Institution: Coventry University
Unit of Assessment: UoA12 Engineering
1. Unit context and structure, research and impact strategy

1.1 Overview

Coventry University's Engineering submission is the result of massive institutional investment in research since REF2014, from which Engineering has been a major beneficiary. The investment has allowed an increase in the submission size of nearly four times, to 120.4 FTE. It has helped us develop into a focused and ambitious research unit that has delivered increased research income, publications, PhD numbers, and delivered significant impact through our collaborative and externally-facing approach.

We are returning 127 staff (headcount): 29 professors; 20 associate professors, 51 assistant professors, 25 lecturers (Grade 7), and two assistant lecturers. Our staffing is therefore well-balanced between early-career, mid-career, and experienced, world-class researchers. 94 staff in this submission have joined the Institution in the current REF period.

The Unit's research spans the Engineering disciplines, from materials engineering, fluid dynamics, cyber-physical systems, data verification and security, and bio-enhanced engineering, to transport design and control systems, energy storage, vehicle electrification, construction, and applications of artificial intelligence. The breadth of our research themes has increased significantly since REF2014. A strength of the Unit is its foundation on Coventry's expertise in research at the nexus between fundamental engineering and applied research. Our Engineering research is carried out collaboratively and at scale through a suite of new partnerships and Institutes such as the Centre for Advanced Manufacturing and Engineering (AME), the Centre for Connected and Autonomous Automotive Research (CCAAR), and the Centre for Applied Low-Carbon Propulsion Systems (C-ALPS) – as well as through the numerous embedded connections with partners from industry and other third-sector institutions which are initiated and maintained by individuals and groups within the Unit, including with TWI and TÜV-SÜD NEL.

The vision for Engineering research at Coventry is to:

- identify key scientific (local and global) challenges to which we can contribute and deliver economic, societal, and policy impact.
- make world-leading contributions in our areas of Engineering expertise.
- develop tools and methods that can solve critical engineering problems, in an inter- and trans-disciplinary way, with our stakeholders and beneficiaries.
- apply our innovations in real-world settings and translate high-quality science and knowledge to the users and beneficiaries of our research.
- ensure that our research focuses on improving the lives and experiences of people and is fully aligned with Coventry's mission of "Creating Better Futures".
- evaluate our impact and open new lines of enquiry for co-creation of future technologies with our stakeholders.

In driving our research, we foster a supportive culture and a firm commitment to continuously develop all our staff and research students so that all our engineers achieve their potential.

The Unit's research interests span the following cross-cutting and overlapping themes:

- **Theme 1: Computer Science and Statistical Methods for Engineering applications:** advanced artificial intelligence and data science methods applied to cyber-physical systems, Internet of Things (IoT), industrial systems, autonomous vehicles, and non-intrusive health monitoring.
- **Theme 2: Future Mobility:** Future mobility concepts; design practice; human factors; design ergonomics; connected and automated mobility; systems security and 5G; transport safety; system modelling and simulation.
- **Theme 3: E-Mobility:** Energy storage; electronics; motors and drives; systems integration; hydrogen.
- **Theme 4: Manufacturing and Materials:** Digital and industry 4.0, metrology; advanced manufacturing processes; intelligent and adaptive systems; people-centred productivity; sustainable manufacturing; manufacturing business models; functional materials; structural integrity; mechanical properties; modelling and predictive methods.
- **Theme 5: Fluid Mechanics and Flow Measurement:** Optimisation of thermo-fluid processes; multiscale modelling of reactive and multiphase fluids and systems; modelling of respiratory air flows; modelling of carbon capture and storage processes; diagnosis and control of industrial flows; multiphase flow in oil and gas systems.
- **Theme 6: Low-carbon Building Materials and Advanced Technologies for Energy Supply and Use Reduction:** Use of natural materials in construction; technologies for carbon capture; materials and technologies for on-building energy generation; modelling of energy use for optimisation and minimisation of carbon footprint.

The Unit's submission draws from seven of the University's Research Centres – all newly established since the last REF submission. Four of the research centres are led directly from within this Unit and are central to the submission, and there are strong inter-disciplinary links with the other centres. The research capacity of the Centres that are at the core of this submission, at census date (inclusive of Post-Doctoral Research Assistants and research students), was as follows:

- The Institute for Future Transport and Cities (IFTC) (Themes 2, 3, 4, 6); 131 strong, with 26 professors and 105 early and mid-career researchers. This is the University's largest research centre. The Centre aims to tackle the fundamental issues that challenge the development of new technologies for transport, energy, manufacturing, and their supply chains. It delivers the Engineering science needed for the transition to hydrogen-powered vehicles, using novel battery technologies, developing new structural and manufacturing concepts for automotive and aerospace systems, and operating in a connected environment that is secure from cyber-attack.

- The Centre for Data Science (CDS) (Theme 1); 20 strong, with five professors and 15 early and mid-career researchers (two staff from this Centre are returned in UoA3 Allied Health and one staff member to UoA10 Mathematical Sciences). Research in CDS drives step changing solutions for real-life, complex problems in industry, society, and nature. With impending threats from climate, pandemics, or civilisation collapse on the global scale, prediction is in the spotlight as never before. Analyse, simulate, and predict: these scientific strands are at the core of the mission carried out by CDS by harnessing data and computational sciences to create cutting-edge mathematical,

computational, and statistical models. The methods developed by the centre's researchers find applications in very diverse areas such as flow characterisation, prediction and measurement, equipment condition monitoring, health data analysis, disease and climate modelling, industrial and socio-technical cyber-physical systems, phase transitions and critical phenomena, and digital humanities.

- The Fluids and Complex Systems Research Centre (Theme 5): 31 strong, with five professors and 26 early and mid-career researchers (16 staff returned in UoA10 and 10 staff in UoA12). With core themes of flow measurement and the Engineering applications of fluid mechanics, the Centre gathers physicists, experimental fluid dynamicists, and numerical modellers who combine expertise to identify, understand, and optimise fundamental problems in industrial and natural processes.

- The Built and Natural Environment Research Centre (Theme 6): 17 strong, with five professors and 12 early and mid-career researchers. Initially established as the Centre for Low-Carbon Buildings, the Centre hosts research that covers building materials and structures, sustainable buildings, and systems aimed at addressing drivers of sustainability and climate change.

Research vision and leadership is provided by Centre Directors. Theme leads within the Centres are responsible for strategy development and provide thought leadership to their research teams, working with centralised support services and communities of practice in operations delivery and management, project support, impact, and training and development. Each of our research themes has developed its own working strategy, aligning with the University Research Strategy. This allows us to emphasise theme-specific skills and capabilities, plans for resource development, and shape routes to achieve common KPIs, with regular overall progress review by research centres' management.

1.2 Major achievements

With a strategic investment in 51 new core research staff and 43 research associates in our centres, a significant growth in the Unit's post-graduate community (from 46 completions over the entire period of REF 2014 (General Engineering), to an active cohort of 181 at census date for this REF), and a research income of over £37M, the Unit is delivering a large and diverse submission.

As a consequence of Coventry's research and impact strategy, the Unit reports a step change in our research intensity, volume, and thematic diversity, as well as significant developments in our research infrastructure, research governance, staff support, and alignment of our research with societal and Engineering challenges, globally and locally.

We present a vibrant, young Unit with state-of-the-art research infrastructure. The Unit has benefited from over £70M infrastructure investment – all devised and delivered to the research base in the past 6 years. The strategic infrastructure is designed to enable us to scale-up even further from the current outstanding Engineering research activity by 2030: growing from the present delivery base, to further the reach, volume, and impact of our research.

The Unit has a profile for innovation in the Engineering disciplines as well as at the interface between Engineering and Computer Sciences, and more broadly intra- and trans-disciplinary

research. An example is our participation in the EU NOMAD project for non-destructive evaluation of damage in nuclear power-plant materials, where artificial intelligence techniques are being applied to inform a materials integrity problem. Another example is the technical leadership we provide in the EU DOMUS project, which aims to radically change the way in which vehicle passenger compartments and their respective comfort control systems are designed, so as to optimise energy use and efficiency while keeping user comfort and safety needs central. To achieve this, the Unit's Machine Learning (and Reinforcement Learning in particular) innovations are core to cabin simulation strategies, thermal modelling, and HVAC control.

In the scoping of their research, our staff promote the conversation between basic Engineering and its applications to real-life, complex problems, with the support of our research delivery partners: industry, charities, governmental and non-governmental organisations, society and the public at large. Our research is thus impactful and robustly anchored in well-specified problems of relevance to the UK's economy and our society. We evidence this through the range of Impact Case Studies we submit, many of which have arisen from research undertaken solely within the current REF period, indicating the close relationship between our research and its application domains.

Over the REF period, we encouraged and supported our researchers to grow new collaborations internally and externally, with colleagues from neighbouring disciplines, and those with deep understanding of the problem domains we are exploring. We sponsor staff, and early-career researchers (ECRs) in particular, through travel grants, and recognise within our research culture the value of real-life research, as well as the difficulties of cross-domain and cross-sectorial work.

We enabled researchers to spend time based in the facilities and research teams of our industrial partners and academic collaborators through both providing them with time and via co-location. Indeed, as described later, we initiated new research centres with new buildings and infrastructure where our researchers work alongside their industry counterparts (see Sections 3 and 4), and where we have been focussed on placing our researchers in the best location to deliver our research: for example, on the sites of partners such as Unipart Manufacturing, HORIBA MIRA, NEL, and TWI. We believe this leads to relevant and impactful discoveries that will be adopted in the practice context. Our strategic partnerships presented in Section 4 support us to deliver research excellence with impact in materials science, advanced manufacturing, fluid mechanics, design and future transport, and powertrain technologies for low-carbon vehicles (evidenced in many of our Impact Case Studies). Furthermore, our collaboration portfolio extends to organisations that help us bring society, local economy, and global challenges into our research focus; we work with governmental and international bodies, NGOs, and standards organisations to root our research in well-specified problems.

The Unit's growth has been the outcome of strategic, sustained investment, backed by a robust recruitment strategy (elaborated on in Section 2) that focused on securing thought leaders for the strategic research themes on the one hand and recruitment of ECRs on the other. To this effect, we recruited 76 ECRs/MCRs (mid-career researchers) and 18 professors into the Unit in the REF period, to bring critical mass to our key research themes. We invested in the development of our staff, raising capability for the ECRs and promoting them appropriately, and supporting MCRs on their journey to professorship.

The step changes undertaken in all aspects of the Unit over the REF period, alongside the sustained commitment to developing our research infrastructure and our strategic long-term

collaborations, means that we are yet to see the full impact of our strategy, but we proudly describe here a unique story of investment, growth, and success that has been driven by firm Institutional commitment and the creation of a high-performing research culture built on quality, collaboration, and impact.

1.3 Research Position relative to REF2014

For the Engineering research areas, Coventry's Research Strategy has enabled the Unit to be much more ambitious than the plans detailed in REF2014, providing us with investment, in staff and infrastructure, to increase the scale and reach of the University's aspirations while building on the University's existing expertise in transportation, manufacturing, fluid mechanics, and data science.

In REF2014, the University submitted 18.7 FTE to General Engineering and 13 FTE to Computer Science. This has increased by nearly four times, to 120.4 FTE (127 staff), in this single UoA12 REF2021 submission. All of the researchers returned in the present submission are members of one of the Research Centres listed previously, and have significant responsibility for research. This growth in the research staff base has led to growth across all research KPIs. Our research delivery has been building throughout the seven-year period of the REF and continues to grow as our 2014 Research "Excellence with Impact" strategy fully bears fruit. The Unit's commitment has been to: consolidate and develop a world-leading research profile in some of the pre-2014 areas and many new ones; develop researchers at all stages of their career, especially ECRs; champion partnerships with experts across disciplinary boundaries and in collaboration with institutions and organisations worldwide; generate significant grant income; and produce a diverse range of outputs.

Some of our achievements are listed below and supporting detail follows in Sections 2-4.

1. There has been a rise in the quality of our research as evidenced by the number of papers in the top 25% of journals by SNIP (subject-normalised impact per paper) from 34.9% to 64.3% from 2009 to 2019 (source: SciVal).
2. The Unit delivered across a portfolio of 370 grants (value to Coventry of £54.8M) during the REF period, of which 290 (value to Coventry of £41.2M) were awarded in the REF period.
3. The Unit has been directly funded by 49 industrial funders over the period, including Jaguar Land Rover, Airbus Group, FEV, HORIBA MIRA, to a total of £5.5M.
4. We engage with a diverse and prestigious range of funders including intergovernmental and charitable bodies such as NATO, the US Air Force European Office of Research and Development, Lloyds' Register Foundation, the Royal Society, British Council, and the Royal Academy of Engineering.
5. Our £70M investment has enabled the Unit's researchers and Post Graduate Researchers (PGRs) to deliver our varied research portfolio sponsored by national and international funders.
6. Our impact has been realised with national and international companies and organisations including General Electric, the US Air Force, BAE Systems, Jaguar Land Rover, and Rolls-Royce.

7. Our PhD programmes are varied, inclusive, and scientifically competitive; 57% of our current PGR population are overseas students and 52% of our awards in the period were made to international students; funding for our PGR programmes spans industry, research councils, and international governmental sources.
8. Our ECRs have had considerable success winning both First Grant and New Investigator Awards.
9. Our research portfolio is diverse and balanced across sponsors and nurtured by the strategic collaborations through our international regional hubs in Dubai and Singapore and Coventry-based institutes (National Transport Design Centre (NTDC), AME, CCAAR, Centre for Advanced Low-Carbon Propulsion Systems (C-ALPS)), as well as the University's impact-oriented Research Strategy.

Building on our achievements and significant investment in infrastructure, we expect the next period to return, at scale, research with excellence and impact, commensurate with the current and newly achieved Unit size.

Our Engineering research ambition and the capacity to deliver it is evidenced further by the strategic high-profile and large projects and funded national capability strands in our REF period portfolio. Some examples are as follows:

- The AME, with £7.9M of HEFCE Catalyst funding, to establish a unique University/industry partnership for research, teaching and knowledge exchange, for which we won a Queen's Award for Higher Education in 2019.
- A cohesive suite of projects that grow the UK capability in Connected and Automated Mobility research including: the £26M CCAV-funded project TIC-IT to create a unique in the UK facility to research verify and validate future connected and autonomous vehicles in a controlled environment; the £2M CCAV/Innovate UK funded PARK-IT project to research bespoke and realistic, controlled parking environments to test and support the development of current and future connected and automated parking solutions.
- MATUROLIFE – a £6M European H2020 project, with Coventry lead, taking a multi-disciplinary approach across Engineering, Design, and Health disciplines to develop assistive wearable technologies for the ageing population.
- H1PERBAT and H1PERCHAIN, funded by the Advanced Propulsion Centre, £14M (combined) projects, working with industry in support of the drive towards net-zero, to develop the technology and associated supply chains and to design and manufacture battery packs and modules for electric vehicle production.
- Sustainable Building Futures, supported by a £2.6M European Regional Development Fund grant, to establish an industry-focused Centre of research expertise in low-carbon building technologies.

Our partnerships are strong and well embedded into the research landscape, practice and infrastructure. From the Unit's 2,760 papers published in the period, 1,410 involve international collaborations and 263 were co-authored with corporate partners.

1.4 REF Period Impact Strategy

Coventry has responded to the emerging impact agenda with the strapline for our new Research Strategy being 'Excellence with Impact'. This sets out the University's commitment to fund

research that makes a 'real-world difference'. As an ambitious and innovative Unit, our research has indeed made a tangible difference to the world we live in. Coventry's Engineering researchers have become known for delivering research that makes a significant contribution to global challenges, promoting and achieving real change.

The desire to make a tangible difference is regarded as an integral part of the research process: the culture of impact creation and development has been fully embraced and embedded into the Unit and is supported by the University's Research Services team through a dedicated team of Research Impact Officers. As previously mentioned, a major feature of our impact strategy has been partnering with leading external organisations and groups, both in the UK and internationally, in a range of areas and sectors as evidence by our Impact Case Study portfolio. We support impact acceleration where appropriate, and build portfolios of research that strategically increase the technology readiness levels of our innovations with trusted partners. Co-location with impact partners has and will continue to be a significant avenue for delivering impact in Engineering.

Professor Mike **Blundell**, for example, has undertaken 20 years of research into the modelling of tyre behaviour to support computer-based design simulation, which involved collaborations with the automotive and aerospace sectors, including Jaguar Land Rover (JLR). The main impact is a reduction in overall tyre test duration and substantial efficiency savings now firmly embedded in the design and development process at JLR – one of our long-standing partners in the co-production of research questions. Dr Svetlana **Aleksandrova** has successfully worked with industrial partners, such as Unipart and JLR, building effective collaborative relationships which have resulted in society and industry-relevant research that can be translated for uptake within the automotive industry. Her work on efficient exhaust system design has become key in the development of the new generations of transport as it directly affects emissions of greenhouse and toxic gases and particulates.

Global manufacturers and distributors of surface and interfacial science measurement equipment have used Dr David **Waugh** and Professor Jonathan **Lawrence**'s findings on the importance of droplet volume on analysing wettability and adhesion properties of liquids on porous media to increase their commercial offerings to clients in the ink-jet printing industry. Our Unit's science is thus responsible for new products that have been developed as a direct result of the implementation of the research findings.

Our research is recognised to build joint infrastructures with our strategic partners: Airbus is progressing the application of laser peen technology through to implementation in manufacturing, maintenance and repair as a result of our Unit's work by Professor Michael **Fitzpatrick**.

The innovative analytical approach on the Team and Collective Training Needs Analysis (TCTNA), championed by Dr John **Huddlestone**, has resulted in new relationships with the armed services in the UK that has been commended at the highest levels in the Royal Navy and Royal Air Force for its utility in shaping collective training specifications. With researchers in our Unit being recognised amongst the UK's and world's leaders for human factors research, Professor Don **Harris**'s investigations to develop single-pilot flight deck concepts have been hailed as a key technology for UK strategic funding by the Aerospace Technology Institute (ATI), the Department for Business, Energy and Industrial Strategy (BEIS), and InnovateUK. His work influences national research policy, covering new ground in the development of design concepts and flight deck technologies

and has involved end-users with whom we have developed and grown our working relationship over the last REF cycle.

Through our strategic collaboration with HORIBA MIRA we have created environments to simulate, test and evaluate the security and safety of connected and autonomous mobility. This strategic approach has resulted in the creation of a doctoral centre with research questions developed with HORIBA MIRA that address the critical Engineering challenges and meet future business needs. The Centre provides a pipeline of talent to support growth in the connected and autonomous mobility sector. We have developed a world-class physical infrastructure for research test and validation, and a pipeline of collaborative R&D.

Across the Unit, we continue to produce impact in the UK and globally as evidenced by all our Impact Case Study narratives. More generally, we utilise a variety of conventional and innovative pathways to impact, including responses to legislative pressure and building on our existing partnerships, through to the identification of new stakeholders and seeding challenge-led research questions with end-users. These approaches stand us in good stead in anticipation of the next REF cycle and over the coming years.

Further to impactful research, the Unit made a commitment to interdisciplinarity over the period. This is partly evidenced by the large number of grants we hold that cross discipline boundaries. For example: the EU REWAISE: REsilient WAter Innovation for Smart Economy project brings together expertise across the water and manufacturing science and technology domains; the EPSRC EnergyREV crosses discipline boundaries with economics, environment science, computer science, Engineering and political sciences; Professor Andrew **Cobley**'s MATUROLIFE project has been co-designed and is co-led by Professor Louise **Moody** (Health Design and Human Factors), and so on.

Many more examples exist in the Unit's portfolio, and we estimate at least half of the projects we deliver on are inter- or trans-disciplinary. Furthermore, appointments were made to our Engineering research base, from other disciplines (e.g., Ergonomics – Professor Paul **Heriotts** working with the Engineering team in the National Transport Design Centre at Coventry). The inter-disciplinary culture that we support and reward enables us to react better to global challenges, frame meaningfully wider and deeper research questions, and eventually draw solutions that encapsulate and consider the eco-systems around our technological innovations. The approach accelerates and diversifies impact and creates positive feedback loops for our researchers.

1.5 Future plans and strategic aims

Over the next REF period Coventry University will continue to deliver its research through challenge-based centres. Our research centres have been recently clustered into a number of challenge-based Institutes targeted at addressing some of the grand challenges. Whilst engineering research will be based predominantly in the Institute for Clean Growth and Future Mobility, and the Institute for Mathematical, Physical and Computational Sciences, we will make a significant contribution to the other institutes (Health & Wellbeing; Sustainability, Equity & Resilience; Peace Security & Social Justice; and Creative Cultures). We will work to design, test and validate technological solutions that will be readily deployed and adopted by the public. Towards this aim we will create multi-disciplinary teams that bring together physical scientists that

can use simulation tools to select potential solutions in the virtual world; engineers with the necessary physical assets to build, prototype, and evaluate these technologies in the physical world; and social scientists to ensure that the technologies will be adopted in a sustainable and economically viable manner. To accelerate this process and ensure impact, we are creating a number of innovation districts: those relevant to engineering include Clean Growth, Cultural and Creative, Health and Wellbeing, and Mobility. Anchored by the University, these areas will bring together companies to connect with start-ups, business incubators, and accelerators. Based in and around Coventry they will exploit the physical assets of the University and the proximity to housing, retail, and office spaces to promote an urban innovation ecosystem.

For example, the Institute for Clean Growth and Future Mobility will tackle the challenges facing mass adoption of autonomous transport and electric vehicles by bringing together the physical assets we have at CCAR, CALPS and AME – along with our partner companies – to create the Mobility Innovation District in Coventry. This will focus on establishing the innovation supply chain required to see the mass deployment of electric mobility and autonomous vehicles. In Health and Wellbeing we will work with medical practitioners and biological scientists to develop technologies that will keep people out of hospital for as long as possible and in hospital for as short as possible. Part of this will be a planned joint venture between the local council, hospital, and University to create a city-centre diagnostic centre. This will include a research laboratory where, among other things, data science and artificial intelligence will be deployed to accelerate the diagnostic process. In the Institute for Sustainability, Equity, and Resilience, based at Ryton Gardens, just outside the City, our engineers will work with human and physical geographers to solve issues around the sustainable supply of food, water, and accommodation to people in both the developed and developing world. In Peace, Security, and Social Justice, our cyber-physical engineers will work with data scientists and social scientists to create safe and secure urban environments. In the creative space, we will work with the art and design community around the digitisation of the creative processes. This will include motion capture in dance research, the application of digital tools to accelerate the design process, digital curation, and the use of augmented reality in articulating our history.

From a discipline perspective many of these challenges will see a need to increase our expertise in the digital space (data science, artificial intelligence, simulation, cyber security, digital twins and sensors) and our Research Institute for Mathematical, Physical, and Computational Sciences will grow accordingly. Our Materials Engineering activity will be focussed towards the energy sector from battery chemistry through to structural integrity. In Manufacturing we will focus on sustainability and productivity. Finally, growing the number of researchers working at the interface between electrical and mechanical engineering will be critical to solve the challenges of e-mobility.

1.6 Open Research

Building on our commitment to research that is open and accessible and that maximises reach and impact, our staff use a variety of dissemination avenues and formats. Our software, data sets, bespoke research tools, hardware designs, and research products are developed under open licences and disseminated appropriately and in line with funder and partner requirements. IP knowledge pervades in the Unit, and IP training is part of the Unit's package of support for ECRs and PGRs. This knowledge informs our methods and our approach to Open Access, and has been key for developing confidence for researchers to publish under open licences.

An increasing number of projects within the Unit are depositing their data sets on common repositories such as Zenodo, figshare, Github, Kaggle and arXiv. Staff deposit software extensively (Github and Zenodo) with full downloads available for pre-products and practitioner tools (such as Professor James **Brusey**'s *Cogent House*: a system for energy and environmental monitoring in homes; and Dr Jonathan **Nixon**'s *Renewable Energy Recommendation Tool*: a software application that supports decision making for humanitarian energy investments). Over the next six months we will move our open data and open software to the University's data management repository.

Our researchers use a variety of modes of dissemination and make use of open channels for sharing non-standard research (including practice-relevant research) through blogs, white papers, and policy briefs. Some of the Unit's projects have practitioners and policy-makers at the core of their impact stakeholders group, and thus briefing papers, white papers, and working papers are very common. Examples here are the EPSRC EnergyREV, the Innovate UK Pilot Auto Runway Taxi System (PARTS)**,** the EPSRC HEED, and many more.

Wherever possible, we publish as Open Access, including workshop proceedings and any other resources emerging from funded projects: for example, in the EU H2020 SC-Square Project (Dr Matthew **England**), proceedings of three workshops were published Open Access using the CEUR-WS Workshop series.

We believe engaging with the public, and especially outreach, sits firmly at the core of our research dissemination approaches: the EPSRC HEED project (**Nixon** and Professor Elena **Gaura**), for example, worked with Futurum to produce educational resources for 15-to-17-year-olds that were disseminated to over 600 schools.

Our commitment to a culture of **Research Integrity** is demonstrated by a robust process of supporting researchers to conduct ethical research. Ethics Leads in all centres are members of the Faculty Ethics Committee, which reports to the University Research Committee. They provide regular clinics to support staff and PGRs in planning, delivering, and monitoring research to ensure adherence to relevant ethical, legal, and professional standards. Ethics is not only core to how the Unit's research is carried out with integrity, but is also the specific focus of research enquiries and funded research, promoting a principle of 'ethics in practice'. Research that is carried out with those who may be vulnerable through experiencing marginalisation, impairment, ill-health, or precarity from other disabling conditions, employs methods that foster researching with the participants, through co-design and participatory research (for example, research by **Brusey, Gaura, Nixon, Harris**). We believe in and adhere to the EPSRC Principles of Responsible Innovation (AREA), and support our researchers at all levels in embedding impact into their research at onset – through training, impact champions, and open forum discussions with research stakeholders.

2. People

2.1 Staffing Strategy

To support the growth of the Engineering research mission, there was a large increase in the staffing base of the Faculty and the Unit's research Centres and Institutes, alongside a transition

from fixed-term staff employed only to support teaching, to staff fully engaged in both teaching and research. Highlights of this included recruitment of over 70 new lecturers in 2015 alone.

The approach to the increase in the research-active staff in our new research centres has been threefold:

- Appointment of new, senior staff to act as group leaders, to develop strategy, and provide mentorship for career-young researchers.
- Appointment of career-young researchers, supported by programmes of development in all of the VITAE areas.
- Supporting the transition to significant, independent, responsibility for research for our ECRs and developing research skills across the Faculty academic base.

The strategy has led to significant critical mass (as evidenced by the size of our submission), excellence in research, and positively asserted scientific leadership in all of the key Engineering areas that we wish to further support, strategically for the Unit, into the next REF period.

We intended and achieved a balanced staffing portfolio for the Unit overall, with 27 ECRs, 71 MCRs, and 29 professorial staff. Alongside the many external appointments, six staff were promoted internally to professorial positions during the REF period (**Brusey, Cobley,** Professor Eshmaiel **Ganjian,** Professor Shuli **Liu,** Professor Vasile **Palade,** Professor Siraj **Shaikh**).

Each of the key Unit themes have now strong leadership from their professoriate and a raft of ECRs that are thriving in the groups. Our research infrastructure and environment meant that we have been able to recruit excellent ECRs and leaders of research, with visionary ideas and potential. For the ECRs, our programmes of training mean that they progress rapidly to achieve research independence and establish leadership in their research specialism. This is evidenced through 14 ECR promotions where research was a major criterion.

2.2 Staff Development

The Unit's staff benefit from support and development through three complementary pathways:

- An Institutional layer of developmental programmes provided through our ReCAp (Research Capability and Development) function of the Doctoral College, which covers development for all career stages – from PhD to Professor.
- A Unit-specific layer of training and development activities that brings discipline focus and specificity to general programmes above (on base skills).
- A group-specific layer that ensures mentoring, one-to-one support for ECRs, and career progression support for all researchers, regardless of their stage in their journey to professorship.

Overall, the development programmes available to staff:

- cover all aspects of the VITAE framework.
- are fully grounded in the Engineering discipline practice and excellence benchmarks.
- provide routes and methods to embrace trans-disciplinary research.

- are tailored and delivered with staff's priorities for development in mind.
- are informed by outstanding research leaders and capability development leaders in the Institution and elsewhere.

Our support for early-career researchers' development has been based on two key principles:

- Train: comprehensively cover key research skills, funding success, impact, and leadership and management of high-performance research teams.
- Sponsor: ECRs competitively secure their first internal grants – with equipment, travel and networking grant categories – available every year with ECR-ring-fenced competitions; in addition to dedicated PhD studentships and other forms of internal grants (described below).

For example, new researchers are comprehensively supported in the process of producing their first major bid. Training is cohort-based, over a 3-month programme to allow for peer-to-peer learning and supporting the emergence of peer networks. Alongside specific theme sessions focused on Track Record and Impact Pathways, the programme includes mock-RCUK funding allocation panels using previously submitted bids, champions and mentors talks, extensive feedback on writing, support to identify partners for the intended bids, and 1:1 buddying for first submissions. This has been a successful approach: 66% of the First Grant bids from our Unit's ECRs were successful over the period 2016-2017 (when the intensive training programme was first delivered), which is significantly above the national average. Other grants-oriented support comes in the form of sponsor-specific bid writing day events for UKRI, EU, Leverhulme and other QR funders, interactive workshops with funders, and grant surgeries.

The substantial range of programmes for ECRs include those aimed at developing strong lead supervisors for PhD programmes, and rapidly increasing supervisory capacity. Programmes specifically designed for ECRs are:

- Designing PhD Programmes: bite-size/day-long workshops covering topics from research ideas formulation to enrolment of students.
- Becoming a PhD Supervisor: year-long programme with follow-up in year 2 and refresher training. This program runs annually in the Unit, to help support ECR transition from "supervisee" to "supervisor" and further, transition from supervisory team member to Director of Studies (DoS). It features a diverse set of activities over the year, from Institutionally mandated modules, to shadowing experienced DoSs, to seminars with external speakers and experienced supervisors on supervision best practice, PhD programme research design, support seminars for identifying funding and collaborators, student recruitment support activities, support with supervision tools development, and so on.
- A suite of bite-size events on PhD supervision best practice in Engineering, complementing the provision from the University's Doctoral College.

As shown previously for ECR grant awards, we complement the above ECR training with sponsorship through ring-fenced schemes that:

- provide funded trans-disciplinary PhD research studentships across themed global challenges – for example focused on the GCRF and COVID recently.
- further support for the ECRs' journey to become Directors of Studies through the Trailblazer scheme.

Training and support extends to experienced supervisors, with training update requirements mandated and dependent on the number of students completed, recent supervisions, context for supervision (UK and abroad, Coventry and elsewhere). We recognise that supervisory practice is continuously evolving and best practice sharing is an important element in all areas of PGR education – from sources of funding identification, to new methods for research, training trans-disciplinary students, and embedding impact into co-funded programmes with industry.

Across the Institution, staff at all levels, upon training, have access to internally half-funded studentships. These are of value to our ECRs in securing their first funding from an industrial collaborator. On top of the significant investment in PhD programmes, the University has further committed to sustainability by funding 44 50-50 Coventry-plus-industry funded studentships that will recruit in 2021 and 2022. For the Centre for Data Science, for example, these include two 50-50 studentships to support collaboration with the Agency for Science, Technology and Research (A*STAR) in Singapore, and two 50-50 studentships to support ongoing research with industrial collaborators on the EU DOMUS project in thermal comfort in vehicles (such studentships help support the Centre's continued interest in automotive AI, and connections with the automotive industry).

Throughout the academic year, a large variety of shorter programmes and individual activities covering general research skills are also available to ECRs, MCRs, and all research staff and PGRs. These include:

- publishing strategies and developing 4* research, facilitated by external members of previous REF panels.
- impact training and best practice on building impact into research from the proposal stage through to delivery.
- "Shut up and write" weekly sessions, creating co-writing environments for staff and PGRs.
- Best Journal Paper annual competitions and training for journal reviewers.
- monthly Research Strategy surgeries for staff at all levels.
- a Summer Research Internship programme, with students from across the globe, including China, India, South Africa and France (250 awards were made to PIs to research with undergraduate and master students, for eight weeks each).
- an International visiting scholar scheme to send/host researchers to/from overseas for up to one term, running throughput the REF period.

The Unit's research environment, staff expertise, and the vibrant research culture is also shared with our Undergraduate and Post Graduate Taught student population through the Summer Research Internship Scheme. The scheme has funded over 200 students (2014-2019) to undertake 8 weeks of paid research over the summer on specific projects led by the Unit's staff. Students acquire a taste for research and develop transferable skills, while supervisors have the opportunity to conduct feasibility studies, investigate adventurous tester research questions, or set up new experiments.

2.3 Support mechanisms, training and supervision of PGRs

2.3.1 Recruitment and funding for PhD students

186 PhD awards were made over the period. Of these, 52% were overseas students. Many students had an external supervisor and/or an industrial partner with their programme (contributing either staff time and facilities in-kind, or with cash contributions towards the fees and stipends for the programmes). The census date PhD student population for the Unit is 181 students, with 57% being overseas students and the rest UK/EU. The Unit has been awarded, and is finalising recruitment processes for, 13 GCRF studentships (that support trans-disciplinary teams of ECRs to supervise students/project within the GCRF remit), and 13 Trailblazers studentships that support ECRs to learn to supervise in joint mentor-ECR supervisory teams.

Over the period, the Unit had a mixed model for funding PhD students, with almost all of our students receiving funding from one or more of: our Institution; UK sponsors; international agencies; and national and international programmes. Over the REF period the University has invested £9.6M of internal funds (including QR) into supporting PGRs, including schemes to fully fund (fees and bursaries) or part-fund, including the provision of fee waivers. Our approach has enabled us to bring in external funding for PhDs of over £2M to the Unit over the period, with PhDs partnered with a wide range of organisations. In particular:

- Industrially funded PhD programmes: this avenue for funded research by industry has been historically a strength in Engineering at Coventry. In this REF period, we diversified the set of industrial sponsors and considerably increased the number of funded PhDs: 18 industrial partners funded 47 students, leading to significant and impactful research (evidenced, for example, in the Impact Case Study 'Efficient Processes to support Tyre Modelling in Vehicle Design', **Blundell**). Industrial sponsors include: Airbus Group, HORIBA MIRA, FEV UK Ltd, Rio Tinto Alcan, IDIADA, TÜV-SÜD NEL, and TWI through the National Structural Integrity Research Centre.
- 10 UKRI and EU funded studentships, including participation in EU COFUND, Marie Curie and ITEM programmes.
- International agencies with a considerable number of students sponsored: Niger Delta Development Commission, Royal Embassy of Saudi Arabia, Petroleum Technology Development Fund (and others with fewer students); these build on strong international links with governments and their agencies, at times from Master's programmes base (notably most of our PGRs in the Construction and Environment thematic area progress from MSc courses and maintain their funding).

Staff in the Unit are also leading joint PhD programmes with international partners in cotutelle models, including a wide range of global institutions, including Deakin University and Macquarie University, Australia; University of Warwick; A*STAR (Agency for Science, Technology and Research), Singapore; University of Cergy-Pontoise, France; University of Shanghai for Science and Technology, China; University of Massachusetts, USA; Universitas Indonesia; Paris Saclay University, University of Lille and University of Grenoble, France; and National University for Science and Technology, Pakistan.

2.3.2 PGR support

The Institutional support for PGRs is outstanding and covers comprehensively the student life-cycle. The Unit's PGR population benefited from the numerous development opportunities deployed through our Doctoral College, as documented in the Institutional statement, alongside a sustained set of support actions and activities deployed specifically in the Unit's respective centres and catering for Engineering research students' needs.

Pastoral support is delivered by dedicated Research Degree Leads (RDL) in the Unit's thematic groups and Centres, with each RDL looking after 20-30 PGRs. The RDLs are concerned with both the students' academic progress as well as their well-being, integration into the cohorts, and access to the facilities they require to conduct their research.

Locally, students self-organise and run seminar series, with internal and external speakers, open to all of the Unit's staff and students. Our longest-running seminar series is in the fluids area (where students from both UoA10 and UoA12 have successfully held a bi-weekly seminar series continuously since 2016). In other groups, the students run reading clubs to proof each other's thesis chapters and papers prior to submission. "Shut up and write" events, organised by PGRs, are common across the Unit and supported and encouraged by staff and RDLs.

Across the Unit, we have consistently deployed a number of impactful activities:

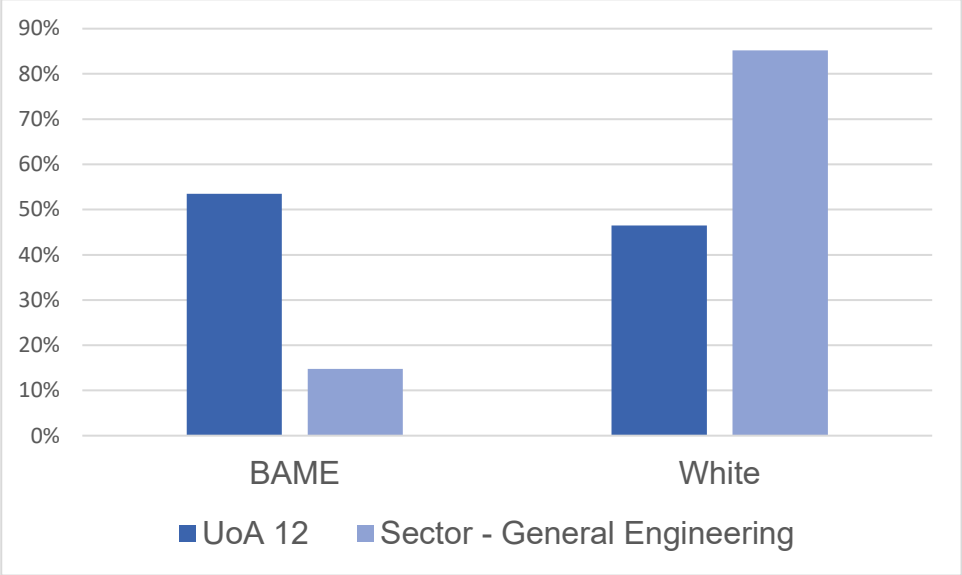
- Thesis bootcamp: this is an annual four-day event run by the programme's creator – Dr Peta Freeman (https://www.petafreestone.com/thesis-boot-camp/). This award-winning intensive writing programme for late-stage doctoral researchers is offered to 25 of the Unit's PGRs.
- Free proofreading of papers and theses for all students in the Unit, hassle-free and accessible at all stages of the programme.
- A PGR career progression events series focusing on career futures, choices, preparation for academic and industrial careers, gaps identification for skills development, etc.
- An annual PGR symposium with posters and verbal presentations depending on the student's programme stage, with feedback provided by industry and academic topical scientists.
- Access to hourly-paid teaching opportunities in all subject areas that are part of Unit's remit.
- We have made a concerted effort and have taken positive action to treat our PGRs in all regards as our Unit staff – whether it comes to access to facilities and labs, support for conferences, annual budget for consumables for each PGR, and open participation in all researcher and capability developments organised for the Unit's staff. This has led to many close-knit teams of PGRs and supervisors working together with industrial collaborators and easing the transition of PGRs post award to either industrial or academic posts. For example, 25% have gone on to secure research assistant/fellow posts, 41% have secured assistant professor/lecturer posts and 18% have roles in industry.

2.4 Equality, Diversity and Inclusion

Issues relating to equality, diversity, and inclusion (EDI) are at the core of many of the decisions about recruitment of staff and students across Engineering, and EDI is embedded throughout role allocation and promotion across all the centres which make up this submission. With some of the

largest centres within Coventry University, we take seriously the effect our staff and student population demographics has across the Institution.

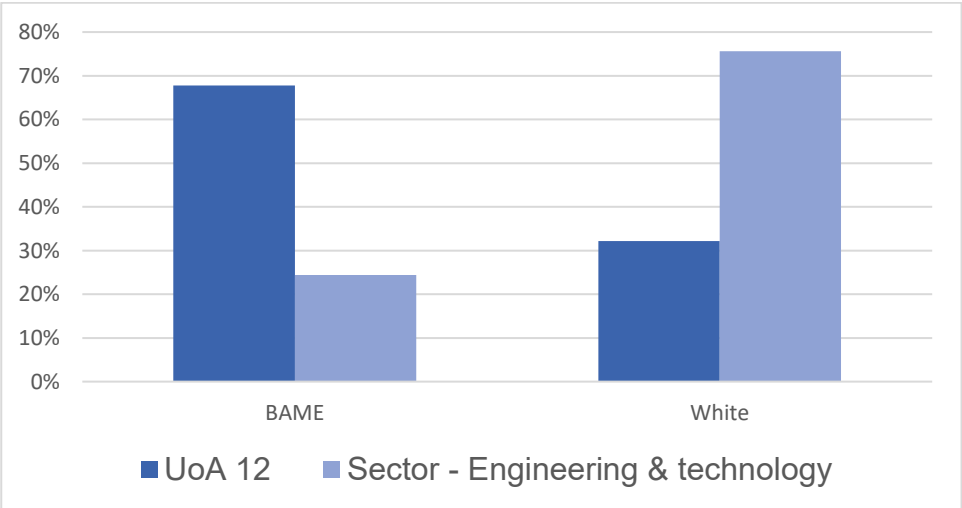
Figure 1: Diversity and inclusion: Ethnicity (staff)



Source: Coventry University UoA12 data, Coventry University People Team, 31st July 2020, Advance HE, 2018/19

The BAME researcher community in Engineering is 54%; significantly above the sector average of 15%. This more-than-threefold proportion reflects the global reach of the research community and is as a result of recruitment which looks to source the best talent regardless of where this is. The PGR demographics follow on from this, providing the Unit with an equally diverse and vibrant research community.

Figure 2: Diversity and inclusion: Ethnicity (research students)



Source: Coventry University UoA12 data, Coventry University People Team, 31st July 2020, Advance HE, 2018/19

Our BAME population of PhDs is 68%, again, considerably higher than the sector average for Engineering of just 24%. The diverse community and rich environment this creates is nurtured and

maintained through robust policies and procedures to ensure we maintain this favourable position amongst our peers.

The leadership team within the centres in the Unit is representative of the diverse demographics. We recognise that our Unit still has much to do, to raise awareness of EDI issues and maintain fair treatment. We intend to continue to work hard to raise our standards further in this area. EDI is a standing item on the current Faculty Research Committee and a new senior-level research leadership team is looking at EDI across all aspects of research in the Institution.

Across the sector, we all have a long way to go regarding female representation in Engineering and particularly in leadership roles. For our Unit, role allocation and leadership development decisions within the Centres are regularly reviewed, with working groups tasked with working alongside People Team representatives when devising processes for recruitment as well as promotion and recognition.

We encourage women to hold leadership roles – and aim to maintain a higher female:male ratio in these posts than is representative across the Unit's staff cohort. For example, the REF submission for Panel B is led by our Associate Dean for Research, **Gaura**; and Professor Xiang **Zhang** leads the Materials group. Further, in our new research structure, **Gaura** holds a leadership role within the Strategic Research Leadership Team, as the Director of the Institute for Mathematical, Physical, and Computational Sciences, and remains a strong advocate for women in science and in particular as an EPSRC Women in Engineering Champion.

More generally, we actively encourage our female staff to take advantage of the support provided by the University. A good example of this is the Advance HE Aurora programme – a sector-wide leadership development initiative for women which we support staff to attend – including providing the time and fees. It is designed to help address the under-representation of women in leadership positions in the sector and we feel is very important for Engineering in particular. The motivational outcomes we have observed have had a very positive effect on the Unit – with attendees making use of their training and networks to help embed improved practice in supporting women to achieve leadership roles in our centres. This commitment applies at all levels. **Gaura** has completed the Executive Development Programme at Oxford University's Saïd Business School's – *Women Transforming Leadership Programme* – with the aim to focus on articulating challenges and exploring solutions specifically for women in leadership roles. Bringing such learning back to Coventry is seen as key – not least as an example of the University's commitment to support female researchers in leadership roles.

Coventry has established the Women in Research Network – a cross-institutional group which was set up by the Engineering Unit. The aim of the group is to build a more inclusive and equal research environment by offering an informal space to share experiences and ideas. This group has grown in strength and even through the pandemic has maintained meetings – with our most recent network meeting having a presentation from Professor Cath Noakes who is a member of SAGE.

3. Income, infrastructure and facilities

The overall investment into research equipment and facilities for this UoA since 2014 has been in excess of £40M. All the Centres have benefited from the investment. We have invested in specialist equipment in support of specific areas of strategy, plus more general investment to ensure that we have "well-found" laboratories that underpin our entire research base. A significant portion of the investment has been directed in support of our major translational centres, where we work closely with industry to drive the impact of our research.

Key investments have been:

1. The **Institute for Advanced Manufacturing and Engineering** (AME), with a new building and equipment in 2014, and current (2020/21) expansion of the facility (total investment >£8M of which a quarter is dedicated to research). This flagship initiative launched the Centre for Manufacturing and Materials in 2014, providing the new research teams with state-of-the-art facilities to underpin research in manufacturing technologies ranging from advanced welding to materials characterisation, with investment in industry-leading 3D printing, advanced robotics, control systems, world-class metrology and metallurgy labs, and state-of-the-art digital technologies. AME has received over £8M of funding and is currently also undergoing an expansion by 60%, investing in the latest advanced manufacturing equipment, including additional resource for lasers in manufacturing. The investment, among other things, has allowed the development of new component designs for the automotive industry (e.g., our Impact Case Study on the development of new exhaust systems that has delivered reduced weight, faster design and production times, and significant fuel and carbon savings); and supported our work on surface Engineering technologies (leading to two further Impact Case Studies in the current REF, one on lead-free bearings, and one on aerospace repair technologies).

2. The **Centre for Applied Low-Carbon Propulsion Systems** (C-ALPS) (total investment >£18M). The building housing this new Centre provides 40,000 sq ft of research and testing space, with over £6M of the latest electrified powertrain and thermodynamic engine test beds. C-ALPS boasts one of the world's few publicly accessible facilities for the prototyping of batteries, specifically pouch cells and cylindrical cells, to near commercial quality. The 21700 cylindrical format that is very topical and used by Tesla can be made in the C-ALPS facility. C-ALPS also has a battery cycling lab with the capability to test coin cells, multiple cell formats and modules; two electronics labs, one focused around sensors and low-voltage devices, and the other around high-voltage and power electronics. In the former we are designing and building advanced sensor arrays. The latter has a $3m^2$ EMC chamber.

3. The **National Transport Design Centre** (NTDC) (total investment >£7M of which almost two-thirds is dedicated to research), including a purpose-built, class-leading, fully functioning design studio that mirrors that found in industry and is a unique facility within academia. By using the latest Simulation and Virtual Reality innovations and combining it with traditional physical prototyping, the NTDC has pioneered a new 'mixed-reality' driving 'buck', which creates complete mixed-reality scenarios for designers and engineers, who enjoy a fully immersive experience to explore, assess, research, and develop new areas of

transport design. A state-of-the-art Driver-in-the-Loop driving simulator is being commissioned now to support future vehicle research into electrified and automated driving technology.

4. **Connected and Autonomous Vehicles**: The collaboration with HORIBA MIRA is a strategic co-investment (total value >£30M) into a shared facility located at HORIBA MIRA's site in Nuneaton. In addition to a vehicle workshop for preparation of research vehicles and office space for researchers, the University has co-invested in the development of the part-CCAAV funded ASSURED CAV (Highway) proving ground. This is a first-of-its-kind 'ecosystem' for developing connected and autonomous vehicles (CAVs) consisting of:
   - A high-speed facility enabling autonomous vehicles to be tested at the limit of controllability – specifically designed for performing scenario-based testing, the facility will enable the testing of driving scenarios such as traffic merging and lane-keep-assist, to be conducted to international regulatory protocols.
   - Urban environments where vehicles will experience pedestrians and cyclists, complex junctions, and on-street parking.
   - An ultrafast 5G mobile private network, supported by Vodafone, which will allow vehicle-to-vehicle and vehicle-to-infrastructure communications to be verified, as well as testing infotainment and cybersecurity.
   - An extensive portfolio of digital replicas where simulated testing can be scaled, reinforcing physical testing. It can also be accessed virtually so technology can be tested from anywhere in the world.
   - An on-site network of campus roads complemented by a 300km network of adjacent CAV-enabled public roads equipped with a range of intelligent transport systems enabling real-world road trials.

In addition to this major investment in support of key activities and partnerships, we have invested over £8M in general "well-found laboratory" equipment to support our key research themes in areas ranging from materials engineering to multiphase flow measurement, including:

- the establishment of a new Residual Stress characterisation facility, with investment of over £1M in equipment for experimental stress analysis.
- growth of the University's mechanical testing facilities, again with investment of over £1M plus the design and commissioning of a new dedicated laboratory, in the Beatrice Schilling Building that opened in early 2020.
- materials characterisation, with over £3M invested in microscopy, X-ray diffraction, and nano-test capability.

In addition to the capital expenditure, the TRAC expenditure allocations to research staff and infrastructure exceed £45M for Engineering at Coventry since 2016-17 alone.

Access to equipment is by open booking system. All researchers are able to access any item of equipment subject to being trained, including safety training, and with the approval of their supervisor. We do not operate an internal charging system, to allow for the highest level of flexibility and to maximise use of the facilities that we have invested in.

In the current REF period, our significant and flagship grants portfolio diversified (in theme and funder), with some key successes being:

- The £1M EPSRC-funded Humanitarian Engineering and Energy for Displacement (HEED) project, led by Gaura, combining Coventry's long-standing theme of Humanitarian Engineering with research into energy efficiency and energy poverty.
- The £2M Lloyd's Register Foundation International Joint Research Centre in Nuclear Safety (£0.5M at Coventry), led by Lancaster University in collaboration with **Fitzpatrick** at Coventry, Harbin Engineering University, and the University of Tennessee, a broad research project covering aspects of nuclear safety from materials for future systems to machine learning techniques for operational monitoring.
- The €7M **HARVESTORE** EU project (€400k at Coventry, led by Professor Alexander **Chroneos**), for the development of beyond-state-of-the-art technologies in the field of IoT. Our "μ-harvestorers" will be able to collect and store energy from heat and light at the same time, in order to serve a whole family of new-generation portable devices.
- The £5.9M EPSRC-funded New Wire Additive Manufacturing (NEWAM) grant (£694K at Coventry, led by **Zhang**), a team of nearly 50 researchers from Cranfield (lead), Manchester, Strathclyde, and Coventry, focused on the process innovation, process and material modelling, quality control and assurance, and structural integrity of additive manufactured materials and parts.
- TIC-IT, £4.8M to Coventry, Innovate UK, described further in Section 4, is a facility built on HORIBA MIRA's 750-acre proving ground, creating a purpose-built realistic, safe environment for testing Connected and Autonomous Vehicles (CAVs) up to the limit of their operability. This is critical in ensuring consumer confidence in the technologies. The test environment will be unique, enabling a wide range of CAV driving scenarios to be tested.
- Advanced Propulsion Centre "Gyrodrive" award, £1.7M to Coventry from TSB (https://www.apcuk.co.uk/case_study/gkn-gyrodrive/). Partnering with GKN Hybrid Power, GKN AutoStructures, S&S Windings and Alexander Dennis Limited, to develop a Gyrodrive sytem solution, optimised for buses to use a high-speed flywheel made of carbon fibre to store the energy generated as the bus slows down, providing fuel savings of 25%.

4. Collaboration and contribution to the research base, economy and society

4.1 Collaborations

Our research collaborations have made rapid impact on their discipline research areas, and economic impact through the partners with whom they work.

The strategy for each of our new Research Centres has been developed with a strong external focus, to ensure that there is a route to impact for the research produced. The success of this is evidenced by the fact that, despite the rapid growth in research in Engineering since 2014, we have been able to submit nine Impact Case Studies, none of which is a continuation from REF 2014. All show economic and/or societal impact:

- Development of a Comprehensive National Test Facility for Connected and Autonomous Vehicles, Professor Andrew **Parkes.**
- Influencing Single-Pilot Aircraft Research Strategy, Professor Don **Harris.**
- Recycling E-Waste though Bioleaching: Turning Motherboards into Gold (and other Precious Metals), Professor Sebastian **Farnaud.**

- Efficient Processes to support Tyre Modelling in Vehicle Design, Professor Mike **Blundell.**
- Using wettability science to enhance industrial processes, Dr David **Waugh.**
- New exhaust system design for reducing transport emissions, Dr Svetlana **Aleksandrova.**
- Development of Lead-free Engine Bearings, Professor Andrew **Cobley.**
- Team and Collective Training Needs Analysis (TCTNA) application in military training, Dr John **Huddlestone.**
- Application of laser shock peening in aerospace applications, Professor Michael **Fitzpatrick.**

Our researchers have a global network of academic and industrial collaborators. Specific examples of the UK collaborations that underpin our impact strategy and that we have previously described are as follows.

The **AME,** our partnership with Unipart Manufacturing in Coventry, was established in 2014, and its success was recognised by the award of a Queen's Anniversary Prize for Higher Education in 2019. AME is an excellent example of the University being highly proactive in building strategic partnerships at the local, regional and international level, helping to meet the long-term strategic needs of regions including skills shortages and to benefit wider society.

The AME building is located not at the University, but at the Unipart Manufacturing facility in Coventry.

AME describes itself as the "UK's First Faculty on the Factory Floor". It has developed a distinct model that brings together academia, industry and R&D directly within a single purpose-built facility, to address the key research questions challenging the industry, and to deliver industry-ready graduates.

AME has already delivered over £7M of externally funded projects, that have led to:

- Unipart securing a new fuel rail project for the Ford Fox engine.
- the production of a lightweight exhaust system for Aston Martin.
- most recently the order to supply battery energy storage systems for the first ever fully electric Aston Martin – the Rapide-e.

In addition, Unipart have formed two technology-based joint ventures – Metlase with Rolls-Royce and H1PERBAT with Williams Advanced Engineering. The H1PERBAT project was established to build a high-performance, low-volume, flexible battery capability in the UK. It started as a consortium of organisations including Unipart, Coventry University and Aston Martin, led by Williams Advanced Engineering with funding from the Advanced Propulsion Centre. In 2018, it progressed to the formation of a joint venture company (H1PERBAT) between Williams and Unipart, with a new factory being built on the Coventry site close to the AME. The AME's role going forward will be to develop the skills and capabilities required for the future, both for H1PERBAT and for the broader electric vehicle supply chain. Unipart has already contributed over £17.9M towards the commercialisation of new technologies, in addition to a further £5.6M towards student scholarships and product research and development.

Located at the University's Technology Park, the National Transport Design Centre, **NTDC**, was launched in 2017 as a hub for technological innovation, not just exploring the future of transport and the insights behind design, but also the development of design itself and the tools used,

identifying novel applications for both new and existing technologies. It encompasses incubator space for regional, national, and international businesses to increase their competitiveness, productivity, and performance by entering collaborative partnerships enabling the embedding of new knowledge and the delivery of solutions, which are led by business and supported by University expertise.

The **NTDC** brings together creativity and innovation by understanding factors which influence vehicle, transport system and infrastructure design: for example, to visualise and develop future vertiports to enable urban air mobility, in an initiative in collaboration with Urban-Air Port and Hyundai Air Mobility, which will result in live demonstrations for Coventry City of Culture 2021. We recently supported the Uber Elevate initiative to develop flying taxis: the resulting Coventry University eVTOL design was based on user-centred design principles as well as meeting strict Engineering constraints. The Centre employs a particular focus on user-centred design, by asking the questions that are often overlooked: for example, how can we ensure that disabled people gain maximum benefit from the push for autonomous transport? (https://theconversation.com/autonomous-cars-could-revolutionise-transport-for-disabled-people-if-we-change-the-way-we-design-137684)

The **CCAAR**, a collaboration between HORIBA MIRA and Coventry University, launched in 2016, builds on existing collaborative activity between the two partners, including work with other leading industry players to test connected vehicle technology in real-world conditions; a project exploring how connectivity will help drivers reach their destinations more efficiently and conveniently; and wide-ranging doctoral research activity exploring, amongst other things, technologies that make journeys safer, cleaner, and smarter, as well as the development of more resilient cybersecurity systems within modern vehicles. CCAAR is at the heart of many industry-leading research projects and specialist areas include vehicle connectivity, automotive cybersecurity, traffic simulation and modelling, human factors, and design.

Highlights have included some of UK's largest CAV projects, including:

- **Trusted Autonomous Parking (Park-IT)** – a £2M initiative to develop a multi-storey car park, on-road parking bays, and parking lot environments within Horiba MIRA's CAV urban driving environment, allowing increasing complexity of use cases for parking scenarios. It will investigate V2X communication connectively for efficient communication and parking assistance. The facility will be supported by a 'digital twin' so users can create and run parking scenarios using simulation techniques in the virtual world.
- The **Trusted Intelligent Connected Autonomous Vehicle consortium (TIC-IT)**, is part of the national strategy to establish the UK as a global-leading centre of excellence for the development, testing and commercialisation of CAVs and as such is a core part of the CAM Testbed UK Ecosystem. It is a **£26M** project part funded by CCAV (UK Government) for the establishment of a world class Connected and Autonomous Vehicle testing facility.

At the **National Structural Integrity Research Centre (NSIRC)** (hosted at TWI in Cambridgeshire), Coventry has established a steady-state cohort of 10-15 PhD research students. Furthermore, a joint **Innovation Centre in Fatigue and Structural Integrity** was launched in 2020, a partnership between TWI and Coventry University, aimed at combining our complementary skills and experience in delivering industry-led research and development in the areas of fatigue and structural integrity. NSIRC students benefit from studying for their PhD in an industrial setting,

and the Innovation Centre will provide a focus for the research activities as our research base grows further at TWI in the next five years.

In partnership with German automotive company FEV, the **Centre for Applied Low-Carbon Propulsion Systems (C-ALPS)**, a combined £50M clean mobility research centre, launched in 2019. The Centre combines FEV's industry-leading Engineering expertise together with our academics' world-class research in battery storage, hydrogen fuel cells and power electronics. The Centre already has a cohort of 10+ PhD students and a project portfolio of >£2M from EPSRC, IUK, and APC.

The **National Engineering Laboratory**, now part of TÜV-SÜD group, partners with Coventry in the area of flow measurement and AI methods in complex and multiphase systems, with applications ranging from oil and gas monitoring through to hydrogen refuelling stations. Coventry partnered with NEL on their successful bid to Scottish Enterprise to build their new £16M Advanced Multiphase Facility. Operating at pressures up to 150 bar, the facility offers measurement capability far exceeding anything currently available in the world to replicate extreme production conditions. NEL is linked to the Centre for Fluids and Complex Systems and the CDS and has seen, in the REF period, our first cohort of EngD students graduate, all of whom were based at NEL's laboratories in East Kilbride.

4.2 Wider influence

Members of the Engineering Research Centres have a strong external profile. We encourage, support, and reward academic and scientific citizenship, and participation in professional networks. We bring about opportunities for our staff to face externally through all relevant means of engagement. We encourage staff to be ambitious, to thrive through partnerships with peers and industry, as well as become astute in the policy context surrounding their areas of research.

Consequently, our researchers are called upon by numerous national and international award and grant-funding institutions to support decision making. 14 staff are working with 48 awarding bodies supporting their peer review process and respective grant award panels. These include UKRI, the European Commission, The Royal Society, NSERC, Royal Academy of Engineering, Science & Technologies Facilities Council (STFC), and various other national bodies across the globe (The Netherlands Organisation for Scientific Research (TNO), the Swiss National Science Foundation (SNSF), and so on).

Furthermore, our staff serve in the EPSRC College of Peers, the Future Leaders EPSRC College of Peers, and have supported the UK National Commission for UNESCO with their competitive award of UNESCO Chairs and IEEE awards (for example the award of Distinguished Lecturer positions). 23 staff serve on a variety of boards (such as for the European Association of Aviation Psychology (EAAP)), the Lloyd's Register Foundation Advisory Council, the International Federation for Information Processing (IFIP) Board, Instinctive Computing Lab Advisory Board, and specialist boards at Carnegie Mellon University).

The Unit's leading contribution to the sustainability of the discipline, within the UK and globally, is evident through staff members taking up a variety of prestigious roles. 45 staff serve on editorial boards of 130 peer-reviewed journals (some prestigious examples are: IET Journal of Engineering, IEEE Sensors, Cognitive Computation, IEEE Transactions on Intelligent Transportation Systems,

Neurocomputing) and guest edit Journal Special Issues in leading journals (IEEE Transactions on Fuzzy Systems, IEEE Sensors, Journal of Manufacturing Systems, Applied Sciences, Applied Ergonomics, Encyclopaedia of Automotive Engineering, Nanomaterials). Many colleagues receive commendations for excellent contributions made to the discipline.

Staff are actively engaged with public dissemination of our research, through schools', lectures, general interest public lectures, participation in events such as the Big Bang Fair and British Science Festival, and interaction with the media. The University partners with The Conversation, and members of the Unit have published articles in the REF period on subjects from nuclear energy to driverless cars to smart cities to cybersecurity.

Staff have co-chaired and organised a variety of conferences over the period, including notable events such as IEEE Mechatronics (ICM), IMechE Lightweight Body Structures, IEEE e-Business Engineering (ICEBE), IMechE Brakes, IEEE Machine Learning and Applications (ICMLA), IMechE Vehicle Ride and Handling, Engineering Psychology and Cognitive Ergonomics (EPCE), SENSOR-COM, SIMBIO-M, Symbolic and Algebraic Computation (ISSAC), and Laser Peening and Related Phenomena (ICLPRP). Our staff are routinely asked to deliver tutorials, workshops and keynotes at worldwide conferences; serve as external examiners for PhD theses in the UK and internationally; and support progression panels for other universities.

We take pride in our staff's external university appointments and support them with travel grants and time release to fulfil their honorary roles. 22 staff hold visiting professorships and 12 ECRs are Visiting Fellows to six UK and 11 international institutions.

Our leadership in the field is demonstrated through the awards received by staff for their world leading contributions to science; examples here include Professor Kevin **Warwick** receiving Honorary Doctorate awards from Saints Cyril and Methodius University of Skopje, Edinburgh Napier University, and Galgotias University, India. **Warwick** also delivered the Morgan-Botti lecture, Cardiff, and the Paul B. Baltes Lecture, Berlin-Brandenburg Academy of Sciences and Humanities. **Zhang** received the Helmholtz Fellowship and **Fitzpatrick** was awarded the Tom Bell Surface Engineering medal. 14 other staff members have received a variety of awards for their work. Equally we recognise the value of our industrial collaborations through Honorary Doctorate awards by Coventry University to senior industry figures in our discipline areas.

More generally, we believe in sharing best practice in supporting our staff and ECRs in their journeys from PhD to professor and have been able to contribute substantially to capacity building in a number of countries around the globe, over the period. With funding from the British Council, we supported hundreds of young STEM researchers in Chile, Brazil, the Philippines, India, and Vietnam. We worked with governments to help devise their strategies for research-force growth and training in Vietnam and the Philippines, and ran a series of Annual Research Summer Schools in the Philippines, 2014-2019 to support the country's ECRs and PGRs to become internationally competing researchers in the area of IoT. Here, we trained 250 young researchers and enabled the host University to become a national Centre of Excellence for Sensing and the IoT.

Our Institution is a member of the Women's Engineering Society (WES) and we support our colleagues to become champions and mentors. For example, **Gaura** is an EPSRC champion for Women in Engineering and a WES role model in their "She's an Engineer" initiative (https://www.wes.org.uk/content/shes-engineer-elena-gaura). We celebrate our women's

achievements through annual awards on the International Women's Day and encourage all the Unit's women to participate – by nominating or being nominated. Furthermore, we actively work towards closing the gender gap in Engineering and more widely in STEM. We do so with all opportunities opened by our varied collaborations and international engagements and, at times, through dedicated programmes. **Gaura** and **Brusey** teamed up with the British Council (with funding from the Newton Bhabha Fund (https://www.britishcouncil.in/programmes/higher-education/newton-fund) and in partnership with the Indian Institute of Science Education and Research, Pune) to help retain and promote women in science by targeting those who are making a transition from education to scientific careers. Over 200 women in science were trained in 2018, with numerous evidenced success stories.

4.3 Other Contributions and Esteem

Finally, our senior staff are strongly externally engaged and have been recognised in many ways for the quality of their research and their personal impact. In addition to the various activities listed in Section 3, the list that follows indicates this, although it is not exhaustive.

Professor Michael Fitzpatrick CEng CSci FIMMM is the Lloyd's Register Foundation Chair in Structural Integrity and Systems Performance. He is an STFC-appointed Non-Executive Director of Diamond Light Source plc, the UK's National Synchrotron Radiation Facility. He has been a member of the EPSRC College for 15 years. He was awarded the Tom Bell Surface Engineering Medal of the Institute of Materials, Minerals, and Mining in 2020 "in recognition of excellence and outstanding contribution of an individual in surface engineering". He is the Materials Engineering Section Editor for the IET's *Journal of Engineering*.

Professor Elena Gaura is the Associate Dean for Research in the Engineering, Environment and Computing Faculty and has been responsible for the research and researcher support and development strategy and infrastructure for this UoA, over the REF period, at Coventry University. She is a member of the EPSRC College of Peers and the Future Leaders College. In 2018 she was added to the VC's Roll of Honour for her work with women in science. She routinely serves on British Council Newton Fund, EPSRC GCRF and H2020 grant award panels. Elena is an Honorary and Adjunct Professor at Deakin and Macquarie universities, Australia.

Professor Kevin Warwick is Emeritus Professor in Computer Science. In the current REF period he has been the recipient of four Honorary Doctorates: Kingston University (DSc, 2014), Edinburgh Napier University (DTech, 2015), Sts. Cyril & Methodius University, Skopje (DSc, 2015), Galgotius University, India (DLett, 2020). He has been elected to European Academy of Sciences & Arts (2014), inducted into the International Academy of Systems and Cybernetic Sciences (2018), and is an Honorary Fellow of Cybernetics Society (2020). Notable Lectures include: Sir Hugh Cairns Memorial Lecture to Society of British Neurological Surgeons, London (2014), Paul B. Baltes Lecture to Berlin-Brandenburg Academy of Sciences and Humanities (2017). TV – 10 entries on imdb in that period: includes 'How the NHS changed our world', BBC2 Documentary (2016), 'Ancient Aliens', History Channel (2016 and 2018).

Professor Xiang Zhang was appointed as a Helmholtz International Fellow in 2016. She has served on funding selection panels on Helmholtz International Labs (2018), Helmholtz European Partnering (2019, 2020), and Empa Swiss Federal Laboratories for Materials Science and Technology (2018). She is a member of the Royal Aeronautical Society's Structures & Materials

Specialist Group, and is an Associate Editor for the Journal of Aerospace Engineering.

Professor Jonathan Lawrence holds six patents relating to the novel use of lasers and laser materials processing. He has served on funding selection panels for Ontario Research Fund (2014, 2016), A*Star (2015-16), National Research Council Canada (2015-20), Austrian Science Fund (FWF) (2018) and Deutsche Forschungsgemeinschaft (DFG) (2018). He is Editor-in-Chief of *Lasers in Engineering* and the *International Journal of Laser Science*.

Professor James Brusey is a Professor of Computer Science with the CDS at Coventry University, leading on AI for the IoT. He serves as an editor for *IJDSN* and is a regular funding panel member for the UK National Centre for the Replacement Refinement and Reduction of Animals in Research, FCT Portugal, and the Academy of Finland.

Professor Vasile Palade is Professor of Artificial Intelligence and Data Science. He is an IEEE Senior Member, the Chair of the IFIP Working Group on Computational Intelligence TC12.9, and member of the Technical Committee on Machine Learning of the IEEE SMC Society. He has chaired several conferences during this REF period (IEEE ICMLA 2015, IEEE ICMLA 2017, IEEE CIFEr 2014, CIMA 2016). He is an Associate Editor for several journals, such as *IEEE Trans. on Neural Networks and Learning Systems*, *Knowledge and Information Systems*, *Neurocomputing* (2014-2019), *International Journal of Artificial Intelligence Tools*.

Professor Petar Igic is Professor in Power Electronics. In 2016, his research team received the esteemed NMI University Research Group of the Year Award, the award that "specifically promotes departments and teams that demonstrate excellent liaison and partnership with industry" and "celebrate the year's key electronics innovations, people and companies from across the UK and Ireland".

Professor Siraj Shaikh FBCS CITP CSci is Professor of Systems Security. He is a Visiting Professor at Nebrija University (Spain). He served as a Royal Academy of Engineering (RAeng) Industrial Fellow (2015) on automotive cybersecurity with HORIBA MIRA. He is co-founder and Chief Scientist at CyberOwl, which is a spinout from his research on early warning systems for threats targeting cyber-physical systems. He is on the Advisory Board of Project ASLAN, which is a global open-source self-driving software community for low-speed environments.

Professor Kuo-Ming Chao is a co-founder and editor-in-chief of *Service-Oriented Computing and Applications* – a Springer journal to promote and influence the research in the area. He is the chair of the IEEE Computer Society Technical Committee on Business Informatics and Systems.

Professor Nigel Jennett CSci CPhys MInstP is Professor of Materials, Mechanics and Measurement. Throughout the REF period he has served as a co-opted UK Expert on the top-level Metrology committee for Hardness, CIPM CCM-WGH (International Committee for Weights and Measures, Consultative Committee for SI unit of Mass - Hardness Working group). He is the chair of British Standards Institute committee (ISE/101/5 Indentation Hardness testing) and Head of UK delegation to International Standards Organisation committee ISO/TC 164/SC 3 – Metals, Hardness Testing. He is Convenor of ISO/TC164/AG1 Mechanical Testing of Materials - Advisory Group on Uncertainties and ISO/TC 164/SC3/AG1 Hardness Uncertainties and is a UK Expert member of: ISO/TC164/WG1 Mechanical Testing of Materials – Terminology and Symbols; ISO/TC

164/SC 03/WG 04 "Revision of ISO 14,577 - Metallic materials - Instrumented indentation test for hardness and materials parameters"; ISO/TC138/SC1/WG4 "Plastics piping systems for underground drainage and sewerage"; and CEN TC155 WG26 Systems for storm water management. He is Associate Editor for *Philosophical Magazine* and *Philosophical Magazine Letters*. He is a member of the International Organising Committee International Conference series 'IIW' (Instrumented Indentation Workshop) and was International Chairman of Versailles Project on Advanced Materials and Standards TWA22 "Mechanical properties measurement of thin films and coatings" from 1998 until its completion during this REF period.

Professor Richard Dashwood is Deputy Vice-Chancellor (Research) and is responsible for the research mission at Coventry University. During the current REF Period he was the Chief Technology Officer for the WMG High Value Manufacturing Catapult (HVMC) leading activity at the University of Warwick and coordinating collaborative work across the seven HVMC centres. He was a member of the UK Automotive Council Manufacturing Technologies Group, an Advisory Board Member for the Knowledge Intensive Product Realisation project at Jönköping University, Sweden, and chaired the Strategic Advisory Board for the Designing Alloys for Resource Efficiency (DARE) EPSRC project based at Sheffield University. He is a member of the IOM3 Advanced Sheet-metal Forming Committee, the ICSAM International Advisory Board, Associate editor of the *Encyclopedia of Automotive Engineering*, and a member of EPSRC peer review college.

Professor Don Harris is Associate Dean for Research and Professor of Human Factors. Between 2014-2017 he was the independent Human Factors Advisor to the National Air Traffic Services, Safety Review Committee and currently is engaged as the Human Factors advisor on the Aerospace Technology Institute advisory committee for whole aircraft. Until 2016 Don was Visiting Professor and consultant advisor to the Institute of Aerospace Science and Technology, Shanghai Jiao Tong University, PR China and was also a visiting academic in the Department of Aeronautics and Astronautics, National Cheng Kung University, Taiwan. He has been Chair of the Engineering Psychology and Cognitive Ergonomics International Conference Series since 1996 (now in its 25th year).

Professor Barrie Johnson is a research professor at both Coventry and Bangor Universities, and has held honorary chairs at Exeter and Changsha (China) universities. He was one of the first elected members of the Learned Society of Wales, is a past Industrial Fellow of the Royal Society, and has held two research fellowships awarded by the US Department of Energy. He has twice represented the International Atomic Energy Authority in South America, acted as an instructor at international workshops and given numerous invited, keynote and plenary talks. His research has been featured in many media outlets and was highlighted by Scientific American as one of "10 World Changing Ideas".

Professor Manus Henry is Professor of Flow Measurement at Coventry University; Director of the Advanced Instrumentation Research Group at the Department of Engineering Science, University of Oxford; and the Head of Laboratory at the Scientific Research Laboratory of Equipment and Systems Self-Validation, School of Electrical Engineering and Computer Science, South Ural State University, Chelyabinsk, Russia. He serves on the BEIS National Measurement System Programme Expert Groups for Flow Metrology and for Digital Metrology, and as a panel member for EMPIR. He has been the Associate Editor for *the Flow Measurement and Instrumentation* Journal since 2008, becoming Chief Editor in January 2021. He has over 130 granted patents (54 of which were granted since January 2014), mostly in the fields of self-validating sensors and flow

metering. He was a member of the OxVent team which won the 2020 Global Challenge E&T Innovation Award for the development of a low-cost mechanical ventilator.

We support our ECRs to build external networks, achieve academic recognition and kick-start collaborations, on the way to becoming future leaders. ECRs are supported in bidding for external fellowships and can access funding to spend time at collaborating institutions. Examples include:

- Dr James **Griffin** to Deakin University, Australia, supported by an Endeavour Executive Fellowship grant from the Australian Government.
- Dr Pratik **Shukla** to the University of Malta, supported by a grant from the Malta Research Council; plus another placement to Vellore Institute of Technology, India.
- Dr Mostafiz **Rahman** to Queensland University of Technology, Australia.
- UK collaborative fellowships including Dr Matthias **Foo** to Warwick and Dr Matthew **England** to Bath.

Summary

In conclusion, this submission returns an Engineering Unit that has transformed since 2014. The scale of the sustained Institutional investment has allowed us to initiate new areas of research at scale, in partnership with national and global collaborators and partners. We continue on a strong upward trajectory, supported by a robust Institutional strategy, and with world class researchers who have been recruited in the last seven years and for whom we have provided mentoring, support, and development. We are proud of the achievements that we have delivered in a relatively short period, and look forward to continued success post-REF2021.