tandem of being as effective and efficient as we can be and being as emission reduced as we possibly can be. But we still need to be able to win the war."

An industry view

After Nugee's stirring introduction, it was time to hear how the UK's biggest defence company, BAE Systems, is responding to the net zero challenge.

Cathy Davis, who heads up BAE's sustainability strategy, explained that energy sustainability is vitally important to the company, which earlier this year confirmed a target to achieve net zero greenhouse gas emissions across its operations by 2030

She explained that a major area of focus has been improving the sustainability profile of many of its key UK sites.



Cathy Davis- Head of Strategy, Sustainability, Simulation & Synthetics, BAE Systems

For instance in Samlesbury - home to manufacturing operations for the Eurofighter Typhoon, and the F-35 Lightning II - the old runway has been repurposed as a solar farm which provides a fifth of the site's peak electric consumption, and has so far saved £300,000 in energy costs. Another key site operated by BAE, the Portsmouth naval base, has used a range of measures including solar energy, heat containment, battery energy storage, and a switch to onsite electric vehicles to drive a 65 percent reduction in carbon emissions.

Alongside the sites and facilities, the challenges posed by climate change are also having a profound impact on both current and future products added Davis. "Climate change will continue to affect temperatures and create extreme weather conditions, and for us it's important to understand these challenges so that we can design systems fit for operation in these future →

environments."

Activities here fall under three broad areas beginning with electrification where – she said - the company is particularly keen to tap into some of the breakthroughs being made in other sectors. A case in point is BAE's collaboration with Williams Advanced Engineering on the potential combat aircraft applications of battery management technologies originally developed for motorsport.

Another key area of BAE's electrification work is around energy optimisation where, for instance, the company has been collaborating with engineers at Oxfordshire aerospace firm Reaction Engines on novel heat exchangers for next generation aircraft. This technology could, said Davis, potentially be used to recycle excess engine heat for powering integrated high energy weapons or computing systems.

Other areas of focus include an emphasis on improving design and manufacturing processes by, for example, exploiting the use of additive manufacturing techniques to produce lightweight parts and, lastly, a concerted effort to reduce the use of fossil fuels, whether it's through the adoption of virtual training techniques that negate a requirement for fuelled training platforms or the use of new sustainable synthetic fuels.

The integration of new fuel types will, she said, be particularly challenging, and significant levels of R&D will be required to both meet demand and bring down the costs (sustainable fuels are between 3 and 14 times more expensive than diesel. "This is an area that needs collaboration across the defence community and wider industry...if we are to transition to net zero for large platforms," she said.

From race-track to the battlefield

With both Nugee and Davis stressing the need for collaboration with non-defence companies, our next speaker - Technical Director of Williams Advanced Engineering (WAE) Paul McNamara – discussed how some of the lessons learned in motorsport - particularly with regard to electrification - can be applied to challenges in defence.

Electrification is a key area of expertise for WAE, which has been heavily involved in the development of batteries and powertrains for electric racing competitions including F1's electric cousin FormulaE, and the ExtremE off-road racing series. Its experiences in these competitions, which regularly push electric systems to their limits, have – said McNamara – delivered defence-relevant solutions to some of the key challenges presented by electrification: particularly around ruggedisation, refueling, and – critically - engineering new products around electric powertrains. "What motorsport is trying to do with lightweight electrification has a lot of overlap into defence," he said.

When considering the challenge of developing an electric vehicle, the key issue is energy density. Batteries – said McNamara - are much heavier than the equivalent bit of diesel. "Kilogram for kilogram diesel is storing about 50 x as much energy. When you to take account of the fact the engines etc. are pretty heavy and not terribly efficient you still end up with a factor of around 20. You have to look at the engineering of the entire product – how to you configure the whole system." WAE's understanding in this area is – he said – already feeding into the defence sector.

In terms of ruggedisation, the ExtremeE competition (where vehicles are pushed to the limit in extremely rough terrain) is also generating useful knowledge. "That is a key area of collaboration between us and defence," said McNamara.

He added that motorsport is also helping to drive forward the practical understanding of how to optimise batteries for different cycles. This is another key challenge for the defence sector, where different types of vehicle require different amounts of power at different points. Here, he said, advances in hybridisation of batteries - where the battery itself has multiple different chemistries tuned for particular parts of the cycle - could prove particularly attractive to defence.

Lieutenant General (Retd) Richard Nugee CB, CVO, CBE - Defence Non-Executive Director for Climate Change

Finally, McNamara turned to the work that WAE has been doing on refueling and explained that the introduction of pitstop refueling for electric racing cars is driving development in rapid battery charging that will have significant military relevance.

Electrifying land vehicles

Picking up the electrification baton, and expandong on some of the benefits discussed by oether panelists our next presenter, Supacat engineering director Steve Austen, took a deep dive into the challenges and benefits of electrifying military land vehicles.

Supacat - a major supplier of high mobility defence vehicles, is now at the forefront of efforts to electrify this aspect of defence, and Austen began by identifying some of the key attractions of electric land vehicles. "It's the capability to reduce your signature," he said, "whether that's through quiet or silent running, a lower thermal signature, or the ability to go on silent watch [i.e. operate in-the-field communication and nav equipment without having to turn your IC engine on]. We've also found through the vehicles we've developed that the use of electric motors gives you a great increase in controllable torque at low RPM. Suddenly your mobility at low-speed increases."

Paul McNamara - Technical Director, Williams Advanced Engineering

Alongside these performance benefits, another key driver for the adoption of electric vehicles identified by Austen is the supportability of existing platforms, which will become trickier as the rest of the world moves on. "As the commercial sector embraces electrification ...the ability to support traditional IC engines →

and components is going to get harder for defence customers," he said.

However, despite the advantages, there are also some big challenges: electric vehicles bring with them infrastructure requirements around charging and maintenance; low torque high RPM motors present some significant cooling challenges; and there are also important safety considerations around the use of HV electrical systems on the battlefield. "There's a lot of work to do to ensure that your electrical components can continue to operate reliably in theatre," said Austen.

Until recently, there have been relatively few electric vehicles to trial so that these issues can be properly explored, but as Austen explained Supacat is now at the heart of efforts to explore the practicalities of the technology, through its development of a prototype hybrid electric variant of the Jackal HMT which is now being evaluated by the MOD at the Millbrook proving ground in Bedfordshire.

Looking further into the future, Austen said that given the rapid advances in different methods of energy storage it will be important to be power agnostic when thinking about electrification. "If we can make it so that the driveline and overall vehicle remains the same then we can take advantages of improvements in power sources as they come along and avoid the risk of built-in obsolescence."

Civil aviation's low carbon push

Our final presenter, Rolls-Royce's director of central technology Dave Smith turned his attention to aviation, and looked at how the trends and technologies shaping the civil aviation sector might affect the world of defence.

The civil aviation sector's rapid drive to net zero, and the development and deployment of new technologies, presents both risk and opportunity for the defence sector, said smith.

It's a risk - he said - because the design and manufacture capability for engines is going to diminish as the civil word adapts and fuel availability is inevitably going to change. "We won't be using kerosene in the future as we do today in civil aviation in 2050, so the current fuel we have designed platforms around will not be available and that is going to be a challenge to military combat operations."

However, if the defence sector can tap into the advances being made in the civil sector, the prize in terms of operational improvements could be huge, he said.

Echoing fellow panellist Richard Nugee, Smith said ignoring these developments is simply not an option. "The world's energy needs will be met by civil energy suppliers using new forms of energy, engine and fuel. You can either choose to be an early adopter or you can go very late, but one thing you can't do is ignore it, because it's going to happen. And you need to work with suppliers of that new technology because you want to influence and understand their roadmaps and understand all of the different energy sources that will shape the future."

Steve Austen- Engineering Director, SC Group & Supacat

Smith said that many of the different technologies coming through – from lightweight fully electric vertical take off and landing (VTOL) vehicles, through to hydrogen fuel cell powered aircraft – could have a useful role to play in the military airspace, but the most significant area of development will, he argued, be the use of sustainable aviation fuel (SAF), a clean substitute for current jet fuel that can be produced from sustainable resources.

"This is technically better than kerosene," he said. "It has slightly more energy per kg per litre; it has better thermal properties, it is a better fuel."

There are also, he added, multiple different pathways to producing it. "You can make it from crop residue, or from municipal waste and you can make it from green electricity. We think nuclear is a very good route to doing that and we're looking at microreactors and SMRs and integrating them into a fuel production plant to produce this net zero sustainable fuel. It's potentially a means of having self-sufficiency for operations wherever they are."

SAF is currently expensive, but as the industry gears up towards producing the volumes that will be required by the civil aviation sector (500 million tonnes by 2050 according to Smith) prices will come down, and this monumental scale-up is already underway. "Available SAF in Europe will be ten times more in 2024 than it is today," said Smith.

"The green energy transition is not a threat to defence," concluded Smith, "it's overwhelmingly an opportunity. But we do have to respond and understand it and work with people we probably haven't worked with before to make sure we get the get the full potential of this massive civilian investment in technology. " THE ENGINEER

Dave Smith - Director of Technology, Rolls Royce

Keeping Automotive Testing on Track

Nick Wignall, Tracks Manager at UTAC CERAM Millbrook explains the role physical test tracks play in vehicle testing and validation, and how recent developments ensure they remain crucial to the future of automotive engineering.

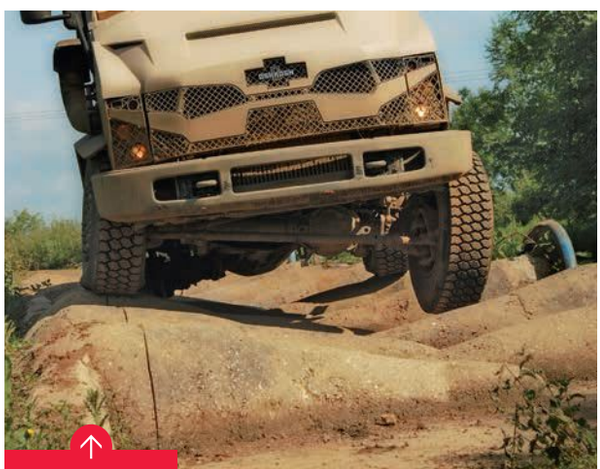
In a world of intelligent simulation technology and highly advanced climatic chambers, it would be easy to think that physical test tracks will soon be a thing of the past. The reality couldn't be further from the truth.

It has been more than half a century since our Bedfordshire site opened its 70km of test tracks. Its mix of high-speed and dynamic handling tracks, as well as city-like low-speed 'real-world' simulation environments makes the facility's tracks just as vital to customer development programmes as the plethora of dynamometers and simulation rigs. The same can be said for our test tracks in Mortefontaine and Linas-Monthléry, France, as well as our indoor and outdoor winter test facility in Northern Finland.

The beauty of track testing is that there are so many different types of track, built to replicate almost any type of real-world environment or situation. Across our sites, we have the capability to test a vehicle in almost any scenario, allowing our customers to integrate track work throughout their development programmes.

Being able to put a vehicle onto a physical track to validate a theory or a development path that you might be exploring in the laboratory or simulator is invaluable. It is also the case that much of the testing needed to achieve type approval requires the vehicle to run on a track, usually tailored to specific technical regulations.

So, what types of tracks does UTAC CERAM Millbrook have, and how do engineers use these to develop new vehicles and components? Below are some of the latest track developments.



Top: Aerial view of UTAC CERAM Millbrook's iconic Bedfordshire proving ground

Above: The proving ground is also used by the armed forces to put military vehicles through their paces

5G-enabled Test Tracks

Millbrook Proving Ground was the first site in the UK to install a 5G network specifically for automotive development and testing. With a network that covers and operates across the full proving ground, including our High-Speed Circuit, Hill Route and City Course, the 5G network was recently upgraded to make it the densest private 5G stand-alone network in Europe.

Our 5G network allows an ultra-low latency transfer of data to and from a test vehicle, meaning that engineers can

Outdoor cold weather facilities in Ivalo Finland

review test data in real time, enabling our track testing to be more efficient than ever.

We also have a test centre in France which is dedicated to testing connected and autonomous vehicles (TEQMO). This is based at the historic Linas-Montlhéry Autodrome and includes 12km of test tracks, platforms, junctions and soft targets, alongside several laboratories.

Off-Road Tracks

Our most varied, and arguably most exciting, tracks include our off-road circuit which used for a range of vehicles, from soft-roaders to military vehicles. These tracks include extremely steep gravel and sand hills, severe twists, wading ponds and ditches, to name a few.

Home of the UK's battlefield Mission, Millbrook Proving Ground is well utilised by the armed forces in determining performance and durability of its vehicles. In fact, the MOD's Technology Demonstrator 6 (TD6) project, which aims to determine the benefits that hybrid vehicles may bring to today's battlefield mission, is being heavily supported by UTAC CERAM Millbrook.

Snow and Ice Testing All Year Round

When developing a vehicle, powertrain or component, a crucial part of the programme often involves exposing the product to extremely cold temperatures. In recent years, the advancement of climatic test chambers has meant that it is often easier, quicker and more cost-effective to create these temperatures in laboratory conditions.

One area where real world cold weather testing is still vital, however, is in developing tyres. We all know how crucial it is that a vehicle's tyres can perform on ice and snow. Based in Ivalo, on the edge of the Arctic Circle in Finland, our winter testing facility has both indoor and outdoor tracks, allowing engineers to test tyres on snow, ice, wet and dry surfaces all year round.

New Test Centre in Morocco

At the other end of the thermometer, is UTAC CERAM Millbrook's latest test centre in Oued Zem, 150km from Casablanca in Morocco. In a similar way to Test World, part of the reason for choosing to build this new facility in North Africa is reliable weather conditions, making testing more repeatable.

The Oued Zem facility will feature a 4km track that is unique to Europe and Africa, and will be certified for use in type approval testing. We are looking forward to this facility opening later this year.

So you can see that with ongoing investment and development, the physical test tracks for which UTAC CERAM Millbrook first built its reputation have a long future ahead of them, as a crucial element to the future vehicle development ecosystem. THE ENGINEER

This article is the latest in a series of guest blogs by engineers at UTAC CERAM Millbrook exploring the technologies that are helping automotive engineers keep pace with consumer and legislative demands. Visit www.theengineer.co.uk to find out more.

The Test World indoor winter test facility

IN-HOUSE INVESTMENT

Multi-tasking machine tool helps hydropower specialist bring manufacturing back home

Founded in 1856 (the same year as The Engineer magazine) Kendal-based Gilbert Gilkes & Gordon Ltd has long been at the forefront of the hydro-electric turbine and engine cooling pump market. The company's pedigree stems from its explicit commitment to quality. However, when it comes to the manufacturing of turbine runners, quality has often come at a cost.

"Turbine runners are traditionally cast and polished by hand, a laborious task taking hundreds of man hours," said Rebecca Sandham, Gilkes' Head of Operations. "We have always had our own in-house machine shop, but have often had to subcontract the machining of runners, before finishing the process in-house. While this was a functional way of operating, deep down we knew it was also becoming limiting."

Historically, the machining of a turbine runner resulted in one of the longest lead times of each project. With a view to increasing Gilkes' competitiveness, in 2019, Sandham set the challenge of fully machining a turbine runner from a solid billet of material, in-house, by the end of 2020.

"While the cost of subcontracting the machining of runners was undoubtedly a major factor in attempting to bring it in house, there were a number of other factors at play," added Sandham. "From an intellectual property perspective, bringing all your key process and equipment under one roof has significant advantages. Likewise, we realised that if we wanted to challenge our production engineering department and reduce overall project lead times, we needed to scale-up our 5-axis machining capability."

For the team at Gilkes, the main issue was not simply finding a machine tool that could replicate the subcontract services to manufacture the runners from solid, but also finding a machine supplier that would enable a truly collaborative approach.

Derek Thomas, Production Engineering Manager explained: "We approached a number of machine tool manufacturers who were more than capable of supplying us with a turnkey machining solution, but not many were able to afford us the level of involvement

Gilkes has used the INTEGREX e-1250V/8 to fully machine a Pelton turbo runner from a solid billet of material.

The INTEGREX e-1250V/8 comes with a 42-tool magazine as standard, but is available with 84/120/162-tool options.

The INTEGREX e-1250V/8 is one of the largest machines in the Mazak range, and is designed for the 5-axis machining of complex large workpieces.

that we wanted. As this would be a new venture for us, we needed to ensure our own engineers could be heavily involved in the process, otherwise we'd have had to spend the next 12 months learning how to develop our next runner. In short, we wanted a partnership but not to become over-reliant."

Among the companies that really stood out to Gilkes was machine tool manufacturer, Yamazaki Mazak. "The fact the company had a UK base was.... incredibly important, from both a training and applications support perspective," said Sandham.

Following the completion of the tender process, Gilkes ordered an INTEGREX e-1250V/8 vertical Multi-Tasking machine, which was delivered and commissioned in early March 2020.

The e-1250V/8 is one of the largest machines in the Mazak range, designed for the 5-axis machining of complex large workpieces. The Multi-Tasking machine is capable of performing a variety of tasks that would normally be completed by multiple machines, including milling, turning, boring and drilling operations.

Sandham continued: "We built a close relationship with Mazak following the machine installation. Mazak engineers were on site with us nearly every week throughout 2020 and, working alongside our other partners such as Brown & Holmes, Iscar, SolidCAM and VERICUT, we were quickly able to tackle any issues we faced. Specifically, we were able to collaboratively overcome the challenge

of completely machining the runner without needing to finish off any hard-to-reach elements with subcontract spark erosion."

Thomas added: "The practical training has ensured that we were able to lead on the programming for our first runner. Our engineers learnt how to use the software, how to verify the program and how to commission the machine. This means we're in a position to programme a new runner within weeks, rather than months. This wouldn't have been the case if we'd chosen a different machine tool partner."

Despite the machine being installed just before the first UK lockdown, the disruption caused by COVID-19 only had minimal impact on Gilkes. As a result, in December 2020, the team was able to successfully complete Rebecca's challenge, with the first Pelton runner fully machined on the e-1250V/8 being completed and delivered to a Hydro site.

"Having the in-house capability, coupled with all the right people under one roof, has made a huge difference," she said. "With outsourced machining, if for some reason a design element isn't feasible, resolving that problem and then going through the FEA process again can significantly add to an already lengthy lead time. The beauty of having the INTEGREX on site is that everyone can sit down right from the very beginning. If we see something the machine isn't capable of achieving, then we can talk through the options and make changes much earlier, which in turn both reduces lead times and any duplicated activity."

As well as using the e-1250V/8 for the manufacture of new runners, Gilkes has also benefitted from the flexibility and innovation that comes with owning a Mazak to deliver refurbishment projects in tight timescales. "In the past, when a customer requires refurbishment, we've had to subcontract the work out," said Thomas. "This is both very expensive, and unpredictable as you are at the mercy of a supplier's production schedules. Now we have the INTEGREX, we've been able to design a fixture which allows for single point accuracy fixturing.

"If a customer comes to us with urgent refurbishment, but we're in the middle of a cycle on another runner, we can pause it, remove the runner, complete the machining, then put the original part back on to the INTEGREX and continue the cycle from within microns of where we left off. That kind of flexibility is invaluable."

Looking to the future, Gilkes has already set its sights on expanding its in-house portfolio. Sandham concluded: "The e-1250V/8 would have been able to process 82% of our historical forecast, which means the future is incredibly promising. Following the completion of our first Pelton runner, we will now be turning our attention to the manufacture of both Francis and Turgo runners. When you walk into the production department now, the excitement is contagious and the team are hungry to see what we can do next."

THE ENGINEER

GARETH L. POWELL

Brave New Worlds?

Now that the world's richest men are turning their attention to other planets, our resident science fiction author, Gareth L. Powell considers what kind of future they might have to build when they get there.

What is it with billionaires and rockets? As I sit down to write this column, the world's richest man has just announced his intention to travel into space in July. It might sound like the plot from a James Bond novel, but Jeff Bezos has decided to ride along on the first crewed launch of his Blue Origin New Shepard rocket.

The announcement was followed by online speculation that Richard Branson's Virgin Galactic might be planning a July surprise of their own, and that California-based Relativity Space has revealed its plans for Terran R, a fully reusable and entirely 3D-printed space launch vehicle.

While the Terran R's primary mission will be launching payloads of up to 20,000 kg into low Earth orbit, the company's longer term vision includes the provision of a space freighter capable of missions between Earth, Moon and Mars. CEO, Tim Ellis said, "Relativity was founded with the mission to 3D print entire rockets and build humanity's industrial base on Mars."

While Bezos seems primarily concerned with the Moon and moving heavy industry into space in order to reduce pollution, Relativity's focus on Mars chimes with the long-term aims of Elon Musk. Musk sees the red planet as an opportunity to establish a back-up to Earth. Rather than keep all our eggs in one basket, he hopes to ensure our survival by turning humanity into a multi-planet species. But what kind of society does Musk envision for Mars, and how might he control it?

At this point, I'm going to move away from real life figures and don my science fiction author's hat.

So, consider a hypothetical billionaire has established a small colony on Mars, consisting of maybe a hundred people who intend to spend the rest of their lives there. Perhaps this hypothetical billionaire is genuinely benevolent, and will work towards creating a fair and egalitarian society. But what if they aren't? What happens if this isn't a humanitarian mission at all, but simply an attempt to escape the existential risks of climate change on Earth? Perhaps they've decided the Earth is a lost cause, and they want to use their money to jump ship. In either case, what will life be like for those colonists? Try to imagine having a job where your boss literally owns the air you breathe. These founders may all set out with the same goals in mind, but what happens when their fledgeling society inevitably runs into disagreements about the direction of its development. Are the colonists going to want to be owned by the same company for their entire lives? How much freedom can they expect when their employer owns everything they need to survive, and can therefore dictate their behaviour?

The idea of being incarcerated in an inescapable corporate panopticon may be enough to give George Orwell nightmares, but will it really be inescapable?

If civilisation on Earth crumbles, how much will our billionaire's money be worth? People will be worried about friends and relatives back on Earth. To maintain authority, our billionaire will need security personnel. But how will they pay them when the banks on Earth are gone? Without anything to spend it on, money's just an abstract series of ones and zeroes in a computer. Without their billions, anyone tempted to act like a dictator may find themselves booted out of the nearest airlock without a pressure suit.

In previous columns, I have explored the implications of using autonomous drones on the battlefield. Our billionaire may consider investing in a few smart machines to keep the populace in line. These drones will have to be pretty smart to stay one jump ahead of resourceful rebels, but how smart do you want a drone to be? At what point will it assess its situation and realise its best chance of survival is to refuse to follow orders or defect to the enemy?

Frankly, the only way for our billionaire to survive and flourish on their new world will be to build a fair and democratic society in which everyone can participate. This will mean huge investments in infrastructure and quality of life, and necessitate a large team of engineers with a wide variety of specialist knowledge. Factories, greenhouses and accommodation units will need to be built, but so will schools, parks, and social spaces.

All of this also applies to the Moon or orbital colonies. Humans are social animals, and if we're creating an artificial environment for ourselves, that has to be taken into account. THE ENGINEER

Gareth L. Powell is an award-winning SF writer from the UK. You can find him online at ***www.garethlpowell.com***

EDITH CLARKE: AMERICA'S FIRST WOMAN ENGINEER

In her remarkable career, American electrical engineer Edith Clarke made huge contributions to the nation's power infrastructure while becoming a role model for women in engineering. Written by Nick Smith

WRITTEN BY NICK SMITH

Almost a century ago, on 9th February 1926, the *New York Times* ran with a story headed 'Woman Addresses Electrical Institute'. Drawing further attention to the significance of the occurrence described, the newspaper further explained: 'Miss Edith Clarke the Only One of Her Sex to Read a Paper at Engineers' Meeting.' The first woman to be professionally employed as an electrical engineer in the United States was literally headline news.

In fact, the delivery of one of her numerous influential papers on electrical power systems was but one of many firsts in Clarke's remarkable career. She was the first female professor of electrical engineering in the US, the first woman fellow of the American Institute of Electrical Engineers as well as the first woman to be recognised by the oldest engineering 'honor society' in America, *Tau Beta Pi*. Her 1943 book *Circuit Analysis of A-C Power Systems* is a classic of its kind, occasionally cropping up on rare book collectors' websites with a price tag of several hundred pounds. Today, perhaps Clarke's best-known contribution to the world of engineering is her graphical calculator that greatly simplified the calculations necessary to determine the electrical characteristics of long electrical transmission lines, for which she was inducted posthumously to the National Inventors Hall of Fame in 2015.

EDITH CLARKE 1883-1959

Not much is known of Clarke's childhood other than it was extraordinary. Daughter of a wealthy farm-owning lawyer and one of nine children, she was born in 1883 during a time of economic recession, and when the great engineering landmarks were the opening of the Brooklyn Bridge and Edison's first overhead electric lighting systems. As a child, she had difficulties with reading and spelling, but showed an exceptional aptitude for mathematics and had a passion for card games, particularly whist. By the time she was 12, the young Edith was an orphan, with the responsibility of her upbringing being placed on an older sister.

Despite resistance from her relatives, Clarke invested her inheritance in acquiring an education. She enrolled at Vassar College where (because there was no provision to teach engineering to women) she took her Bachelor of Science degree in mathematics and astronomy. After graduating she became a teacher of mathematics and physics (first at a private girls' school in San Francisco and then at Marshall College in West Virginia), but became disillusioned after realising, as she later recalled, that "teaching is not at all like a game of Duplicate Whist! I therefore turned to something else." That 'something else' was of course engineering, and Clarke duly enrolled in the civil engineering programme at the University of Wisconsin in 1911. A summer placement as a mathematical computing assistant at AT&T in New York led her to change direction again, taking the decision to remain full-time, where she would eventually become the manager of a group of women 'computers' who made calculations for the Transmission and Protection Engineering Department during the First World War. Ever willing to travel, she also studied radio at Hunter College and electrical engineering at Columbia University.

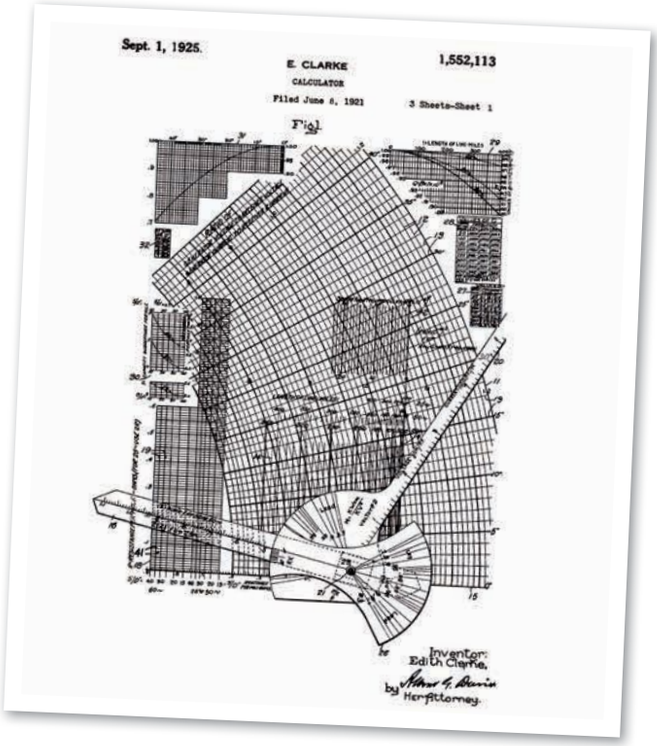
At the end of the war, in 1918 Clarke decamped to the Massachusetts Institute of Technology, where she became the first woman to earn a master's degree in electrical engineering. Supervised by the

Supported by

electrical engineer Arthur E Kennelly, her thesis was entitled *Behavior of a lumpy artificial transmission line as the frequency is indefinitely increased.* Her next career step was to take a position at General Electric where she was to work for the following quarter of a century, with the exception of two years spent on leave as a professor of physics at the Constantinople Women's College in Turkey, before returning to GE in 1922 as a salaried engineer. Part of the purpose for this career hiatus was to highlight her irritation at the lack of career opportunities for women and to draw attention to gender pay inequality. As a woman, Clarke neither earned the same salary nor was afforded the same professional status as her male colleagues. Later in her career, as a leading woman engineer of her day, she was to tell the *Dallas Morning News*: "I had always wanted to be an engineer, but felt women were not supposed to be doing things like studying engineering."

One of the defining moments in Clarke's career happened on 8th February 1926 when, as the first woman to deliver a paper at the annual midwinter convention of the American Institute of Electrical Engineers (AIEE), she demonstrated the use of hyperbolic functions for calculating the maximum power that a power line could carry without becoming unstable. Although the main reason this attracted national media attention was undoubtedly Clarke's gender, there was also the matter of reporting on a solution to a problem in America's critical national infrastructure. Geographical penetration of the American power grid meant that transmission lines were getting longer, leading to greater loads and the increased likelihood of instability in the supply.

Responding to the fact that the mathematical models available at the time applied only to small systems, Clarke set about modelling larger-scale systems by using the 'method of symmetrical components' mathematical technique. This level of mathematics would have been seen as esoteric by most electrical engineers



// THERE'S ALWAYS A DEMAND FOR ANYONE WHO CAN DO A GOOD PIECE OF WORK. //

EDITH CLARKE (1883-1959)

of the day, and so to simplify and reduce the laborious calculations that went into resolving issues associated with larger power systems, Clarke translated her approach into a kind of 'ready reckoner'. At a time when systems were rapidly increasing in size and complexity, Clarke's graphical calculator was making the everyday lives of the electrical engineer much easier. These new methods for the analysis of complex systems were arguably the first tentative steps towards what we know today as smart grid technology.

During her time at General Electric, Clarke was also a prolific writer, publishing 18 technical papers as well as the much-respected book *Circuit Analysis of A-C Power Systems* that was a required reading on the topic for decades in engineering schools and colleges. This seminal textbook includes adaptations of her lectures on the $\alpha\beta\gamma$ transformation for simplifying the analysis of three-phase circuits, later to become known eponymously as the Clarke Transformation. Another of her papers, co-authored by Clarke and published in 1941 in the *Transactions of the American Institute of Electrical Engineers*, received an award from the AIEE for being the first published mathematical examination of transmission lines more than 300 miles long. This distinguished publishing aspect of her career propelled Clarke to become recognised as an authority on the manipulation of hyperbolic functions, equivalent circuits, graphical analysis and electric power systems. Her citation in the National Inventors Hall of Fame draws attention to an often overlooked segment of Clarke's career in which she worked on the design and development of hydroelectric dams in the West Hoover Dam, contributing her electrical expertise to the installation of turbines that generate hydropower there to this day.

In 1947 Clarke left General Electric with the intention of retiring. In fact, she made a comprehensive return to her roots and bought herself a farm in rural Maryland, only to come out of retirement two years later to teach in the faculty of electrical engineering at the University of Texas, Austin. It was here that she left another mark on the history of engineering by becoming the first female professor of electrical engineering in the US, and where she was still critically aware of women's lack of representation in her field, telling the *Daily Texan* in 1948: "There is no demand for women engineers, as such, as there are for women doctors; but there's always a demand for anyone who can do a good piece of work." Clarke eventually withdrew from academia in 1956 and spent the remaining three years of her life on her farm, where she died of a heart attack in 1959 at the age of 76.

In his paper *From Computer to Electrical Engineer – the Remarkable Career of Edith Clarke*, Dr James E Brittain says that as a woman working in an environment traditionally dominated by men, "she demonstrated effectively that women could perform at least as well as men if given the opportunity. Her outstanding achievements provided an inspiring example for the next generation of women with aspirations to become career engineers." Clarke was honoured with listings in *Who's Who in Engineering*, *American Women*, *Careers for Women*, *Women Can Be Engineers* and also, as if to bear witness perhaps to how little prepared the establishment was to accept a woman engineer of such high accomplishment, *Men of Science*.

THE ENGINEER

Photos: Alamy

JULY 1960

Driving ambition

A new simulator for learner drivers offered everything except a clear view of the road ahead

WRITTEN BY JASON FORD

Learner drivers in Coventry have the option of paying for a service that puts them in a simulated environment before heading onto the road.

SmartLearner Driving School claims to be the first driving school in England to have its own driving simulator, which comes with eye trackers, motion detectors and an advanced PC system to monitor learners as they get to grips with car controls.

In the broader automotive world, car manufacturers make extensive use of simulators for the purpose of research and testing and the advent of autonomous vehicles is driving a simulator market valued at $4.6bn in 2019 and is expected to expand at a CAGR of 3.4 per cent to 2027 as manufacturers invest in tech that helps them iron out glitches prior to production.

By 1960 the use of simulators had gained traction in industries where training at full scale was too expensive or dangerous but in July of that year General Precision Systems, Ltd. of Aylesbury, Bucks was bringing simulators to the masses with Sim-L-Car.

Described by The Engineer as 'basically a mechanical rather than an electrical analogue', the Sim-L-Car was designed for learners with no prior motoring knowledge and was not 'sufficiently refined to deceive the experienced driver'.

"With the simulator it will be possible to ensure that pupils know the functioning of clutch, brake, throttle, gear shift, and steering before entrusting them with a car on a road," our correspondent said. "It is also possible to use the simulator to develop drills and skills - for instance, releasing the hand-brake before starting, and changing gear without disturbing the course of the car. If the car is driven so as to touch the verge of the "road," an alarm sounds. A device measuring the time taken to apply the brake after a signal is illuminated can be incorporated."

The driver's view was created through the projection of a transparent model on to a screen in front of the car. The light source was positioned opposite the driver's eyes and the model landscape, made of transparent plastic, was moved below it by a drive unit.

"The velocity of the model is determined by the driver of the car; the direction of movement is established very simply by linking the turntables carrying the front wheels by mechanical remote control to the drive unit," The Engineer noted.

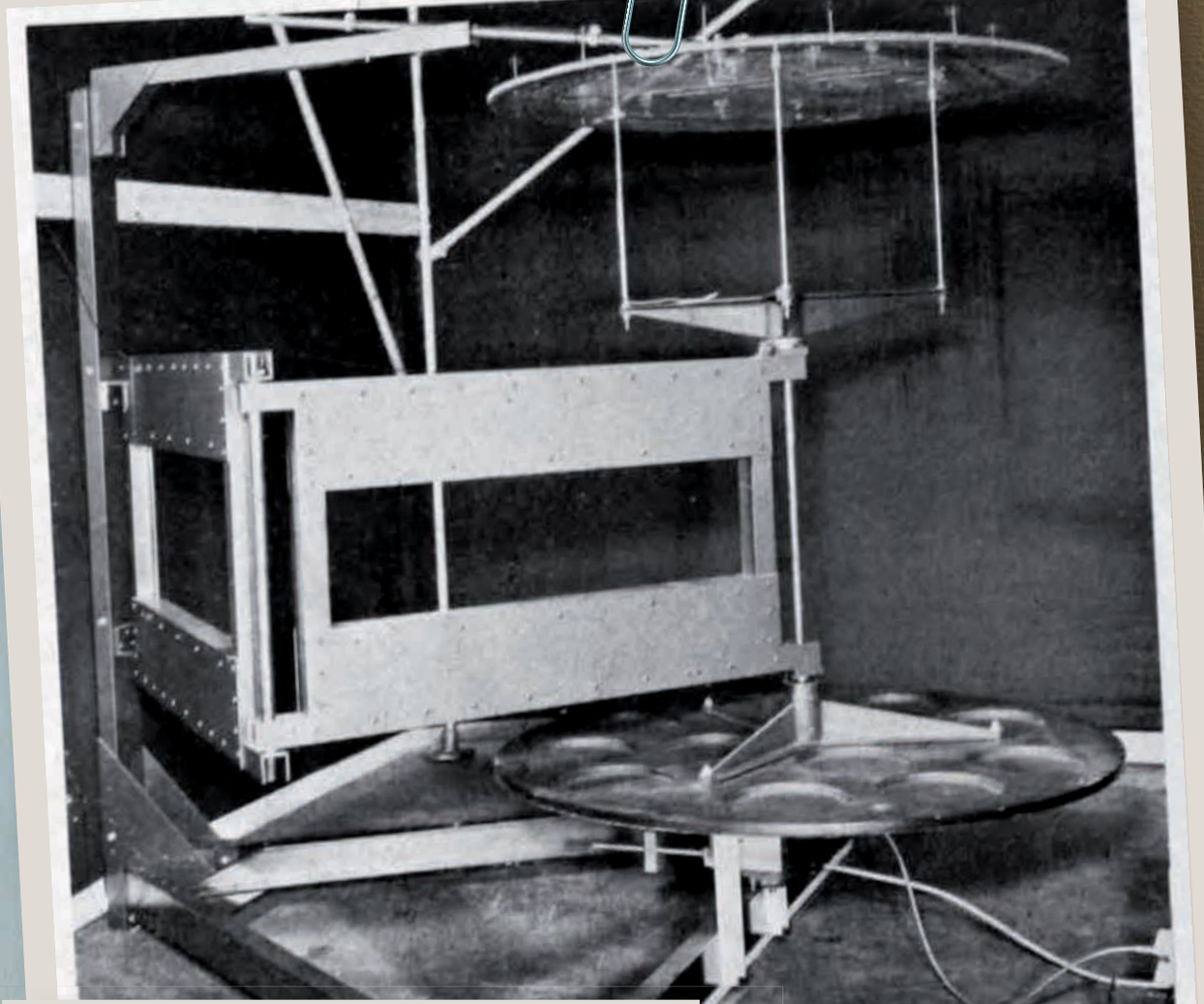
Speed of movement was dependent on the position of the throttle pedal and gear ratio - established by friction drive to different sized drums - selected by the instructor on a panel.

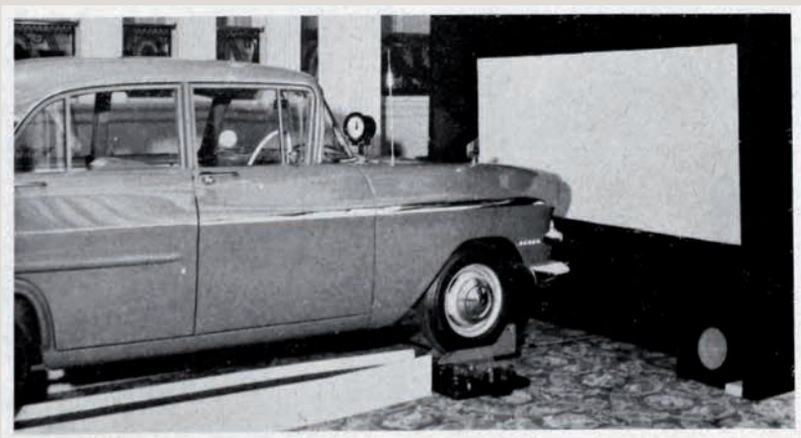
"Depression of the clutch lights a lamp on the instructor's panel, reminding him to change "gear" and allowing him to check that the pupil is disengaging the clutch at the appropriate moments," our correspondent said. "The pedal position pick-offs form a sub-assembly which is individual to a particular car model, and the different assemblies are readily interchangeable, being linked to the instructor's panel and the simulator proper by electric and, for the brake, Bowden cable."

The basic simulator, which was supplied with pedal assemblies for six popular cars at the time, is said to have cost less than any four-wheeled car in England. It ran off the mains supply electricity supply but could be supplied in a lower cost version that ran off the battery of a 12V car.

In a demonstration carried out in London, our correspondent noted 'the finite size of the light source in the projector gives a faintly fuzzy image'.

It was further observed that the 'image of the filament in the far side of the spherical envelope projects a second, fainter, image above the first; at certain attitudes, the columns supporting the model appear as black shadows on the screen. Since the drive unit is turned by the front wheels of the car, the response of the simulator is that of a car with an infinitely short wheelbase, and hence extremely quick."





A certain type of learner driver may have been disappointed to find that real tyre effects were not reproduced by Sim-L-Car.

"These imperfections are immaterial for the speeds used by pupils making their first acquaintance with a car," our correspondent concluded. THE ENGINEER

DR HILARY LEEVERS

The future is bright with these students creating a big bang

EngineeringUK CEO Dr Hilary Leevers pauses to celebrate the students who have reached the finals of The Big Bang Competition

Alongwith the number of disruptions we've faced this year due to the pandemic, this year's Big Bang Competition is running a little differently, as you might expect.

Young people throughout the past 15 months have shown great resilience and determination – coping with multiple lockdowns, periods of remote learning and restricted access to equipment. The pandemic has also made working together hard to organise. While we've done our best to support young people, including through a new mentoring scheme with support from Network Rail, we were concerned how all these challenges would affect young people entering the Big Bang Competition. In fact, we at EngineeringUK have been marvelling at the quality of entries received for the Big Bang Competition this month. Over 200 projects were submitted and that in itself feels like a triumph.

Vying for the prestigious titles of GSK UK Young Engineer and GSK UK Young Scientist of the Year are 10 projects. What's striking about all, is not just the ingenuity of each of these young people working together on these projects, but their desire to help other people or improve society.

In a sign of the times, one student created a face mask designed to be worn for long periods from more breathable fabrics while still offering good protection from viruses and other particles. Health issues and how to alleviate symptoms or manage conditions are a focus of many projects. One finalist created an app to manage diabetes and another designed an app to manage symptoms associated with obsessive compulsive disorder. One student investigated the impact of a low-carbohydrate diet on her father's diabetes, while another looked at the microbial properties of mouthwash. Patients affected by Parkinson's or Vertigo could be helped by a custom device designed by another finalist, which improves the wearer's sense of balance.

Other projects looked at engineering solutions for more efficient and sustainable transportation and energy storage, with potential for helping remote communities in Africa. Another student came up with their own novel algorithm to compare travel package holidays. And an even more 'green' project looked at whether willow water, from the native UK tree species could be used to promote root growth for a range of different plant cuttings.

This diverse range really shows the breadth of creativity of these young people and the real-world problems for which they have sought solutions. To see their ambition, passion and enthusiasm for STEM at such a difficult time is truly inspiring.

Sustainability, climate change and green issues are threads running through many projects and this is a trend we've observed in recent years with several further projects, for example, looking at reducing plastic use, increasing society's efforts to recycle or reducing energy consumption.

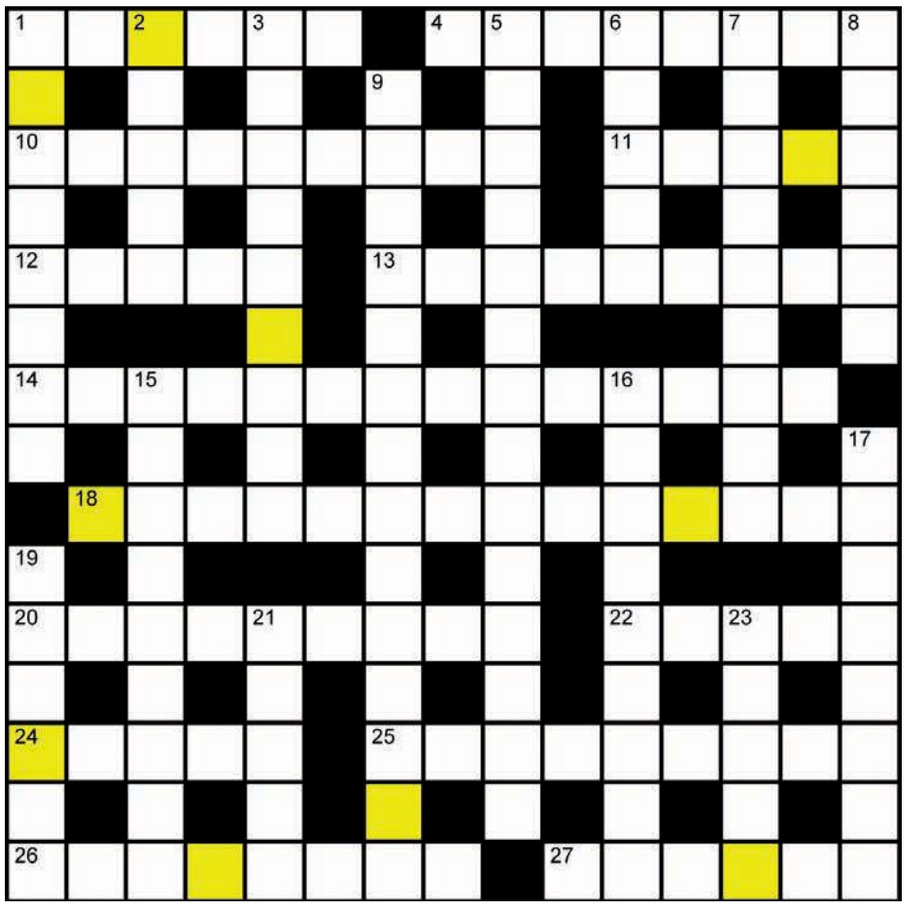
It's fitting therefore that the next Tomorrow's Engineers Week, due to be held from 8 to 12 November this year, will focus on how engineers and engineering can contribute to tackling climate change and achieving net zero. #TEWeek21, held for the ninth year running, will take place as the UK hosts the much-anticipated COP26 conference in Glasgow.

Engineers and engineering will be crucial to helping the UK achieve its net zero ambition and Tomorrow's Engineers Week is an opportunity for all of us in the sector, including engineers, employers and Professional Engineering Institutions, to engage with schools, colleges and universities to showcase how engineers can make the world a better place. For young people, it's a chance to spark ideas and consider how they could address local and global challenges in their future careers.

The global climate strikes brought young people around the world together so powerfully to demand action over climate change. We know engineering will be central to generating affordable and sustainable energy and solving other global challenges related to our changing climate, like providing access to clean water. COP26 provides an opportunity to show the next generation how they can be part of the solution by choosing engineering careers.

We need to work together to inspire the next generation of engineers and showcase how careers in engineering, technology and computing are key to tackling these important issues and sustaining the planet for generations to come. It's ever more crucial that we involve young people who traditionally wouldn't think of choosing STEM to provide them with valuable careers as well as meeting the need for a diverse and insightful workforce to secure our future. THE ENGINEER

CROSSWORD



Across

1 Opening that permits escape or release (6)
4 Clerical worker (8)
10 Step-up transformer with an air core (5,4)
11 Make more attractive by adding ornament (5)
12 Adjust again after an initial failure (5)
13 Vehicle with a single wheel (9)
14 Heavy tool powered by compressed air (9,5)
18 French architect who used early metal construction (5,9)
20 Fixing to (7,2)
22 Affecting things past (5)
24 Engineer of huge coral structures (5)
25 Material used for fine cabinetwork (9)
26 Small refracting telescope (8)
27 Tie with a rope (6)

Down

1 Comes to the surface on the ground (8)
2 Specific pieces of work (5)
3 Material that resembles rubber (9)
5 Office furniture used to keep papers in order (6,8)
6 Mr Newton, English mathematician and physicist (5)
7 Triangle with two sides of equal length (9)
8 Horizontal beam over a door or window (6)
9 Beauty experts (14)
15 For a limitless time (9)
16 North American river flowing into Gulf of Mexico (3,6)
17 Equipment for making and storing measurements (8)
19 Any spatial attributes (6)
21 Cause to move forward with force (5)
23 Uniform projection on a gear (5)

When completed rearrange the highlighted squares to spell out the total amount of raw materials processed by a plant in a given period. The first correct answer received will win a £20 Amazon voucher Email your answer to **jon.excell@markallengroup.com**

Last issue's UPSTAND

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