The University Of Sheffield. /AMRC Journal Issue 12

20/30 Vision: The future of the AMRC

Made in the North -
ACT Blade's ultralight wind turbine blade promising greener, cleaner energy

From game changer to life saver -
AMRC Cymru plays an essential role in helping save lives as a production facility for thousands of vital medical ventilators

5G productivity boost -
AMRC North West helps win £10m investment in open access 5G industrial testbed

CATAPULT High Value Manufacturing
UKRI Innovate UK
European Union European Regional Development Fund

Welcome to the

AMRC Journal

A new chapter opens

When the first reports of a new virus emerged from China in the early months of this year, it was impossible to predict the speed with which it would spread, the impact it would have on human health and the damage it would inflict on the global economies. In this issue of the Journal we explore some of the ways the University of Sheffield Advanced Manufacturing Research Centre (AMRC) and the High Value Manufacturing Catapult responded to the pandemic. But we also look to the future: for ways of making things better.

As we emerge from the Covid-19 pandemic, still unsure and uncertain of what winter might bring, two things remain clear. The first is the vital importance of manufacturing to the health and wellbeing of the nation: providing not just the medical equipment, from ventilators to visors, gurneys to gowns, that enable our doctors, nurses and paramedics to carry out their life-saving and life-enhancing roles, but also for the contribution it makes to the quality of our lives, from the salaries we receive and the export income it generates, to the inward investment and the pride we take in a job well done.

The second is that while the pandemic has changed the world forever: much still remains the same. Climate change, the productivity slump, the consequences we face as we leave the European Union, are all challenges and problems that must be tackled. But, as this issue of the AMRC Journal shows, engineers and manufacturers like nothing more than a challenge: the grander the better.

As a proud part of the nationwide network of High Value Manufacturing Catapults, the AMRC's role is to help make things better. We will do this, as our AMRC CEO Steve Foxley explains in this issue, by a laser-like focus on five key pillars: sustainability, industrial digitalisation, future propulsion, economic resilience and levelling-up to ensure that the impact of our R&D is shared fairly across the regions where we currently operate and where we might expand into.

We're hearing all these exciting announcements about investment in hydrogen, net zero flight and zero carbon transport - but it is pointless if we do not manufacture them in a sustainable way. By 2030 we want to have a fully living and breathing circular factory demonstrator at the heart of the Advanced Manufacturing Innovation District. We want to be the leading light on how to adopt circular principles; how to design for sustainability, minimise waste, switch to clean energy, reuse materials, repair and recycle products.

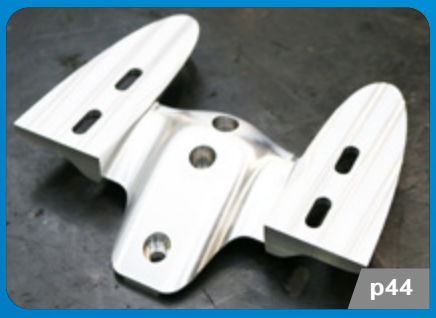
Chapter One of the AMRC is the story of how our founders transformed Orgreave from a scene of industrial decline into one of industrial regeneration. Chapter Two will be no less ambitious in taking this remarkable legacy and using it as a platform to transform UK manufacturing in a way that tackles the grand challenges the world faces; harnessing our R&D talents to make things better, for our region, our industrial partners and the next generation of entrepreneurial and innovative manufacturers. Turn the page and begin the next chapter with us....

Katia Harston
Editor

Got a story to tell? Contact:

Katia Harston: k.harston@amrc.co.uk, 0114 222 4784
John Yates: j.yates@amrc.co.uk, 07789 551 904
James Crossling: j.crossling@amrc.co.uk, 0114 215 8149

Driving South Yorkshire's green economic recovery p16



Cover image: Steve Foxley, CEO, The University of Sheffield AMRC.

The survival of the agile

There are few certainties in the aerospace supply chain right now, according to Andy Silcox, Research Director at AMRC Cymru.

"For the last two decades, commercial airline manufacturers and their associated supply chains have enjoyed unprecedented demand for their products. With Boeing and Airbus each exceeding 800 aircraft deliveries in the last two years – and with a large backlog of orders – the industry felt supremely confident that the market would continue to grow strongly," said Andy, who is responsible for overall strategy and technical delivery for the new AMRC Cymru in Broughton and is the focal point for the Airbus Wing of Tomorrow programme.

"But, even as we approached 2020, troubling signs began to appear on the radar screens to punch holes in that confidence. Having grounded its entire fleet of 737 Max aircraft, following two fatal crashes, Boeing began the decade with orders for just 54 planes: compared with 893 the previous year. All this against a surging swell of public opinion pushing the industry to go further and faster in reducing aviation CO2 emissions and the warning lights went red. Then Covid-19 struck."

According to figures from trade organisation ADS (Aerospace, Defence, Security and Space), 370 aircraft order cancellations were recorded between January and April this year. Deliveries of planes hit a record low of just 20 in April and it is likely to take several years before production is restored to pre-crisis levels.

With the world turned on its head, Andy believes manufacturers in the supply chain will need to be able to pivot their operations if they are to survive: "One thing we know for sure is that the established commercial aviation supply chains will need to adapt quickly if they are to survive a prolonged slump in demand. But, to adapt, they need to be agile; and that means wholeheartedly embracing Industry 4.0 technologies."

The agility created by these technologies was prominently displayed when a consortium of UK manufacturers pivoted their operations to join the fight against Covid-19 as the rest of the country went into lockdown. The Welsh Government-funded AMRC Cymru was quickly turned from a sparkling new R&D facility into a production line making thousands of life-saving medical ventilators.

"For us, and for many others around the country, having flexible, digital manufacturing processes enabled us to do this. Industry 4.0 technologies, such as modelling and simulation, automation and augmented reality (AR), are key tools in giving manufacturers the flexibility to respond rapidly to changing market conditions. Businesses that invest in these technologies will be at a significant competitive advantage as they will be able to execute changes in direction quicker than their rivals," said Andy.

"At AMRC Cymru, with our partners Airbus and the help of the VentilatorChallengeUK consortium, we deployed these digital tools to safely install 16 assembly lines into our vast, mostly-empty R&D facility, in less than a fortnight. We needed a shop floor where 88 operators could work simultaneously while maintaining safe social distancing. Quite a task, but one that is very similar to the challenge many manufacturers are now facing as recession looms.

"Fundamental to our agility was the use of Discrete Event Simulation (DES) modelling. By creating a digital model of the building, the mobilisation team were able to experiment with different layouts and run different scenarios to maximise the efficiency of production, logistics, flow of people around the facility and even the welfare breaks whilst all the time ensuring safe social distancing."

Andy believes that by investing in such a modelling exercise now, aerospace supply chains and other manufacturers can not only minimise the productivity impact of the Covid-19 restrictions, but also be equipped with a tool that enables them to plan effectively for future similar scenarios: "At Mercedes AMG High Performance Powertrain, the AMRC provided two MiR Automated Guided Vehicles (AGVs) to assist in the

Transformed: The newly-opened R&D facility AMRC Cymru was stripped out and converted into a production site for life-saving ventilators.

> "One thing we know for sure is that the established commercial aviation supply chains will need to adapt quickly if they are to survive a prolonged slump in demand. But, to adapt, they need to be agile; and that means wholeheartedly embracing Industry 4.0 technologies." **Andy Silcox,** Research Director at AMRC Cymru.

production of ventilator devices being made at their Northamptonshire facility.

"In just a few hours, with no additional infrastructure, the AGVs were put to work delivering parts to workstations, removing the risk of cross-contamination from human operatives conducting logistic operations. The use of collaborative robots and AGVs have obvious immediate benefits for implementing social distancing, but their ability to be integrated into a safe, shared working environment with human operatives means they can be quickly deployed as a flexible resource anywhere they are needed around the factory."

Andy says digital technologies have really come to the rescue of manufacturers during the Covid-19 pandemic and have set a model for the future: "For those of us from the punched tape fed CNC generation, the idea of using technology like AR headsets in day-to-day manufacturing operations may seem like a step too far down the digitalisation route. However, by using Microsoft HoloLens devices to deliver step-by-step assembly instructions, the VentilatorChallengeUK team were able to rapidly train hundreds of automotive and aerospace assembly technicians to build medical devices. Again, the headsets also provided the opportunity to further reduce the Covid-19 contamination risk by using them to deliver remote fault finding and technical assistance."

Moving forward, by digitalising work instructions and delivering them on AR headsets or tablets in conjunction with digitally connected SMART tools, manufacturers can create a much greater flexibility in their workforce without compromising quality or productivity.

"Understandably, at a time of such great uncertainty, the idea of large investments in such technologies is not particularly enticing; but from our experience over the past few months we have proven these technologies can be deployed quickly and at relatively low cost and risk, to get manufacturing operations back up-and-running safely while maintaining productivity despite Covid-19 restrictions," said Andy.

"Implementation of such technologies on their own can have a significant impact in helping manufacturers to operate efficiently in the testing circumstances we find ourselves in. But, by taking these steps now, they can provide the foundations to begin to build a digitally connected, reconfigurable production facility."

The AMRC's Factory 2050 is the UK's first state-of-the-art digital factory entirely dedicated to collaborative research into reconfigurable robotic, digitally assisted assembly and machining technologies.

Andy says Factory 2050 is designed to address the rising need for high variation and mass customisation manufacturing throughout a diverse range of engineering sectors which were put into action on the shop floor to manufacture life-saving ventilators: "That knowledge and expertise isn't the property of just the AMRC though, it is available for all manufacturers to take advantage of and our team of engineers are on hand to help manufacturers understand how these technologies can be deployed in any production environment.

"For some time now we have known that factories operating in the aerospace supply chain need to become more flexible, sustainable and operable with minimal human interaction if they are to have a profitable future. Even before the world was turned upside down by the Covid-19 pandemic, digital agility was needed to enable the industry to meet the two great challenges of climate change and decarbonisation. Today, that agility is needed more than ever: simply to survive."

Airbus employees using the Microsoft HoloLens kits on ventilator production lines set up at AMRC Cymru.

Business Minister sees innovation and enterprise at AMRC Cymru

The Minister for Business and Industry used a visit to AMRC Cymru to tell the aerospace industry it must continue to focus on developing green aviation technologies so the government can reach its ambitious target of net zero carbon emissions by 2050.

Grand challenge: Mr Zahawi delivers a speech at AMRC Cymru about the role of green aviation technologies in transition to net zero.

Nadhim Zahawi MP called the UK the 'home of innovation and enterprise in aerospace' on his visit to Broughton and said technologies being developed by the University of Sheffield Advanced Manufacturing Research Centre (AMRC) are crucial to reducing the environmental impact of air travel.

"In 2019 we became the first major economy to put a net zero emissions target into law, ending our contribution to climate change," said Mr Zahawi. "It is clear that the aerospace industry will be critical as we make this massive transition and the demand for green aviation technologies will be immense."

Mr Zahawi visited the AMRC's newest facility, the first High Value Manufacturing (HVM) Catapult centre in Wales, as part of an event to launch the 'Aerospace Sector Deal – One Year On' report by the Aerospace Growth Partnership (AGP) which called the UK's aerospace sector a 'world leader in the manufacture of engines, wings and advanced systems'.

But to remain globally competitive, the report said the sector needed to focus on the 'delivery of technologies that help reduce the environmental impact of air travel', citing Airbus' Wing of Tomorrow programme, being delivered with the help of engineers at AMRC Cymru.

In his speech, Mr Zahawi highlighted the importance of the aerospace sector to the national economy: "I've been pleased to see that the sector is focussed firmly away from the South East with more than 90 per cent of businesses located elsewhere across the country. The UK is the home of innovation and enterprise in aerospace with a significantly large number of companies creating thousands of jobs for local communities."

Backed by £20m from Welsh Government, AMRC Cymru is built on the Deeside Enterprise Zone close to where Airbus is developing the Wing of Tomorrow programme, which is part of a global Airbus investment in research and innovation.

The state-of-the-art facility opened in November 2019 with Airbus' Senior Vice President, Paul McKinlay, calling AMRC Cymru a 'game changer for Airbus to change its environmental footprint for the future'.

AMRC Cymru's Research Director, Andy Silcox, said: "We were delighted to host the Minister for Business and Industry and representatives from all of the major UK aerospace manufacturers, including Airbus, Bombardier and Rolls-Royce, for the AGP event to mark the first year of the Aerospace Sector Deal.

"The event gave the AMRC team the opportunity to explain how we are working with the Welsh Government to help all Welsh manufacturers, regardless of which sector they serve, to adopt innovative manufacturing technology and help them reach new levels of productivity and sustainability.

"Aerospace will undoubtedly play a huge part in AMRC Cymru's development and we are extremely excited to be working on the automation and digitalisation of the Airbus Wing of Tomorrow."

Colin Smith, co-chair of the AGP, added: "The aerospace sector is now focused upon supporting the UK government's commitment to achieve net zero carbon emissions by 2050. By working ever more closely with the government, industry, through the AGP, will continue to invest in the development of third generation technologies required to address this challenge. This will require further industry and government commitment to the already successful Aerospace Technology Institute."

Seeing is believing: Minister for Business and Industry, Nadhim Zahawi MP, tries out some of the technology on show at AMRC Cymru.

Prof David Ramsay Harra (second left) and colleagues at Airbus.

Strengthening ties with an aerospace giant

The man who spearheaded Airbus' partnership with the Advanced Manufacturing Research Centre (AMRC) on the pioneering Wing of Tomorrow programme is now passing on his passion for manufacturing to the next generation of engineering graduates at the University of Sheffield.

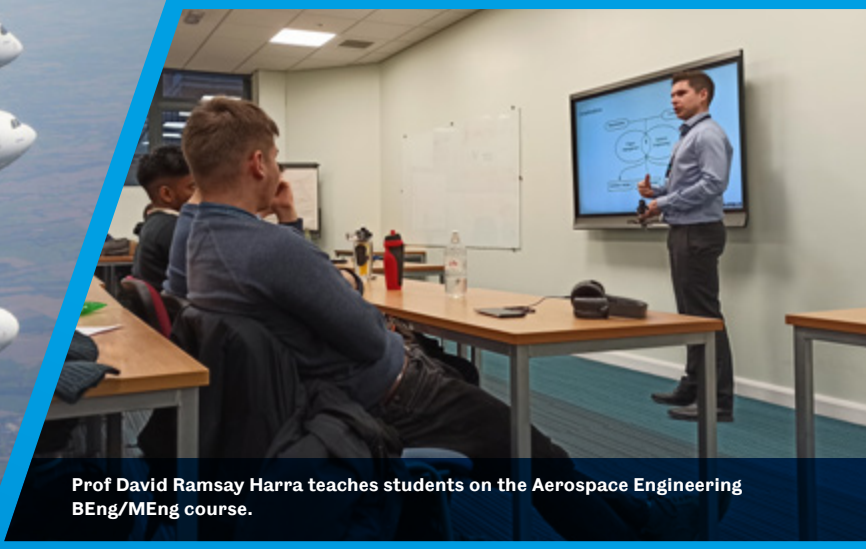
Head of Assembly Technology at Airbus, Professor David Ramsay Harra, has started a three-year teaching position through the Royal Academy of Engineering (RAEng) Visiting Professors (VP) scheme and will be the industrial lead on an industrial training programme module, hosted by the university's Department of Automatic Control and Systems Engineering (ACSE). The scheme utilises the experience of people in industry to enhance teaching and learning, augment the employability and skills of engineering degree students and reinforce external partnerships in the sector.

"The VP scheme is good for the students' development and also benefits Airbus," said Prof Harra, RAEng Visiting Professor in Digital Manufacturing for Aerostructure Assembly. "The idea isn't new to Airbus, but I hope what we have created with RAEng and the University of Sheffield will increase the number of people who see that a link with academia can benefit the wider manufacturing sector."

Prof Harra already has close ties with the University of Sheffield having led Airbus' involvement in the opening of AMRC Cymru in November 2019. The state-of-the-art research and development facility was purpose-built close to the Airbus wing-manufacturing plant in Broughton thanks to a £20m investment from Welsh Government and is the first High Value Manufacturing (HVM) Catapult centre in Wales. Airbus is developing the Wing of Tomorrow programme in Broughton as part of a global investment in research and innovation.

Prof Ashutosh Tiwari, Airbus/RAEng

© Airbus


Prof David Ramsay Harra teaches students on the Aerospace Engineering BEng/MEng course.

Research Chair in Digitisation for Manufacturing at the University of Sheffield, said: "David was an obvious choice for the RAEng VP scheme. With his extensive experience in manufacturing and his passion to help the future generation of engineering graduates, I know his lead on the industrial module would benefit both the students and Airbus.

"David is the industrial lead on an industrial training programme module within the Aerospace Engineering BEng/MEng course. It has been designed to prepare students for professional practice via a real, industry-led group project in aerospace engineering."

Prof Harra said his role is more than simply delivering lectures: "We have presented a real-life, industry-relevant technical challenge to the students and, over the course of a semester, they are expected to develop a project around it. Throughout the module, there are a number of specific 'project gates' where I engage with the students and provide focussed industrial feedback as their projects mature as we would do in Airbus."

Prof Harra said there are clear benefits for both Airbus and the students: "I have managed graduates and apprentices in our factories so I have a real appreciation of what we are looking for and have noticed shortfalls in students coming through to industry.

"This industrial project gives students the key skills we're ideally looking for; it requires teamwork, theory, development, awareness of timescales and an appreciation of the end user. That final point, how customers are involved, is regularly overlooked by applicants at interview but has hopefully been impressed upon these students very clearly."

Airbus is a tier one member of the AMRC and Research Director, Ben Morgan, said Prof Harra's appointment reinforces the already strong relationship: "The AMRC has worked with Airbus for years and now we have both Ashutosh and David at the university which confirms the strength of our association.

"David's new position gives the AMRC a link with Airbus' lower technology readiness level (TRL) research, but it also means graduates coming off the course have some genuine insight into the real world of manufacturing.

"Anything the AMRC can do to connect the wider University of Sheffield to major original equipment manufacturers (OEMs) has to be a good thing."

Prof Harra said work being carried out at AMRC Cymru proves how different expertise at Airbus, the AMRC and the University of Sheffield can complement each other: "We're currently looking at conveyor belt technology at AMRC Cymru, for instance the mobile photogrammetry system for inspection.

"That was first developed at the low TRL scale at the university, then passed through the skilled engineers at the AMRC in Rotherham before being delivered to the team at AMRC Cymru to test it in the final environment.

"So the conveyor belt technology went through academia, passed through the technology centre and was finally placed into industry. Having that clear process is key."

During his time as a visiting professor, Prof Harra has been asked by ACSE to focus on three key areas: curriculum and strategy development, face-to-face teaching and the mentoring of engineering undergraduates.

"From a University perspective, we see this as very important for the future skills acquisition for engineering and manufacturing students," said Prof Tiwari. "David can tension test our teaching for a company like Airbus and that is very important in terms of future-proofing our curriculum and questioning whether we are covering all the key topics.

"Then there is the opportunity for the students to visit Airbus during the semester and, finally, we want this one-to-one teaching to excite students about manufacturing. It's a kind of agenda that touches on the skills development but also the perception of manufacturing in people's minds; ideally, that will increase interest in the field."

Prof Harra said others in the engineering sector are already following his lead: "I know one of my colleagues at Airbus is interested in participating in a similar scheme at the University of Sheffield. There is also someone else who is interested in working with another institution as well."

Ben Morgan added: "It would be nice to invite David to the AMRC to deliver lectures to some of our more junior engineers who haven't got that experience of industry.

"It would be great to have more industrial lectures and industrial speakers coming to the AMRC to talk about the challenges of their day jobs. The more we have of those, the more our engineers will benefit."

100 not out

Research engineers at the University of Sheffield AMRC North West have delivered more than 100 innovation projects for Lancashire SMEs and are now helping companies find the 'new normal' as they look to get staff safely back into the workplace.

The North West team is using the experience gained by colleagues at AMRC Cymru during the work for VentilatorChallengeUK to support businesses in Lancashire as they move towards a return to full production under the 'new normal'.

Melissa Conlon, Commercial Director for AMRC North West, said: "Not only did our AMRC team in Wales have to strip out an R&D facility to install 16 new production lines from scratch in less than a fortnight, they also needed to create an environment where 88 operators could work simultaneously while maintaining safe social distancing.

"To do that they made real use of the AMRC's modelling and simulation capabilities. That included creating a model to safely control operator movements around the facility to allow them to organise shift breaks and lunch times to suit what they have on the shop floor.

"We are looking to use our experience gained from the ventilator challenge at our factory in Wales to support Lancashire manufacturers in this 'new normal'. Some of the things we did would be really useful - not just to manufacturers but other organisations too as they work to get more staff back into the workplace safely.

"As the go to place for innovation and advanced manufacturing expertise, we're reaching out to businesses across Lancashire and urging them to come and talk to us and to use the experience we have to their advantage."

Milestone: Mahesh Pandya, CEO ELE Advanced Technologies; Nick Hall, Business Engagement Manager AMRC North West; David Dudley, Technical Director ELE Advanced Technologies; Farhana Norazman, Project Engineer AMRC North West.

Precision engineers ELE Advanced Technologies was the milestone 100th company to benefit from that experience, taking advantage of the AMRC North West's fully-funded ERDF support which helps manufacturers to embrace, de-risk and adopt new digital technologies and processes.

The company - which holds a portfolio of blue chip clients including Rolls-Royce, Safran, Siemens, GE Avio, GE Power and MAN Diesel & Turbo - is a leading maker of specialist components for aerospace, industrial gas turbines and commercial diesel sectors. Its precision engineering capabilities enable it to produce complex parts for turbine blades, vanes and compressor blades. ELE Advanced Technologies also supplies turbocharger components to the automotive sector from its manufacturing plant in Trencin, Slovakia.

As the 100th firm to receive help from AMRC North West, it understands how valuable R&D manufacturing innovation expertise can be to a business: the Colne-based company approached the team for help developing its Additive Manufacturing (AM) process as it looks to provide leading-edge technologies to its customer base.

ELE Advanced Technologies' technical director, David Dudley, said: "We have extensive experience of working with the AMRC in Sheffield, to improve both existing processes and the potential for adopting new disruptive technologies. Following our

"As the go to place for innovation and advanced manufacturing expertise, we're reaching out to businesses across Lancashire and urging them to come and talk to us and to use the experience we have to their advantage."

Melissa Conlon,
Commercial Director for AMRC North West

introduction to AMRC North West, we have now started working with them on new projects, using their expertise, that could help place ELE in a strong position as a technology leader for future business growth."

Ian Brooks, Technical Fellow for additive manufacturing at AMRC North West, said it was a pleasure to work with the business to investigate the potential of integrating AM into their services. "The novel, high-value manufacturing techniques they currently offer fits a similar business model to that of producing AM components and the innovative culture that exists within the organisation is accepting of new, potentially disruptive technologies."

AMRC North West currently operates from an interim site in the centre of Preston until it moves to a soon-to-be-built research centre on the Samlesbury Aerospace Enterprise Zone.

It now employs 33 staff specialising in digital manufacturing, battery assembly, machining, additive manufacturing, robotics and automation, and has worked with a range of companies in Lancashire each looking to improve their business.

The team is urging Lancashire manufacturers to embrace digital technology as they adapt to work in the 'new normal' created by the coronavirus crisis, helping businesses explore other measures as they look towards ramping up production, including the possible use of collaborative robots, automated guided vehicles (AGVs) and other Industry 4.0 digital technologies such as automation.

The message from the North West is clear - the time to act is now - and to help SMEs onto the new digital road in these challenging times, it is delivering online 'digital strategy assist' sessions at no cost to the business.

"Manufacturers are under huge pressure; our role is to convince them and assist them to adopt new technologies that will enable them to survive and remain competitive in challenging circumstances and what may feel like an uncertain future.

"When thinking about adopting new technologies, manufacturers should think big and start small. Having a digital strategy roadmap is the first part of the journey to digital transformation."

To find out more about how AMRC North West can help your business contact Nick Hall, SME Engagement Manager:
n.hall@amrc.co.uk

Case study: Viroklenz

An infection protection services supplier, which accessed 3D modelling expertise at AMRC North West to develop an innovative new dispenser system, has been further supported by the team to apply for funding to take the product to market.

Viroklenz, launched in 2012, has established itself as an innovative supplier of infection protection services and products, helping businesses to combat the spread of infection in premises including MRSA, C.difficile, Influenza and Meningitis.

The Chorley-based company is designing and building a prototype demonstrator of a novel delivery system application for its hand-sanitising product and approached AMRC North West for assistance in developing a 3D CAD model for the design.

AMRC North West engineers began creating a CAD model of components required for the prototype but a rapid UKRI open call for research and innovation ideas to address Covid-19 challenges saw the North West team pivot their capabilities to help the company submit a proposal bid.

Ian Brooks, Technical Fellow for additive manufacturing at AMRC North West, said: "Viroklenz originally approached the North West team with a view to developing their concept further, possibly by way of prototype manufacture.

"We were in the process of developing a CAD model when the funding call came up. We quickly switched our focus to that. The AMRC team proceeded with a far wider remit and pulled together a consortium to write a bid submission for the latest UKRI call for products to take to market imminently in the wake of Covid-19.

"Technical leads from across the AMRC groups worked closely with the consortium to generate a funding application in accelerated timescales. This was possible through the ERDF-funded support AMRC North West can offer to Lancashire based SMEs "

Case study: Multipack

A Blackburn contract packing specialist has been shown how low-cost automation on its production line can reduce bottlenecks and increase production efficiency by the AMRC North West team.

Multipack viewed handling of bespoke products, differing sizes and varying volumes as a major hurdle to embracing automation and were referred to AMRC North West by the Made Smarter UK pilot programme to discuss how the industrial digital technology could be implemented at relatively little expense.

Engineers at AMRC North West, part of the High Value Manufacturing (HVM) Catapult network of research and innovation centres, came up with a low-cost, flexible automation solution able to handle the bespoke products, differing sizes and varying volumes. They also showed the company that automation would in fact increase production efficiency, decrease changeover times of products, cut human variability and reduce bottlenecks.

The engineers did this by conducting a feasibility study for Multipack based on two products that were being packed. In the first, a low cost SCARA Robot was used to assemble a greeting card in an envelope; in the second, a packet of biscuits was placed in a box using a pick-and-place flexible automation concept.

In both cases a detailed concept design was produced for Multipack to incorporate the idea into their production line and the company was shown integrators who are capable of providing a turnkey solution. Crucially, AMRC engineers only used off-the-shelf automation equipment such as conveyors, robots, grippers, rollers, hoppers and clamps, which would be readily available to Multipack.

Made in the North:

the ultralight wind turbine blade promising greener, cleaner energy

'Game-changing' technology adapted from the sailing industry has been used to develop an ultralight offshore wind turbine blade capable of producing more energy than conventional designs.

The novel lightweight composite blade structure, which is wrapped in a high-tech engineered sail-like textile shell, has been developed by UK yacht-sail developer spin off ACT Blade. It is up to a third lighter compared with typical fibreglass blade designs, can be made longer to generate more energy and, ultimately, has the potential to make offshore wind - already one of the cheapest major energy sources in the UK - even easier and cheaper to harness.

The first prototype produced under the Innovate UK-funded project was manufactured and tested in collaboration with a consortium of northern research partners that includes the University of Sheffield Advanced Manufacturing Research Centre (AMRC), the Lightweight Manufacturing Research Centre, sister centre to the University of Strathclyde's Advanced Forming Research Centre (AFRC), both part of the National Manufacturing Institute Scotland, and the Offshore Renewable Energy (ORE) Catapult.

Dr Sabrina Malpede, chief executive of Edinburgh-based ACT Blade, said: "The novel ACT Blade is a tensioned textile-covered wind turbine blade that can actively change shape to control loads. It is 32 per cent lighter than conventional blades, enabling it to be ten per cent longer and directly contributing to the production of nine per cent more energy."

She explained that the blade's power to disrupt the market lies in its reduced manufacturing costs.

"The ACT Blade is not only the lightest but also the most modular blade," said Dr Malpede. "That means we use components that can be manufactured in parallel, using smaller and therefore cheaper tooling, reducing costs by 60 per cent. It also requires lower space - its factory will be 47 per cent smaller than those of conventional blades - and lower energy which makes the manufacturing process less expensive compared with that of conventional blades."

The AMRC's John Halfpenny headed up the Sheffield team that worked on a 13m prototype blade alongside High Value Manufacturing (HVM) Catapult colleagues at the Lightweight

CEO Sabrina Malpede in front of a wind farm in Edinburgh.

© Wattie Cheung

Manufacturing Centre.

John, who is technical lead at the AMRC Composite Centre, said: "This is a completely new type of offshore turbine blade developed by ACT Blade that could be a major disruptor in the renewable energy sector.

"Through cross-Catapult collaboration we have been able to combine and apply our world-leading expertise in lightweighting, advanced technologies, composites design and manufacture to take ACT Blade's innovative idea, develop and improve the design to increase strength, stiffness and stability of the blade, and then assist with the novel manufacturing process."

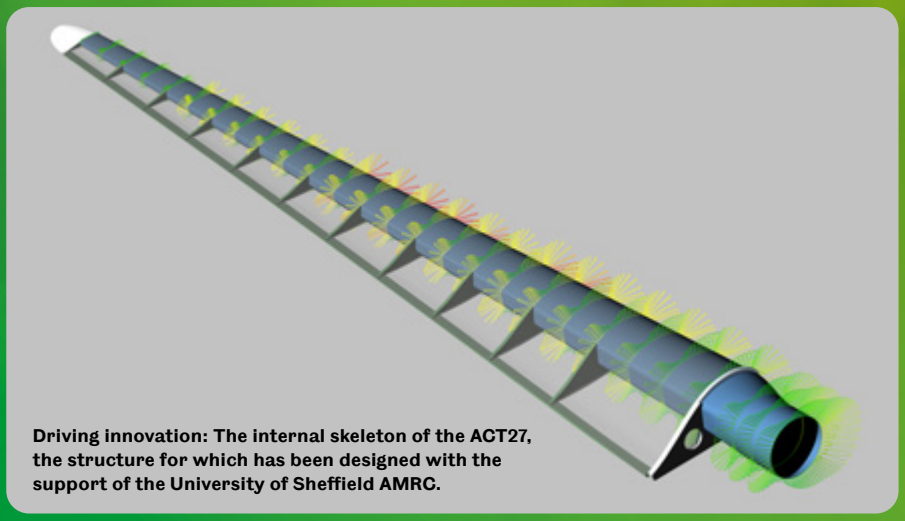
Dr Malpede said the AMRC was 'the right partner' to support the design and manufacture of the ACT Blade concept.

"As a micro-innovative start up, we have a small but highly competent R&D team in aerodynamic structure and composite design," she said. "As we were engaging with the engineering of the first prototype, we knew the AMRC was the right partner for us - providing the design for manufacturing support, assisting with advanced finite element analysis and, ultimately, supporting the manufacturing process."

The AMRC undertook the crucial Finite Element Analysis (FEA) work to validate the new blade design. This allowed John and his team to locate potential problems in the design, including areas of tension and weak spots, before producing CAD data to optimise the structural design of the prototype. They also designed patterns, moulds and associated fixtures to manufacture the first blade.

John explained that turbine blades are being made longer to generate more energy, but are becoming heavy and expensive to produce, install and maintain. He said the ACT Blade manufacturing process is less energy-intensive compared with that of conventional blades - offering significant cost, sustainability and environmental advantages.

"The ACT Blade is lighter, lower cost, has increased efficiency and will be easier to recycle," explained John. "This is a real game changer for offshore renewable energy with considerable benefits to be gained - not only by new wind farm developers but for existing wind farm operators - to improve performance, reduce costs and cut carbon emissions in the manufacturing process.



Driving innovation: The internal skeleton of the ACT27, the structure for which has been designed with the support of the University of Sheffield AMRC.

Image: ACT Blade

"It is a great example of how technology can be adapted from one sector to create something truly ground-breaking in another industry."

Professor Iain Bomphray is Director of the Lightweight Manufacturing Centre (LMC), which is hosting the ACT Blade development, supporting the engineering and manufacturing of the new technology.

He said: "Wind energy is a natural energy source but even this clean energy source can be made even more sustainable still, by reducing the carbon footprint associated with the manufacture and transport of parts and by making the harnessing of the energy more efficient.

"The LMC was established as a centre of excellence for innovative lightweight solutions, with the aim of helping manufacturing businesses large and small to overcome the challenges of the modern world. Our cross-Catapult collaboration working with ACT Blade on this exciting technology has allowed us to do exactly that."

The UK is the world leader in offshore wind, with more installed capacity than any other country. Already, offshore wind powers the equivalent of 4.5 million homes annually and is set to power more than 30 per cent of British electricity by 2030. But industry is always looking for ways to innovate, reduce cost and increase efficiency.

ACT Blade, founded in 2015, developed its novel blade concept in response to an innovation challenge launched by ORE Catapult, tasking companies to improve the performance of wind turbine blades and enable industry to 'generate cleaner, greener power in ever deeper waters'.

Dr Malpede, who made her name designing super-fast sails for yachts, responded to the challenge with a game-changing idea: take the light, durable structure of yacht sails and adapt the technology to improve the performance of offshore wind turbine blades.

The 13m prototype was completed in February this year and testing began soon after with static tests completed at ORE Catapult's National Renewable Energy Centre in Blyth in April. Results showed the blade could withstand extreme loads and every type of direction and twist, going beyond those predicted for an in-service turbine.

Dr Stephen Wyatt, Director of Research and Disruptive Innovation at ORE Catapult, said: "This is great news for the development of novel wind turbine blade designs, ensuring we can continue to improve offshore wind productivity and reduce costs, embedding offshore renewables at the heart of the UK's future energy mix.

"The ACT Blade team has pushed the limits of what is physically possible, putting UK technology in pole position in the innovation race. It's also an inspirational story, showing how an Eureka moment can be turned into a future export that could generate billions in revenue for the UK. We've come a long way since Sabrina first answered one of our Innovation Challenges back in 2015, and I am excited to see the journey ahead."

The blade is now undergoing further testing and in the coming months ACT Blade will work with the Energy Technology Centre to prepare for installation of three blades on a working wind turbine at the Myres Hill Wind Farm in Scotland.

Support blows in for Sheffield

Magnomatics has teamed up with the University of Sheffield AMRC to drive big productivity improvements in offshore renewable energy generation using smart robotics and automation.

The market-leading magnetic gear manufacturer won government funding to help solve the challenge of robotic placement of large rotor magnets on wind turbines.

The Sheffield-based university spin out is one of seven UK companies that was awarded grant funding from the Offshore Wind Growth Partnership (OWGP) to carry out supply chain improvement projects for offshore wind power. It is working with engineers from the Integrated Manufacturing Group (IMG) at the University of Sheffield AMRC to deliver the ambitious ROBOMAG project.

Dr Lloyd Tinkler, Senior Project Engineer at IMG, said: "This project is a fantastic opportunity to support Magnomatics in increasing production rates to capitalise on demand for offshore wind generation, by automating the task of manipulating high-strength permanent magnets. A clear benefit of this would be the elimination of any potential trapping hazard when manually placing the magnets as they snap into position.

"It also links in with the AMRC's activities within the EPSRC Future

Electrical Machines Manufacturing Hub to address challenges in the production for high-integrity, high-value electrical machines in order to secure the UK as a leader in this area."

As a world leader in offshore wind, the equivalent of 4.5m homes annually in the UK are powered by wind and is set to power more than 30 per cent of British electricity by 2030.

Minister of State for Business, Energy and Clean Growth, Kwasi Kwarteng, said: "The UK is a global leader in offshore wind and this funding will help our brilliant supply chain to innovate even further. Renewables are not just good for our climate, but for jobs and the economy as well – with up to two million new green-collar jobs by 2030. I look forward to seeing what these companies go on to achieve."

Magnomatics develops and manufactures products for a range of industries, from hybrid and electric vehicles to marine propulsion, aerospace, rail, and oil and gas. David Latimer, Chief Executive Officer, said: "We are delighted with the funding from the OWGP. Magnomatics has secured strong commercial interest in our technology for offshore wind. This project is all about developing the processes and methods to help anchor the manufacturing in the Sheffield City Region and the UK."

The Offshore Wind Growth Partnership is a key part of the joint government-industry Offshore Wind Sector Deal announced in 2018, funded by the Offshore Wind Industry Council (OWIC).

Andrew Macdonald, Offshore Wind Growth Partnership Programme Director, said: "This was a very competitive process and we received a high number of quality applications, totalling almost £2m in project costs, demonstrating the huge opportunities to maximise the economic benefits of our world-leading position in offshore wind. The OWGP is committed to delivering increased productivity and competitiveness that will drive increased UK content into offshore windfarms in the rapidly growing global market, as well as in the UK."

Halfdan Brustad, Offshore Wind Industry Council sponsor for the partnership, said: "On behalf of OWIC, I am delighted to see these contracts awarded by the OWGP. Utilising the funding provided by OWIC members, the OWGP has been able to identify an exciting range of projects from UK companies which merit support and investment. Activities undertaken by the OWGP, such as through these Pilot Calls, are important opportunities to support the growth of the UK supply chain and to help us deliver on our ambitions under the Offshore Wind Sector Deal. I look forward to seeing the outputs from all seven companies."

Other companies successful in winning were: Cedeco, Global Energy Group and W3G Marine, while Cognitive Business, Sennen Tech and Smart Component Technologies will work to develop advanced sensors, Internet of Things (IoT) and communications solutions for offshore wind.

Cedeco is working with the National Composite Centre in Bristol and Global Energy Group has joined forces with the Nuclear AMRC in Rotherham. Both centres, along with the University of Sheffield AMRC, are members of the High Value Manufacturing (HVM) Catapult network.

Top: The Reconfigurable Factory Demonstrator cell which shows the robot proposed for the project on the AMRC's custom reconfigurable floor to which the rotary table and fixture will be mounted.

Driving South Yorkshire's green economic recovery

A £74m investment in green automotive technology could bring more than 200 high-value added jobs to the Sheffield City Region thanks to a partnership between an innovative electric automotive drives manufacturer and the University of Sheffield Advanced Manufacturing Research Centre (AMRC).

"Fears over a climate emergency are driving change across the global transport industry and Magtec is at the forefront of the technology needed to make it happen," said Andrew Gilligan, Managing Director at Sheffield-based electric vehicle manufacturer Magtec, which is leading part of the nationwide project recently announced by government.

"We are delighted to be working with our OEM and research partners to industrialise our manufacturing operations and satisfy demand for our class-leading electric vehicle drive systems. We are creating high-quality engineering jobs across our company and regional supply chain and strengthening the UK's standing in this emerging global sector."

Ten projects across the UK will receive a share of a £73.5m government investment to develop cutting-edge technology for the next generation of electric taxis, cars and vans – including recyclable batteries, advanced electrical systems and ultra-lightweight components.

£3m has been awarded to Magtec to allow them to scale up the UK-production of their world-leading electric motors using the latest automation technologies. It is expected to create 65 jobs at Magtec and a further 165 across South Yorkshire and the wider region as the company strengthens its UK supply chain.

Magtec will work with the AMRC and fellow High Value Manufacturing (HVM) Catapult centre the Manufacturing Technology Centre (MTC) in the £6m project, as well as four leading transport sector OEMs – Dennis Eagle, Paneltex, Volta Trucks and strategic partner Angel Trains.

Dr Lloyd Tinkler, Senior Project Engineer and lead for the AMRC's research on electrical machines manufacture, said: "We're incredibly excited to be part of this project which will help Magtec upscale production volumes of their electric motors for hybrid and electric commercial vehicles.

"The AMRC's role will focus on factory planning and simulation, composite overwrapping of rotors, coil inspection and lamination core manufacture. The latter two are closely aligned to our ongoing research being undertaken as part of our Engineering and Physical Sciences Research Council (EPSRC) Future Electrical Machines Manufacturing (FEMM) Hub."

> "It's an exciting time for the UK automotive industry – we are on the precipice of an innovation landslide."
>
> **Jon Beasley,** Director of Technology & Projects at the APC.

The £28m FEMM Hub, underpinned by a £10m award from the EPSRC and led by the University of Sheffield, aims to develop new manufacturing techniques and technologies to improve the reliability and performance of high-value electrical machines.

The cash boost announced by the government will aid the development of highly efficient and ultra-lightweight components and help drive the automotive industry further away from its reliance on fossil fuel technologies. The move towards electric transport will be vital in helping the UK meet its target of net zero carbon emissions by 2050, while growing the economy and creating jobs in greener industries.

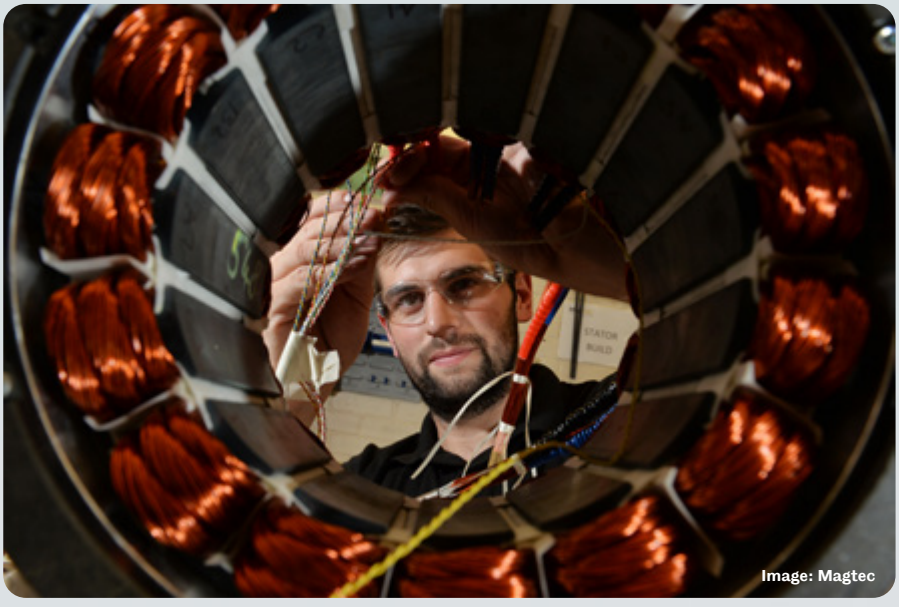
Business Minister Nadhim Zahawi said: "Whether it's researching future battery design or creating a lightweight version of the Ford Transit, companies in every part of the United Kingdom are leading the world in advanced automotive technology.

"Not only will this funding ensure automotive companies can play their part in keeping us on the path to net zero emissions by 2050, it will also support thousands of jobs and be a welcome step towards the industry's economic recovery."

The successful projects were chosen by the Advanced Propulsion Centre (APC), which seeks to maintain the UK's position as a centre of excellence for the research and development of low carbon vehicle technology.

Jon Beasley, Director of Technology and Projects at the APC, said: "It's an exciting time for the UK automotive industry – we are on the precipice of an innovation landslide. The technology we invest in now is set to make an impact on the next generation of vehicles."

Announcing the funding, the government said the investment will contribute to the automotive sector's recovery from the coronavirus pandemic by safeguarding more than 14,000 UK research and manufacturing jobs.



An engineer manufactures one of Magtec's electric vehicle drive systems.

Hydrogen
and the road to net zero

By Richard Jones

First the good news.

The latest release of the UK government's energy statistics shows that the fraction of electrical power generated from renewable sources in 2019 reached a record high of 37.1%, driven largely by an increase in offshore wind of 20%, to a new high of 32 TerraWatt hours (TWh) a year.

Now the bad news.

This record high will make little difference to the UK's overall energy consumption: of the 2,300 TWh used, 78.3% was obtained from burning fossil fuels. This is a decrease from last year's fraction of 79.4%; but this pace of progress remains much too slow.

While the UK used 346 TWh of electricity in 2019, the country directly burnt gas to provide 512 TWh heat for domestic and industrial purposes (not counting here the gas converted to electricity in power stations), and 152 TWh of petrol and 301 TWh of diesel to power vehicles.

This means we've no chance of reaching net zero greenhouse gas emissions by 2050 without displacing this directly burnt fossil fuel contribution. And, given the longevity of energy infrastructures, we haven't got long to start building the technologies to do this at scale.

Can hydrogen help? This technology – or more accurately, group of potential technologies – is having a moment of attention, not for the first time. It could well make a significant contribution, but there are some awkward choices to make.

> So how might hydrogen be used to reduce the carbon dioxide currently produced by the nearly 1000 TWh of energy we derive from burning gas, petrol and diesel for heating and transport?

Right now we could add some hydrogen to natural gas – perhaps up to 20 per cent – making a significant lowering of its carbon intensity without substantial changes in our existing systems.

The replacement of natural gas by zero-carbon hydrogen for domestic heating and many industrial processes is probably technically feasible, but quite a lot more expensive. Some changes will be needed to the gas distribution system (e.g. replacement of iron/steel pipes with thermoplastic pipes), and boilers and appliances would probably have to be replaced too.

Hydrogen can be used for transport, as fuel for internal combustion engines, or more likely, converted to electricity via fuel cells to power cars and trucks.

Finally, hydrogen might make possible the very large scale seasonal storage of energy (potentially on the scale of tens or even hundreds of TWh) generated by intermittent renewables, by storing it underground in rock salt formations.

All these ways of making hydrogen and using it are technically possible. They're also all enormously expensive, with the potential for locking the country into solutions which turn out to be inappropriate or made redundant by rival technologies. Some experimentation is necessary, and some blind alleys are probably inevitable, but

what needs to be taken into account as we make our choices?

To start with the basic physics and chemistry: hydrogen is a light gas which burns completely and cleanly to yield only water vapour. Perceptions of hydrogen are inevitably shaped by the Hindenburg disaster – but all flammable gases are potentially dangerous, and these are risks of the kind that industrial societies have got used to managing.

Hydrogen is more easily set aflame than methane and it burns hotter, but on the other hand at atmospheric pressure burning a given volume of hydrogen produces less energy than the equivalent volume of methane, and much less than petrol vapour. In fact it's this low volumetric energy density of hydrogen that poses the biggest problem. Even compressed to 70 MPa (as it would be in typical compressed gas tanks) its energy density is only 1.3 MWh per cubic meter, compared to petrol or aviation spirit at about ten MWh per cubic meter. Even liquified, its energy density is still only two MWh per cubic meter, and this needs a temperature of -250 °C, considerably colder than liquid nitrogen.

Moving on to economics, how can we find the most cost-effective solutions? The problem is that technologies don't stand still – indeed, it's essential that costs come down, and substantial research efforts are needed to make sure that happens. Where can we hope to see the biggest cost reductions? Existing technologies – like steam reforming of natural gas with carbon capture – are probably the cheapest options with current technology, but being mature further improvements are likely to be more difficult to find than with newer technologies like proton exchange membrane or high temperature electrolysis.

It's important to remember that the UK accounted for just 1.4 per cent of the world's energy consumption in 2018, and this fraction will inevitably (and desirably) fall over the next few decades. The choices we make must take into account what the rest of the world is likely to do; while the UK might hope to influence that path, perhaps by helping develop new technologies cheap enough for wide adoption, the UK isn't a big enough market to be able to make unilateral decisions about technology directions.

If battery electric vehicles win the race for zero-carbon personal transport, it would be pointless for the UK to develop a hydrogen network for fuel cell cars. Likewise, if the UK is the only country to back hydrogen boilers for domestic heating while the rest of the world chooses electric heat pumps, it won't be a big enough market to justify the development of hydrogen domestic boilers by itself, so its plans would be left high and dry.

We have well-developed existing energy distribution systems, so the question for any new energy vector is whether these systems can be incrementally adapted, or do new ones need to be built out entirely from scratch?

We currently have a well-developed electricity distribution system. Distributed PEM electrolysis plants could take zero-carbon from the grid, and produce hydrogen locally. We also have systems for distributing natural gas: it's likely that the core high pressure network would have to be entirely rebuilt for hydrogen, but the low pressure local distribution system could be adapted. We don't have a cryogenic liquid distribution system at scale, and this is likely to limit global trade in hydrogen.

Finally, we have to consider our plans for low-carbon electricity. Whatever we do, we need to replace the 512 TWh of gas we use for heating, and the 453 TWh of petrol and diesel we use for transport, with zero-carbon alternatives. If this involves electrification – either directly or through the production of hydrogen from zero-carbon electricity – this will need a huge expansion of power generation capacity from the current 346 TWh per year. It is difficult to see how this can happen without both a massive increase in offshore wind – possibly including floating offshore wind – and new nuclear build, possibly next-generation nuclear able to produce high-temperature process heat for production of additional hydrogen.

These are difficult choices, but we haven't got much time. Let's get on with it!

A longer version of this article appeared in Richard's blog, Soft Machines, which can be accessed at **www.softmachines.org/wordpress**

Professor Jones is Chair in Materials Physics and Innovation Policy at the University of Manchester.

20/30 Vision:
The future of the AMRC

Smart, sustainable and resilient manufacturing beats at the heart of a bold new vision for the University of Sheffield AMRC. Steve Foxley, CEO, talks to Katia Harston about writing the next chapter for the research centre and what is planned for the future.

Steve Foxley, CEO, The University of Sheffield AMRC.

As an opening chapter, the first 20 years of the AMRC makes for impressive reading; a compelling start to a story of aspiration and hope.

From humble beginnings on a bleak, post-industrial wasteland, it has enjoyed a meteoric rise to become the 'jewel in the crown' of the UK's innovation and research community, sitting at the heart of a thriving, advanced manufacturing park home to industry heavyweights, crucial supply chains and some of the brightest and best minds in engineering.

But there is more to the AMRC's story than buildings, big names and cutting-edge kit. It is about the power to transform, says Steve Foxley, who took over the reins as chief executive officer at the start of the year from retiring founder Keith Ridgway.

"I use the analogy of a book," says Steve. "What's in the first chapter of the AMRC, what has been achieved? I think if you look back, it has just been incredible. The AMRC has had this meteoric rise, it is now seen as the jewel in the crown. And it has grown, year over year, becoming more and more successful.

"If you look back to those early days, the vision and purpose for the AMRC was made clear in that first chapter: create sustainable wealth for all. A quick glance out of a window at the AMRC today is proof of its transformative success with the regeneration of Orgreave from a landmark of industrial confrontation to one of industrial collaboration."

The home of the former coke works, once seen as an area of decline and deprivation, has outshined those gloomy shadows of the past to become a leading light and a beacon of hope for the future. More importantly for Steve, it is a powerful symbol for what is possible in other forgotten northern towns scarred by lost industry and lack of opportunity.

"The before and after picture reads like a checklist for success," says Steve with Orgreave transformed; 600 researchers, technicians and support staff employed at the AMRC; £300m of investment

brought to the Advanced Manufacturing Park creating 1,750 jobs; home to manufacturing sites for Boeing, Rolls-Royce, McLaren and others critical to supply chains; more than 120 industrial partners; innovative, new technologies and processes bringing impact to the UK and international manufacturing sectors; 1,000 new homes; a training centre for the future pipeline of engineering talent; and more than 1,300 engineering apprentices putting £20m of new income into the region's homes.

It is an incredible platform from which to build upon, at scale, around the region, says Steve, who has helped pen a roadmap for the future to deliver the next ambitious chapter of the AMRC's story.

"There is recognition, a feeling in the stomach of the organisation, that we have reached a turning point," says Steve. "With the original founding fathers leaving, reaching the size we have, we've been discussing whether we are in shape for the next decade, and is it more of the same we need to do or is it something different? Do we continue on the same path or is it a different path that we want to take?"

He uses the analogy of the New Zealand All Blacks jersey, referring to the James Kerr book 'Legacy' about the legendary rugby team and the 'mantras' it has adopted to become the best in the world.

"One of those mantras is 'be a good ancestor' - that means planting trees you'll never see and 'leaving the jersey in a better place', essentially adding to the legacy of a great team.

"The jersey and the incredible platform achieved in the last 20 years has been passed to us from Keith and the team. When we fast forward and think about how we hand the jersey to the next generation who will lead the AMRC - what things would we like to have achieved when we hand over the jersey? What do we think the future looks like and what do we want to see in the book in 2030 to say 'Here's what we delivered in chapter two'. It is about building on this legacy."

> "We want to use our regeneration skills to bring R&D funding, productivity and industrial commons to level-up other forgotten northern towns."

The AMRC's purpose is clear - it is here to make things better. With a proven track record of regeneration, of creating ecosystems and communities, and with collaboration in its DNA, the AMRC delivers and takes risks; it sees things that others don't. The AMRC likes to change the game when it is at the top of its game.

At the core of the next chapter are four big themes: sustainability, digital, future propulsion and levelling up but also a clear commitment to supply chain resilience and making sure more of the fruit from its R&D work makes its way into industry and onto factory floors.

The AMRC knows sustainability is a fast-moving field but one that must be grappled with if manufacturing is to change for the better. The AMRC wants to drive that change, creating a world-leading UK circular factory demonstrator and test bed to become an exemplar in sustainable manufacturing.

"We're hearing all these exciting announcements about investment in hydrogen, net zero flight and zero-carbon transport - but it is pointless if we do not manufacture them in a sustainable way," says Steve.

"By 2030 we want to have a fully living and breathing circular factory demonstrator; we want to be the leading light on how to adopt circular principles; how to design for sustainability, make sure you are minimising waste, minimising energy, that you are reusing materials as much as you can and you are repairing equipment or recycling it into other sectors or other industries.

"We're looking to put part of our capabilities into a new building that will be operated as a mini-manufacturing site but from a circular economy perspective; looking at how to achieve minimal impact to the environment but still manufacture the things we need to manufacture.

"A lot of people have talked about circular factories and the circular economy but I don't think anyone has yet got a true demonstrator to show how you can bring all those things together: design, energy, waste, right to repair, the infrastructure of the building. I think many of our partners would be fascinated by an exemplar in the UK in how to manufacture in a sustainable way."

Steve says the organisation needs to 'walk the talk' when it comes to meeting net zero targets and has ambitious plans to measure sustainability for each project undertaken by its research engineers.

"We're very good at capturing KPIs to say how much productivity we have achieved, how much cost-saving we have achieved - but our partners have also told us that they would still back projects even if there were no efficiency or cost improvement but there was a CO2 reduction.

"So we're going to put a sustainability KPI on every project. That means we are not only measuring cost-saving and

efficiency-savings but we can identify what the CO2 or waste reduction is. That's one of the big goals for us."

The AMRC leadership team intends to build on the success of its flagship Factory 2050, with plans to have the UK's first fully-connected, open-access digital manufacturing test bed that will focus on data, connectivity, visualisation, complete integration with suppliers, and digital twins with AI learning.

"We have done some magnificent work at Factory 2050 but what's the next evolution? We want to create the first fully-connected, open-access digital manufacturing test bed that we can use for any sector. This means we would have the factory fully-sensored and all of the data connected - and it would connect not just within Factory 2050 but into all of the supply chains as well.

"It would be open-access so that people could use that data and run whatever analysis they want. We'd like to have a fully-digital site at Factory 2050 and put that together with a digital twin and bring in AI learning to then run the physical environment based upon insights from the digital. We want to have that digital thread sewn all the way through the manufacturing process, so whether that's design into manufacturing, repair and servicing, all the way through to the supply chain."

The AMRC will play to its strengths in the aerospace sector and support global zero-carbon goals through the development of whole product lifecycle capabilities for future propulsion systems such as hydrogen, high-power density batteries and biofuels.

"We know the future of flight will be going greener - whether that is electrification, biofuels, hydrogen, or some sort of hybrid across all of those, that is the direction of flight for future propulsion," says Steve. "In the next ten years we want to focus on delivering the manufacturing techniques and innovations that we are going to need to build the future propulsion technologies."

Audacious goals have been laid down to improve manufacturing productivity and resilience by mapping national supply chains and vulnerabilities, and linking partners together to identify UK supply options. However, perhaps the hardest challenge Steve and the team have set for the AMRC is delivering a step change in productivity.

"We're going to put a sustainability KPI on every project. That means we are not only measuring cost-saving and efficiency-savings but we can identify what the CO2 or waste reduction is. That's one of the big goals for us."

"We are incredibly proud of what has been achieved in chapter one but there are probably two things that the team want to do better in the next chapter," says Steve. "The first is around productivity. There's no doubt the AMRC has brought inward investment from big companies like Rolls-Royce, Boeing and McLaren but we haven't really shifted the dial on the overall productivity in the Sheffield City Region, and in Yorkshire and the North.

"One of the things we wanted to have in the core strategy was around levelling-up. We think the AMRC has a really important role to play there with what has been learned from the Orgreave regeneration and how we can use the 'ten commandments' captured from that experience. We want to use our regeneration skills to bring R&D funding, productivity and industrial commons to level-up other forgotten northern towns."

Smaller firms have a crucial part to play too when it comes to nudging the dial on productivity.

"We have a vast array of businesses in South Yorkshire and if you are going to make a step change in productivity you have got to move a significant amount of those businesses. If we look at SMEs for example, you have not only got to move the very innovative ones at one end of the spectrum, you've also got to move the middle.

"The vast majority of SMEs only need a small incremental improvement. In this next chapter we need to do more with local SME businesses. We need to be helping new, innovative businesses spin out at the one end - so where do we find the next Razor and FourJaw - but we're also going to have to move the lower end of SMEs and what can be done to help move their productivity. Smaller firms won't want international capability or drive for international business but how can we help make them be more productive?

"We are here to help UK productivity improve. We have had this valley of death from research not getting into production and into industry. The reason we want that research to go onto factory floors is to improve productivity. There is more we can do to get our innovation into manufacturing and into industry."

Alongside the big themes sit adjacent and transformational strategies that encompass everything from emerging markets and international spokes to smart assembly services, licensing, spin-outs and

joint ventures to fast tracking innovation into industry.

Pulling all this together during a global pandemic has had its challenges, says Steve, but what started out as 12 individuals trying to write the future has now become a tight team, sharing ideas.

"Trying to get 12 peoples' thoughts and ideas aligned on something like innovation and R&D which is so vast, and across all the sectors which we work in, and all of the technologies, is a mammoth task. The first few weeks was a case of capturing everything in a massive funnel and trying to sort it as a team and hear each person's opinion on why they think something is important." And all this against the backdrop of Covid.

"We had to agree on how we were going to structure this. We knew that directly post-Covid there were going to be some topics that were urgent and important that we needed to work on and we gave that a first initial 12 months. We then recognised that is only one year out of the next decade and actually our job is to be looking further ahead, medium term and longer term."

A key part of this was going out to staff and asking what they think the AMRC should be focussing on in the next 12 months, five and ten years.

"Employees shared their opinions and ideas, and from that we had some quite exciting thoughts about how we can keep that skunkwork, innovative muscle that is really well developed in the business. We are going to use the employee feedback as a stepping stone and an exciting way for the rest of the organisation to contribute to our roadmap for the future."

The strategy planning process was due to kick off in March, a week after the Covid-19 pandemic brought the country to a standstill. Two physical workshops were planned, one in March and another in April, ready to go live in June. But lockdown restrictions forced those plans to be scrapped and in the end Steve and the team instead ran a daily virtual workshop, every day, for about eight weeks.

"It put us a couple of weeks behind where we wanted to be but I think we had much better experience doing it virtually," says Steve. "We have a living strategy now; if anyone has to play back why we've picked a topic, all of us can instantly go to it and remember. There is a lot of detail in there and it is a lot richer than it would have been if we'd had two days off site. It taps you straight back into why people wanted to achieve what we have set out."

Steve doesn't believe one single person can lead the AMRC.

"One person can't have all the right answers, we need a collective brain. It's a very changing environment that we work in, at the very cutting edge of innovation. We work across every single part; whether that's design, castings, composites, subtractive processes like machining, inspection and testing or automation - and it is not possible to do that in one person's head.

"Where our power lies is that we have 600-plus incredibly passionate people who know what's going on at the leading edge of technology and what we need to make an even greater impact is a collective idea of where we're heading. As long as everyone knows roughly where the north star is then people can make the right day-to-day decisions.

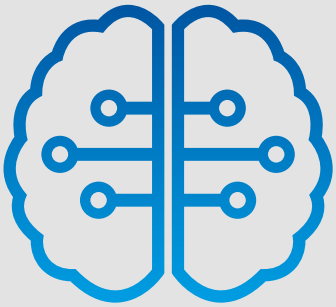
"The feedback we've had around developing a new strategy is that people want to get back to that agile, start-up mentality. To do that in a bigger organisation you just need to have clarity of purpose and vision, and people who are empowered. We've got that in buckets."

Above, an AMRC Training Centre apprentice gets to grips with robotics and automation skills as part of their apprenticeship.

Below, AMRC Head of Digital Prof Rab Scott and former Siemens boss Juergen Maier discuss industrial digitalisation during one of Maier's visits to the AMRC.

Level up and smarten up

When the Made Smarter Review was launched as a key plank in the Industrial Strategy in 2017 it promised to boost UK manufacturing by £455bn, raise productivity by 30% and reduce carbon dioxide emissions by 4.5%. Professor Rab Scott, Head of Digital at the AMRC looks at how the pandemic could add new pace to its adoption.



Few could doubt the ambition of the industrial consortium who gathered behind the Made Smarter banner three years ago. Their prescription – a suite of industrial digitalisation technologies (IDTs) – would deliver nothing short of an economic miracle for a country that has seen its productivity levels stubbornly flatlining since the financial crash of 2008.

Rather than a big bang approach, with an immediate nationwide roll out, the government led by the then Prime Minister, Theresa May, chose instead to test industry's appetite for what the review's lead author, Juergen Maier, called the fourth industrial revolution by establishing a single pilot project in the North West of England.

The results of that pilot have been encouraging – 20 emerging tech start-ups, GVA up by 15 per cent over three years – so much so that Maier is now pressing the case for Made Smarter to be extended (a National Adoption Programme) across the UK as part of the government's economic recovery plan. This time, however, there is an additional focus on digital skills development and training alongside the three pillars of leadership, innovation and adoption. As many as one million workers are to be upskilled in a programme that Maier and his industry backers are now urging on government.

This new focus on skills follows industry's remarkable response to the Covid-19 pandemic which brought together digital skills training material from across the manufacturing landscape in a platform coordinated by Enginuity (formerly SEMTA) in the North East. This platform, launched in the spring of 2020, pulls together contributions from the High Value

The pandemic perfectly demonstrated **the power of these industrial digitalisation technologies to transform manufacturing** and its role as an 'essential service' in protecting the health and well-being of the nation.

Manufacturing Catapult, the Institution of Engineering and Technology, MakeUK and Futurelearn with added content from Formula 1 and the Royal Academy of Engineering.

With support from Made Smarter's industrial partners, including Rolls-Royce, the platform has courses on digital technology and its role in manufacturing and engineering. Among the key technologies covered are data analytics, the Industrial Internet of Things, cybersecurity resilience, industrial and autonomous robotics and additive manufacturing. The ambition is for the platform to grow significantly over the coming months.

And grow it must. The pandemic perfectly demonstrated the power of these industrial digitalisation technologies to transform manufacturing and its role as an 'essential service' in protecting the health and well-being of the nation.

With NHS hospitals and frontline clinicians just weeks away from being overwhelmed by the Covid-19 pandemic in the spring, UK-based manufacturers rose to the Prime Minister's challenge to build 20 years' worth of life-saving ventilators in just 12 short weeks.

This monumental task was made possible because the core companies in the VentilatorChallengeUK consortium either use, or are receptive to, the same digital technologies that are at the heart of the Made Smarter Review. It was tools such as the Microsoft Dynamics 365 Supply Chain Management software that helped the consortium acquire the more than 15 million parts from 88 suppliers worldwide that they needed in just four weeks through a complex logistics network. Many parts had two, three, four or even five suppliers to enable the consortium to meet the rate required and to ensure there was always a back-up plan.

AMRC partner, McLaren, managed the supply chain, deploying engineering, project management, purchasing, logistics and manufacturing teams. They worked with around 100 suppliers and deployed their own machine shop and inspection capacity to support the work whilst coordinating input from other UK-based Formula 1 teams. McLaren itself produced over 70,000 complex parts with zero defects in five weeks to fill gaps in the supply chain. Truly made smarter.

The big lesson from the pandemic is that UK manufacturing needs urgently to adopt Made Smarter IDTs – from supply chain management tools to simulation and modelling, from automation and intelligent robots to augmented reality – if it is to become more resilient, productive and competitive. But can government move at the speed of a McLaren?

Certainly, there are signs that government is picking up the pace. Funding for the roll out of the Made Smarter National Adoption Programme beyond the pilot activity in the North West is now being considered by BEIS; but key to any decision on this is likely to be the attitude of the growing group of special advisors around Dominic Cummings in Downing Street and the Treasury who are driving major changes in the UK's R&D infrastructure with the creation of a new funding agency designed to boost productivity and innovation – twin goals of Made Smarter.

While the funding of fundamental research remains vital to the long-term success of the UK economy, the pandemic has shown there is an equal, if not more pressing, need for immediate fixes to help manufacturers to 'build back better.' Made Smarter is integral to that; but it must now be implemented at pace and at scale if the UK economy is to become more productive and competitive in a post-Brexit, post-Covid climate.

The Made Smarter Industrial Strategy Challenge Fund recently launched two new calls to tackle a number of the weaknesses in the UK economy dramatically exposed by the Covid-19 pandemic. Both address the vulnerability of the UK to complex and extended global supply chains, with one developing technological solutions to the challenge or the other at how technologies can be best applied in an industrial setting.

It is expected that additional calls will be issued early next year to accelerate the Smart Factory theme, and that the underpinning fundamental research behind the Made Smarter initiative will be addressed by the launch of funding competitions by EPSRC and ESRC to create much more connected research centres. The wave of 5G bids – one of which the AMRC won in the North with the highest score – helps provide the high speed infrastructure needed if firms are to maximise the benefits of these digital technologies. The connection of all these digital threads could see UK productivity on the upturn, the skills based re-aligned to industrial need, R&D refocussed on impact, and a levelling up of the economy so that the South no longer has to subsidise the North.

The connection of all these digital threads could see UK productivity on the upturn

Made Smarter, made real

By Rikki Coles and Alex Godbehere

When Juergen Maier launched the Made Smarter review at the AMRC's Factory 2050 a little over two years ago he made a passionate plea for the North to lead what he called 'the fourth industrial revolution.' His audience – captains of industry, civil servants, northern political leaders and technology experts – cheered him to the rafters.

Maier called on business to 'embrace digital, embedding technology, data and information' into everything they do. But how to do that? Even for those who understand the often confusing language of Industry 4.0 and the Industrial Internet of Things (IIoT), the thicket of frameworks, protocols and methods that have been developed to aid the adoption of these new technologies can be an impenetrable 'jungle-like' landscape reducing shop floor agility and stifling adoption among UK manufacturers.

To begin to cut a path through this thicket, the AMRC has produced a literature review as the first deliverable from the Factory+ project that gives UK industrialists, large and small, the confidence to embark on what should be a rewarding journey. At just 20 pages, it is not only significantly lighter than the 230-page Made Smarter Review, but also concisely summarises the current IIoT landscape, enabling the upcoming Factory+ Specification to drive the implementation of a site-wide digitally-connected shop floor at its Factory 2050 facility: Made Smarter, made real.

The goal of the Factory+ Specification is to standardise the connection between devices on the shop floor, creating an operational tool, a research sandbox and a development test bed for future IIoT research at the AMRC. In this way, Factory+ is a clear response to Maier's plea to reduce the barriers to adoption – data standards, interoperability and knowledge capture – here in the North. The literature review is a vital stepping stone, enabling better informed decision-making at the architecture definition phase of the project using the latest information and best practice.

The literature review examines two key frameworks. First the Industrial Internet Reference Architecture (IIRA) which is a more generalised blueprint that enables IIoT architects to design systems according to a common set of standards, concepts and best practices. It also addresses the need for a common framework to develop interoperable IIoT systems across a broad range of cross-industry verticals. The second framework, Reference Architectural Model Industrie 4.0 (RAMI4.0) is much more manufacturing focused and ensures all participants share a common perspective and develop a common understanding.

To keep the connectivity architecture manageable, IIRA suggests a single core connectivity standard per functional domain, but allows for multiple connectivity standards across domains if business rules dictate a requirement. This is especially the case where the implementation and management of multiple legacy systems and connectivity standards can generate additional work, increase risk and stifle innovation. Here, gateways should be used to connect non-compliant devices to the core connectivity standard in a single domain (analogous to administration shells in RAMI4.0) and to bridge connectivity standards between functional domains.

Similarly, RAMI4.0 recommends common communication structures (networks, protocols, rules, syntax and languages) to reduce complexity

DRIVING THE NORTH'S AMBITIONS

HOW THE NORTH CAN DRIVE THE NEXT INDUSTRIAL REVOLUTION

Right: Juergen Maier launched the Made Smarter review at the AMRC's Factory 2050.

and enable standardised processes across the business and between administration shells.

Having explored which protocols should be adopted for secure, reliable, future-proof factory communications, the literature review then investigates whether an industry-standard network topology and architecture exists that allows for optimised communications, enables efficient maintenance and adheres to strict cyber-security policies whilst still being flexible enough to adhere to diverse business rules.

Smart factory architecture is deployed to ensure that data is unified in a single namespace with a single source of truth so that Operational Technology (OT) and Information Technology (IT) entities can access it, providing they have the correct permissions, to process or present the data. A common approach, advocated by the Sparkplug specification, is to refer to any number of entities consuming data as 'Applications', with a single 'Primary Application' responsible for the monitoring and control of a given group of edge nodes (in addition to being able to consume data).

Edge devices can be categorised as either 'near-edge' or 'far-edge'. The latter connect the factory network to the cloud and act as a single access point to the factory network for the cloud. Near-edge devices, by contrast, are typically used at the other side of the factory network to handle the interaction between field devices such as PLCs, controllers and sensors, and usually handle protocol translation logic, local buffering, logging, alert management and additional processing such as machine learning or data tagging.

On the question of whether a gateway should be used as a single point of entry to a cell, the report finds that, while the decision should always be based on the business rules and legacy requirements, the vast majority of the literature strongly favours the adoption of a gateway-per-cell approach, including the official 'Practical Security Recommendations for building OPC UA Applications' guide by the OPC Foundation.

But what of disruptive technologies? How could these affect smart factory development? Perhaps one of the most significant new technologies on the horizon is the deployment of 5G. Although the likely impact is primarily to catalyse and accelerate the spread of smart factories in both greenfield and brownfield sites, it will also be a key component in supporting the massive amounts of manufacturing data that will be generated as more facilities and machines are connected to smart factories around the world.

The migration to cloud platforms such as Microsoft Azure is becoming increasingly widespread as the benefits of distributing computational power to the cloud is realised and more organisations adopt the RAMI4.0 and IIRA frameworks, both which propose distributed architectures. By adopting a containerised strategy on-site – say for data capture, storage, processing and analytics – software functions can be deployed easily on gateways or edge devices to repeatably process data at the machine/cell level in the same way that they would be deployed at a factory or cloud level. This enables firms to align their operations for effortless migration to the cloud – on or off premises – if required.

The literature review concludes that established technologies such as OPC UA are still widely adopted in industry and are continuing to be supported by the foundations that maintain and update them. OPC has been a standard in manufacturing for decades due to its security, standardisation and robust data modelling and appears to continue to dominate factory floors as I4.0 technologies are rolled out across factories globally.

That said, frameworks such as Sparkplug are making some more forward-thinking firms reach for lighter-weight solutions such as MQTT as a replacement for traditional client-server, poll-response architectures to benefit from significantly reduced network traffic and better compatibility with IT systems. The recognition of MQTT as a communication standard is further solidified by its recommendation in both IIRA and RAMI4.0 specifications and the compatible offerings of market leaders such as Siemens.

Having analysed and understood the limitations of the state-of-the-art in the literature review, AMRC researchers are now writing a specification that they believe will change the rules of the game and re-define the future of the connected factory, pushing back the boundaries of what digital can deliver for manufacturing.

5G productivity boost for the North

Manufacturing in the North West received a massive confidence boost with the announcement of almost £10m public/private investment in an open access 5G industrial testbed led by the University of Sheffield Advanced Manufacturing Research Centre (AMRC).

The 5G-Factory of the Future programme will be based primarily at the AMRC North West's soon-to-be-built facility on the Salmesbury Enterprise Zone, and will enhance Lancashire and the North West's reputation as a hot-bed of advanced manufacturing innovation and expertise.

The £9.5 million award, which includes match funding from industry, was made by the Department for Digital, Culture, Media and Sport (DCMS) and is part of the government's £200m investment in 5G test bed facilities across the country.

"This is a big vote of confidence in Lancashire and the North West and a potential game changer for the region," said AMRC North West Commercial Director, Melissa Conlon, whose team, part of the High Value Manufacturing (HVM) Catapult, led an industrial consortium that includes global players such as BAE Systems, IBM, and telecoms and private 5G network provider, Three, along with Burnley based MTT, an SME developer of digitalisation technologies for machine tools, the Lancashire-based data-driven logistics specialist Miralis. The Digital Catapult will be the technical authority lead and coordinate 5G integration, working closely with Three and use case developers.

Conlon added: "Lancashire is home

to leading global businesses in the advanced manufacturing sector; aerospace, automotive and energy. While the region's manufacturing has high levels of economic activity, it lags behind the rest of the North West and the UK in productivity. This investment will change that. It will enable Lancashire's manufacturers to close the productivity gap with the implementation of 5G technologies the adoption of which will be de-risked and fine-tuned at the AMRC."

Announcing the award, Matt Warman, Minister for Digital Infrastructure, said: "The government is investing to help innovative thinkers in brilliant British industries harness the power of high-speed 5G connectivity. With the North West's strong industrial heritage it is fitting that a project to create the factories of the future should take place in the region.

"I look forward to seeing how 5G's role in boosting economic productivity can be employed in other sectors."

The benefits of the 5G-FoF programme should dramatically improve the performance of manufacturers across the North of England, with significant reductions in defects and waste through real-time monitoring; enhanced machine utilisation and energy saving through digital twin track and trace; and a big reduction in travel and maintenance times brought about by shared 'hybrid reality spaces.'

BAE Systems' Manufacturing and Materials Technology Director, Andy Schofield, said: "This is a big win for the region and shows our commitment to keep Lancashire at the forefront of advanced manufacturing in the UK. The 5G research and development test bed will support the development and growth of our new intelligent, smart factory which is applying game-changing digital technologies to the defence sector."

The 5G-FoF programme will also have a significant footprint at BAE Systems' site in Warton, which is the result of a multi-million pound investment and collaboration with more than 40 blue chip and SME companies along with academic institutions.

Schofield added: "The 5G-FoF programme will drive forward holistic connectivity and unlock the potential of industrial digitalisation. It will define a new paradigm for how future factories will operate enabling connectivity and business agility both across manufacturing operations and beyond, into the supply chain. The transformative potential of 5G technology will be developed and demonstrated via a strong consortium, including the UK Catapult Network and the BAE Systems Factory of the Future to advance manufacturing on the UK's next generation combat aircraft system, Tempest."

Charles Lupton who led the project for IBM said: "Data is now our most valuable asset and 5G will help us to gather it quickly and securely through the increased number of IoT sensors provided by MTT. Once securely gathered, IBM's data integration, advanced analytics and artificial intelligence can be utilised to provide detailed insights on productivity and quality control. IBM is providing hybrid Public and Private Cloud instances to the consortium with a Red Hat OpenShift container platform. This allows for flexibility and agility between platforms and the IT and OT environments found on the factory floor."

AMRC Director of Research, Ben Morgan, said: "This was the highest scoring bid for the 5G Test Bed and Trials which is testimony to the talent and hard work of the consortium but also to bid lead, Dr Aparajithan Sivanathan. It also shows the power of industrial collaboration and the benefits of long-term relationships with pioneer companies like BAE Systems and MTT who are embracing smart technologies to give the UK, the North and Lancashire a competitive advantage in an uncertain and challenging world.

"There are so many possibilities for innovation and productivity improvements that 5G can open up. The digital twin work strand will enable reconfigurable assembly lines, while the high-level monitoring of machines and shop floors will allow partners to develop, integrate and test products-as-services previously limited by bandwidth/latency.

"The use of 5G connected sensors in the chain of custody system work stream will help make UK manufacturers more resilient to blockages and breaks in extended supply chains, by enabling tracking across different businesses/supply chains, improving on-time delivery and dramatically reducing lost assets and cost, improving productivity."

FourJaw
Manufacturing Analytics

A Fitbit for manufacturing

A fitness tracker for UK manufacturers to measure and improve productivity – from the shop floor to the top floor – is being tested with Yorkshire companies by a tech start-up that has grown out of the University of Sheffield's globally recognised Advanced Manufacturing Research Centre (AMRC).

John Yates reports.

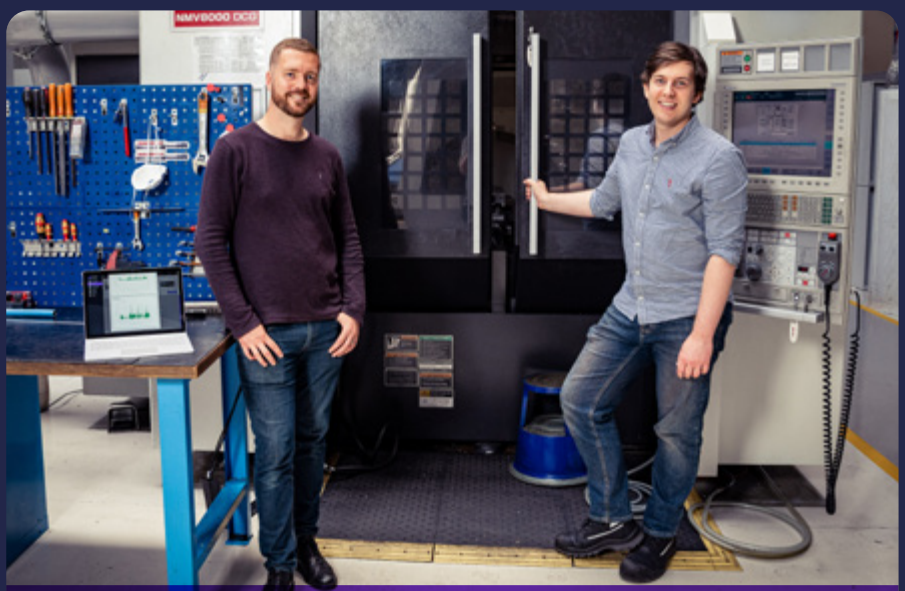
FourJaw Manufacturing Analytics (FourJaw.com), the brainchild of AMRC researchers Chris Iveson and Robin Hartley, have developed a new Manufacturing Execution System capable of unlocking valuable data hidden within machine controllers and converting it to deep insights that enable production managers to turbocharge their productivity.

It does this by getting inside the brains of the machine – the Computer Numerical Control or CNC – which actuates the motors to achieve the complex geometries needed to make a part. For all but a few firms, the raw data stored inside these brains is so difficult to translate into knowledge that it is simply discarded as a form of digital swarf.

To achieve this, the two budding entrepreneurs turned to Sheffield-based software engineers, Razor, to perfect a technology that interfaces with, and extracts data from, complex and varied machine tools, before securely sending the data to the cloud for detailed analysis.

Razor CEO, Jamie Hinton, says: "You don't get much better than helping a brand-new business being formed and the first customer created. FourJaw is now in production and receiving some incredible feedback. We are astonishingly proud of being a part of its journey and being instrumental in bringing it to market."

Having achieved this goal, however, Hartley and Iveson wanted to simplify the process still further for ease of adoption and usability. They have now teamed up with Sheffield-based software development and technology company, The Curve, whose on-demand technical expertise and "big data" know-how is being used to develop an app to present the data analytics in a readily digestible format for production managers.



The AMRC's Chris Iveson and Robin Hartley: engineers turned entrepreneurs.

"It's been great working with another recent start-up, and one with an incredible pedigree," says Iveson of the firm set up by Paul Ridgway former CTO and co-founder of the global telematics firm, The Floow, and a software engineering graduate of the University of Sheffield.

Ridgway said: "Productivity in the current market is key to the viability of any business, helping free up resource, lower costs and ultimately beat competitors. The analytical solutions FourJaw are providing are incredibly important and it's been fantastic to help make this accessible to the market and help them in their journey in establishing the business."

For Jon Bray, Deputy Head of Digital at the AMRC, who leads the Digital Meet Manufacturing Campaign: "This is a beautiful example of what can happen when digital meets manufacturing. You can only get this kind of breakthrough when you bring really, really good software guys into close collaboration with really detailed engineering knowledge to interpret what the software is telling you. Sheffield has both these skill sets in spades."

Jamie and Paul are in the vanguard of the digital meets manufacturing renaissance and are seeing the benefits not just for their own businesses but for the wider prosperity of the region.

For information about FourJaw, visit: **fourjaw.com**

For information about the AMRC's Digital Meet Manufacturing initiative, visit: **amrc.co.uk/pages/digital-meet-manufacturing**

Ground Control to major surgery

Industry 4.0 technologies that once remotely guided the Mars Rover millions of miles from Earth are now being used to create a virtual reality platform to remotely train medical students and transform how surgery is observed, in a project between a machine vision company and the University of Sheffield Advanced Manufacturing Research Centre (AMRC).

"The Covid-19 pandemic has highlighted the global need for a digitally-connected world that allows for seamless remote working conditions. The ability for senior surgeons and doctors to remotely view and be immersed in a virtual representation of an operation will have a game-changing impact," said Dr Ben Crutchley, Senior Machine Vision Engineer at i3D robotics (i3Dr).

i3Dr worked with engineers at the AMRC, part of the High Value Manufacturing (HVM) Catapult, on a bid for funding from Innovate UK for the Stereo Theatre project. The money, part of the Fast Start competition, is a share of a £40m government investment to advance innovative projects which tackle economic and societal issues resulting from the coronavirus crisis.

Stereo Theatre will build on the work already done by the Medical AMRC in Rotherham where an Industry 4.0 Digital Operating Theatre proof of concept has been built. The demonstrator combines a virtual reality (VR) digital twin, projection mapping and smart tools that enables the position of objects and clinicians to be accurately tracked in the theatre space, with relevant information displayed digitally using screens, projections and augmented reality (AR) devices.

Ben said: "Currently, the AMRC's Digital Operating Theatre can provide a virtual representation of the real-world theatre and monitor movements with commercial off-the-shelf (COTS) sensors and smart tools but does not have the ability to produce updated 3D models of patients. Stereo Theatre will fill this gap, allow for further upscaling of the technology and offers a revolutionary approach to both the teaching of medical students and surgical procedures."

Both i3Dr and the AMRC believe the technology could transform surgery and teaching by enhancing the way medical students can learn remotely, performing simulated surgeries on a virtual reality

"The technology developed and demonstrated within the AMRC's Digital Operating Theatre is translatable across sectors with AMRC partners currently investigating new applications within the manufacturing environment."

training platform. The Stereo Theatre project also enables senior consultants to be engaged in surgical procedures conducted by junior colleagues remotely, meaning more patients being observed by experienced surgeons.

Digital Design Manager in the AMRC's Design and Prototyping Group, David King, said: "When the AMRC started the Digital Operating Theatre project our vision was to develop a fully immersive real-time digital twin of the surgical environment that would be as realistic as possible and allow the possibility for remote clinical collaboration and training.

"The integration of i3D robotics' real-time stereo mapping technology within the AMRC Digital Operating Theatre brings us closer to our vision and provides a solution to the need for accurate real-time 3D visualisation of patients within the digital twin environment."

Machine vision company i3Dr, based in Tonbridge, specialises in producing hardware and software solutions for industrial environments such as steel, nuclear and aerospace. i3Dr's core technology, stereo vision, has evolved through decades of development for the Mars Rover missions.

"i3Dr's sister company, IS-Instruments, is also developing technology to address the challenges faced by the Covid-19 pandemic. Our fluorescent imaging device to determine contamination levels could also further develop the Digital Operating Theatre concept," said Ben.

The Stereo Theatre simulator will be tested in the Medical AMRC's Digital Operating Theatre demonstrator to prove the technology can monitor the real-world patient to update a digital twin displayed in VR and AR in real or near-real-time.

"The AMRC will provide the requirements for the 3D vision system to be installed in the Digital Operating Theatre and i3Dr will use this information to produce a vision system capable of capturing 3D data of the chest of a patient," said Ben.

"We will further develop software to allow this 3D model to incorporate into the AMRC's digital twin of the theatre. The system and software will finally be tested at the AMRC with the view that it may act as a demonstrator beyond the end of the project."

David added: "This is our first collaboration with i3Dr and we are already in discussions about significantly larger new programmes. The aligned vision of the AMRC and i3Dr with our combined knowledge and experience makes us confident this is the start of a long and exciting partnership.

"The technology developed and demonstrated within the AMRC's Digital Operating Theatre is translatable across sectors with AMRC partners currently investigating new applications within the manufacturing environment."

The Fast Start competition aims to fast-track the development of innovations born out of the coronavirus crisis while supporting the UK's next generation of cutting-edge start-ups.

Business Secretary, Alok Sharma MP, said: "The coronavirus crisis has created challenges that impact the way we live, work and travel but has also prompted a wave of new innovations as businesses look at ways to solve some of the challenges facing our world today.

"This funding will support UK start-ups to deliver potential solutions, services and ways of working and help ensure the long term sustainability of these businesses."

AMRC signs 'lighthouse' deal with PTC

Immersive software that enabled automotive and aerospace workers to make the rapid transition to building life-saving ventilators will become accessible to UK manufacturers as the University of Sheffield Advanced Manufacturing Research Centre (AMRC) helps industry adopt augmented reality training solutions for reskilling and upskilling their workforces.

The AMRC agreement with PTC, a tier one partner, is one of the largest ever deals for Vuforia® Expert Capture (VEC) software in the UK and will see the AMRC become a lighthouse demonstrator for a growing range of digital technologies and AR solutions for industry.

The agreement builds on the long-term relationship between the two organisations and follows the vital role VEC played in retraining operatives on new production lines to build more than 13,000 ventilators for the VentilatorChallengeUK Consortium (VCUK).

VEC is an out-of-the-box digital solution from the US-based global technology company that allows tasks to be recorded using a wearable device and the content turned into step-by-step instructions for workers to follow to get a job done quickly and accurately the first time.

Professor Rab Scott, Head of Digital at the University of Sheffield AMRC, said Vuforia Expert Capture will be used to deliver upskilling and reskilling solutions for its aerospace partners, with the potential for much wider application into other sectors.

"Our involvement in VCUK gave us first-hand experience of the power of AR in helping to quickly set up new manufacturing lines safely by rapidly transferring production knowledge to different facilities.

"The VCUK activity has really increased the exposure of AR as a viable tool set for the manufacturing enterprise and we expect to see a dramatic uptake in the technology on the shopfloor in the near future.

"It has the potential to transform future supply chains and this is something we wanted to explore in more detail by giving researchers, our existing manufacturing partners and SMEs easy access to VEC and other PTC technologies.

"We already have a number of projects where we think it will accelerate the deployment of solutions into manufacturing."

PTC, a leading provider of industrial innovation technology, became a tier one partner of the AMRC in 2017, with its ThingWorx® IoT platform helping connect machinery and devices at its Factory 2050 facility, the place where digital meets manufacturing.

This latest deal is one of the largest ever signed for Vuforia Expert Capture in the UK and will see the AMRC become a lighthouse demonstrator for its growing range of digital technologies and AR solutions for industry.

In addition to VEC, research engineers across the AMRC will also be able to maximise the capability of Vuforia Chalk, a remote assistance product that leverages AR to help employees collaborate in operational, maintenance and repair situations.

The technology is like Facetime, with AR superpowers for industrial settings, with the emphasis on being easy to set up and use.

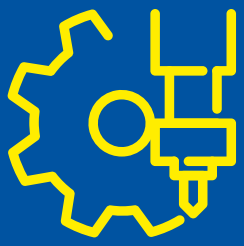
David Grammer, UK Country Manager at PTC, went said: "The high-profile nature of the VentilatorChallengeUK has really thrust augmented reality into the spotlight and proved that it is a technology that manufacturers can easily adopt and successfully implement now and not in five, ten or even 20 years' time.

"Using Vuforia Expert Capture and Vuforia Chalk allowed us to parachute a virtual Smiths Medical manufacturing expert into new production lines, giving engineers who had never worked on ventilators before access to all the guidance and advice they required to complete the build.

"AR reduced the time taken to create the new supply chain by a number of weeks and also protected all the workers involved in the project by ensuring staff were not moving from site to site, reducing the risk of Covid-19 spreading."

He added: "We now want to increase the adoption of augmented reality and remote assistance in other manufacturing environments and the AMRC will provide a perfect gateway to engaging with research projects, new supply chains and in the development of new products."

Tools for the job



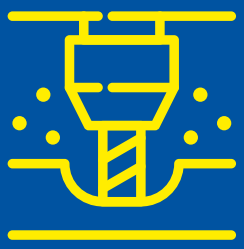
When the unexpected call came to assess and verify parts for life-saving medical ventilators, the AMRC's Head of Machining Phil Kirkland launched into action, coordinating his team's rapid response from a makeshift 'mission control' in the spare bedroom of his home.

The components proved out by the University of Sheffield AMRC were quickly being manufactured at sites across the UK by an army of British companies who rallied in response to a government call to make more life-saving ventilators for Covid-19 patients. For Phil and his team, it proved one small step for the AMRC and one giant leap for a united national effort to save lives.

Phil is 'hugely proud' that his group was called upon to help with such an important project.

"I have no doubt that we all saw this as an opportunity to get involved in a national effort. What it showed is that when we need to react and adapt quickly, we can do so. It is a great example to us all of just what can be done when the will is there.

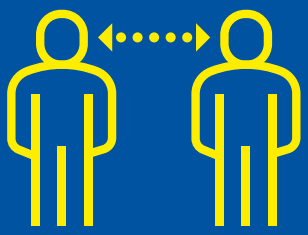
"That is a spirit I intend to take forward once we return to 'normality'. As a research centre, the AMRC is consistently challenged to work at pace and this proved to me that we can do that superbly."



The UK's first confirmed case of Covid-19 came in February and by March the country was well and truly in the grips of the Coronavirus pandemic. The deadly virus had swept across the globe at an alarming rate, pushing populations from liberty into lockdown, including right here at home.

As households up and down the country jostled with the challenge of adjusting to life on lockdown, Britain's manufacturing industry was facing a difficult task of its own.

Government had warned that some 30,000 additional ventilators would be needed to cope with the peak of Covid-19 and Prime Minister Boris Johnson set the challenge for industry to manufacture as many new ventilators as possible to support frontline NHS staff in



Mission control: Head of Machining Phil Kirkland in his makeshift 'mission control' where he coordinated the response to help assess and verify critical components for lifesaving ventilators.

the fight against the virus and to save lives.

And so VentilatorChallengeUK was born – a powerful industrial consortium bringing together some of the world's most innovative manufacturers and suppliers – and led by Dick Elsy, chief executive of the High Value Manufacturing (HVM) Catapult, the seven-strong group of manufacturing research centres in the UK which includes the University of Sheffield AMRC and Nuclear AMRC.

It was Professor Sam Turner, former head of the AMRC Machining Group and now chief technology officer at the HVM Catapult that approached his old comrades for help.

"Initially, we were asked to review a set of engineering drawings for the Smiths Medical Group ParaPac ventilator design," explains Phil. "There were about 60 drawings in total and the initial ask of us was to recommend the type of machine tool best suited to manufacture the parts.

"This soon developed into a request to manufacture some of the parts for the prototype assembly prior to going into production at assembly sites across the UK."

As we're all too aware, time is a luxury no-one can afford during this pandemic: not those infected with the deadly virus, not the frontline health workers in desperate need to increase ventilator numbers, nor the industrialists driving the response to ramp up production of the life-saving devices.

Phil knew he needed to act fast. From his home office - the nerve centre of operations dubbed 'mission control' by his wife - Phil used his intimate knowledge of the Machining Group's diverse skill set to quickly pull a team together, ensuring little time was lost in supporting his former colleague Turner and VentilatorChallengeUK.

"I've been at the AMRC for almost ten years and have the advantage of knowing the team very well; it was a matter of assigning the tasks to the relevant staff.

"With the aid of Ash Godbehere, our workshop manager at the Factory of the Future, we were able to identify the machine tool requirements relatively quickly. We assessed our capability to manufacture and we identified eight parts that we could help with.

"This initial requirement was then followed by identifying the staff we would need to manufacture the parts. This ranged from machine operators, maintenance, health and safety, and logistics. With some staff self-isolating and unavailable due to caring for vulnerable family members this really tested our staff knowledge. Fortunately we had already started a log of all staff

Rising to the challenge: Engineers Matt Young, left, and George Bateman, right, in front of the Haas VF6 machine used during the Covid-19 response.

noting their individual working needs, so we were able to act quickly."

The scale of 'behind the scenes' work involved in readying the troops to support the wartime-style effort was huge. The team had to consider what machines could machine proponent parts, categorise parts into families for those suitable machines, work with supply chains, source tooling; and all the while keeping regular contact with Turner at the HVM Catapult and other consortium partners.

Phil did some quick maths and worked out his team put in between 300-350 working hours in total, not counting the 'endless telephone conversations and emails'.

"The interesting thing for me initially was the scale of the work we took on," said Phil. "I had to remain practical into what we could achieve and what we would like to have helped with. This meant being open and honest with the team and sticking to our key skills.

"We selected six aluminium parts and two brass parts for manufacture. Locating the material was the first challenge and this is where practicality took over as we have quite a stock of aluminium that we use almost daily.

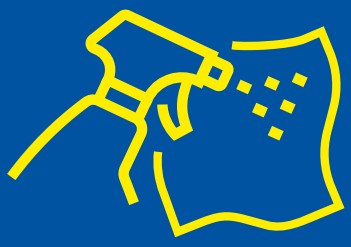
The brass was slightly more difficult to locate but Paul Rigden, our workshop apprentice trainer, used his local knowledge to liaise with Ian Cocker Precision Engineering who supplied material, tooling and took on some machining activity for us.

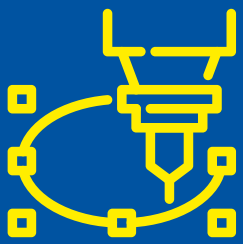
"Certain tooling requirements were complicated to fulfil as we were working over the weekend and some stockists were on reduced capacity and resource. Again, this is where our adaptability came to the fore, utilising similar tooling where possible.

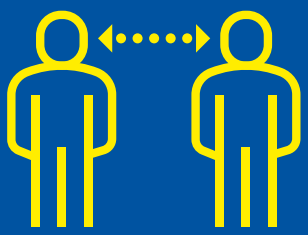
"The 'goalposts' were moving all the time, and Sam and I were in contact almost on the hour as priorities changed and different suppliers came on board with the project."

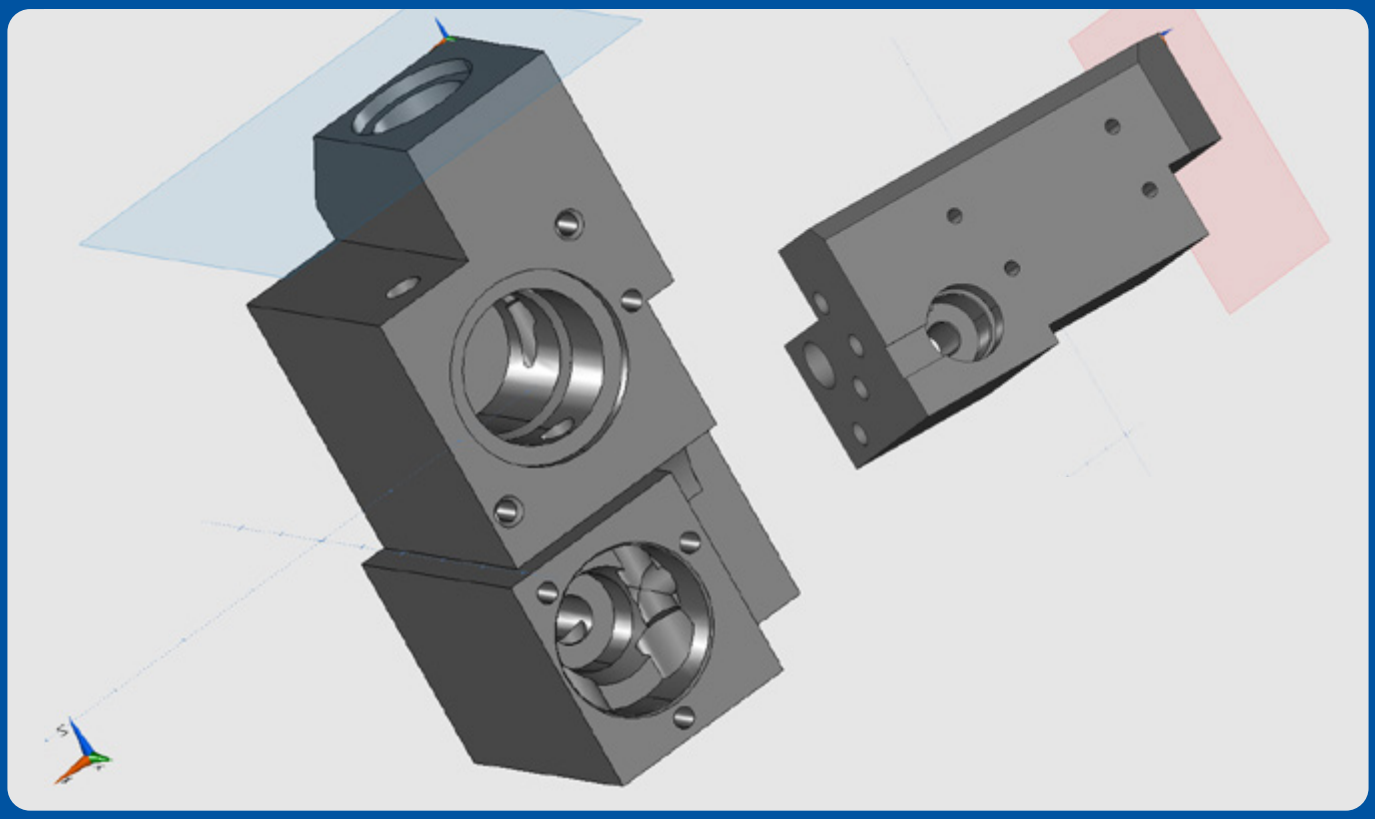
For the manufacturing element of the work, the Machining Group had two maintenance staff on site at Factory of the Future on Thursday, March 26 - followed by ten staff on site over two full days, from Friday, March 27 to Saturday, March 28,

The parts were completed by 8pm on the Saturday evening and shipped the following Sunday ready for assembly at consortium partner GKN's Luton site.









Making things better: A CAD image of the components produced by the Machining Group, an input manifold made from aluminium.

"Initially we were asked to make two off of each of the eight parts," said Phil. "Experience told us that we may as well aim to make four off of each part, so a number of spares were available and in actual fact in some instances we made five off of parts. All in all 38 items were delivered to GKN."

The manufacturing team was supported remotely by the Factory of the Future's workshop management team and programming support supplied by tool room manager Chris DePledge.

Before anyone could re-enter Factory of the Future, which had been put on temporary closure due to national guidance advising people to work from home, Phil had to enlist the help of Steve Davies, Head of Safety, Health, Environment and Quality at the AMRC.

Steve, with assistance from the University of Sheffield estates and facilities management team, compiled a Risk Assessment Method Statement to be adhered to by the team while on site - this enabled safe working practices with the necessary social distancing and personal hygiene measures for coronavirus, as well as the usual fire marshal and first aid cover.

The team didn't stop at manufacturing ventilator parts - Phil also offered the group's capability to help with verification of 3D CAD models of critical ventilator parts. This was done by replicating 2D drawings from the 3D models and ensuring that the 2D drawings provided were an exact match.

"A team from across the AMRC was scrambled to do this work. Eight engineers from across the Machining Group, the Design, Prototyping and Test Centre, Integrated Manufacturing Group and Nuclear AMRC worked over a weekend checking 20 off component parts," said Phil.

"Any discrepancies were reported back to Sam Turner at the HVMC so all the data could be updated - a vital part of ensuring the production parts would be manufactured to the correct specification. It's a great example of how the AMRC pulls together expertise from across its groups.

"In addition, the following weekend, we were then asked to make an additional three off of one of the more complex parts. A team of three worked over two days (April 3 - 4) to complete the task and Ash Godbehere delivered the parts himself on the Sunday morning."

The enthusiasm and can-do spirit at the heart of the AMRC's DNA has 'really shone through', says Phil.

"The willingness to work long hours over the weekend was remarkable. All the individual heads of groups were so keen to be involved and it was amazing that we held an impromptu conference call at 10.30am on a Saturday to assemble the team to check the 3D models and by the Sunday evening the team had completed the task.

"I could not have asked for a better response and it has confirmed my opinion that the Machining Group team, and the wider AMRC, is unbelievably talented."

While it has been a challenging period, it is one Phil has enjoyed having only recently been appointed as interim head of the Machining Group.

"I have to say I really enjoyed the experience. It has been good for me to understand our capabilities under pressure. It was great to interact with Sam Turner again too - I have known Sam for ten years – and I was pleased he turned to us for help."

From game changer to life saver

Six months after being hailed a 'game changer' for the North Wales economy, the University of Sheffield Advanced Manufacturing Research Centre (AMRC) Cymru played an essential role in an unfamiliar game, helping save lives as a production facility for thousands of vital medical ventilators.

"To be just a small part of this national effort will undoubtedly be the biggest highlight of my entire career and I'm extremely proud to have led our amazing AMRC Cymru team through it," said Andy Silcox, Research Director at AMRC Cymru.

"However, it has definitely been sad at times knowing the team has worked so hard over the last 12 months to get the building up and running; to see it completely stripped out before we've done any real research was tough."

Turning AMRC Cymru, which officially opened in November 2019, into a production facility for ventilators was suggested on the very day Boris Johnson first called on manufacturers to join a wartime-style effort to mass-produce the equipment following the outbreak of Covid-19.

"The idea of using AMRC Cymru was first put forward on Monday, March 16, but for the next week and a half there was a lot of confusion around what was being asked of us while the VentilatorChallengeUK consortium zeroed in on which design they would progress," said Andy.

The industrial consortium came together after the Prime Minister made a plea for thousands of ventilators to be delivered to the NHS within a matter of weeks. Under the leadership of the High Value Manufacturing (HVM) Catapult, of which the AMRC and the Nuclear AMRC are a part, the consortium focused production on two existing ventilator designs which met the high-level specification, one made by Penlon and the other by Smiths Medical.

Andy said AMRC Cymru's role in the ventilator project became real on Wednesday, March 26: "That was the day we were chosen to be involved in the manufacture of the Penlon device. We were the venue for the manufacture of two key sub-assemblies: the absorber and the flow meter units."

Where once a single security guard supervised a handful of people entering the open access research facility, a large security team in white tents screened the 350 shop floor workers using the building. A two-stage security process meant each engineer had to thoroughly sanitize their hands in the tents outside and then have their temperature taken by a thermal imaging camera. Anyone with a temperature above the average of 37.5°C was not allowed in.

Once authorised by the Medicines and Healthcare products Regulatory Agency (MHRA) for use in hospitals, following extensive testing, the Government confirmed an order for 15,000 Penlon devices. Hundreds of units were built in the first

The AMRC Cymru workshop floor was transformed to produce ventilator parts in fewer than two weeks.

Economy and North Wales Minister Ken Skates called AMRC Cymru a 'game changer' when it opened in 2019.

An Airbus engineer manufactures a component of the Penlon ventilator at AMRC Cymru.

few days, with production further scaled up.

Situated in the Deeside Enterprise Zone and backed by £20m from Welsh Government, AMRC Cymru will focus on advanced manufacturing sectors including aerospace, automotive, nuclear and food. The facility operates a 2,000 square metre open access research area with Airbus the first major tenant with a platform to develop their next generation wing technologies aligned to its 'Wing of Tomorrow' programme.

"Airbus, who were also part of the VentilatorChallengeUK consortium, were the driving force behind this," said Andy. "We integrated into their mobilisation team and provided as much support as possible to ensure that our building was fit for purpose as a safe production facility.

"There were eight assembly lines for each sub-assembly, requiring 88 operators per shift. There were two shifts a day, with everyone working in a four days on, four days off pattern. That meant 352 shop floor staff; add in the office, logistics, security and cleaning staff and it took the full complement to about 500."

Andy said the logistical problems alone would have been challenging enough, but became extremely complicated while adhering to strict health and safety guidelines: "Not only did we have to strip out an R&D facility to install 16 new productions lines from scratch in less than a fortnight, we also needed to create an environment where 88 operators could work simultaneously while maintaining safe social distancing.

"We made real use of our modelling and simulation capability. Our engineer Xuan Sheng Tie created a model in Process Simulate to safely control operator movements around the facility to allow us to organise shift breaks and lunch times to suit what we have on the shop floor."

Andy and AMRC Cymru's Workshop Manager, Matt Booth, were working 12-hour shifts, in line with Airbus' four days on, four days off pattern since Saturday, March 28 and were the only AMRC staff allowed on site.

But Andy said it has been an incredible team effort from staff across the AMRC: "We limited it to myself and Matt to minimise the infection risk across both the AMRC and Airbus but we had unbelievable support.

"Chris Garlick at the University of Sheffield's estates team arranged 24/7 cleaning, security and maintenance cover for the building throughout the production period, which we anticipated to last up to four months. Then there are all the other members of our team in particular Xuan, Bobby Manesh, Michelle Hibbert and Harri Williams, who supported Matt and myself.

"To see the way everyone has pulled together to get this done has been massively uplifting. It has also been an affirmation for me of just how brilliant the UK manufacturing sector is and it gives me a lot of faith that the overall AMRC mission is worthwhile and that we will be part of an incredible bounce back by the sector once this crisis is over."

Leading manufacturers into the **new normal**

A blueprint for safe, productive working by manufacturers during Covid-19 will give the food industry in Wales the confidence to adjust to the 'new normal' way of working as we begin to emerge from the pandemic and set it on the road to big improvements in productivity and innovation.

The blueprint – drawn up by the University of Sheffield Advanced Manufacturing Research Centre (AMRC) and Welsh Government - builds on the experience of turning AMRC Cymru into a production facility for life-saving medical ventilators by the industrial consortium VentilatorChallengeUK. In fewer than two weeks, the state-of-the-art research institute was stripped out to allow 88 operators to work simultaneously while maintaining safe social distancing and allowing shift breaks and lunch times.

"We know food manufacturing companies are being forced to revisit working protocols, manage employees' safety and are exploring innovative opportunities to continue working productively. We want to help manufacturers on that journey," said Welsh Government Minister for Environment, Energy and Rural Affairs, Lesley Griffiths MS.

AMRC Cymru's Operations Director, Jason Murphy, added: "The challenges posed to ready our site for the ventilator work meant that we made real use of our modelling and simulation capabilities. What we now want to do is help food manufacturers facing many of the same issues and challenges so they can successfully transition their business to the 'new normal'.

"We want manufacturers to be productive but safe during this difficult period and I think this document will help them do that. Moreover, it could be the first step to creating a more digitally enabled, resilient and agile operation."

Engineers at AMRC Cymru in Broughton, North Wales, have partnered with Food and Drink Wales to produce the guide which contains lots of helpful advice on things such as factory flow, adapting workstations, adjusting break times, redesigning toilet facilities, parking arrangements and how to safely organise deliveries.

In addition, the comprehensive document, called The New Normal, highlights some of the many possibilities

The New Normal document has the potential to form the basis of guidance for businesses across the UK.

> "Everything we used to help in the manufacture of the ventilators is detailed in The New Normal document and, crucially, can be implemented by any business."
>
> **Bobby Manesh**, AMRC Cymru's Food and Drink Technical Lead

and opportunities of implementing new technologies to tackle the current situation and to create a more resilient operation. The guide is initially being sent to food, drink and packaging companies in Wales, but has the potential to form the basis of guidance for businesses across the UK.

Bobby Manesh, AMRC Cymru's Food and Drink Technical Lead, said: "This document will hopefully provide clear guidance for management and staff to safely return to food manufacturing work while adhering to strict government guidelines; but we also want to open people's minds to the technological opportunities available right now.

"Before going into the production of two key sub-assemblies for the ventilators, we ran Discrete Event Simulation (DES) modelling software which led us to use staggered lunch breaks and reduce production line downtimes. At other sites, autonomous guided vehicles (AGVs) and Microsoft HoloLens augmented reality (AR) headsets have proved invaluable in the production process of these life-saving devices.

"Everything we used to help in the manufacture of the ventilators is detailed in The New Normal document and, crucially, can be implemented by any business."

AMRC Cymru was opened in November 2019, backed by a £20m investment from Welsh Government, and is the first High Value Manufacturing (HVM) Catapult centre in Wales. AMRC Cymru operates a 2,000 square metre open access research area with Airbus the first major tenant with a platform to develop their next generation wing technologies aligned to its Wing of Tomorrow programme.

Minister for Economy, Transport and North Wales, Ken Skates, said: "Although AMRC Cymru is not being used as we first imagined when it opened last year, we're incredibly proud of how this facility is part of the national effort to beat Covid-19.

"What we now need to do is learn lessons from that fantastic work, safely return to shop floors when restrictions allow and use this as a springboard to explore new opportunities."

AM nanosatellite fuel tank design cuts weight and triples capacity

A lightweight fuel tank for small-scale satellites has been designed and developed by metal additive manufacture engineers at the University of Sheffield Advanced Manufacturing Research Centre (AMRC) as part of a pioneering UK Space Agency-funded programme.

Abdul Haque, technical lead in metal additive manufacturing at the University of Sheffield AMRC, inspecting one of the AM fuel tank prototypes.

With the annual number of small satellites deployed forecast to reach about 400 this year – an increase of 300 per cent compared to 2016 – there is a growing market need to dramatically expand their mission capabilities, extend their orbital life and decrease the cost of constellation deployment.

AMRC engineers used topology optimization techniques to reduce the weight of the tank by over 25 per cent, combined with an almost three-fold increase in fuel capacity over conventional spheroidal storage tanks. This could have a significant impact on satellite launch costs.

"Developing competitive propulsion solutions for small satellites is a game changer for UK space capability," says Abdul Haque, technical lead in metal additive manufacturing at the AMRC. "The MiniTANK project lays the groundwork for adding a key miniaturised, low-cost propulsion technology to the UK's portfolio."

MiniTANK is a collaborative endeavour between the AMRC and global SME technology company Added Value Solutions (AVS) UK Ltd. to develop a propellant storage system for a nanosatellite that maximises the internal volume whilst minimising mass – utilising novel features that can only be manufactured through Additive Manufacturing (AM).

Backed by the UK Space Agency's Pathfinder programme, AMRC researchers have produced a lightweight, high-strength fuel tank for a Cube Satellite (CubeSat for short) that meets the demanding performance and cost targets desired by Oxford-based AVS, a company that designs propulsion systems for small-scale satellites.

AVS chose to work with the AMRC's Design and Prototyping Group (DPG) because of its leading expertise and experience in designing AM parts. In return, MiniTANK has given the AMRC an invaluable foothold in the UK space industry and provides a significant new offering to current and future industrial partners.

"Using a pressurised tank without the AMRC's work on AM optimisation would have forced us to choose between a heavy design or a volume-inefficient tank holding much less propellant in CubeSats," says Daniel Staab, system engineer at AVS UK.

Kyaw Swar, the liaising mechanical engineer from AVS UK, added: "This project has allowed us to understand much better the requirements and objectives of AM in the Cubesat market, which is crucial for other developments around mechanisms and optomechanical systems for small satellites that we are involved in.

"We even see great knowledge transfer skills that are beneficial for high-value missions, such as our involvement in the development of the gripper and sample restraint mechanisms of the Sample Fetching Rover where additive manufactured parts will most likely be part of the mission."

Abdul says MiniTANK has successfully demonstrated that metal AM is an alternative route for the manufacture of complex fuel tank designs.

"The final AM fuel tank mass was 360 g which was a 28 per cent decrease in weight when compared to the original dry mass of 500 g for a conventional tank," he said.

"The volume utilisation (amount of usable space within the tank) of the cuboidal fuel tank was estimated at 90 per cent which is an improvement when compared with spherical tanks at approximately 60 per cent. The fuel tank can hold approximately 2.8 times the fuel volume of a 78 mm diameter sphere, which is the largest size sphere that could fit within the allocated design envelope.

"During testing, the fuel tank withstood all non-destructive tests without observable deformation. The fuel tank ruptured at a test pressure of 74 bar, which is 1.9 times the safety factor of the design burst pressure specified in the European Cooperation for Space Standardisation (ECSS).

"We were able to demonstrate the successful application of AM to achieve performance benefits of a component, the geometry of which is not possible to produce through conventional manufacturing methods."

Current nanosatellite and microsatellite propellant storage systems either use volume-inefficient but structurally strong cylindrical and spherical tanks. This means there is much interest in the development of fuel tanks, currently one of the heaviest components of a CubeSat's propulsion system.

AMRC engineers were able to produce

a viable satellite fuel tank optimised through generative design techniques to meet weight, strength and volumetric fuel storage requirements. Using AM to produce a freeform generatively designed geometry, DPG researchers successfully applied a novel design approach to create a cuboidal fuel tank that would give AVS a competitive edge in the marketplace.

Abdul said the purpose of the MiniTANK project was twofold: first to show it is possible to design an improved fuel tank but also demonstrate what can be achieved by using the AM process to do this.

"Typically CubeSats are used for technology and research so can be a contributor to some sort of telecommunications research, large-scale monitoring - so science-focused programmes. Essentially they collect data or do some sort of monitoring or provide platforms for telecommunications. They can do anything, it depends on how they are configured and what the end requirement is."

He said heritage propulsion systems are expensive and do not scale well to the small size and/or power budgets available on nanosatellite and microsatellite platforms.

AVS provided the DPG with a set of technical requirements for a CubeSat fuel tank. These included: a single propellant line with inner and outer diameters of 2 mm and 3 mm; fitting within an envelope of approximately 96 mm x 96 mm x 78 mm; achieving a propellant volume of 0.6 litres; and having a dry mass of less than 500 g.

"With AM you can create complex forms that you can't manufacture via conventional methods. The concept we generated was a cuboidal fuel tank.

"Through the concept developments we did in-house, using software tools such as Altair Inspire, Autodesk Netfabb Simulation and PTC Creo Simulate, we were able to assess the design space and identify areas for optimisation; for example where material from low-stress areas could be moved and placed in high-stress regions where more material is required.

"By moving away from a sphere to a cube immediately allowed us to increase the amount of propellant stored in the tank, the volume utilisation was increased from 60 per cent to 90 per cent.

"As you would expect a sphere to be structurally stronger than a cube, we used topology optimisation tools to optimise the design, which suggested using a stiffening geometry to resolve some anticipated distortion.

"We did this by creating a series of rib structures on the inside of the cuboidal tank to resist the high displacement or high-stress regions predicted by the software these were designed in such a way as to be self-supporting. This allowed us to build the tank in a single piece, eliminating the requirement for joining multiple components post-build as there was no need to remove build-supports for the internal structures of the fuel tank."

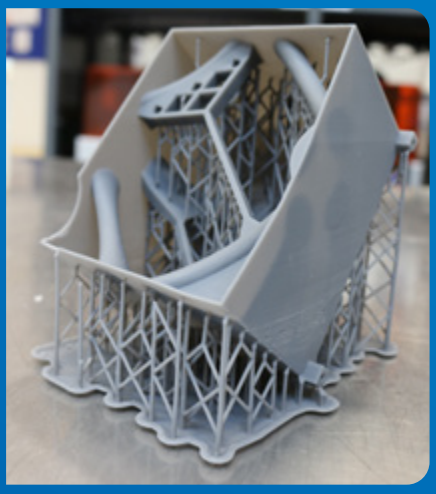
Laser Powder Bed Fusion (LPBF) was used for the fuel tank manufacture; this is where a fibre laser is used to impart thermal energy selectively to fuse regions of fine metallic particles to form a Near Net Shape (NNS) component. It is also known as Selective Laser Melting (SLM) and is capable of creating highly complex geometries with features not possible through subtractive manufacturing processes.

Abdul added: "We printed the fuel tank out of titanium because it allows us to create a lightweight structure as its specific strength is high compared to other alloys. The original cuboidal tank without any mass optimisation via 3D printing techniques tank that was given in the specification was around 500 g and we managed to redesign that cuboidal tank into a highly mass-optimised tank – and even with internal stiffening structures the final weight came out at 360 g.

"For space, although we're talking a matter of grams, such a weight saving is hugely significant. If you can shave one kilogram off your launch load, it can be potentially £7,000 to £15,000 in terms of cost-saving off the launch.

"What AVS is working towards now is designing a CubeSat propulsion system potentially using the fuel tank that we've 3D printed and are developing several other components that need to be amalgamated into the whole system. They want to print some further iterations of the fuel tank in the future and do some actual launch tests."

MiniTANK has a wider impact too, as Abdul explained: "Although this project focused on the fuel tank – if you take a system-level approach and carry out the same optimisation to other components of the CubeSat – the microwave generator housing, the propulsion system, brackets that connect solar panels, the framework – you are shaving weight off every assembly component. In total that might save a lot more material, so MiniTANK is not an isolated case, we should be looking at the entire satellite system to get the maximum benefits offered by AM."



These early stage prints show some of the initial ideas for the internal structure of the fuel tank.

Getting a handle on marginal gains

HUUB wattbike

A British track cycling team say ground-breaking bicycle parts manufactured at the University of Sheffield Advanced Manufacturing Research Centre (AMRC) could provide the marginal gains they need to break three world records.

HUUB-Wattbike, an independent Union Cycliste Internationale (UCI) team based in Derby, have earned an enviable reputation since they burst onto the scene in 2017, employing innovative techniques to unlock incremental improvements on performance.

The pioneering approach to achieving aerodynamic gains has earned the team wins at two World Cups, Commonwealth Games medals and national titles. In 2021, four HUUB-Wattbike riders will travel to South America where it is hoped the reduction in air density from high altitude will deliver another marginal gain so they can break the 4km Team Pursuit world record, 4km Individual Pursuit world record and UCI Hour Record.

Founder, rider and engineer, Dan Bigham, said: "Our aim has always been to ride fast and enjoy it. We employ a pragmatic approach to performance; creating and optimising the systems around us within the bounds of our strict financial and competitive constraints."

In November 2019, a sudden change in UCI regulations meant Bigham needed to quickly redesign the state-of-the-art interface plate which connects the bicycle stem and handlebars. To be ready in time for the December World Cup event in Brisbane, the parts had to be machined in under two weeks from aerospace-grade aluminium.

"One of our team partners, Meggitt, are a tier two member of the AMRC," said Dan. "When we reached out to Meggitt with this project they went straight to the AMRC, knowing just how capable they are at executing unique manufacturing projects to a tight timescale."

Research Director at the AMRC, Ben Morgan, said: "In the past, the component had a fairly prismatic design and Dan had turned it into an extremely aerodynamically-efficient design. It was full five-axis machining of the part, pulling together materials and programming exceptionally quickly, all to make this small, incremental difference in aerodynamics."

Dan said those marginal gains were central to their huge achievements at the National Track Championships in January where the quartet of himself, John Archibald, Jonathan Wale and Will Perrett set a new championship record.

"We had our most successful National Championships yet and the new part machined by the AMRC definitely contributed to that success. The team took the top five spots in the individual pursuit, the top three places in the

The interface plate, made from aerospace-grade aluminium, helped HUUB-Wattbike achieve their most successful National Championships yet.

kilometre time trial and dominated the team pursuit.

"Details matter and having everything as optimised as possible is a big boost. From an equipment performance perspective and a mental perspective, knowing you have every piece of equipment as dialled-in as possible is incredibly powerful.

"The next goal on our journey is to break the 4km Team Pursuit world record, 4km Individual Pursuit world record and UCI Hour Record. We will have the best chance of achieving it in Bolivia and had planned on travelling there in October, but that has now had to be delayed until next year due to Covid-19.

"I'm planning an assault on Bradley Wiggin's sea-level hour record - which is also the British record - in October as a bit of fun in the meantime."

With a master's degree in engineering and a year spent working as an aerodynamicist at Formula 1 team Mercedes AMG Petronas, it was perhaps inevitable that Dan would one day collaborate with the AMRC, part of the High Value Manufacturing (HVM) Catapult. A former Great Britain rider, competing at the 2018 UCI Track Cycling World Championships and 2018 Commonwealth Games, Dan created Wattshop in 2016 to utilise his engineering expertise to develop cycling products.

Trade team HUUB-Wattbike became a spin-off of Wattshop a year later, with the backing of triathlon clothing retailer HUUB Design.

Ben said: "You could call Dan a disciple of Sir David Brailsford, in terms of bringing that marginal gains mentality to cycling; what he is doing is effecting every small part. He is really driving them from an engineering perspective; from the suits, the socks, the cleats, he has considered the aerodynamic profiling of it all. So I view him as a bit of a revolutionary in that respect.

"The team at HUUB-Wattbike always talk about '7-10 watts' in their Twitter and Instagram posts and that refers to how much power they need to create when they're cycling.

"If you can reduce your aerodynamic drag, or reduce your weight, then you need to create less power; so they suggest that maybe our upgrade on the interface plate was worth 7-10 watts. It might not seem a great deal, but if you're cycling for an hour at high speed, that can make a huge difference."

Ben said the project was a perfect fit between two organisations at the cutting edge of innovation: "There is a definite synergy between our mantras and our ways of working. The mind-set for HUUB-Wattbike is to constantly innovate and optimise, and that is exactly what drives the AMRC forward.

"We can learn from Dan. In terms of some of the thinking, we could learn a lot in the AMRC about mentality and drive to win."

As Great Britain struggled to maintain their usual dominance in February's UCI Track Cycling World Championships in Berlin, a competition not open to HUUB-Wattbike or other trade teams, Dan applied that drive to win in his role as performance engineer for the Danish team, helping them set a new world record in the men's team pursuit.

Dan is still very much part of HUUB-Wattbike though and said the interface plate project could be the start of a long relationship with the AMRC: "We have a few ideas in the pipeline. The AMRC has such great facilities and the engineers there are leading the way on Additive Manufacturing research so we hope to take advantage of that with a few Direct Metal Laser Sintering (DMLS) components in the coming months."

Ben added: "Hopefully this can be the start of a long association between HUUB-Wattbike and the AMRC. Dan has a real passion for innovation and is a real success story; if the AMRC can help to deliver some more aerodynamic wins which help HUUB-Wattbike on their journey, then great."

Jewel in the crown

A watch-style bracelet made from 'space glass' that has a custom, uncut diamond in its crown could be the centrepiece of a new luxury lifestyle brand, thanks to design and machining experts at the University of Sheffield Advanced Manufacturing Research Centre (AMRC).

The sophisticated piece of jewellery is the brainchild of entrepreneur and open-banking specialist Steffan van Molendorff, who has taken his passion for motorcycles, engineering and diamonds and used them as inspirational fuel for his adventure lifestyle brand, 6ixt9 (pronounced sixty-nine).

The 50-year-old South African has big ambitions for the brand and one of the concepts he is currently developing is a bracelet which looks just like a regular watch except in the place of a clock face sits a raw, uncut diamond.

The idea was little more than a pencil drawing on a scrap of paper when AMRC machine tool partner Starrag put Steffan in touch with engineers at the AMRC in Rotherham, which is part of the UK's High Value Manufacturing (HVM) Catapult network of world-leading research centres.

It is there that machining research engineer Emma Parkin, together with design and prototyping engineer Valdis Krumins, began work on turning the rough sketch into a reality.

The designs they created have 'exceeded all expectations', says Steffan.

"I knew from early on that one of the products I wanted to do was something really unique and different and aimed at a very niche, sophisticated market," he said. "That's how I came up with the idea of taking a rough diamond and putting it inside a watch casing.

"I came to the AMRC and met Emma and Valdis, sharing with them an idea and a simple paper drawing. About two weeks later the first CAD designs came through from Valdis and they were amazing. At that stage I knew we were on to something special and unique.

"Emma spoke so enthusiastically about the machining process and the different materials we could make the watch-case from - that's when she told me about Zerodur®, a type of glass-ceramic that can be machined and is used a lot in space applications. I loved the idea of having 'space glass' as the material for the watch casing.

"The whole process has been fantastic. Emma and Valdis have been so supportive and creative in coming up with ideas. They have been wonderful to work with.

"The designs which Valdis completed have now been registered for design protection in the UK and EU and I'm very excited to work with the AMRC team on this project and look forward to an interesting future."

The three ideas consisted of a 'crown', 'slim' and 'rectangular' designs, as Valdis explained: "The 'crown' is inspired by the 6ixt9 brand itself. The curves of the logo and bikes are smooth while the leather accessories are chunky and honest. It lets the stone not only be displayed proudly but also admired in full 360 degrees by rotating the crown.

"The 'slim' is designed around not exceeding the height of the stone. Imagine a dress watch, if you will, which slides under the cuff of a shirt almost unnoticed. There are no layers of components as all the structural interfaces are designed to assemble flat in one plane.

"The 'rectangle' stems from a drawing by Steffan that he showed me when we first met. The resulting design is a middle ground between the flashy 'crown' and subtle 'slim' designs. The 'rectangle' is the one we selected to prototype."

The machining work for the prototype is on hold due to coronavirus restrictions but the extra time has allowed Emma to carry out further investigation into UK suppliers of the Zerodur® material, which is manufactured by international technology group Schott. She is also exploring suitable cutting tools and machining strategies.

The render by AMRC Project Engineer Valdis Krumins from the Design and Prototyping Group.

The 'rectangle' prototype design which has been chosen for machining trials at the AMRC.

Emma said: "The favoured machine for the work is the DMG Ultrasonic 10 that we have here at the AMRC. It's a small machine more commonly used by dental laboratories to make dental prostheses such as bridges and crowns. It's perfect for machining hard materials like glass."

Dr David Curtis, AMRC Technical Fellow for abrasive processes, said due to the material being an engineered glass-ceramic - which is brittle, has an extremely low coefficient of thermal expansion and a hardness similar to borosilicate glass – careful consideration of the machining process is required.

"Techniques developed for satellite mirror grinding may need to be utilised to manage brittle to ductile material removal, controlling subsurface defects that are generated for aesthetic rather than functional performance" said Dr Curtis. "The DMG Ultrasonic 10 platform will allow us to explore material removal strategies for a range of feature geometries, material removal rates and surface quality requirements with both conventional diamond grinding and ultrasonic assisted methods.

"With ultrasonic grinding, the cutting tool oscillates at a fraction of the width of a human hair at a rate of 25,000 times per second, which acts to reduce forces and increase achievable material removal rates. A balance between efficient stock removal and surface / subsurface quality will likely be required for this application."

Emma said three to five prototypes will be made which Steffan can use to market his jewellery idea. She added: "Part of the project will also involve documenting everything we do so we can create a knowledge transfer pack that can be shared with Steffan so he can take that information away with him and know what machines need to be used, which cutting tools, and have a detailed method of manufacture for his product."

With a price tag of between £10k-£12k, and even up to £100k depending on the level of customisation, Steffan's jewellery does not come cheap.

"You can't use small diamonds in the bracelet itself because of the design and size, so you're looking at using three and four carat quality stones. The target for this product is high net worth individuals, markets in the Middle East, Far East and perhaps New York."

Steffan is no stranger to the lucrative diamond industry. His family's farm in South Africa was mined for diamonds for a short period after a prospector discovered a nine carat stone on their land, changing the family's fortunes forever.

Entrepreneur Steffan van Molendorff with the three AMRC-developed design prototypes for his watch-style diamond bracelet.

"I grew up in an engineering environment, my dad had a company in South Africa manufacturing heat exchangers for the mining industry. One day someone showed up to dad's work and said he thought there were diamonds on the farmland he owned and wanted to do some prospecting. A nine carat diamond was found on the land and that changed the whole dynamic forever.

"The farm was mined for about 18 months. It wasn't very yielding, the operational costs were quite high in terms of the diamonds recovered. After 18 months we gave it up and I moved into the rough diamond trade and travelled through Africa looking for diamonds. But it was a tough industry to operate in and I didn't have enough capital to compete so I had to stop.

"But what it did do is plant the love I have for rough diamonds. I wanted to take that love, and my passion for motorcycles and engineering, and use my creative side to build these into a lifestyle brand that is bold and different. It took me a while to find the courage to do it but that's how 6ixt9 was kick-started into life."

The project, paid for by the AMRC using funds from the High Value Manufacturing (HMV) Catapult, is part of the AMRC's commitment to supporting smaller and medium sized businesses.

The art of micro-machining

The Queen's head has been beautifully micro-machined onto pieces of brass by engineers at the AMRC using cutting tools so small they are barely visible to the naked eye.

One of the machined portraits of Her Majesty, measuring just 1.4mm, is so small that the intricate detail can only be seen clearly through a powerful microscope. It is a major achievement for University of Sheffield Advanced Manufacturing Research Centre (AMRC) engineers Emma Parkin and Joe Thickett who wanted to create the tiny artworks to show off the AMRC Machining Group's capabilities with the goal of bolstering industry knowledge on micro-machining to help UK firms win business.

The faces were created using a seven-axis Starrag Bumotec S-191 mill-turn centre, an industry leading high-accuracy machine tool platform. Emma and Joe's deep understanding of the machine's behaviour allowed them to produce four remarkably detailed Queen's heads – with diameters of 11.2mm, 7mm, 2.8mm and 1.4mm - on a single circular piece of brass measuring 25mm.

They used micro-end mill cutting tools supplied by Sandvik Coromant to achieve the basic shape of the design before switching to tiny but incredibly precise ball-nose cutters - the smallest of which measures just 0.2mm - to carry out the detailed contouring of the Queen's face.

"We chose the Queen as a portrait because we wanted to do something similar to a coin as it is relatable, people generally know the size of a coin; so to be able to scale it down in size yet still keep the Queen's face on there is the 'wow' factor.

"We wanted to show our partners and wider industry what is achievable; that we can work to an accuracy of 0.001 mm on work pieces as small as 1.5 mm and make use of these tiny cutters whilst still maintaining detail."

Emma drew on the vast expertise from across the AMRC to create the micro-machined portraits.

"To get Her Majesty's face, we scanned a real coin using a 3D microscope that's normally reserved for detecting surface roughness of texture on a material. It works by taking a series of pictures which are then layered up to create a 3D image. We then gave that digital 3D image to an engineer in the Design and Prototyping Group - Valdis Krumins, who was able to turn it into a file format I could work with called STL that is used in stereolithography CAD software.

"We were able to take that STL file and upload it into Siemens NX 12, which is a CAD design software package. In this environment we were able to make a programme for the tool paths; roughing, semi-roughing; semi-finishing; and finishing which is standard practice for any high-precision machining.

"We require a high degree of accuracy and repeatability from our tool paths to avoid tool failure. The software is important because the difficulty with micro-machining is that you can't hear the cutter's health so you have to get the feeds and speeds right the first time.

"We started at 4mm to remove the bulk material and then went down in size.

The portrait being micro-machined into brass using the Starrag Bumotec machine.

Engineers Joe Thickett and Emma Parkin in front of the seven-axis Starrag Bumotec S-191 mill-turn centre used to micro-machine the miniature portraits.

When we got to the finishing operations with the 0.2mm ball-nose we were doing micron step overs, which is literally moving a micron every time, back and forth."

It is this high precision and ability to achieve accuracies to one micron that is increasingly important for modern micro, ultra-precision and high-value manufacturing; across a broad range of applications from automotive, aerospace and medical to watchmaking, electronics, cryogenics and space. That makes micro-machining and micro-engineering big business, with latest reports (by IndustryARC) suggesting a global market value of $12.5billion last year, concentrated mainly in the US and Europe.

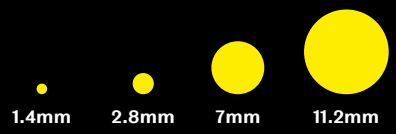
Emma said: "In the UK it is mostly SMEs that use micro-machining. It's a bit of a forgotten art over here. It is expensive to do because of the machinery you need to purchase in order to achieve the accuracies desired. You may be producing tiny little parts but there is so much precision that goes into it, it ends up becoming quite expensive.

"The majority of micro-machining is produced in Europe with Switzerland being the most well-known, and because of this a lot of work gets sent there - incurring a further decline in knowledge in the UK.

"There are a lot of companies that use micro parts but there are only a very few companies in the UK now that actually specialise in micro-machining; mostly people just send work out of the country.

"We have a few places in the UK that specialise in high precision but the numbers are few. It's more machine tool companies and cutting tool companies who tend to sell you their machines and pass on some knowledge but to me that is not the best way, which is where we come in, and what we're trying to do - have tech that we can give out to companies to bridge that gap.

"At a retail price upwards of £600k, the Bumotec machine is not affordable for every SME, but what we can do is get those best practices out there around machine tool down selection, machine tool inspection, environmental considerations, cutting strategies, tooling, tool run out and component metrology.

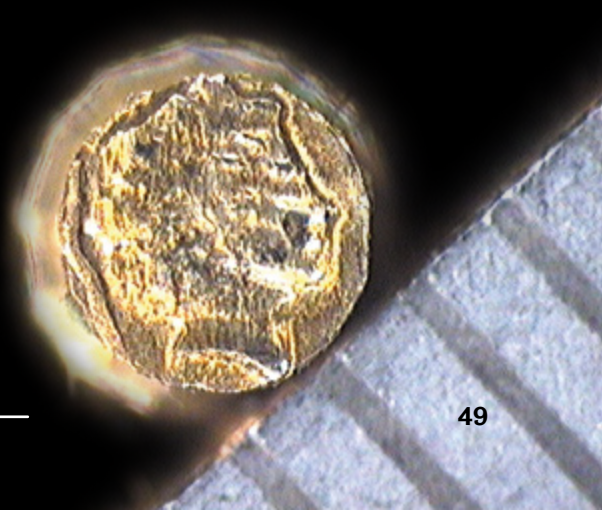


Above, the actual sizes of the micro-machined portraits and right, the smallest of the four at 1.4mm.

"The gain is that by adopting this best practice, companies could potentially increase productivity and manufacture components that would normally be deemed as too difficult, in house."

Emma is hoping the 'coin' demonstrator will lead to further micro-machining R&D and commercial projects for the AMRC, which is part of the High Value Manufacturing (HVM) Catapult network. "I just want people to come and have a look at what we're doing. At the moment when people come to the AMRC, and here to Factory of the Future, what they see is aerospace, with massive aerospace components on display and huge machines.

"I want people to think bigger than that, by thinking smaller and walk onto the shop floor, down to the Bumotec or the Kern, and go 'wow' the AMRC can make some really small parts. Let's work with them."



Safety decking company loads up for market

Load testing by the University of Sheffield AMRC has paved the way for a family-run firm to go ahead with production of their innovative plastic safety decking system.

Revdek Limited, based in Howden, aims to disrupt the market with its lightweight, easy to assemble, flexible panel design for working and safety platforms which are used in the construction industry, particularly house building.

But before it could hit go on production and take the system to market, the brains behind the bright green decking, Mike Bramley and son-in-law Chris Bateman, needed to test and validate the system's structural integrity and safety.

To help them achieve certification, Chris approached the Advanced Structural Testing Centre (ASTC) team at the University of Sheffield Advanced Manufacturing Research Centre (AMRC), which is part of the High Value Manufacturing (HVM) Catapult.

Chris said: "It's quite hard to find someone to test a product like this. Most places I spoke to were offering material testing - tensile testing the plastic material - but we needed more than that. We approached the Advanced Structural Testing Centre at the AMRC and we've not looked back."

The Revdek system was put through rigorous testing by the UKAS-accredited ASTC team, who applied loads of up to 305kg per square metre to ensure the panels met the standards required by the company. The system passed with flying colours, achieving Class 4, which Chris says makes it stronger and safer than other plastic systems on the market.

"We've been working on the design and development of the safety decking system for several years now and so to reach a point of having a product that is ready for industry standard testing is very exciting," he said.

"Furthermore, having the system pass the tests means that our time, energy and resources invested in developing the system have been well spent, and this is a particular success and achievement for Mike who has been the key innovator behind the unique features of the Revdek safety decking system."

Phil Spiers, head of the ASTC, said Revdek were a pleasure to work with as the group develops its capability for offering test solutions to industry.

"This is just the sort of testing that the AMRC is geared up for, supporting SMEs with accredited testing that enables them to get a certified product to market," said Phil. "The testing of complex and 'out of the ordinary' products and assemblies is what the Advanced Structural Test Centre excels at and being able to secure this testing as part of the AMRC's commitment to funding SME projects makes access to a world class accredited test facility possible for the small businesses who form the backbone of UK production."

Once assembled, the bright green injection moulded plastic panels form a sturdy access deck that allows craftsmen to work at height safely and prevents falls as it is able to reach the storey height for the installation of things such as floor joists, beams or roof trusses.

It is not only strength that sets Revdek apart from its competitors, it is the innovative design. The panels are rectangular in shape, measuring 1200mm x 900mm. The majority of other systems currently on the market

Shane Smith (left) from the ASTC team pictured with Chris Bateman from Revdek during testing of the safety decking system at the AMRC.

The ASTC team put the decking system through its paces.

feature square panels and measure 1000mm x 1000mm.

The advantages of the rectangle shape, Chris says, is the flexibility and fewer components.

"We have tried to innovate and do things a bit differently," he said. "Not all building plots are square so you can get what we call 'overlaps' when fitting the panels. But if you have a rectangular board that is 1200mm x 900mm, it is designed in such a way that it allows more versatility.

"We think we will use eight per cent fewer boards than we would if using square boards because the surface area is slightly more which means fewer panels being required and also fewer overlaps. This is important because if you have an overlap it becomes a trip hazard. It also means you are using more boards; more boards means more product, more plastic, and more environmental waste."

Chris says the other major innovation of the design is what lies beneath the panels – a 'spring clip' mechanism.

"All other safety decking products on the market use a straight pin to lock the panels together whereas we have designed this spring clip," he said. "The advantages of that is you don't have to secure it with nylon rope like you do with straight pins. The spring clip is nylon-based plastic so it springs outwards and locks in to stop it falling out.

"As there are fewer component parts being used, it means the system is a lot quicker to assemble and dismantle."

Revdek is an entity of Prodek Safety Systems, which was set up by Chris's father-in-law Mike Bramley more than 13 years ago. Chris joined the company two years ago and soon after the pair set up Revdek.

Chris said: "We have spent the last two years developing our own system with the knowledge we have gained from supplying and fitting safety decking for the last 13 years.

"One of Mike's visions was he didn't want to copy what is already available, he wanted to innovate.

"We took the decision to do things differently and outthink the competition. We were stubborn to the point of saying 'no we can do something better' – creating a system that uses fewer components and is easier to erect and dismantle for our operatives. That means we can do more in a day – increasing our productivity.

"We have been through a number of iterations of the designs, looked at different versions of the polymer plastic, different cooling cycles for the components, and it has been a journey and to get to the testing stage."

The project was paid for by the AMRC using funds from the High Value Manufacturing (HMV) Catapult as part of its commitment to supporting smaller and medium sized businesses.

The testing:

The AMRC was given three panels to test, which were assembled into the centre of a nine panel platform deck. Three deadweight footprints were used for the test:

- **A local class 3 uniform distributed load of 1.92kN (195.6kg)**
- **A local class 4 uniform distributed load of 2.88kN (293.67kg)**
- **A load class 4 concentrated load of 3kN (305.91kg)**

The Class 3 and Class 4 uniform distributed loads were applied for three minutes before being reduced back to zero, and then applied for 24 hours before reducing to zero. The Class 4 concentrated load was applied for 90 seconds and reduced to zero, and then given the same 24 hour treatment.

All three safety platforms met the required load class specifications as defined in the National Standard; the uniform distributed load met Class 3 and 4; and the concentrated load on an area 500mm x 500mm with a centre support leg installed met the Class 4 criteria.

Automation makes the cut for Powertherm

An insulation jacket manufacturer with an appetite for digitalisation has ramped up its use of automation technologies for labour-intensive manual production processes thanks to help from composites research engineers at the University of Sheffield AMRC.

Mike Taylor, Flexible Products Division Manager, operating the Eastman CNC ply-cutting machine.

Powertherm Contract Services Ltd makes thermal insulation jackets for the power generation and petrochemical industries; relying largely on a hand-crafted process due to the bespoke nature of the designs and the varied application of their products.

The Sheffield-based company purchased an Eastman CNC ply-cutting machine to automate some of its time-consuming processes - such as the manual cutting and marking of high temperature resistance glass fibre fabrics – but needed help optimising their use of the machine as it was only in operation two or three times a month due to not being fully incorporated into the company's manufacturing process.

The ply-cutter is now used daily following a project by the University of Sheffield AMRC which looked at ways they could better integrate the kit into shop floor production.

Mike Taylor, Flexible Insulation Products Division Manager at Powertherm, said: "The decision was made to purchase this machine but the challenge for us was around how we integrated it into our production process. That's what we wanted to push along so we got in touch with the AMRC whose research engineers produced a very thorough report that highlighted some of the problems we were up against.

"One of the recommendations in the report was to have a different design program that works better with the machine so we invested in the SolidWorks 3D modelling program. Two of us have now been trained on that and we're making progress. We were using a 2D program before and while there are similarities, the 3D program goes much further in what it can do.

"It means we are using the ply-cutting machine a great deal more than we were

and we have started setting up some user defined tables and inputting data for the different types of covers that we manufacture to create a library of designs.

"For us, the main benefits of this machine are around saving time and maintaining quality.

"We still cut things out by hand because we have nine sewing machines on the shop floor and for the cutting machine to keep churning out enough work to satisfy those nine machinists is quite a big task while we're still trying to build up the design library. But once that library is full, it will contain thousands of designs and will be able to cut more."

Mike said the work done by the AMRC was fundamental in giving the company ideas as to how it could progress: "I think that's been the important thing we have got from the project. We knew in our minds that we needed to develop libraries of different drawings but we didn't know how to go about doing that and the AMRC has given us the direction for doing that."

Research engineers from the University of Sheffield AMRC's Composite Centre visited Powertherm's Handsworth factory to evaluate its current process for making glass fibre insulated jackets. They found that while this involves skilled operatives cutting fabric by hand, they largely work to paper drawings which means the company doesn't have the digital drawings of designs required by the machine.

A number of recommendations were made by the AMRC team to help Powertherm better integrate the ply-cutter into day-to-day operations, including trialling the use of computer assisted design (CAD) tools to create a model able to generate digital product designs to be interpreted by the ply-cutter.

Calum Dickinson, research engineer at the AMRC Composite Centre, said: "In order to digitise the current design process to complement the use of the CNC ply cutter on the shop floor, we suggested CAD methods could be used for flattening of 3D geometry to 2D patterns to streamline some of the simpler product designs.

"Once set up, that model would generate digital 2D line wire frame drawings which can be sent to the CNC ply cutter for it to then automatically cut out the required glass fabric shapes needed to construct the insulation jackets. We think this would be possible for about 30-40 per cent of what they currently manufacture and would definitely mean a reduction in production time."

During the visit, Calum and the team found that the 'made-to-measure' nature of the jacket manufacture process posed a number of challenges when considering digitalising operations.

Calum said: "The majority of the products designed and manufactured are one-off bespoke items, made-to-measure for a specific pipework installation. This means, at the moment, the glass fabrics are cut out by hand with operatives working to a job card and paper drawing of what they are supposed to be cutting out.

"The process works but it also means they can't just jump straight onto the Eastman CNC ply-cutter and use it because they don't have the digital drawings of these jacket designs which the machine requires. The objective for us was to understand what they were doing and come up with a set of recommendations on the next steps they could take."

First, the team needed to understand the current design and production process. Calum said: "There is one experienced designer, Mike Taylor, who figures everything out. He follows a set of rules and relationships from the measurements taken on site which he uses to develop a jacket design and produces technical drawings by hand which are then sent to the shop-floor with a job card for skilled operatives to manufacture.

"The process is very labour intensive and because of the bespoke nature of the products, the design stage of the process is quite a large proportion as it's done for every single product made. This factor, coupled with limited CAD experience within the company, means that potentially the time invested in making a CAD drawing of each part isn't necessarily beneficial."

To find a way forward for the company, AMRC engineers and technicians with significant experience of automation in composite and technical textile manufacturing processes visited the factory on two separate days to carry out process timing trials.

A trial was set up to measure, mark and cut a 2m piece of fabric by hand, it took about 30 minutes. On the ply-cutter it was five minutes. However, the AMRC team found this wasn't the same for all the different sizes of materials because for some pieces the operatives use templates which takes out the measuring step.

Calum said: "For some parts, they will save time using the ply-cutter, particularly the bigger parts where it takes longer to measure if they haven't got a template. They will definitely save time using the machine but it is hard to say precisely how much time because each of the products they make are different sizes.

"Another useful suggestion we made to them when using the ply-cutter was automatically nesting all designs onto fabric to make good use of the material. Nesting means rotating and positioning pieces to minimise scrap, typically resulting in 70 to 80 per cent material utilisation.

"The other saving by nesting is not just on the material. We saw that when Powertherm operatives are manually cutting out fabric, they save big 'scrap' pieces and store them in a box for later. When they have a pattern they think they can use the fabric for they take it out and measure it, and perhaps find it is not quite the right size so they put it back. That isn't an efficient use of time. Nesting would help eliminate this.

"We have clearly seen areas where they can make changes and save on time, material and, ultimately, on cost."

Alongside the AMRC report recommending the next steps, Calum and the team hosted a workshop held to show Powertherm the next stages to explore once it has digital files for their fabric pieces.

Calum said: "They were really happy and I think they got a lot out of it. The workshop involved people from all aspects of the business: the finance officer, lead designer, shop floor operator and machine operator. We had a brainstorming session to talk about the machine and understand the process. That's the beauty of working with an SME – you can get all those people in a room together and they all have knowledge about different aspects of the business, which helps us to help them.

"They were keen to set up that model and follow the recommendations we have made. It's good to see some of that is now in place and taking shape."

Locked down but not closed down

By Nikki Jones, Director of the University of Sheffield AMRC Training Centre.

The biggest challenge for the manufacturing sector right now is simply how to survive.

To continue operating, manufacturers and training providers alike are being forced to adapt. In the last five months they have had to pivot their operations swiftly and smartly to a completely new way of working and, without doubt, the digital world has come to the rescue.

Not so long ago, some manufacturers would have considered applying Industry 4.0 technologies in day-to-day operations a threat to jobs and a step too far.

For a training provider like the AMRC Training Centre, we would have hesitated at the idea of teaching our 800 apprentices and liaising with our near 300 employers without face-to-face communication for an entire summer term.

It's amazing what a worldwide pandemic can do to focus the mind; and throughout the manufacturing sector the Covid-19 outbreak has brought digital tech to the fore.

At AMRC Cymru in North Wales, Industry 4.0 technologies were central to turning a brand new R&D facility into a factory for making thousands of life-saving medical ventilators in less than two weeks. Applying augmented reality (AR), automation and modelling allowed our engineers to adjust to constraints of Covid-19 and provided a blueprint for how other companies could create a safe, productive, and therefore profitable, business post-pandemic.

Similarly, the use of digital tools has been central to maintaining training. The same technologies that enabled the remote training of operators in industry without the need for human interaction, have meant apprentices' education at the AMRC Training Centre hasn't missed a beat.

We locked down but we did not close down, because we acted quickly and effectively to move over to the digital world; essentially switching our learning from the real-world classroom to the virtual one. In this, we have built on the innovative way we have been running remote apprenticeship training to some students for the past two years – originally this was done to save apprentice time and employer travel and accommodation cost; now it has come into its own.

We made sure we communicated with our employers and apprentices at every stage of this new normal for learning; and we listened at the same time. For those apprentices who told us they couldn't access online resources, we provided laptops and dongles. When they told us they were working irregular hours, we recorded our virtual classroom sessions and ensured our one-to-one support was flexible.

Without abundant

AMRC Training Centre apprentices Will Morton and Joe Burns at their employer, Tribosonics in Sheffield.

Learning before the virus: Apprentices learning valuable skills at the AMRC Training Centre before the virus struck and right, the flagship training facilities in Rotherham.

digital technologies, we simply could not have achieved this. Today, digital thread is woven through everything we're doing to adapt, and, by moving quickly and efficiently, it means our teaching and student experience hasn't suffered.

The Covid-19 outbreak has accelerated the need to adopt new digital technologies: some we didn't know were out there, some we didn't know we needed, but plenty will be perfectly normal to teachers and apprentices now and in the future. Beyond that, our experiences are shaping our future thinking as we consider how we can develop our digital offering with increased online learning, CPD courses and webinars.

In a number of ways, the pandemic has shone a light on UK manufacturing, highlighting what can be possible, but it has also emphasised where the sector can further develop to increase its profits in the future: one is that need for greater agility in manufacturing operations, another is the need for a highly-skilled and adaptable workforce.

These aren't necessarily new, post-Covid-19 ideas. Even before the world was turned on its head, the rise of Artificial Intelligence (AI) and the translation of data into knowledge meant industry was going through a period of rapid and profound technological change which was having a major impact on the skills requirement. Businesses were beginning to appreciate that having engineers with the right digital skills allows them to properly embrace technological advances and sure up the pipeline of skilled engineers.

The upheaval of Covid-19 is pushing those considerations to the front of people's minds and – while organisations like the AMRC work with manufacturers to implement the Industry 4.0 technologies that will allow them to adapt to changing market demands – there is a responsibility on training providers to deliver the workforce employers need to exploit the benefits of digitalisation.

That is not to say there is a lost generation of engineers working right now who will suddenly become obsolete: retraining existing staff is a proven way of developing skills within a company while retaining valued, experienced employees.

Indeed, we could be getting nearer to the 'golden goose' engineer – someone who has a background in traditional engineering, such as mechanical or electrical, but who can code, design and, most importantly, understand digital integration.

As we slowly emerge from lockdown and managers reassess the make-up of their shop floors, multi-dimensional engineers such as these will be crucial to the economic recovery of manufacturing.

Experience has shown that many employers are very happy to take apprentices who are part way through their apprenticeship because they know they are recruiting highly-skilled, motivated staff who have high levels of technical and practical skills as well as being exposed to automation and business improvement techniques at Advanced Apprenticeship level and at degree level.

It's about future-proofing the industry while also learning from past mistakes. Where some employers have been forced to make staff redundant, others have actually prioritised apprenticeship recruitment, thus avoiding the consequences of the last recession where a cut back on apprenticeship recruitment led to a huge gap in key skills.

Apprentices going through their training at this moment might think themselves unfortunate to have their apprenticeships coincide with a time of such turmoil. This is understandable. But these young men and women will rapidly become some of the most employable engineers on the market.

Apprentices have been working longer hours, different shifts and often from home with minimal supervision. Many have been asked to check in on colleagues to make sure that everyone is coping well while others have been furloughed; but all have been continuing with their studies and training in a new digital environment. Those attributes of flexibility, resilience and dependability are at the forefront of employer requirements.

Once again, it's that ability to adapt. The Covid-19 pandemic has proved to manufacturers how important a digitally-enabled, agile business is – not just in their operations but in their staff as well.

Apprenticeships vital to economic recovery

Undeterred by the global pandemic, manufacturers across the Sheffield City Region and beyond are recruiting 'vital' apprentices through the University of Sheffield AMRC Training Centre as they prepare to hit the ground running as the Covid-19 lockdown begins to ease.

"Things may be uncertain but we do need to maintain skill levels now and looking to the future, so continuing with an apprentice programme is incredibly important," said Phil Longden, Operations Director at NE Components in Hope Valley, who took on an apprentice during the coronavirus outbreak.

His sentiments were shared by Managing Director of Sheffield-based Atlantic Pumps, Andy Smith, who said: "Business is down but there is still a huge amount to do, supporting our clients in protecting their assets and helping them to fulfil obligations. We wanted to take on a new apprentice now because, ultimately, we believe in both our future and the future of apprentices.

"Our business relies on having quality engineers with a great attitude for customer care. These are in short supply and we've found the best way to get them is to invest in creating them ourselves, in partnership with the AMRC Training Centre.

"It isn't a quick fix though, so we have gone ahead, knowing that if we want this resource for 2021 and beyond we have to invest now."

The AMRC Training Centre responded quickly to the outbreak of Covid-19, suspending face-to-face teaching in March. Teaching swiftly went online, with tutors in constant contact with apprentices and extra support being offered by the University of Sheffield to help transition to online learning.

Anne Griggs, Head of Business Development and Contracts at the AMRC Training Centre, said: "It is fantastic to see new apprentices starting their journey to becoming engineers and shows the value employers place in the AMRC Training Centre and its apprenticeships, even in these uncertain times.

"The training centre moved quickly to ensure teaching has continued throughout the lockdown period and that is thanks to the hard work and flexibility of our teaching staff, apprentices and their employers.

"The AMRC Training Centre remained open for business. Our meetings are being held via video link and we are still processing new applications for apprenticeships."

Apprentices at the AMRC Training Centre have access to state-of-the-art facilities and are taught by trainers with an innovative approach to the delivery of advanced manufacturing apprenticeships. The curriculum is carefully designed with employers in mind and in 2019 the first cohort of apprentices graduated with degrees from the University of Sheffield.

Recent official figures show the AMRC Training Centre is top of the regional league table for engineering apprentice achievement.

Phil said it is the high standards expected of every apprentice that keeps NE Components coming back to the AMRC Training Centre: "The AMRC Training Centre provides an excellent grounding for apprentices and prepares them to hit the ground running when they enter the workplace full time. When looking to recruit, there is always a good selection of high calibre candidates."

"Apprentices of this quality are vital to Atlantic Pumps," said Andy. "A great attitude to customer care along with great engineering skills is the core and foundation of our business and, sadly, there just aren't a lot of people looking for jobs who bring both of those attributes.

"With the AMRC Training Centre, we can recruit the right attitude and rely on the training centre teaching the skills to create a powerful mix and provide exactly what our customers need."

Anne added: "When the government decides we are able to return to our workplaces and go back to some form of normality, focus will turn to economic recovery. A skilled UK workforce will be a key ingredient for that and apprentices have an essential part to play."

AMRC Training Centre apprentice Niall Dawson, a design engineer at Pryor Marking Technologies whose innovative ideas are saving his company £50k a year.

‘Remarkable’ apprentice makes mark with **£50k-a-year production savings**

Assembly efficiencies made by a ‘remarkable’ design engineer during his apprenticeship are now saving his employer £50,000-a-year and slashing product build time by more than 60 per cent, from 3.5 hours down to just one hour.

Niall Dawson works at Sheffield-based Pryor Marking Technology, which was established in 1849 and is a world leader for design and manufacture of intelligent marking, identification and code reading solutions.

The 21-year-old from Sheffield completed a Technical Support Apprenticeship with the AMRC Training Centre this year and says one his finest hours during that time was being lead designer in Pryor’s first wave implementation of dedicated assembly stations for standard products.

Nat Russhard, Business Improvement Manager at Pryor Marking Technology, said Niall is the company’s first Technical Apprentice and his contribution to the organisation has been ‘truly remarkable’ in many ways.

“Niall has shown a flexibility to work across all areas of the business from shop floor to top floor. The practical skills he has picked up from a hands-on approach has helped significantly in providing outstanding cost savings to his re-engineered design of a standard product.

“He is a very important part of the Pryor organisation. His contribution, delivery and results speak for themselves. He has promoted and demonstrated the merits of the AMRC Training Centre apprenticeship scheme throughout the company.”

The project began with Niall looking at

the assembly time of a standard product that was notoriously difficult to assemble with a right first time falling as low as 70 per cent.

"When looking at the bill of materials I quickly noticed some high cost parts that seemed very over-engineered for their function. Many colleagues within the fitting department had commented on the product taking multiple attempts to get right and this adds a lot of time on to the build," says Niall.

"As well as designing the stations to reduce assembly time, we also looked at the ergonomics of a cell and provided assembly operatives with all the tools and parts required for a job so they didn't have to spend time locating or fetching parts from the warehouse, reducing overall time and improving efficiency.

"After a two-year project, the changes are now implemented with results showing a saving of £50,000 a year along with more than a 60 per cent reduction in the time it takes to build each product - the timescale being 3.5 hours down to one hour. It's still early days but 'Right First Time' yield is now back where it should be at 100 per cent. A planned follow up process will take place later this year to check compliance to the Standard Operating Procedure and to study any feedback for further improvements.

"The skill level now needed to build the machine has also been reduced, opening up opportunities for lower-skilled labour from other areas in the factory to assemble these products. The benefit to the company through this project has been huge and it now means other standard products can be investigated using the same methodology to reduce cost, assembly time and improve quality."

Niall is fully integrated into the design team at Pryor, working on sales orders and standard product development alongside five other fully qualified designers. He works independently on projects, tapping into the knowledge and experience of the experts around him to develop his core design skills. He added: "I am at a point now where I can support my own weight in the business."

Nat Russhard agrees: "Through working with casting suppliers, shop floor and purchasing teams, Niall has exceeded all expectations with cost savings totalling £50,000 per year, a reduction in assembly time of more than 60 per cent and developing opportunities to use low-skilled labour through the introduction of Standard Operating Procedures.

Image: Pryor Marking

Pryor's BenchDot machine in action which Niall redesigned.

"Niall also has a mature level of confidence and is entirely trusted to visit and represent the Pryor company with major customers such as Rolls-Royce where he has designed, installed and commissioned modifications to a radio frequency identification (RFID) tracking system. To date, Niall is now developing cost estimates and quotations for bespoke customer projects where values can exceed £100k."

He is also part of the team developing Pryor's approach to Industry 4.0 - the adoption of digital industrial technologies to create smarter, connected factories.

"Niall is an important part of the technical team where he is continually developing his technical skills and successfully challenging our current processes, procedures and products with outstanding results," says Russhard. "It may be regarded as a soft benefit and hard to quantify, but Niall has certainly changed people's mind-set and approach to business change through continuous improvement, and in turn has set a very high bar."

Nikki Jones, Director of the AMRC Training Centre, said Niall is a shining example of the success that can be achieved through apprenticeships and of the benefits employers can reap by taking on an apprentice.

"Niall is an absolute credit to the AMRC Training Centre and to his company. During his apprenticeship, and beyond, he has displayed the right attitude, passion and commitment that companies are crying out for in manufacturing and engineering."

The University of Sheffield AMRC Training Centre has the best engineering achievement rates in the region, so you can be sure to get the best when looking for an apprentice, or to upskill your team. Invest in the future with an apprentice or training now. Visit www.amrctraining.co.uk.

Best apprentice achievement rates in the region

The latest official figures released by the Education and Skills Funding Agency, show the University of Sheffield AMRC Training Centre is top of the regional league table for engineering apprentice achievement.

Head of Business Development at the AMRC Training Centre, Anne Griggs, said the latest figures are testimony to the continuous improvement culture at the centre and the pivotal role its industry board plays in shaping a fit-for-purpose curriculum.

"Engineering and manufacturing skills are vital to the success of the Sheffield City Region economy and these figures show that the AMRC Training Centre is top of the league when it comes to delivering these skills," said Anne.

The training centre – part of the world-leading Advanced Manufacturing Research Centre and the elite Russell Group University of Sheffield – opened its doors just six years ago and has been instrumental in attracting global brands such as McLaren, Rolls-Royce and Boeing to establish production facilities in the region.

"These are difficult and confusing times for industry, with employers rightly thinking hard about whether and where to invest in their talent pipeline. The success figures show that an apprenticeship with the AMRC Training Centre is a safe investment in the region for strengthening the skills and talent base of their business with tangible benefits to the bottom line," Anne added.

"We are delighted with these figures and the recent award of the Ofsted Good ranking, which are great achievements for such a young organisation," said Anne. "But we are not complacent. We have rapidly switched to online recruitment methods to make it easier for employers and apprentices to access our wide range of courses."

"Although we had record numbers of employers wanting to sign up in March, the pandemic has led many to put things on hold. Nevertheless, many engineering and manufacturing firms in our region are still working and we have switched to virtual and online learning to support the growth and development of their apprentices. Like them, the AMRC Training Centre is open for business, providing the region's manufacturers with access to world-leading facilities and the best apprentice achievement rates in the region," said Anne.

The figures were released as evidence grows of manufacturers in the region continuing to invest in quality apprenticeships, despite the impact of the global pandemic on business confidence.

Anne added: "When the government decides we are able to return to our workplaces and go back to some form of normality, focus will turn to economic recovery. A skilled UK workforce will be a key ingredient for that and apprentices have an essential part to play."

New partners at the AMRC

dse CONSULTING

DSE Consulting is the sole distributor of AnyLogic and are providing software, training and support.

Upcoming events at the AMRC

15 September, 2020
AMRC Forum
Latest developments in high accuracy, micro manufacturing (Webinar)

22 October, 2020
Great Northern Conference
(Sponsoring and attending)

3-4 November, 2020
Tech Fellows 2020

Go to **amrc.co.uk/events** for the most up-to-date AMRC events information

CPD courses at the AMRC Training Centre

28 October, 2020
Metals Processing & Manufacturing Technologies
Warwick Manufacturing Group, Coventry

29 October, 2020
Carbon & Alloy Steel Metallurgy
National Composites Centre, Bristol

3 November, 2020
Carbon & Alloy Steel Metallurgy
Institute for Mechanical Engineers, London

4 November, 2020
Principles of Heat Treatment
Institute for Mechanical Engineers, London

5 November, 2020
Testing Techniques
Institute for Mechanical Engineers, London

17-18 November, 2020
Metallurgy for non-Metallurgists
National Composites Centre, Bristol

25 November, 2020
Metallurgical Failure Analysis & Prevention
Warwick Manufacturing Group, Coventry

26 November, 2020
Non-Ferrous Alloys
National Composites Centre, Bristol

3-4 December, 2020
Metals Processing & Manufacturing Technologies
Online course

9 December, 2020
Carbon & Alloy Steel Metallurgy
Warwick Manufacturing Group, Coventry

10-11 December, 2020
Quality & Quality Control
Online course

17-18 December, 2020
Testing Techniques
Online course

For more information visit **amrctraining.co.uk/employers**

Keep up to date with all the **latest news from the AMRC**

@TheAMRC **AMRC** **amrc.co.uk**

The University of Sheffield AMRC, Factory of the Future, Advanced Manufacturing Park, Wallis Way, Catcliffe, Rotherham, S60 5TZ

e: **enquiries@amrc.co.uk** t: **+44 (0)114 222 1747**