Institution: University of Nottingham
Unit of Assessment: 12 – Engineering
1. Unit context and structure, research and impact strategy

1.1 Faculty of Engineering Context and Structure

The Faculty of Engineering (FoE) was established as an integrated unit and budget centre for engineering teaching, research and knowledge exchange in 2009. Our faculty supports approximately 3800 Undergraduate, 600 PostGraduate Taught, 540 PostGraduate Researchers and 828 academic, technical, research and administrative staff (July 2020), with 2014-20 research awards of £272.1M.

Supporting our people to achieve their potential is at the heart of our strategy, evidenced by our 2020 Award of Athena SWAN Gold, the first ever to an Engineering Faculty or School in the UK. As the Faculty Pro-Vice Chancellor (FPVC), Professor Sam Kingman has led the Faculty since 2018, succeeding Professor Andy Long FREng (2011-2018), now Deputy Vice Chancellor of the UoN. The FPVC is supported in setting research strategy by the Faculty Associate Pro-Vice Chancellor for Research & Knowledge Exchange, Professor Chris Tuck (2018 – present) succeeding Professor Sarah Sharples (2015-2018), now UoN PVC for Equality, Diversity, Inclusion and People. Our academics (278 FTE) are organised into 6 teaching departments *Architecture and Built Environment; Chemical and Environmental Engineering; Civil Engineering; Electrical and Electronic Engineering; Foundation Engineering & Physical Science and Mechanical, Materials and Manufacturing Engineering*.

FoE research is organised into a structure to deliver a vibrant interdisciplinary research culture that cuts through traditional departmental silos. Our research active staff (244.4 FTE) are aligned to 15 research groupings (Table 1) to promote creativity and collaboration between disciplines. This mechanism enables research ideas to cross groups and promotes the making of active connections across FoE, the wider university and external research landscape. It supports development of multidisciplinary themes of research, exemplified by 29% of our research outputs being co-authored with groups external to that of the lead author.

A 2015 FoE review of research strengths and stakeholder strategies (e.g. UKRI, EC, Industrial partners - Rolls-Royce, Siemens, etc.) saw a departure from our divisional structure (REF2014) to better align with UoN's research ecosystem. Our groups link underpinning research into a pipeline of activities, allowing new research to be translated into cross-university initiatives and to provide wider societal/economic/environmental impact. This research structure augments that articulated in our Institutional Statement (IS); UoN has implemented 6 high-level Beacons of Excellence (IS section 2.1a) seeing new investment (£100M) in: Future Foods, Green Chemicals, Precision Imaging, Propulsion Futures, Right's Lab, and Smart Products. Additionally, we support bottom-up initiatives such as Interdisciplinary Research Clusters (IRCs, IS section 2.1a), (co)leading 5. The mapping between the research groups, Beacons and IRCs is shown in *Table 1*.

Table 1. UoA12 Research Groups mapped to UoN Beacons of Excellence and IRC leadership (**bold)**.

UoA12 Research Group	Associated Beacon of Excellence
Food Water Waste (**IRC Lead: Water Works**)	Future Food
Low Carbon Energy and Renewable Technologies Sustainable Process Technologies	Green Chemicals
Optics and Photonics (**IRC Co-Lead: Technological Innovation in Healthcare and Wellbeing**)	Precision Imaging
Advanced Materials (Propulsion Futures Beacon Lead) Composites Gas Turbines and Transmissions George Green Institute for Electromagnetic Research Fluids and Thermal Engineering	Propulsion Futures
Nottingham Geospatial Institute	Rights Lab
Advanced Manufacturing Technology (**IRC Lead: Advanced Manufacturing**) Centre for Additive Manufacturing (**IRC Lead: Additive Biofabrication**) Human Factors Infrastructure Engineering (**IRC Co-Lead: Transport, Mobility and Cities**)	Smart Products

Beacons have fuelled our research groups with new and unique laboratories (see section 3), new research staff (e.g., Nottingham and Anne McLaren Research Fellows (NRF and AMF) - IS section 3.2) and partnerships (e.g., Smart Products with School of Computer Science, Green Chemicals with School of Chemistry). This acceleration of research is evident in our 11 Impact Case Studies (ICS), influencing sectors from Healthcare to Aerospace, with specific examples provided in section 1.3. The success of this approach led to The Nottingham Energy Institute being inaugurated in 2020 (comprising 9 challenge leads from Engineering, Science and Social Science; 29 individual academics; 6 support staff and 2 EPSRC CDTs in energy *EP/S023909/1, EP/S022996/1*) supporting the civic (IS section 2.2d) and UK's ambitions towards Net Zero.

1.2 Research Strategy Development and Review

The overarching Faculty strategy is owned by our Faculty Executive Board (FEB), chaired by the FPVC, with membership from senior management across research, teaching, finance, infrastructure and HR.

FEB is supported in research by the Faculty Research and Knowledge Exchange Board (FERB) chaired by the FAPVC with membership including Directors of Research for**,** PostGraduate Research, Research Equipment & Infrastructure, Research Excellence & Fellowships, and Knowledge Exchange & Impact, alongside representatives from: Beacons of Excellence, Heads of Research Groups (HoRG), Research Staff, Technical Services and Research Support. FERB has responsibility for developing and delivery of the research elements of the FoE strategy and identifying future priorities, which are communicated through our Research Leaders Network (RLN) (see section 2.3.1).

This integrated approach to strategic development enables large-scale strategic opportunities to be supported and targeted, whilst maintaining the highest quality of outputs. For example, this allows us to embed administrative and technical support across our research portfolio including: 24 FTE project managers embedded in groups, centres and institutes, a pool of technical specialists (144 FTE), and our Engineering Research & Knowledge Exchange Team (ERKE), which supports the full

research lifecycle (18.9 FTE). Success of this approach since REF2014 is evidenced by an increase in our overall value awards of 73%, an increase in publication quality evidenced by improvement in Top 10% by SNIP (~40% in 2015 to ~50% in 2020, Filter: Engineering, Scival) and annual PGR registrations of ~540. Total staff growth over the period was 22%.

In consultation with our research community, our REF2014 strategic vision was to: *"address global societal challenges and deliver sustained advantage to our stakeholders through research excellence"*, to be delivered through the following strategic objectives:

SO1: Talented people and teams.
SO2: Targeted initiatives in areas of global importance.
SO3: Effective and efficient research performance.
SO4: Strategic and focused activity to support short, medium and longer-term ambitions.

Our research groups develop annual strategic delivery plans to identify areas of growth and potential, highlighting opportunities to invest in next generation underpinning science and engineering.

1.2.1 Research Income and Impact Strategy (SO1, 2, 3, 4)

FoE contributed £272.1M in new awards to UoNs overall portfolio in the period, enabling research across our scientific interests and technology readiness levels (TRL) (1-9). High TRL activities are delivered through an integrated Knowledge Exchange Impact (KEI) strategy (IS section 2.2) with industrial collaboration at its heart to maximise the value and impact of our innovation. This has created an environment where KEI is rewarded and recognised at all career stages. This is exemplified by our two Rolls-Royce University Technology Centres (UTC), Manufacturing and On-Wing Technologies and Gas Turbine Transmissions Systems.

Our dedicated KEI team (since 2014) supports colleagues through public engagement to IP protection and exploitation and KE activities (2.8 FTE). The vibrancy of this portfolio is evident in our commercialisation and impact activities, with an overall income of £4.9M in consultancy and over £4.7M services-rendered income (i.e. work that does not meet the Frascati definition of research). We have 9 active spin outs, 1 exit, 75 patents and 23 IP licence/option agreements in the period. Further, our staff are listed on 266 live patent cases from 62 patent families that are assigned to our external stakeholders. The KEI team integrate with colleagues within the UoN IP and Commercialisation Office (IPCO) to deliver training, capture IP disclosures, and develop commercialisation plans for triage to IPCO where protection is appropriate.

Spin outs formed within REF2021 period include: [*TARAZ Metrology*] and [*TextureJet*], joint ventures [*Pulse with Building Test Services Ltd*] and a service-based company [*Added Scientific*] for commercialisation in 3D Printing. Success in exits is evident in our fetal heart monitoring company Monica Healthcare sold to GE Healthcare in 2017 (section 3.1.3). We allow all research staff (above Level 4a) 50 days p.a. to engage in external work including knowledge exchange and consultancy supported through Nottingham University Consultants (NUC). The KEI team supports Public Engagement (e.g., Royal Society Summer exhibition, 2016 and 2020 moved to 2021) with the Faculty Director for Public Engagement *[Wu]*, the Institute for Policy & Engagement, and outreach teams.

1.2.2 Open Access and Research Integrity (SO3)

To ensure compliance with open access requirements of funders and open data repositories usage (e.g., Open Notebooks, GitHub), we embed training as part of our Enhancing Excellent Engineering Research (E3R) programme. The E3R programme enables researchers to establish/refresh their career and to develop a sustainable research portfolio. Support consists of regular face-to-face meetings to discuss personal research plans along with targeted sessions across the full research lifecycle and is aimed at capacity building in our research staff. Our Engineering Ethics Committee chaired by [*Morris*] provides guidance on participatory research activities, use of animal subjects and wider ethics and research integrity (IS section 2.4). Through the UoN Digital Research Strategy (IS section 2.1c) and our dedicated digital research specialist, support is provided for research data

management ensuring staff understand and adhere to FAIR (findable, accessible, interoperable, reusable) principles and are GDPR compliant. A digital research specialist works with our academic digital research lead [*Wright*] to feedback requirements, communicate and facilitate access to digital services (IS section 4.1d) (e.g., HPC clusters, transcription, data storage).

1.2.3 Human Resource and Training Strategy (SO1, 2, 4)

People are at the heart of all we do, and therefore FoE has developed a strategic approach to all aspects of our staffing in order to recruit, recognise, reward and retain our talented people and teams. We have developed our existing staff and attracted the very best candidates for academic positions (60.6 FTE recruited in period). Our recruitment processes have been strengthened to embed equality, diversity and inclusion (EDI) principles including implementing our own research from the EPSRC Inclusion Matters STEMM Change project (section 2). This approach has allowed expansion in strategic research (section 1.3) – e.g., Rolls-Royce UTCs (3 new positions) and the Centre for Additive Manufacturing (5 new positions, 5 promotions and 3 NRFs). New areas of research such as Food Water Waste (2 new positions, 2 promotions and 3 NRF/Fellows) and joint appointments for multidisciplinary activities (section 2.1) and external collaboration e.g., with Virginia Polytechnic Institute and State University (Virginia Tech) [*Muljadi, Gilliland & Nojabaei*] in 2017.

These people are supported by post-doctoral staff (260 FTE) and a Post Graduate Research (PGR) community of ~540 students, ~980 PGR awards in the period. PGRs are supported by our significant UKRI Centres for Doctoral Training (CDT) portfolio (leading 4 with total funding of £20.2M), in addition to EU Horizon 2020 Marie Sklodowska-Curie Actions-Innovative Training Networks (£8.9M) (leading 5 and contributing to 11 over the period). Coupled with these we lead the TALENT programme *(Research England [Vere] £4.9M),* on behalf of Midlands Innovation, the largest ever investment in research on technical skills development and further reinforcing UoN's leadership as a founding signatory of the Technician Commitment (IS section 3.4).

1.2.4 Equipment and Infrastructure Strategy (SO2, 3 and 4)

Our equipment and infrastructure strategy provides unique facilities augmented by high quality underpinning space, equipment and technical support for all of our research to be conducted efficiently and at the highest quality. Physical experimental facilities are complemented by our digital infrastructure to accommodate specific expertise in theory, modelling and verification across our research portfolio. Our work is characterised by the ability to carry out pilot and industrial scale experimentation; examples include:

A **150 tonnes per hour microwave processing plant** (the largest ever built).
A **commercial Rolls-Royce Trent 1000 gas turbine engine** for experimental demonstration.
A **three-shaft transmission rig** as a national facility.
A **commercial scale robotics manufacturing** and assembly facility (8900 m^2).
A cluster of seven **Creative Energy Homes** (each inhabited) for community energy research.

Our work is supported by unique experimental facilities, such as EPSRC Strategic Equipment funding for High Volume Composites Manufacture *(EP/T006420/1 [Warrior] £454k)* and High Resolution Scanning Electron Microscope (EP/S021434/1 [*Brown*] £1.5M) part of Nanoscale and Microscale Research Centre (nmRC). Investments in new buildings has totalled over £50M and doubled our research space to ~32000 m^2, including the Advanced Manufacturing Building (2018; £24.1M) the Research Acceleration Demonstrator (RAD) building (2017; £7M); and the expansion of the Energy Technologies Building (2015; £1.3M). This investment continues with the dedicated Power Electronics building due for completion in early 2021 (£40M). Further off-site facilities include the ERA-funded Trent Basin Community Energy Project (2016; £3M), and CO_2 sequestration borehole facilities (2016; £1.6M).

1.3 Research Group Progress since REF2014

Research groups are our pipeline of research endeavour, continuing to develop diversity and strengthen our portfolio of projects and expertise to meet changing international and national

priorities in research and supporting the UoN strategy. Different levels of maturity exist within this portfolio, categorised as follows:

Established – Groups established as world-leading in their field.
Revitalise – Pre-existing groups undertaking reinvention and renewal.
Emergent – Groups in new fields of research for FoE.

A description of progress for groups since 2014 follows, with highlights of investments and success:

1.3.1 Established

Advanced Manufacturing Technology (AMT) *[Lead Dr J. Segal]* works across manufacturing technologies to research Industry 4.0, mechatronics, metrology and non-traditional manufacturing. ***Strategic plans for this period*** were to cement a lead as an international manufacturing research centre. **By REF2021**, AMT established a PGR programme co-created with industrial stakeholders, such as Airbus, the Manufacturing Technology Centre (MTC) and Rolls-Royce plc. The MTC - Engineering Doctorate Centre (*EP/017933/1 [Ratchev] £1.3M*) supported 17 PGRs. Within AMT, the Precision Manufacturing Centre supported over 70 local SMEs in the D2N2 Local Enterprise Partnership (LEP), through the "Enabling Innovation" European Regional Development Fund *(ERDF [Ratchev] £9.87M)*). For example, Precision Engineers near Mansfield received an order from a US customer, which was outside of their capability; working with AMT, both samples and finished components were delivered resulting in the client investing in new equipment. AMT's transdisciplinary team spans Engineering, Science, and Business, combined with industrial partners, to deliver flexible and agile manufacturing (e.g., FA3D2 *(IUK113163 [Ratchev] £3.8M);* Cloud manufacturing *(EP/K014161/1 [Ratchev] £2.4M));* process simulation and optimization (e.g., Connected Factories *(H2020-723777 [Ratchev] €1.9M));* and dissemination and training of the latest developments in digital manufacturing (e.g., DiManD *(H2020-MSCA-ITN-814078 [Ratchev] £441k).* These projects have led to understanding and capability in manufacturing that have already directly contributed to impact (e.g., Project TEMPEST with BAE Systems).

The strategic appointment of Leach (2015) as EPSRC Manufacturing Fellow *(EP/M008983/1 [Leach] £1.23M)* in Manufacturing Metrology has grown this activity to deliver bespoke optical measurement in manufacturing solutions. Through additional investment, the appointment of [*Piano*] in 2015 and awards from H2020 EU (e.g. Precision additive metal manufacturing" with KU Leuven; PAM2 (*H2020-MSCA-ITN-2016-721383 [Leach] €4M*)) has contributed to [*Leach*]'s appointment to RCUK Catapult Researchers in Residence award (MTC) to develop an "Integrated metrology 10-year roadmap for advanced manufacturing" *(EP/R513507/1 [Leach] £50k)*. Engagement with Nottingham alumnus Graham Siddal has secured the Phil Willey prize, sponsoring research activities between the UK and USA in metrology. In 2020 the team were awarded a Research England project for a "Midlands Centre for Data-driven Metrology" £3.33M.

In machine and condition monitoring *[Axinte]*, collaboration with Rolls-Royce has in the UTC in Manufacturing and On-Wing Technology, resulting in the filing of 22 patents and the receipt of 38 Rolls-Royce Patent Awards. Since 2018, FoE committed to invest in "manufacturing mechatronics", providing a wider offering to Rolls-Royce which includes: 3 new academic posts [*Gameros, Liao, Mohammed*] in Robotics, Mechatronics, and Manufacturing, a UTC Senior Administrator and 2 dedicated technicians. These appointments support the UTC portfolio (e.g. INSPECT *(IUK103989 [Gameros] £1.2M); COBRA (IUK104066 [Alatorre] £1.3M);* RAIN Hub led by Manchester (*EP/R026084/1 [Axinte] total £12.2M);* Through-life performance: From science to instrumentation led by Cranfield *(EP/P027121/1 [Axinte] total £1.2M)).* These innovation activities are supported by our Entrepreneur in Residence (Royal Society funded) Peter Winton (formerly Global Process Owner at Rolls-Royce) who provides innovation advice and expertise to this group and FoE. Rolls-Royce contribute underpinning funding to this UTC of £250k p.a. in addition to further direct funding (over £500k in 2017 for example). This collaboration won The Engineer's Collaborate to Innovate Award (2018) in the Defence, Aerospace and Security category for remote-controlled robotic jet-engine maintenance. These UTC activities have led to two ICS in the period in Advanced Machining and Robotic Snake Arms for monitoring and maintenance. Further [*Clare*] was awarded the Royal Academy of Engineering and Rolls-Royce Chair in Non-traditional machining in 2019 (£0.45M) and

in 2018 span out TextureJet Ltd based on Nottingham-developed electro-chemical jet machining techniques. **Future plans** are to continue to lead Advanced Manufacturing science and engineering, using this platform for effective succession planning in people and disciplines.

Advanced Materials Research Group (AMRG) [*Lead Professor D. Grant]* encompasses materials science and engineering research across energy, healthcare and aerospace. **Strategic plans for this period** were to expand collaborations internally and externally in academia and industry to enhance research in advanced materials and attract new capability. **By REF2021** AMRG has doubled to 18 academics and 80 researchers with 4 new internal and external fellowships: AMF [*Williams*], NRF [*Ling*] and Leverhulme Early Career [*Oluwafunmilola*, *Luo*]. In energy materials [*Walker/Grant*] have developed novel thermal stores funded directly by E.ON (£1M), as well as metal hydride hydrogen storage projects *(EPSRC (EP/R00143X/1, £202k; EP/P003435/1, £925k)* and UK-India *(EP/K036297/1, £711k; EP/J000345/1, £1.40M; EP/J000345/2 £1.02M)* and UK-China *(EP/F061919/1 £429k)* collaboration. AMRG has driven aspects of the £9M Energy Research Accelerator (ERA), in relation to Hydrogen storage (*IUK160052 [Walker] £1.45M*) resulting in pilot hydrogen energy systems situated within the Research Acceleration and Demonstration Building on Jubilee Campus. In healthcare, [Seddon/Furniss] have continued exploration of novel photonic glass through EU FP7 MINERVA project *(FP7-ICT-317803 [Seddon] £735K)* and [*Grant, Ahmed*] are partners in the EPSRC Centre of Innovative Manufacturing in Medical Devices *(EP/K029592/1 [Grant] £5.7M).*

AMRG has continued to deliver industry impact case studies in novel materials processing. For example, the collaboration of [*Kingman/Dodds*] with Teledyne e2v, and initially with Rio Tinto and now Anglo American (£11.5M total investment in period) has led to significant impact in the use of Microwave technology for efficient ore production and separation methods (ICS Te2v). Kingman and his team were awarded the Royal Academy of Engineering's Colin Campbell Mitchell award (2018) (section 4.3). *[Lester]* has continued innovation in hydrothermal synthesis of nanomaterials (*EU-FP7-NMP280983 SHYMAN. [Lester] (£1.84M to UoN €9M total*)) which continues to feed a pipeline of impact through our spin-out Promethean Particles (ICS – Promethean) which is now providing innovative nano-materials to commercial markets including electronics and telecoms. AMRG are partners in the *EPSRC EP/L016206/1* CDT in Innovative Metal Processing (IMPACT) led by Leicester [*Voisey*] and contribute with colleagues in our Gas Turbine and Transmissions group to the EPSRC Prosperity Partnership Cornerstone *(EP/R004951/1 [Garvey] £6.14M)* with Rolls-Royce through [*Shipway*]. In addition, [*Shipway*]'s work with Rolls-Royce tackles wear resistance in aggressive environments (over £2M from Rolls-Royce in the period). Beacon investments (IS section 2.1a) have grown our advanced materials provision in new material synthesis and processing, for example £229k in Spark Plasma Sintering and X Ray Diffraction. **Future plans** are continued development of novel processing and characterization of new materials applications within energy and biomaterials.

Built Environment Engineering (BEE) *[Lead Professor S. Riffat*] delivers research on enhancing the built environment, seeing significant growth through investments and linkages to strategic initiatives such as the Energy Research Accelerator (ERA). **Strategic plans for this period** were to develop novel energy saving solutions and establish the Transport, Mobility and Cities research agenda. **By REF2021**, growth has occurred through promotion of Associate Professors to Professor [*Rodrigues*, lead of Transport, Mobility, Cities IRC] and [*Wu*, Director of Public Engagement] and new academic appointments [*Calautit*]. BEE has provided impact with projects such as the Trent Basin Demonstrator (part of *ERA IUK160052 [Gillott] £2.96M*) with "Project SCENe (Sustainable Community Energy Networks)" being awarded "The Engineer" prize in the Energy and Environment Category 2019. This research is bolstered by sustainable energy technologies (e.g. n-CoSH, led by Exeter *(EP/P003435/1 [Giddings] £1M);* Innovative Energy Saving and Climate Control System for Greenhouses *BBSRC BB/M018199/1 131784-298175 [Riffat] £138k))* and sustainable and urban living (e.g. REZBUILD *(H2020-EEB-2017-768623 [Riffat] €9M)).* Theses have led to significant engagement with the "The Active Building Centre" led by Swansea *(EP/S016627/1 [Boukhanouf, Gillott, Rodrigues] £598k).* **Future plans** are to mitigate and adapt to climate change impacts, reducing energy use in the built environment and enhancing comfort, productivity and the well-being of building users e.g. with the Trent Basin Community.

Centre for Additive Manufacturing *[Lead Professor R. Hague]* performs research across TRL levels in the area of Additive Manufacturing, processes, materials and computational methods. Established at UoN in 2012, CfAM has expanded during the period in staff as follows: 3 Nottingham Research Fellows [*Maskery, Simonelli, Aboulkhair*], 2 Transitional Fellows [*Cantu* and *He*], 2 new Assistant Professors [*Turyanksa* and *Baumers*], promotion of [*Goodridge* and *Tuck*] to Professor, Appointments of [*Tuck*] as APVC RKE and [*Ashcroft*] as Head of Department for M3. Space has increased from 480 to 690 m^2 with dedicated cleanroom facilities funded through a £1M Wolfson Award, within the Advanced Manufacturing Building. **Strategic plans for this period** focused on extending its fundamental Additive Manufacturing (AM) science base (established through the EPSRC Centre of Innovative Manufacturing in Additive Manufacturing (*EP/I033335/1 and EP/I033335/1 [Hague] £5.9M)* and developing collaborations to facilitate the transfer of next generation multi-functional AM into industry. This is augmented by our leadership of AM R&D with the Manufacturing Technology Centre (MTC). Another key aspect of the strategy was to establish a hub of AM Research in Ningbo, China; this has now delivered a dedicated AM facility (RMB1.5M) to work with local SMEs and has underpinned development of a strategic relationship with system manufacturer BLT Inc. **By REF2021** CfAM secured the Centre for Doctoral Training in Additive Manufacturing and 3D Printing *(EP/L01534X/1 [Tuck] £4.5M)* co-created with industrial partners (e.g., MTC, DSTL, AWE Plc, Stryker, Renishaw). To address a long-term vision in multi-functional AM, CfAM secured the EPSRC "Future Additive Manufacturing Platform Grant" *(EP/P027261/1 [Hague] £1.7M)* (with the MTC), and the EPSRC Programme Grant "Enabling Next Generation Additive Manufacturing" *(EP/P031684/1 [Hague] £5.9M)* collaborating with Universities (Birmingham and Warwick), industry partners (Texas Instruments, AstraZeneca) and international partners (Lawrence Livermore National Laboratories and Karlsruhe Institute of Technology). "Future Formulation for 3D printing" *(EP/N024818/1 [Wildman] £3.5M)* investigates new functional AM materials in collaboration with the Universities of Reading and Birmingham.

The focus on more fundamental research has led to publications outside of AM, e.g., in journals such as Advanced Functional Materials (Modulating cell behaviour in 3D printed scaffolds) and Acta Materialia (Microstructural behaviour of AM magnetic materials). In 2015, the group established Added Scientific Ltd, to work with industrial clients such as Henkel and QinetiQ. Additionally, CfAM's close industry relationships over the period include GSK (£675k) and AWE (£1.2M) to translate its lower TRL research to commercial use. This continues with EPSRC Prosperity Partnerships with GSK led by Strathclyde *(EP/S035990/1 [Wildman] £715k)* on pharmaceuticals, and with BAE Systems led by Southampton *(EP/S03661X/1 [Tuck] £715k)* on acoustic devices. Further collaborations include with the Schools of Chemistry *(Atoms 2 Products CDT EP/S022236/1 [Wildman, Lester, Irvine] £6.2M)* and Physics, as part of the Quantum Technology Hub *(EP/M013294/1 [Wildman] £815k).* **Future plans** are to build upon the pioneering multifunctional and multi-material additive manufacturing platform that will deliver entire working systems in a single process step.

Composites Research Group, [*Lead Professor N. Warrior*] develops the scientific understanding required to exploit composite materials manufacturing technology, with this activity being significantly accelerated via the EPSRC Centre of Innovative Manufacturing in Composites Manufacture (CIMComp) *(EP/I033513/1 [Long] £5.9M).* **Strategic plans for this period** were to provide continuation of CIMComp via expansion in the scope of partnerships and growing the scope of applications. **By REF2021** this was realised through leadership of the EPSRC Future Composites Manufacturing Hub *(EP/P006701/1 [Warrior] £10.3M)* with partner Universities (Bristol, Cranfield, Imperial College, Manchester, Southampton). The Hub aims to accelerate advanced polymer composite materials for automated manufacturing technologies forming a key element in the UK's composites manufacturing R&D strategy. Highlights include: a collaboration with Hexcel Reinforcements UK, Gordon Murray Design, GKN Aerospace and Dassault Systèmes to "Design Simulation Tools and Process Improvements for Non-Crimp Fabrics Preforming"; the hosting of international meetings such as SAMPE 2019; and the funding of two 2-year post-doctoral Innovation Fellowships for Edinburgh and Warwick.

[*Brown*] is an EPSRC Fellow in Research Software for Textile Modelling and Simulation (EP/N019040/1 [Brown] £400k) promoting efficient composite manufacture. Continued research in bio-composites has occurred through the Integrated Molecular Design of Melt-processable Bioresorbable Engineering Nanocomposites for Healthcare (BENcH) *(EP/J017272/1 [Irvine] £1.2M).* Impact from this work has featured heavily in the automotive sector, exemplified by collaborations with McLaren Automotive and Gordon Murray Designs. **Future plans** are to widen the understanding of the underpinning science required for composites manufacture, and through the Hub, to expand the reach and significance of composites in industry.

Optics and Photonics Group (OPG) [*Lead Professor M. Clark*] bring optical science and understanding to understand biological and engineering systems promoting aspects of non-contact inspection from aircraft components to cellular materials. OPG includes the Director of the Centre for Healthcare Technologies (CHT) [*Morgan*], a partnership with Nottingham University Hospitals Trust that provides a pathway to support translation of fundamental research into healthcare tools. **Strategic plans for this period** were to grow the area of nano-biophotonics and high-resolution microscopy across the TRL spectrum. **By REF2021** OPG recruited five independent research fellows: 2 NRFs ([*Abayzeed*] (nano-electrical imaging); [*Kenny*] (optical metamaterials)), 2 RAEng fellows ([*Perez-Cota*] (nano-phononic imaging); [*Powell*] (photo-acoustic imaging)) and [*Mather*] with her TransPhorm ERC Consolidator Grant *(H2020 683108 €2.4M).* Transphorm pioneers new technology to enable the proteins found in the membrane of cells responsible for the regulation of cell function and communication to be studied in their natural environment with unprecedented sensitivity and resolution. In addition, three academics ([*Smith*] (acoustic and plasmonic imaging), [*Gordon*] (photonics and medical imaging) and [*Correia*] (fibre sensing)) have been recruited in the period.

This work is exemplified through publications across a range of fundamental science from “Quantum Sensing in Physiological Cell Niches” (Small) [*Mather*] to Crystallographic orientations of hexagonal crystals in materials (Ultrasonics) [*Smith*]. Impact is exemplified by the award-winning spin-out Monica Healthcare Ltd which developed a range of wireless, wearable products for fetal and maternal heart monitoring (Novii) (acquired by GE Healthcare 2018). Further Nottingham IP has been licensed to Moor Instruments to create the FDA-approved and commercially available moorLDLS-BI. Used in specialist burns centres across the globe, the device produces scans of burns 30 times faster and with a greater degree of accuracy than existing technology enabling more accurate diagnosis (ICS Burns). [*Morgan*] was awarded a Royal Society Industry Fellowship *(IF170060 [Morgan] £169k)* to work with local SME (Footfalls and Heartbeats) on commercialising innovations in optical fibre sensing in healthcare. [*Perez-Cota*] was awarded a prestigious Royal Academy of Engineering Fellowship *(RF\201718\\17144, £493k)* to develop a new ultrasound microscope. A license for spatially resolved acoustic spectroscopy (SRAS) for microstructural imaging was made to CPI LLC in the USA to exploit SRAS in engineering companies worldwide and is represented by ICS “SRAS” with Rolls-Royce on materials inspection. OPG continue to break ground in new areas of super-resolution imaging and sensing, materials science and healthcare diagnostics. **Future plans** are to widen the applicability of nano-optics and ultrasonics to biological and manufacturing applications across disciplines to realise the potential that this capability affords.

The Gas Turbines and Transmissions Group (G2TRC) *[Lead Professor C. Eastwick]* conducts research on analysis and understanding of existing and future gas turbine cores and transmissions. It hosts our second Rolls-Royce UTC, in Gas Turbine Transmission Systems [*Garvey*]. Through this collaboration with Rolls-Royce, G2TRC has been able to expand its applicability of low TRL modelling research into experimental verification. **Strategic plans for this period** have been to strengthen the UTC with Computational Fluid Dynamics (CFD) and design methodologies for aero-engine transmissions, enhancing key experimental facilities, and expand research on heat and flow management within transmissions. **By REF2021,** the promotion of academic staff to Assistant Professor [*Ambrose, Dakka, Magnini*], Associate Professor [*Bennett, Jefferson-Loveday, Hyde*] Professor [*Eastwick*] and appointment of 4 dedicated Technicians are evidence of the growth in this research in support of the aims of the Beacon in Propulsion Futures (IS section 2.1a) and the Institute for Aerospace Technology. G2TRC has expanded its experimental testing facilities (£2.85M) to

support computational fluid dynamics expertise and has attracted PWC and Saffran to strengthen their industrial network.

The EPSRC Prosperity Partnership - Cornerstone: Mechanical Engineering Science to Enable Aero Propulsion Futures" *(EP/R004951/1 [Garvey] £6M),* is a collaboration with Rolls-Royce, Imperial College and Oxford University which seeks to enable the transition to all-electric flight. With growing needs to reduce noise and increase efficiency of engines, G2TRC secured over £3.7M from the Aerospace Technology Institute and industry for a three-shaft rig for engine dynamics and £3.45M from the EU's CleanSky2 programme. These projects are delivering industrial impact for example in developments in oil system and transmission design being incorporated into a large civil ultra-high bypass engine (Ultra-fan demonstrator, Rolls-Royce). **Future plans** are to translate from aerospace across energy and electrification settings allowing G2TRC to lead research across mechanical sub-disciplines integrating with electrical and chemical engineering research within the faculty to diversify portfolio.

Power Electronics and Machines Control (PEMC) *[Lead Professor P. Wheeler]* research spans power electronics and electrical machine technology for applications including transportation electrification and the integration of renewable energy into electricity supply networks. PEMC is aligned with the Propulsion Futures Beacon, hosting a fellowship [*Zou*]. **Strategic plans for this period** included delivering the Underpinning Power Electronics 2012: Hub *(EP/K035304/1 [Johnson] £4.1M),* an international centre of excellence for power electronics research; seeking new strategic partners at international level as a clear route to generation and maximising research impact; engaging pro-actively in CleanSky2; and establishing a novel high-impact research programme bridging the gap between advanced manufacturing and power electronics. **By REF2021,** PEMC expanded with appointment of [*Degano, Lophitis, Vakil and Walker*] to academic positions; promotions of [*De Lillo and Gerada*] to research-only position of Principle Research Fellows and [Yang] to Associate Professor. PEMC won UK-RPIF funding (£9.37M) as part of a £52M project to build a dedicated research building (5500 m^2) on Jubilee Campus with our industrial partners committing an additional £19.2M. UoN investment of ~£7M in this building has been augmented with a further £1.5M from the Wolfson Foundation for a 4MW electrical drive train test bed matched with £4.5M of internal investment in electrical drive train facilities with contributions of ~£3.9M from the UoN Propulsion Futures Beacon. In partnership with the D2N2 Local Enterprise Partnership, [*Gerada*] has been awarded £7.6M for a UK Electrification of Aerospace propulsion facility. PEMC partnered on the EPSRC Centre for Doctoral Training *(Sustainable Electric Propulsion (CDT SEP) EP/S024069/1 [Clare] £5.3M)* for training the next generation of UK power electronics specialists. Excellence in training is evidenced by winning the Best PhD of the Year Award in the European CleanSky 2 programme in 2016, 2017 and 2020. [*Yang*] (winner in 2016) is now an Associate Professor in PEMC. The EU-funded CleanSky 2 JTI has £11M of support to date. This has put PEMC at the heart of Aircraft Electrification with industrial and IUK funded projects for electrical propulsion, demonstrated with hardware at up to 4MW. *[Watson and Clare]* have worked with Teledyne e2v on the development of high-power systems for microwave technologies (£154k), an opportunity seeded by work from *[Dodds and Kingman]* on microwave processing. PEMC [*Gerada*] secured the Midlands Centre for the UK Government's 'Driving the Electrical Revolution' (DER) programme to be sited in the new PEMC Building and the Aerospace Technology Centre. PEMC lead the Aerospace-UP programme (£20M with Midlands Aerospace Alliance) funded by the Midlands' LEPs this innovative programme aims to embed knowledge in aerospace-related industry.

These connections and facilities are exploited by the Institute for Aerospace Technology (IAT), (Director [*Bozhko*], Deputy [*Galea*]) which integrates and promotes our multi-disciplinary aerospace research portfolio to provide translational impact. The IAT's 400 researchers work across the faculty alongside both global aviation leaders (including Rolls-Royce, GE Aviation, Airbus, Boeing, BAE Systems, Bombardier and GKN) and SMEs to shape future aerospace technology. IAT is a founder of the UK Aerospace Research Consortium (UKARC) launched at the 2018 Farnborough Air Show, alongside the Women in Aviation and Aerospace Charter of which UoN is a founding signatory. Through a portfolio of 29 EU CleanSky2 (CS2) projects, the IAT works with over 40 partners, including 20 SMEs across seven countries. IAT has won a total of €52.9m; 25% with Airbus, 22% with Rolls-Royce. Example projects include: electrical propulsion technologies including lightweight

generators *(CS2-LIFT, [Gerada] €600k),* power electronics *(CS2-PHiVe [Klumpner] €375k)* and solid-state protection device *(CS2-H2LSPC [Wheeler] €400k)* for the Rolls-Royce and Airbus e-Fan-X demonstrator; and advanced affordable manufacturing and assembly technologies for Airbus Helicopters RACER Compound Helicopter *(CS2-ASTRAL [Ratchev] €2.8M).* This work has impacted the sector through a variety of technological and policy advances including SAE International Aerospace Standards for electrification. ***Future plans***: to expand international partnerships with new state-of-the-art buildings and facilities; with a focus on DER and UK-RPIF projects to enable research impact with our partners.

Low Carbon Energy Research Technology (LCERT) *[Lead Professor H. Lui]* studies and develops cleaner and energy efficient use of energy resources. FoE have invested in LCERT through appointments of [*Meredith, Dimitrou*] (Assistant Professor) and [*Irons*] (Associate Professor) and the promotion of [*Binner*] to Associate Professor. **Strategic plans for this period** were to undertake international research in fossil energy and carbon abatement technologies. **By REF2021,** LCERT secured funding for two CDTs - Carbon Capture and Storage and Cleaner Fossil Energy *(EP/L016362/1 [Snape] £3.5M)* and Resilient Decarbonised Fuel Energy Systems (*EP/S022996/1 [Irons] £5.5M*). As one of the six core academic partners, LCERT secured EPSRC funding for: the "UK Carbon Capture and Storage Research Centre" led by Sheffield *(EP/P026214/1 [Snape] £6.2M];* the "Ultra-Supercritical (USC) steam power generation technology with Circulating Fluidized Bed (CFB)" *(EP/M01536X/1 [Liu] £1.03M); "*The Advanced Building Façade Design for Optimal Delivery of End Use Energy Demand" (*EP/S030786/1 [Wu] £1.7M).* This has enabled us to establish extensive collaborative partnerships with many large industries (e.g. Tata Steel, GE, EDF Energy, Johnson Matthey, Drax, CPL Industries) and SMEs. LCERT CDTs led to the Industrial Doctorate Innovation Centre at Ningbo [*Sun*, *Snape*], funded by Ningbo City to train 100 PGRs on energy in the digital economy. Examples of LCERT's strong international relationships include: the Nottingham/Shanghai Centre for Low Carbon Research, with Shanghai Advanced Research Institute, China; the Joint Research Centre for Transformative Climate and Energy Technologies Research with Shandong University, China; direct funding of ca. US $500k from the Korea Institute of Energy Research. The recent publication on Shale Gas reserves in Nature [*Snape and Meredith*] led to significant coverage (BBC, The Guardian) and provided a basis for governmental decision-making on the future of UK shale gas fracking operations (ICS "HyPy"). **Future plans**: to accelerate the development of low carbon energy and resources technologies, training engineers of the future to help de-carbonise the power, heat and industry sectors.

1.3.2 Revitalise – Pre-existing groups going through reinvention

Fluids and Thermal Engineering Group (FLUTE) *[Lead Dr. B. Hewakandamby]* works on the fundamental and applied aspects of fluid mechanics and thermal energy in engineering systems. Following the retirement of Professor Shayler in 2016 and the deaths of Professors Azzopardi and Power in 2017, FLUTE has been renewed through investments in personnel and the consequent expansion of research areas. The appointments of [*Mao*] in wind turbine modelling, [*Jabbal*] in aerospace aerodynamics, and the strategic appointment of [*Cairns*, 2016] in automotive propulsion, has diversified FLUTE from internal combustion engines to sustainable energy and electrification. **Strategic plans for this period:** were to the application of fluid and particle science, focusing on those areas where scientific understanding is a barrier to application in a range of industries, including the process industry, aerospace and automotive. **By REF2021**, FLUTE has continued to develop aerospace systems to reduce power consumption and noise, e.g. GAINS *(H2020 CS2 [Choi] £760k)* with Meggitt Plc on smart ice protection systems. [*Cairns*] has established the Powertrain Research Centre working in close collaboration with major OEMs (JLR, Tata, Ford, Caterpillar), energy companies (Shell, BP), Tier 1 suppliers (MAHLE, GKN, Denso) and numerous SMEs *(IUK "Advanced Integrated and Cooled Electric Drive" [Yan, Cairns, Gerada] £1.4M)* in collaboration with PEMC. [*Cairns*] leads the EPSRC Sustainable Heavy Duty Truck, Marine and Rail Transport project on electrification *(EP/T025522/1, £1.1M)* as well as research for CO_2 reduction, improved refinement and extended service intervals, particularly through research on soot-in-oil *(EP/N50841X/1, EP/N50841X/2 [Cairns] £230K, £111k); (IUK102660 [Cairns] £174k).* Research on friction and lubrication engineering builds on this base, linking further with industry a new UK national facility has been created to allow testing of up to 3 drives (transmissions) to support IC engine research. This activity has been recognized through Research England's Strength in Places fund where [*Cairns*],

working with the Propulsion Futures Beacon, GKN and Cummins secured feasibility funding (£50k) to develop a proposal for Trans-Mid: a £50M centre on transport and electrification. **Future plans** are to further the underpinning science for specific industries, i.e., transportation, manufacturing, environment protection and process intensification.

Human Factors Research Group (HFRG) *[Lead Professor G. Burnett]* investigates the application of human/person centred theories, methods and approaches to tackle contemporary, real world challenges faced by individuals, organisations, communities and societies, across a variety of application domains. Previously led by [*Sharples, Cobb*], HFRG has been supported by fellowship investments [*Houghton, Harvey*], and Assistant Professor positions [*Lang*] to expand capability in the medical area. **Strategic plans for this period** were to develop international impact, expanding activities into new areas of science and technology by addressing the challenges of big data and requirements for visualisation of large condition monitoring, sensor-rich data sets. **By REF2021**, HFRG has pursued international links with Virginia Tech through, for example, collaborative PhD supervision funded by the USA National Science Foundation International Research Experiences for Students programme. HFRG have hosted 11 Virginia Tech students between 2014 – 2018, supported by FoE and Rieger scholarships (see Section 3.1.2) to facilitate studies at Virginia Tech [*Topliss; Lamas; Eren*]. HFRG have extended their vehicle simulation activities, developing a strategic research framework with key automotive partners (including with its long-standing relationship with Jaguar Land Rover (JLR) on autonomous vehicles (~£728k direct investment on projects)). The JLR relationship has underpinned our ICS on Human Machine Interfaces. HFRG has led projects developing partnerships between academia and industry in digital manufacturing (e.g., Digital Toolkit for optimisation of operators and technology in manufacturing partnerships (DigiTOP) *(EP/R032718/1 [Sharples] £1.9M);* and Connected Everything II: Accelerating Digital Manufacturing Research Collaboration and Innovation *(EP/S036113/1 [Sharples] £1M)).* These platforms have engaged with the Industrial Strategy Challenge fund, specifically, Made Smarter *[Sharples]* with colleagues from AMT [*Ratchev*]. HFRG's link with the School of Computer Science has been cemented through the Horizon Digital Economy Centre and Centre for Doctoral Training *(EP/L015463/1 [Sharples] £3.36M; EP/S023305/1 [Sharples] £5.8M).* These activities formed the basis and impetus, along with manufacturing research, for the formation of the Smart Products Beacon which has had internal investment of £1.1M. **Future plans** are to exploit expertise around autonomous vehicles and electrification, and development of new areas of research in healthcare linking with our Centre for Healthcare Technology.

Nottingham Geospatial Institute (NGI) *[Lead Professor S. Marsh]* is cross-disciplinary, with specialisms including satellite navigation and positioning systems, geospatial engineering and spacecraft engineering and avionics. Previously led by [*Moore*], [*Marsh*] was an appointment from the British Geological Society (BGS) in 2013. NGI saw the retirement of [*Moore and Aquino*] in 2020 with renewal supported through appointment of 2 Assistant Professors ([*Cappaletti, 2018*] (Satellite Design and Manufacture) and [*Grebby, 2016*] (Earth Observation)) with [*Grebby*] linking the group into the GeoEnergy Research Centre, a joint venture between UoN and BGS. **Strategic plans for this period** were to pro-actively engage with stakeholders to maximise research impact. **By REF2021**, [*Bingley*] continues to lead the NERC British Isles continuous GNSS Facility, expanding into new multi-disciplinary areas to advance the science of positioning. Partnerships, with the Satellite Applications Catapult, and subsequently with Future Cities Catapult were key to delivery of this strategy. [*Marsh*] is working on earth observation providing collaboration between NGI and research within the Rights Lab Beacon supporting their ICS "Fighting Slavery from Space". A major success supports the development of next generation of geo-spatial scientists through an EPSRC CDT in "Geospatial Systems" led by Newcastle *(EP/S023577/1 [Marsh] £6.8M).* GRACE (the Geospatial Research and Applications Centre of Excellence) continues to engage with businesses for consultancy, training, testing and business incubation (211 in the period), supporting the European Space Agency's (ESA) Regional Ambassador Programme (Midlands and North East, 2020) to connect local companies via ESA business applications. **Future plans** include expanding relevance through the IRC "Transport, Mobility and Cities" (IS Section 2.1a), to enable new applications in both Earth Observation and positioning technologies, and to capitalise on the development of small satellites to carry relevant sensors and the architectural applications of our data and technology.

Our **Infrastructure Engineering Grouping** includes a range of interdisciplinary activities with research goals focussed on the built and natural environment. These include architecture, resilience, civil and environmental engineering disciplines, together contributing to research related to Energy and Transport with specific links to the Smart Products and Propulsion Futures Beacons. **Strategic plans for this period** were to consolidate areas of strength and exploit these focused activities with industry, national and international funders.

By REF2021:
Architecture, Culture and Tectonics has broadened the scope and reach of FoE's research impact. [*Beccarelli*] has published new industry-standard testing methods for fabric structures, applied to the design of novel lightweight and deployable buildings through Knowledge-Transfer-Partnerships (inside2outside Ltd. KTP11330; Holscot Fluoropolymers Ltd KTP010169). [*Hale, Hanks* and *Wang]* have engaged internationally on their work on museum architecture and exhibition design. This led to the "world-first" exhibition of Chinese Dinosaurs, attracting visitor numbers of 130,000 to Nottingham (Wollaton Hall 2017) with notable awards following (e.g., The Guardian's Internationalisation Award 2018; Regional Heritage Award 2019), a route for CPD training for museum practitioners (e.g., 134 delegates across 17 provinces in China and winner of Times Higher International Strategy of the Year Award 2017); and influencing two new museums under construction in China.

In Structural Engineering, FoE have invested in four new academic appointments at Assistant Professor: [*Ghiassi, 2018; Ninic, 2018; Thermou, 2018; Wang, 2020*], Thermou transitioning from a Marie Curie Individual Fellowship. This has expanded research into new fields including structural and computational mechanics and biomimicry *(Leverhulme Trust [Liu] £323k);* and simulations for multi-level Analysis of Interactions in Tunnelling based on BIM technology, *(H2020-MSCA-IF-702874 [Ninic] €196k).*

To understand the effects of geo-processes in earth, systems, water, sediments and atmospheres, work in Environmental Fluid Mechanics has linked into the GeoEnergy Research Centre (GeRC), in collaboration with the Schools of Mathematics, Chemistry and BGS [*Rigby*] and the NERC Centre for Doctoral Training in Oil and Gas ([*Rigby*] led by Heriot Watt, Total £4.3M). Environmental fluid mechanics research has been applied to a range of environmental situations, such as particle collisions *(EP/M005860/1 [Turnbull] £763k)* with [*Munro*] regularly publishing in the Journal of Fluid Mechanics on the fundamentals of fluid interactions at boundaries for geophysical applications. In geology and geo-processes, CGI IT UK Ltd works with The School of Geography and [*Large*] on UK Space Agency funded Peatland Assessment in SE Asia with Satellites (PASSES) £235k. This work has led to collaboration with the Indonesia Government (2017-On) [*Muljadi*] (section 4.1).

In Geomechanics, [*Hall, McDowell, Marshall* and *Heron*] investigate fundamental and applied geomechanics, specifically for soils and granular materials. Funding for fundamental science has been secured from EPSRC: "Discrete element modelling of clay" (*EP/S016228/1. [McDowell, de Bono] £508k); and* "Discrete Element Modelling of Critical State Soil Mechanics" *(EP/L019779/1. [McDowell] £414k* with McDowell awarded the 2018 British Geotechnical Medal by The British Geotechnical Association. Applied research with the rail sector has supported the science and analytical tools to design long life, low noise railway track systems (led by Southampton) (*EP/M025276/1 [McDowell] Total £5.2M).* Support has been received from the EU Research Fund for Coal and Steel *(H2020-RFCS-SUMAD-847227; H2020-RFCS-RAFF-847299 [Heron and Marshall] £1.1M)* on sustainable use of mining waste. Geomechanics forms part of the Energy Research Accelerator (ERA) (see section 3.1.1); funding from ERA was allocated *(BEIS-160052 [Garvey] £1.6M)* to demonstrate CO_2 injection, borehole testing and sequestration with BGS in the Trent Basin. This has led to collaborations with the University of California, Berkeley; and National Yunlin University of Science and Technology, Taiwan, on tunnel and offshore modelling and with industry partners (e.g. ARUP and Golder Associates).

Geomechanics informs our Pavement research activities that address transport infrastructure, smart materials and sensors, ballast and subgrade stabilisation (e.g. Whole-life Cost Assessment of Novel

Material Railway Drainage Systems *(EP/M023028/1 [Marshall] £592k)*; Pavement LCM *(CEDR-16740708 [Airey], £141k);* intelligent infrastructure (e.g. SMARTI ETN *(H2020-MSCA-ITN- 721493 [Airey] £983k));* coastal modelling (e.g. The Morphodynamics of Large Bodies of Sediment in a Macro-tidal Environment *(EP/N007379/1 [Dodd] £395k);* and self-healing materials *(EP/T019506/1 [Thom] £385k).*

In Resilience Engineering, our research is dominated by direct industry funding related to large infrastructure investments, understanding their assets and risks. Relationships with Network Rail (since 2009) and Lloyds Register Foundation (£3.2M and £1.9M respectively) have expanded our portfolio as members of UKRRIN (UK Railway Research and Innovation Network). Resilience has expanded into nuclear safety prediction working with BARC and IGCAR Indian Nuclear Research Centres *[EP/R021988/1 and EP/M018210/1, Andrews, £707k].* This initiated collaboration with University of California, Los Angeles, Norway Safety Modelling, and industry (e.g., Rolls-Royce, HS1, HS2, FirstGroup, BAE Systems). Our resilience experts chair three Technical Committees for the European Safety and Reliability Association (ESRA) - Mathematical Methods in Reliability and Safety *[Andrews],* Aeronautics and Aerospace *[Prescott]* and Healthcare and Medical Industry *[Remenyte-Prescott]* which has enabled contribution to best practice of safety and reliability techniques and risk management.

Future plans for infrastructure engineering are to continue to consolidate areas of strength, expanding the influence of these activities through the IRC "Transport, Mobility and Cities" (IS Section 2.1a) to highlight the potential applicability of this work and its influence on funders.

1.3.3 Emergent

Food Water Waste (FWW) *[HoRG: Lead R. Gomes]* was initially established as the Food Engineering Research Group in 2017, subsequently expanding its research remit in 2018 to include the broader food lifecycle and to deliver sustainable and resilient solutions to global challenges in the areas of food, water and resource security. **Strategic plans for this period** were to work alongside UoN investments in the Future Food Beacon, including the strategic appointment of academic roles (Professorial [*Bakalis* (2017); *Cullen* (2017)] and Assistant Professors [*Ferrari* (2016); *Gouseti* (2017); *Watson* (2014)] and 3 Fellows [*Gomes, Mora, Vats*]. **By REF2021,** the group has taken lead of the IRC "Water Works" (IS section 2.1a) and contributes to the EPSRC Connected Everything II Network Plus award (*EP/S036113/1 [Sharples] £1M)* with [*Watson*] bringing together academic and ECR colleagues in Digital Manufacturing. [*Gomes*] was promoted to Professor in 2020 and is a member of the EPSRC Early Career Forum in Manufacturing Research. Gomes heads Water Quality for the Leverhulme Trust 'Modelling and Analytics for a Sustainable Society' Doctoral Scholarship Programme *[DS-2014-024 [Gomes, Walker] £378k)* led by our School of Mathematical Sciences. FWW has targeted sustainable development activities through International Fellowships (e.g. *Royal Society NIF\R1\181345, £100k*) to tackle global issues such as antibiotic contamination of wastewater. **Future plans** are to increase critical mass to facilitate both discovery and delivery of global solutions to address complex industrial, environmental and societal challenges associated with the management of food, water and waste processes and products.

Sustainable Process Technologies (SPT) *[Lead: Professor A. Conradie].* Sustainable Process Technologies was established in 2015 to directly support the Beacon in Green Chemicals. **Strategic plans in this period:** Provide technology aimed at clean growth through circular economies and decarbonisation. **By REF2021** a relationship with Lucite International was established alongside new collaborations with Unilever, Johnson Matthey, CRODA, Biome Bioplastics and AB Agri. In addition, institutional relationships have been made with CPI, IBioIC and the Manchester Institute of Biotechnology. SPT directly contributes to the Green Chemicals Beacon and has formed collaborations with colleagues in the School of Chemistry [*Moody and Licence*] through the EPSRC Centres for Doctoral Training in Sustainable Chemistry *(EP/L015633/1, £5.3M) and Atoms to Products (EP/S022236/1, £6.2M)*; and also, with the Beacon of Excellence in Future Foods. The Beacon funded sustainable processing facility (£1.1M) places the group at the forefront of producing biochemicals and biofuels from renewable feedstocks exploiting their work in the use of enzymatic

polymer processes and ionic liquids and, as a result, [*Conradie*] successfully secured the "Continuous bio-production of commodity chemicals" *(BB/N023773/1 [Conradie] £1.58M)* project and "Sweet Perspex" *(IUK103761 [Conradie] £400k)* in collaboration with Lucite Intl. **Future plans** are to work with national and international centres of excellence, and create a shift away from the linear take-make-use manufacturing framework, towards circular economies for future of clean growth.

1.4 Future research strategy beyond REF2021

Our future research strategy is to energise and capitalise our pipeline of research through a greater emphasis on the place and sustainability agenda. This will support our University strategy: *cementing global, societal and economic problems at the core of our research, through specific alignment with the United Nations Sustainable Development Goals.* Given the uncertainty of the external landscape and the likely changes to funding due to the economic impact of the Covid-19 pandemic, this is the time to do what engineers do best – resolve challenging problems to improve society through the following objectives:

Enabling our people through excellence and equality of support and environment with targeted interventions to support the highest quality Research, Knowledge Exchange and Impact.

Partnering with local, national and internationally diverse stakeholders enabling the benefits of our research to impact society through improved sustainability, health and well-being and socio-economic impact.

Embedding Equality Diversity and Inclusion within our research and knowledge exchange ecosystem, providing opportunities for all our staff and students to perform at their best.

Addressing key societal, industrial and environmental challenges within our research through specific targeting of UN Sustainability Development Goals within our portfolio.

2. People

Staff development and recruitment is our primary strategic objective in "talented people and teams" embodying both the recruitment and retention of the best talent and providing support to *all staff from all job families* and recognise and reward the delivery of our values and priorities. As a faculty of 828 staff (Academic Research & Teaching 214; Teaching & Learning 64; Post-Doctoral Research Associates 283; Administrative, Professional & Managerial 123 and Technical Services 144) our duty is to support all staff with specific support.

We actively seek diverse, collaborative and supportive teams across the faculty through the following strategies and actions that have been established to embed these values. Further, as a Faculty, a responsible and proactive approach to Health and Safety is vital, as it underpins all our research, we have further enhanced our safety culture and its management through systematic development of protocols and procedures, supported by a dedicated H&S manager [*Braithwaite*].

2.1 Recruitment and Retention

Working with Diversity by Design in 2017, FoE initiated and led work to support application to academic posts from under-represented groups through expansion of the applicant pool and removal of unconscious bias from the selection process. This led to the EPSRC project "STEMM CHANGE" *(EP/S011897/1 [Kingman] £524k)* that worked alongside the Schools of Physics & Astronomy [*Burrage*]; American & Canadian Studies [*Salt*], English [*Mullany*], Medicine [*Walker*] and Psychology [*Wilding*] to embed inclusivity in our recruitment processes and PGR recruitment through DTP and CDTs. The progress of our work in EDI is evident through our Athena SWAN Gold Award (2020) (section 2.2), the first UK engineering unit to receive such recognition.

FoE has embraced the UoN "100 fellows" initiative, known as Nottingham and Anne McLaren (female STEMM) Research Fellowships (IS section 3.2) (NRF and AMF respectively). We have recruited 11

NRF and 6 AMF since 2014 to bolster our research activities. Each fellowship represents investment of ~£250k providing 3 years of concentrated research to establish research leadership before transition to a permanent academic post.

To support non-traditional diverse career paths, we have engaged with Daphne Jackson Trust Fellowships that encourage "return to research following career breaks" (2 awards), enabling [*Luo*] to secure a Leverhulme Fellowship (2019). An AMF award in 2009 has supported [*Gomes]*, with her taking up the role of Head of the Food Water Waste Research Group and being promoted to Professor (2020). Both [*Luo]* and [*Gomes]* were recognised for their research contributions and been named as "Top 50 Women in Engineering 2020: Sustainability" by the Women's Engineering Society (WES).

Co-recruitment has enabled development of strategic collaboration, including [*Gradoni*] (School of Mathematical Sciences, now Royal Society Industry Fellow at BT Cambridge), and [*Mata*] (School of Pharmacy). Through external fellowships we have recruited staff with prestigious awards, including [*Mather*] (European Research Council Consolidator award (ERC-683108, €2.43M)), Marie Curie Individual Fellowships [*Jaeger, Zhu, Ghiassi, Thermou, Zhu, Weaver, Pillai, Yuan, Sujecki, Rengasamy, Jiang, Meng, Ninic, Psimoulis*]; and [*Powell] (Royal Academy of Engineering Research Fellow)*. Our Director of Research Excellence *[Clark]* sets and supports our fellowship strategy for internal, UKRI, Royal Academy of Engineering and other opportunities.

2.2 Equality, Diversity and Inclusion

Our Equality, Diversity and Inclusion Board (FEDIB) is co-Chaired by the Faculty PVC [*Kingman*] and [*Ridgway*]*;* it includes 22 members of staff from all job families including researchers, technical, professional and academics. FEDIB promotes EDI principles, considering the impact of policy and processes on all staff and students with protected characteristics.

We are the first UK Engineering unit to receive an Athena SWAN Gold award recognising and celebrating our leadership and practices towards the advancement of gender equality: representation, progression and success. Our action plan targets a range of interventions to ensure equity of opportunity and treatment for all staff and students involved in research such as: research staff promotion workshops; supporting women in the preparation of promotion applications (between all levels); senior role shadowing targeted towards under-represented groups; new training for interview panellists and identifying career development needs; and improving access to training, flexible working and uptake of parental leave. FoE supports the UoN's Sphere Programme, a key element of UoN's equality diversity and inclusion delivery plan. For example: our "Curious about Identity" training event ran in March 2020 to 55 people to support Trans-inclusive workspaces; and activities as part of the Women in Aviation and Aerospace Charter (WiAAC) network (143 signatory organisations from all parts of the UK including Universities, OEMs, SMEs, contractors, airports and membership organisations). UoN is a founding signatory of the WiAAC coordinated through our Institute for Aerospace Technology. We influence the wider EDI discussion in engineering research through *[Sharples] UoN PVC of EDI* and chair of the EPSRC Strategic Advisory Group on EDI. All research responsible staff have attended mandatory EDI and unconscious bias training in 2019.

REF Eligibility and Support: our policy is that all eligible staff are included in REF2021, supported by digital content, workshops and roadshows to ensure familiarisation with the REF strategy. We support the holistic contribution to the REF submission, avoiding explicit reference to number of outputs for an individual in order to balance genders, job roles and cultural background in selected outputs for submission in REF2021. Comparing our REF eligible staff (19.6% female, and a total of 22.7% from Black, Asian and Minority Ethnic (BAME) groups), with our HESA contracted staff (19.8% female and 23.5% BAME), we are confident in the inclusivity of our processes. Support has been provided to a range of staff groups and role levels for outputs and impact cases studies, accessible to all, including those with caring responsibilities and part time staff; for example, specific funding was provided to staff for extended leave to complete high-quality outputs [*Ekici, Mirzaei, Porter, Hanks*]. Dedicated staff (1.3 FTE) have been tasked to encourage and develop research excellence within FoE and alignment with UoN's REF code of practice.

Career Development: our annual (since 2018) Faculty Promotions Workshop event for Research Staff, mirrors our R&T promotions workshop best practice with targets to increase in number of research staff applying for promotion (Research Fellow to Senior Research Fellow) each year (starting from 6% in 2017). We aim to have parity of success rates for women and men applying for promotion to Senior Research Fellow (SRF) by 2022. Between 2014-16, we had no female applications for promotion to SRF, but between 2017 -19 this increased to 6 applications with a 67% success rate compared to 16 from male colleagues at a 75% success rate. For promotion from Assistant to Associate Professor, female success rates are higher than male (89%:72%). We prompt all Research staff to consider gaining teaching experience via their "Appraisal and Development Conversation" (ADC) with this being supported through courses within the Researcher Academy with a view to staff gaining recognised status with Advance HE. We insist on equal recognition and representation of all staff in research contributions, e.g., technical services staff in publications.

For mid-career staff, we link staff to development courses through needs raised at ADC. We provide workload balancing ensuring that women at Associate Professor are not disproportionately administratively loaded, protecting their research time. Group mentoring for women is offered by UoN's PVC for EDI and we have a process of encouraging application for promotion through best practice workshops and Faculty PVC 1:1 meeting with staff considering applying for promotion from Associate Professor to Full Professor, providing guidance and feedback to strengthen applications. In 2020 the results of this approach were a 100% success rate for academic promotions to Professor, with a 5:2 female to male ratio and an overall 90% success rate across all promotion levels.

2.3 Researcher Career Development

Induction is supported by our HR team (2.0 FTE) with all academic staff meeting heads of operational services and given personal research planning support in consultation with their HoRG, their ADC reviewer and our Engineering Research & Knowledge Exchange (ERKE) support team (18.9 FTE). Mentors are assigned to new academic staff and staff are supported at all stages of research development through ERKE including representatives from Contracts and Digital Research. ERKE supports the ambition, success and quality of our research and knowledge exchange activities including the facilitation of a number of initiatives within the faculty from post-doctoral training to research leadership.

2.3.1 Career Mentorship, Support and Leadership

FoE established Engineering Research Futures (ERF) in 2017 providing guidance and support for our research community. ERF includes representatives from our research groups at differing career stages and an academic champion [*Ahmed*] (Researcher Academy Faculty Lead). UoN's Researcher Academy (IS section 3.1) facilitates the strategy around the Concordat to Support the Career Development of Researchers, with ERF supporting local delivery. As well as teaching opportunities, FoE enables all research staff to gain sole-supervisory experience through the Nottingham Summer Engineering Research Programme for undergraduates. **Early Career Researchers (ECRs)** are supported through our Enhancing Excellent Engineering Research (E3R) training programme to establish/refresh their research career and develop a sustainable portfolio. Support consists of regular face-to-face meetings to discuss personal research plans plus fully-funded PGR studentship and cash support for travel, networking and research expenses. Targeted sessions are provided (e.g., EPSRC New Investigator Award Scheme, Introduction to Innovate UK etc.). E3R provides peer networking to discuss similar challenges and potential collaborations and one-to-one or group sessions to cover topics such as publications, Impact or Intellectual Property (IP). The Concordat Career Development of Researchers, Vitae Researcher Development Framework and changes to the funder strategy are used in planning and development of E3R sessions in conjunction with the UoN Researcher Academy. Where relevant they are supported by research leaders and central teams e.g., Research Data Management, Knowledge Transfer Partnerships (KTP).

Policies and processes for research and impact leave are based on fair and transparent practices. We provide **Impact and Policy leave** for staff to focus on the outcomes of their research, publications or impact case-studies. Exemplars include [*Wildman, Wilson*]. Further policy-based support is available through the UoN Institute for Policy and Engagement, where dedicated support

can be found for policy activities. Examples include public and policy engagement streams of large grants (e.g. Trans-Mid), opportunities for contribution to policy enquiries (see section 4.3) and delivering training and seminars on how to engage with policy makers and the public.

Supporting mid-career academics (MCAs) is vital to accelerate or re-energise their research portfolio, with this support being particularly useful for staff moving from leadership roles back to research [*Pickering, Large, Wilson*]. Support is provided to identify external opportunities and collaborations, opportunities to influence and gain experience through panels, consultation events, networking with stakeholders, influencing policy etc. We seek to support staff into industry secondments covering teaching commitments (e.g., Rolls-Royce [*Clare*]; MTC [*Leach*]; Jaguar Land Rover [*Burnett*]). Our strong relationship with Rolls-Royce has led to the Royal Society appointing its first "Entrepreneur in Residence" [*Winton*] to accelerate links with business, and to increase the impact of our research (see section 1.3.1).

To develop **effective research leadership**, FoE uses the UoN Leadership and Management Academy (LMA) programmes to develop leaders at all levels and job families. In addition, the UoN Florence Boot Programmes support women's development through formal training and informal networks. Engineering initiated the Future Leaders Programme (FLP) in 2013, since then 83 staff have participated, with the 2017 intake having its first technical services member. The LMA has supported staff into leadership positions (e.g., APVC RKE [*Tuck*]; Director of Admissions [*Clare*]; Heads of Research Group e.g., [*Eastwick, Gomes*]). FoE's Research Leaders Network (RLN) provides an environment for heads of research to meet with each other to share best practice, discuss issues, and provide informal mentorship. Chaired by the APVC RKE, the network includes: Research Directors, Heads of Research Groups, ERKE, as well as external business partners from digital research, libraries, research & innovation (R&I).

Our 144 technical services staff represent 23.8% of this University staff group and play an essential part in our research success. As a University we have recognised this through our founding signature on the Technician Commitment (IS section 3.4), a sector wide initiative to ensure visibility, recognition, career development and sustainability for the technical community in higher education and research. Locally, we have gone further with technical staff through the involvement within the EPSRC programme 'Inclusion Matters' [*Vere and Kingman*]. Our four-year apprenticeship scheme for trainee technicians was the first in the UK to be accredited (2015) by the Institute of Mechanical Engineers. One of our trainees *[Sewell]* won the bronze medal for CNC Milling at the World Skills National finals in November 2019. Leadership in Technical Services continues beyond 2020 through the Research England TALENT programme *[Vere]* (section 1.2.3).

Supporting part-time, job share and remote working practices. Flexible working is possible across all job families. We support staff on maternity and paternity leave through tailored work patterns on return [*Wright*], by supporting work-related training through the UoN Conference and Training Care Fund for those with childcare constraints and (following positive feedback in 2019) formal shared parental leave. The impact of these mechanisms is evidenced through successful promotions [*Binner, Rodrigues*]. These initiatives are supplemented by UoN's guides for Psychological Wellbeing and the Avoidance and Management of Stress that provide guidance on counselling services and Occupational Health for staff returning to work. Our network of Dignity Advisers provides impartial and confidential advice to staff with issues/concerns regarding harassment, bullying or victimisation. Staff can take research leave or sabbaticals to focus on research (including publication) or impact activities (section 2.2). Our policy for research and impact leave is based on fair and transparent practices.

Health and well-being activities – creating a healthy, collegial community. Recognising its importance, FoE initiated a staff well-being programme for staff in 2017 (investing in the "Juice" platform developed at the University of Sheffield). In that first operational year, 364 Juice users registered, with participation high in the Virgin Pulse Global Challenge competition, requiring 10,000 steps a day over 100 days in teams of seven. This annual event has since seen around 40 teams participating each year.

Celebrating success. Individuals and teams are recognised through the Nottingham Reward Scheme (NRS) and exceptional contributions recognised through the Vice-Chancellor's medal (e.g., 2020 [*Morgan*] translational work in healthcare; [*Gomes*] circular economy of water; 2018 [Wang] Dinosaurs of China Exhibition). For celebrating excellence in KEI, UoN has a biennial awards ceremony to which more than 250 colleagues, industry and civic partners from the UK and across the world are invited. Engineers were recognised for: On-wing robotics technologies with Rolls-Royce [*Axinte et al.*]; Camstent [*Irvine et al. awarded the Faculty of Science prize*]; Antislavery Data [*Marsh with the team awarded the Faculty of Social Science prize*]; and the prestigious Vice-Chancellor's award for Sustained Excellence in Knowledge Exchange [*Hayes-Gill*] in 2019.

2.4 PGR Students

PGRs are an integral part of our research community, culture and environment. Our PGRs are supported by trained supervisors, with access to dedicated facilities and IT resources (see section 3.2), training and wellbeing support.

Table 2. PGRs Awards 2014-2020 (total headcount based on supervisor share in UoA12)

Year	13/14	14/15	15/16	16/17	17/18	18/19	19/20
Total Registrations	524	531	570	525	528	528	542
Awards	145.99	123.2	133.93	142.32	159.47	147.85	135.65

Our strategy to attract, retain and support world class PGRs includes enhancing recruitment processes and procedures; providing a high-quality research and training experience; and improving access to resources and funding. Our Director of PGR [*Porter*] and Deputy [*Bennett*] implement this strategy supported by:

Faculty Research Operations Group (FROG): allocates internal and DTP funding based on applicant quality and staff support requirements.

Postgraduate Research Experience Group: oversees PGR experience, progression and training. Chaired by Deputy Director of PGR, with academic, administrative and PGR student representatives.

Postgraduate Research Engineering Community: the main student representative forum, provides feedback on all aspects of PGR experience. Each research group is represented with the Director of PGR and representatives from Students Union, Student Services and Digital Learning.

Post Graduate Engineering Society: an active, student-run society that organises social events (e.g., PGR Gala).

We attract future research leaders by promoting our PGR offer to a wide audience and embedding EDI principles in our processes. Our processes are informed by our work in the STEMM Change project (section 2.1), e.g., by anonymising all faculty funded studentship applications with all research leaders and FROG members undertaking unconscious bias training. Our PGRs are funded from various sources, including UKRI, industry, internal, sponsored and self-funded. FoE offers a number of studentships:

FoE awards (£1.9M p.a.)

FoE Research Excellence Scholarships for outstanding international students. 56 full scholarships; 20 fees only (26 female/50 male) awarded since 2015.

Vice Chancellor's Scholarship for Research Excellence rewards for outstanding EU students. 13 (5 female/8 male) awarded since 2015.

Nottingham Engineering Excellence Scheme (NEES) Scholarships (5 p.a.) support UoN's top performing Home undergraduate students to enter our PhD programmes, supporting fees and an enhanced stipend. 8 (4 female/4 male) awarded since 2018.

Neville Rieger Scholarships (section 3.1.2) for fees, stipend, research travel or consumables. 6 (2 female/4 male) awarded since 2017 supported by philanthropic donation.

George Bethell Scholarships in novel Materials processing from 2020/21 onwards (section 3.1.2) supported by philanthropic donation.

We are involved with **10 Doctoral Training Programmes (DTProg)** in collaboration with other universities and industrial sponsors. We lead four Centres for Doctoral Training (CDT):

Additive Manufacturing and 3D Printing *(EP/L01534X/1 [Tuck] £4.6M)* with Universities: Loughborough, Newcastle and Liverpool and 23 sponsors (e.g., GlaxoSmithKline (GSK), Materialise, MTC, Nikon, Pfizer, Renishaw, Siemens).

Carbon Capture and Storage and Cleaner Fossil Energy (*EP/L016362/1 [Snape] £3.5M)* with Universities: Sheffield, Loughborough, Birmingham; the British Geological Survey (BGS) and 43 sponsors (e.g., Caterpillar, Castrol, EDF, GE, Tata Steel).

Resilient Decarbonised Fuel Energy Systems *(EP/S022996/1 [Irons] £5.5M)* with Universities: Cardiff, Sheffield; and 38 sponsors (e.g., Chinese Academy of Science, EDF Energy, Energy Systems Catapult, General Electric Company, Johnson Matthey). Aligning with projects including the Energy Research Accelerator *(BEIS-160052 [Long] £17.41M).*

Sustainable Hydrogen *(EP/S023909/1 [Walker] £6.6M)* with Universities: Loughborough, Birmingham, Ulster; and 37 sponsors (e.g., the National Grid, nPower, BP, ARUP).

We partner in a further six - **Horizon My Life in Data** *(EP/L015463/1 [Sharples] £3.36M)*; follow-up **Horizon: Creating Our Lives in Data**. *(EP/S023305/1 [Sharples] £5.8M)*; **Atoms-2-Products** *(EP/S022236/1 [Wildman] £6.2M);* **Transformative Pharmaceutical Technologies** *(EP/S023054/1 [Wildman] £6.4M);* **Geospatial Systems** *(EP/S023577/1 [Marsh] £6.7M);* and **Power Electronics for Sustainable Electric Propulsion** *(EP/S024069/1 [Johnson] £2.*5M). In addition, we participate in BBSRC and EPSRC Doctoral Training Partnerships in collaboration with the Faculty of Science. These have had a positive impact on our overall training, research and teaching environment, for example specialist courses now embedded in MSc modules, and cohort development activities e.g., joint workshops and cross-faculty conferences.

2.4.1 PGR training and supervision

Irrespective of funding source, every PGR benefits from a Faculty-based programme of induction, training, supervision, research group events, dedicated administrative and wellbeing support. Five induction events p.a. welcome new starters and ensure awareness of the support and resources available. A PGR Moodle page provides an online one-stop-shop for all PGR related information, established in response to student feedback. PGRs complete a skills audit during our induction programme providing support with training courses and resources available to them.

PGR training is organised with UoN's Researcher Academy in line with the Vitae framework. Over 20 sessions are offered annually, supplemented by those offered in CDTs and research groups. Courses are annually reviewed with PGR input, supporting specialist training, transferrable skills development and future career planning. To progress, all PGRs must complete mandatory **research integrity** training in their first year. Peer learning between PGRs is enabled via the Annual Engineering Research Showcase, a community-building event including a 3-minute thesis competition, seminars and a Gala Dinner. We fund teams in the Engineering Young Entrepreneurs Scheme (YES) each year. In 2016, FoE PGRs won YES for a cot death-reducing domestic baby heart rate monitor using green light technology.

Quality PGR supervision is ensured through:

A supervisory *team* for each PGR, with a minimum of 2 supervisors in place providing continuity and support to both PGRs and less experienced staff.

Recorded meetings are mandatory (min. 10 p.a.). Supervision provides specialist support in all aspect of research planning, methodology, funding, publication, and completion.

PGR supervisors are in turn **supported by Researcher Academy** supervisor training courses and the Faculty research operations team.

PGR student supervision between newer and established supervisors is encouraged; supervision alongside academic staff colleagues is formally considered in the promotion of post-doctoral staff.

Both the Engineering Student Support & Wellbeing team and the University Welfare teams support supervisors to ensure PGRs are referred and signposted appropriately for additional requirements. Eight PGR Advisers (6 male, 2 female), comprising academic staff across disciplines, offer independent advice on academic and pastoral matters. Our Disability Liaison Officer for PGR students ensures that adjustments are recorded, and supervisors are kept aware. These resources, along with Researcher Academy responses ensured additional support to PGRs in response to Covid-19 in 2020.

3. Income, infrastructure and facilities

Effective and efficient research performance is our third strategic objective and is driven through a pipeline approach, seeding new activities, supporting established capability and reinvigorating areas in flux and ceasing areas where appropriate. This has supported our input into the 6 Beacons of Excellence referred to in Section 1 through investments in people and resources across specific research areas. Growth in research awards has been 73% (£272.1M from 1168 projects) since REF2014 (which saw awards of £156M, 851 projects for UoAs 15 &16); our targeted increase was 10%. Awards have the following breakdown: UK Research Councils (£97M), IUK (£45M), EU (£50M), Industry (£62M) and charities (£4M). In outputs we have increased in Top 10% by SNIP (39% in 2015 to 51% in 2020, Filter: Engineering, Scival). To support this increase in activity we have invested and expanded our administrative support from 9.2 FTE (2014) to 18.9 FTE (2020); in addition, we ring-fence an annual infrastructure budget of ~£875k.

3.1 Strategic Support for Research

FoE invests ~£2.5M p.a. directly in research, split between PGR scholarships (£1.9M), research groups (£0.5M), early career researcher (ECR) start-up funds (~£2k p.a. for 3 years) plus incentives for KTP, conference funding and a £100k strategic opportunities budget (e.g. The Nottingham Energy Institute). PGR scholarship allocation prioritises our ECRs and (where appropriate) strategic grant applications. Additional investments have been made in areas of strategic importance, for example through University flexible investment funding business cases supported by FoE for the development of our Aerospace Taught Programmes strongly linked to our Institute of Aerospace Technology (£2.2M, 2014).

3.1.1 Strategic Research Awards

Our environment is designed to support a culture that promotes diversity and multidisciplinary research, exemplified by our extensive strategic awards bringing together researchers from different disciplines across academia and industry:

EPSRC Future Composites Manufacturing Hub *(EP/P006701/1 [Warrior] £10.3M)* seeks to deliver a step-change in manufacturing with advanced polymer composites. The Hub is led by FoE in partnership with the following Universities: Bristol, Cranfield, Imperial College London, Manchester, Southampton. The Hub has expanded to include an additional 7 UK Universities.

Industrial partnerships include Dassault Systemes, GKN Aerospace, Heraeus, Hexcel, QinetiQ & Rolls-Royce; whilst international collaborators include: (EU) KU Leuven, Ecole Polytechnique Lausanne and University of Twente; North America: Purdue, McGill and University of British Columbia.

Energy Research Accelerator (ERA) *(BEIS160052 [Long] £17.4M)* is a Midlands Innovation initiative which addresses the most pressing global energy challenges. Based on themes of energy conversion, energy storage, energy distribution and energy use, ERA works across the Universities of Aston, Birmingham, Leicester, Loughborough, Nottingham and Warwick, plus the British Geological Survey.

Centre for Industrial Microwave Processing established in 2008 [*Kingman and Dodds*] has continued with £3.2M in the period from Teledyne e2v. This interface between companies and leading academics improved microwave process efficiency and product quality, to significantly minimise process waste, environmental impact and energy consumption across sectors including pharmaceutical, extractive industries, waste processing, food processing. See ICS Te2v.

Continuous bio-production of commodity chemicals (ConBioChem) *(BB/N023773/1 [Conradie] £1.58M)* aims to accelerate the continuous bio-manufacturing of commodity chemicals by developing superior, highly productive and cost-effective fermentation techniques. Working with the University of Cambridge, University College London, and industrial partners (e.g. Lucite, CPI, Ingenza and Chain Biotech), the project utilises synthetic and systems biology to develop highly efficient cell factories to produce target molecules of commercial interest.

Enabling next generation additive manufacturing Programme Grant *(EP/P031684/1 [Hague] £5.9M)* focuses on overcoming the challenges of spatially controlled 3D co-deposition of dissimilar materials in Additive Manufacturing and is working with Karlsruhe Institute of Technology (De), Birmingham and Warwick Universities and Lawrence Livermore National Labs (USA).

The EPSRC **Formulation for 3D printing** (*EP/N024818/1 [Wildman] £3.5M)* investigates high throughput methods to identify materials and formulations suitable for Additive Manufacturing and 3D Printing, in pharmaceutical, food and agrochemical sectors, with University partners (Reading, Birmingham) alongside industrial partners (GSK, Unilever, Syngenta, PPG Inc). The work is supported by “3D printed formulations: Additive manufacture” *(GlaxoSmithKline Research & Development Ltd. [Wildman] £652k).*

Frequent Integrated soft stop/start technology (Firs3T) *(IUK101894 [Gerada] £2.28M)* demonstrates novel cost-effective compact diesel electric propulsion system initially for bus vehicle applications. The consortium includes Cummins; Dynex and Castlet, and key UK bus vehicle manufacturers.

Electrical Machines and Drives for Next Generation Aircraft (EMINEO) *(EU-H2020-CS2-807081 [Wheeler] £3.5M)* provides the technology to enable More Electric Aircraft. Refining tools for the prediction of electrical system reliability as well as extending the understanding and application of the physics of failure models for aging mechanisms and life-time consumption modelling in electrical equipment through practical testing and model validation based on operational environmental requirements.

Siemens 4MW Geno - Generator Drive - Phase 1 *(Siemens Aktiegesellschaft [Gerada] £3.68M)* brings a multidisciplinary team across engineering to research an innovative electrical machine-drive configuration and demonstrate the feasibility of achieving 4MW, 3kV, 18 kW / kg generator for a turbo-electric hybrid aircraft.

Cornerstone: Mechanical Engineering Science to Enable Aero Propulsion Futures *(EP/R004951/1 [Garvey] £6.14M)* is a Prosperity Partnership led by FoE, with Rolls-Royce, Imperial College London and the University of Oxford to undertake research in six key areas of mechanical

engineering science which will enable Rolls-Royce to remain at the forefront of aircraft propulsion through the transition to all-electric flight.

Advanced Wing Structure for Rotorcraft Additional Lift (ASTRAL) *(EU-H2020-CS2-807083 [Ratchev] £1.99M)* has produced a lighter stiffer fully optimised prototype wing structure taking full advantage of the use of high-performance ecological materials, integrating components for reduced assembly complexity and delivering dramatic weight and drag reduction for the next generation of rotor aircraft with Airbus Helicopters and GE Aviation.

Future Automated Aircraft Assembly Demonstrator (FA3D2) *(IUK113163 [Ratchev] £3.8M)* is delivering a national experimental testbed and technology demonstrator in digital- and informatics-enabled aerospace manufacturing technologies with Airbus, Airbus Helicopters, BAE Systems, GKN and GE Aviation.

Digital Toolkit for Optimisation of Operators and Technology in Manufacturing (DigiTOP) *(EP/R032718/1 [Sharples] £1.9M)* is developing a predictive toolkit to optimise productivity and communication between human workers and robots in collaboration with Cranfield University, Loughborough University and the Bristol Robotics Lab.

Our **strategic partnership with Network Rail** *(Network Rail Infrastructure Ltd [Andrews] £1.7M)* works in infrastructure asset management of the UK's rail infrastructure and provides modelling techniques to support decision making.

Materials, Manufacturing and Oils Technologies for High Power Gearbox Systems (MAMOTH PGB) *(IUK113046 [Simmons] £1.35M)* is developing the materials, coatings and oils, and the optimisation of manufacturing processes required for the high-power gearbox which translates power from the Intermediate Pressure Turbine (IPT) to a low-speed high propulsive efficiency fan required in the Rolls-Royce Trent family of engines.

Pressurised Rotational Oil Transfer – Experimental Unit & System (PROTEUSS) *(EU H2020 CS2-831966 [Garvey] £1.78M)* has developed an experimental rig and computational models to study the operation of oil transfer bearings.

MICA Project *(MR/R025266/1 [Morgan] £900k)* seeks to develop wound dressings incorporating inexpensive optical fibre sensors to monitor wound healing and infection.

EPSRC **Robotics and Artificial Intelligence in Nuclear industry (RAIN)** is led by Manchester University *(EP/R026084/1 [Axinte] £814k)* and links with our activities in the UTC for Manufacturing and On-Wing Technologies, providing insight into robotics applications in maintaining Nuclear infrastructure.

EPSRC **Centre for Innovative Manufacturing in Regenerative Medicine,** led by Loughborough University *(EP/H028277/1 [Mather, Crowe, Segal, Lui, Ratchev] Total £5.8M)* FoE collaborated on manufacturing and sensing capabilities related to biology.

EPSRC **Active Building Centre Research Programme,** Swansea University *(EP/S016627/1 [Boukhanouf, Gillott, Rodrigues] £598k to UoN)* is one of two hubs funded through the Transforming Construction Industrial Challenge to meet targets set in Construction 2025 strategy.

3.1.2 Advancement

Working with a dedicated advancement officer [*Ashford-Smith*], FoE have established a strategy for donation, philanthropy and advancement. In addition to alumni and individual donors, this has resulted in engagement with charitable Foundations such as Wolfson Foundation, Lloyds Register Foundation and Leverhulme Trust in order to support and develop our staff and facilities. This is exemplified by two (£1M and £1.5M respectively) Wolfson awards (supporting a clean room within

the Advanced Manufacturing Building and a test cell propulsion unit in the upcoming (2021) Research and Innovation Centre for Power Electronics (section 3.2)) and a Lloyds Resister Foundation award (Next Generation Prediction Methodologies and Tools for System Safety Analysis *([Andrews], £827k)*).

We have worked alongside [*Ashford-Smith*] to attract donations for our PGR students. For example, the George Bethel scholarship provides 3 scholarships to support Blue sky research (£180k) in new material processing. The Neville Rieger scholarship supports 5 scholarships for 4 years (US$1M).

3.1.3 Impact and knowledge exchange support

KEI support includes an IP budget (~£30k p.a.) to sustain our IP portfolio, matched funded (33%:66%) by the University. Since 2014, we have held an interest in nine companies; eight are going concerns and one [*Monica Healthcare*] completed successful exit in 2017. Seven of these companies were either incorporated or received investment from Nottingham Technology Ventures (NTV) (IS section 2.2b) to support commercialisation of IP. FoE support former staff wishing to exploit IP developed in the FoE, for example, Terra Motion Ltd [*Sowter*]. Examples include:

Monica Healthcare Ltd, a spin-out based on technology developed by [*Hayes-Gill* and *Crowe*]. In 2017 Monica was acquired by GE Healthcare for an undisclosed sum (total investments prior to sale £7.5M). The acquisition ensures that Monica Healthcare's innovative products can be distributed widely, benefitting thousands of expectant mothers across the world.

Surepulse Ltd [*Morgan, Hayes-Gill*] received CE approval in February 2020 for the VS Newborn Heart Rate Monitor product meaning that it can start selling the device in Europe. SurePulse moved to new premises in MediCity Nottingham and in June 2018, the company was awarded the best start up at the Medilink East Midlands awards.

Footfalls & Heartbeats UK Ltd [*Morgan*] supports the development of novel sensors integrated into textiles. In March 2018, [*Morgan*] was awarded a prestigious Royal Society Industry Fellowship to work with directly with Footfalls & Heartbeats UK Ltd.

Promethean Particles Ltd (ICS Promethean Particles) is a spin-out company operating the largest capacity multi-purpose nanomaterial production facility in the world (over 1000 tonnes p.a.) based on research by [*Lester*]. The company has recently secured new investment and is selling products commercially on a large scale.

Pulse, a technology to test building airtightness, was licensed to Build Test Solutions Ltd (BTS) in 2017. [*Wood and Zheng*] continue to work with BTS and delivered data to the National Physical Laboratory to enable Pulse to be included in the 2019/2020 consultation of the part L and F building regulations in the UK.

Added Scientific Ltd. [*Ashcroft, Dickens, Hague, Tuck and Wildman*] is a company that provides technical services to blue-chip companies in the area of Additive Manufacturing; providing bespoke development of materials, equipment and software based on the 20 years of experience in the field, leading to revenues of over £3M since inception in 2014.

Faculty staff are actively encouraged to engage in consultancy and are allocated up to 50 days p.a. to do so, Nottingham University Consultants Ltd helps administer this work with revenues of £4.9M related to engineering in the period. In addition, the University's IP Commercialisation Office successfully granted 23 IP license or option agreements related to Engineering research during the REF period.

3.2 Space and facilities

World-class facilities are vital to delivery of the highest quality research. In 2014, we had 14,000 m^2 of space, supported by 1510 m^2 of workshops and 123 technical staff. Strategic investment has

resulted in expansion of 4800 m^2 research offices space, plus 19,143m^2 of workshops and labs, supported by 144 technical staff.

Our research strategy for infrastructure and small equipment is based on need and complementarity; in 2017-18 FoE was able to invest £800k into small equipment through an open call across technical, early career and established academic staff. During REF2021, we have secured several awards for large strategic capital equipment, including a total of £6.25M from the EPSRC strategic equipment fund including Electron Microscopy capability *(EP/L022494/1 [Brown] £1.2M)* and a Nano Fabrication facility *(EP/M000583/1 [Clark] £1M)* linked to the nmRC opened in 2016].

Specialist research equipment is identified through research group (and associated IT) strategies (annual and 5-year plans), with reference to the UoN Equipment and Digital Research strategies (IS section 2.1c), and the UoN Working Group for the Well-Found Laboratory. As well as investments for newly built and refurbished infrastructure, a range of unique state-of-the-art equipment and infrastructure has been supported. Future investment by UoN has been made in IRCs relevant to Engineering (IS section 2.1a) – (i) advanced manufacturing (ii) end-to-end therapeutics; (iii) additive bio-fabrication; (iv) transport, mobility, cities; (v) technological innovations for health and wellbeing; (vi) water works; (vii) digital health; and (viii) advanced molecular materials.

Our environment has been improved through the following new buildings. The **Advanced Manufacturing Building (AMB)** opened 2018 (12000 m^2) (£18.1M UoN, £5M D2N2 Local Enterprise Partnerships, £1M Wolfson Foundation). AMB houses AMT, CfAM, Composites and our Rolls-Royce UTC in Manufacturing and On-Wing Technologies, providing significant space for expansion of activities. For example, AMT (2120 m^2 - an increase of 148%) created a national experimental demonstrator in digital and informatics enabled aerospace manufacturing technologies - Future Automated Aerospace Assembly Demonstrator platform (*ATI IUK113163 [Ratchev] £3.8M*). Our Manufacturing Metrology research includes a suite of metrology equipment and capability (£2.2M) funded through EPSRC and industrial collaborations and supports the future Midlands Centre for data-driven metrology (*RE [Leach] £3.3M*). CfAM (690 m^2 – an increase of 143%) received Faculty investment of £1M for equipment and refurbishment, with an additional £1M Wolfson Foundation award for a cleanroom equipped with 3D printing and characterisation equipment for pharmaceuticals. This has strengthened relationships with industry e.g., GSK (*Direct funding of £675k* and supporting *EP/S035990/1*). Composites (799 m^2 – an increase of 139%) leads the EPSRC Future Composites Manufacturing Research Hub *(EP/P006701/1 [Warrior] £10.3M)* providing automated robotics cells, autoclave and out-of-autoclave facilities including compression moulding, a range of preforming technologies and a new activity in automated fibre deposition. An EPSRC strategic equipment award has provided a high-volume composite manufacturing cell with digital twinning capability *(EP/T006420/1 [Warrior] £454k).* Our Rolls-Royce UTC (894 m^2 – an increase of 275%) was able to expand its activities into mechatronics manufacturing in response to Rolls-Royce requirements. Work within this UTC has contributed to 2 of our 11 impact case studies submitted.

The **Research Accelerator Demonstration Building** (RAD) (£7M) meets Passivhaus and BREEAM energy efficiency standards and opened in 2018 as part of the ERA project funded by Department for Business Innovation & Skills *(BEIS160052 [Long] £17.4M).* Nottingham's cluster of funding is sited in Engineering with RAD forming a fulcrum building, currently housing: Hydrogen Systems Testbed *(BEIS160052 [Long] £1.45M)*; High Performance Compression & Expansion Lab *(BEIS160052 [Long] £1.1M)*; Next Generation Carbon Capture Technologies *(BEIS160052 [Long] £2.5M)*. Additional investments supporting RAD, includes the Geo-Energy Testbed at Sutton Bonington *(BEIS160052 [Garvey] £1.6M)*; a unique multi-borehole (11) array between 21 and 285m in depth acting as a national facility designed for the monitoring of fluid flow (liquid or gas) through natural subsurface pathways to research remote sensing technologies, validate fluid flow simulation software and access fully instrumented, logged and cored boreholes. The facility is supported by a state-of-the-art Gas Adsorption Analysis Suite (GAAS) funded through EPSRC Strategic Equipment Grant *(EP/M000567/1 [Hall] £522k).* The 240 home Community Energy Demonstrator *(BEIS160052 [Long] £2.96M)* at Trent Basin in Nottingham has Europe's largest community battery (2 MWh), and

solar photovoltaics that generate, store and distribute energy at a neighbourhood level, including the launch of a unique energy company for residents.

The seven house Creative Energy Homes facility, based on University Park, is a £1.9M project that is a key resource for work on micro-smart grids, energy storage, demand-side management and occupants' acceptance of innovative technologies working directly with E.ON, David Wilson Homes, BASF, Roger Bullivant, the Mark Group, Tarmac and Saint Gobain. It attracts over 3000 visitors p.a., including the Chancellor of the Exchequer and Climate and Housing Ministers. Research has fed into the UK's Green Deal strategy and the Nottingham Community Climate Change Strategy, reaching out to over 5 million people.

The Energy Technologies Building Extension (ETBx) in 2015 (£1.3M) provided an additional 760 m^2 of space for research and development in sustainable energy technologies (total 1720 m^2). Through this investment, a 400 m^2 Prototyping Hall provided a world-class facility for construction and testing of full-scale prototypes. A flexible micro-grid facility (FlexElec) was commissioned for testing of smart grid technologies, along with a climate chamber to test efficiencies of equipment and technology within real-world climatic conditions. It has underpinned the EU project "Storage Enabled Sustainable Energy for Buildings and Communities (Sensible) *(H2020-645963 [Empringham] £0.8M)*. ETB has expanded to demonstrate a range of low carbon technologies (e.g. energy efficient materials) supporting work towards meeting governmental targets for public buildings to be 'zero carbon' by 2018, and achieved an 'Outstanding' BREEAM rating (the highest level for environmental sustainability awarded to the top 1% of UK non-residential buildings). From Jan 2020, space for the Smart Products Beacon has been allocated to house a Cobot Maker Space facility (~£150k) (delayed due to COVID).

In 2018, approval for a Research and Innovation Centre for Power Electronics and Machines was given to provide research accommodation for PEMC with support of £9.4M from the UK Research Partnership Investment Fund (UK-RPIF) (Research England), £19.2M industry match (e.g., Cummins, e2v, Siemens) and ~£7M of cash investment from UoN. The 5500 m^2 space located on Jubilee Campus, will open in 2021, a further £1.5M Wolfson Foundation award [*Wheeler*] will fund an Aerospace and Electric Flight Test Cell Propulsion Unit. The Centre will be the largest University facility of its type globally and the only independent lab with test rigs up to 20 MW for future propulsion systems and transportation electrification systems forming a research cluster with AMB, ETB and RAD.

We have an ongoing programme of laboratory renovations**. Significant refurbishments** include the development of **Sustainable Processing** space for the Green Chemicals Beacon (IS section 2.1a) (£1.1M) contributing synergistically to the BioPilotsUK Biorefining Centres. The **Innovation Technology Research Centre** has seen investment in advanced materials processing for the Propulsion Futures Beacon (£3.3M) including unique equipment such as an Electron Paramagnetic Resonance facility, Spark Plasma Sintering supporting Power Hardware in the Loop, a Liquid Plasma Processing platform, Processing technologies for novel 2-D materials and energy storage device laboratories. This capability has led to £11.4M of research funding from industry (Cummins, BAE Systems, Wurth Elektronik, Rolls-Royce, UTC Aerospace Systems, Huawei Tech, AVL_List), UKRI IUK, EPSRC and the EU. It has promoted integration between the disciplines and supported early career researchers in fellowships and awards such as Daphne Jackson and Leverhulme Trust Early Career Fellowship. Further refurbishment includes **Easter Park** (1180 m^2) which provides a safe and secure off-site, low visibility, reconfigurable facility: and has housed projects ranging from microwave processing for Rio Tinto [*Kingman, Dodds*] to manufacturing for defence applications with BAE Systems and Airbus (Advanced Wing Structure for Rotorcraft Additional Lift *(EU-H2020-CS2-807083 [Ratchev] £1.99M)*, Future Automated Aircraft Assembly Demonstrator (FA3D2) *(IUK113163 [Ratchev] £3.8M)* respectively.

In addition to Rolls-Royce UTCs, aerospace activities are focused around the 1800 m^2 **Aerospace Technology Centre** (ATC) (2010). ATC hosts the UoN Aircraft Electric Power Systems (EPS) Innovations Laboratory, an independent UK facility for experimental investigations into novel

concepts for future More- and All-Electric Aircraft, as well as for validation and testing of different aircraft equipment. The facility attracts projects through the EU CleanSky 2 programme to reduce CO_2 and noise levels from aircraft. UoN has a portfolio of 25 CleanSky projects worth €49 million. Additional electrical Aerospace activities are undertaken in the PEMC group on University Park with 2500 m^2 of research space and a construction and testing capability up to 1 MW with test speeds up to 120,000 rpm. A Magnetic Material Characterisation facility for electrical components (one of two globally) enables measurement of the electrical properties of any type of electrical machine component under different thermal, electrical and mechanical conditions, replicating operating conditions, ultimately leading to better electrical machine design. Power Semiconductor Device Evaluation and Testing facilities comprise transient thermal impedance testing, environmental chambers, X-ray tomography, supporting packaging, reliability and thermal management of power semiconductor devices and highly integrated power conversion systems. For Aircraft Electrical Systems Evaluation, a dedicated electrical power system laboratory has been established with "on-ground" representation of aircraft systems for testing to aerospace standards.

In 2014, Nottingham Geospatial Institute established the Global Navigation Satellite System (GNSS)/Galileo Research and Application Centre of Excellence (GRACE) for **Earth Observation.** GRACE contains laboratories, industrial outreach and business development and training facilities for national GNSS projects. Facilities include an enhanced GNSS simulation facility, a mobile positioning test vehicle, the Midlands Real Time Kinematic (RKT) Global Positioning System (GPS) network, a rail track for mobile positioning and a high precision laser scanning equipment. This wide range of facilities, some unique in the UK, represents the most modern technology (e.g. photogrammetric digital camera calibration frame; calibration pillar ensemble, roof-based navigation systems test train; punnet Synthetic Aperture Radar (SAR) interferometric processing suite; GNSS testing and simulation; dynamic captive test platform for navigation systems; systems for surveying, mapping, monitoring and scanning; road test vehicle for navigation systems; wireless positioning infrastructure; access to anechoic chamber; and operation of the NERC British Isles continuous GNSS Facility (BIGF).

In **Healthcare**, the UK's first Centre for Healthcare Technologies (CHT) was launched with Nottingham University Hospitals NHS Trust in 2016 with UoN investment of £216k and £203k via Medi-link (D2N2 INSTILS [*Morgan*]). Research within CHT has contributed to 2 ICS (MONICA and Burns) and links to the Precision Imaging Beacon and the Sir Peter Mansfield Imaging Centre [*Mather, Wright*]. CHT has jointly formed the IRC in "Technological innovations for health and wellbeing" to address healthcare technology research and accelerate their translation to adoption.

In **Autonomous Vehicles,** our interactive driving simulator within the Human Factors Research Group is one of the most sophisticated UK university facilities, funded through faculty investment ~£50k matched by industry ~£100k [*JLR, Honda*]. The core simulator software enables manipulation of the driving experience, for example, by inducing a safety-critical event with a large number of driver behaviour and performance variables measurable (e.g., lane position, time/distance to lead vehicle etc.). In addition, the interior is fully configurable to allow integration of prototype solutions, allowing issues such as driver distraction, workload and acceptance to be investigated. The simulator provided a platform for the Human Machine Interface ICS, embedded in 825,000 JLR vehicles.

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

The strategy to "target initiatives in areas of global importance" is supported by our Knowledge Exchange & Impact Team (2.8 FTE) with UoN Corporate Partnerships. We engage with SMEs, local partners and other strategic stakeholders, to deliver research impact and create commercial and socio-economic opportunities through intellectual property and KE. This is further supported by our Intellectual Property and Commercialisation Office (IPCO), Nottingham Technology Ventures (NTV) and Nottingham University Consultants (NUC) (IS section 2.2b). Furthermore, this activity allows us to deliver a programme of professional and work-based learning through Continued Professional Development and Degree Level Apprenticeships (our second of these, *Electro-Mechanical Engineering*, is recruiting for September 2021).

4.1 Research collaborations, networks and partnerships

In the period, across the **UK,** we formally collaborated with over 45 Universities, in 85 projects with a value of more than £70M. Examples (section 3.1.1) include the EPSRC Future Composites Manufacturing Hub *(EP/P006701/1 [Warrior] £10.3M)* with Bristol, which has 13 University spokes, 4 High Value Manufacturing Catapult Centres (NCC, AMRC, WMG, MTC) and links with leading companies (e.g. Boeing, Airbus, Aston Martin, BAE Systems, Bentley, Dassault Systemes, GE Aviation, Rolls-Royce, GKN Aerospace). In addition, FoE are a spoke in the UK Quantum Technology Hub for Sensors and Metrology (£35M), led by Birmingham *(EP/M013294/1 [Benson, Tuck, Wildman] £815k)* with Universities: Birmingham, Bradford, Glasgow, Lancaster, Southampton, Strathclyde, Sussex and 60 other partners. Coupled with leadership and collaborations in doctoral training (section 2.4), we support global priorities with significant activities in Transport, Energy, Healthcare and Manufacturing.

European Collaborations in FoE are significant (total project value of ~£63M across 202 projects (FP7, H2020, MSCA, COFUND, CS2) with ~25 countries since 2014). CleanSky2 (CS2) is the largest European research programme developing innovative, cutting-edge technology aimed at reducing aircraft generated emissions. As part of CS since inception (2008), we are the only academic partner on the board which comprises 23 founding members (including Airbus, Fraunhofer, Leonardo Aircraft/Helicopters, Rolls-Royce, Thales); and six core partners - GKN Aerospace, Avio Aero, Aciturri, Honeywell Aerospace, iSQ and UoN.

In addition to our DTProg programmes (section 2.4), international PGR students and researchers work with us through the Marie Skłodowska-Curie Actions - Initial Training Networks (MSCA-ITN), Research and Innovation Staff Exchange Evaluations (RISE) and Individual Fellowship schemes (48 projects, £15.67M) e.g.:

TREASURE - Training research and applications network to support the ultimate real time high accuracy EGNSS solution *(H2020-MSCA-ITN-722023) [Aquino] €3.4M).* 9 beneficiaries, 21 partners, 15 countries (Australia, Belgium, Brazil, Canada, China, France, Germany, Italy, Netherlands, South Korea, Poland, Portugal, Russia, UK, US)

SMARTI - Sustainable multi-functional automated resilient transport infrastructures *(H2020-MSCA-ITN-721493 [Lo Presti] €4M).* 9 beneficiaries, 20 partners, 10 countries (Australia, China, France, Denmark, Germany, Ireland, Italy, Spain, UK, US,)

SAFE-FLY - Damage modelling and online detection in aerospace composite structures *(H2020-MSCA-ITN-721455) [Chronopoulos] €0.8M).* 1 beneficiary, 2 partners, 3 countries (Spain, UK, US)

N2N - advanced, lightweight and silent, multifunctional composite structures *(H2020-MSCA-ITN-765472) [Chronopoulos] € 0.8M*). 2 beneficiaries, 4 partners, 4 countries (Australia, Canada, France, UK)

OptiMACS - efficient multidisciplinary design Optimization of Multifunctional Aerospace Composite Structures *(H2020-MSCA-ITN-764650 [Chronopoulos] €1.2M).* 4 beneficiaries, 4 countries (Austria, Germany, Portugal, UK).

UoN International Campus Collaborations. Our three campuses in the UK, China and Malaysia, enable a global platform for our research. In China, research focuses on large-scale projects, funded by the Ministry of Science and Technology that enable us to impact on Chinese industries and work alongside other prestigious academic institutions, such as Zhejiang University and large state-owned companies, e.g., China HuaNeng, one of the largest power companies in China *[Wu].* Work between *[Chen and Gerada]* focuses on electrical power sources and storage, and the related chemistry and engineering. In Malaysia our Institute for Aerospace Technology (IAT) supports the Malaysian Government's ambition to be a regional aerospace leader by 2030 [*Gerada*]. We further link to our Campus in Malaysia (UNM) through joint PGR students supported by the Future Foods Beacon and

UNM Beacon "Nurturing global food security" via EU project PROTECT *(H2020-MSCA-ITN-2018-813329 [Gomes] £200k).*

North America - Our relationship with Virginia Tech has been nurtured and expanded since 2009 to include biopolymers and materials [*Irvine, Kingman*], gas turbine propulsion [*Garvey, Morvan*], geo-energy and mining [*Grebby, Hall, Marsh, Muljadi*], human factors and virtual reality [*Burnett, Cobb, Large*], advanced manufacturing [*Ashcroft, Axinte, Ratchev, Tuck*], polymer composites [*DeFocatis*], power electronics and transportation materials [*Clare, Dawson, Johnson, Parry, Wheeler, Zanchetti*], involving ~50 researchers. This is strengthened through programmes such as, the US National Science Foundation (NSF) International Research Experience for Students (IRES) which since 2013, has supported ~30 Virginia Tech engineering undergraduate and postgraduate students in research exchanges. FoE reciprocated with internal and industrial investment to fund 13 PGRs. In 2019, Virginia Tech was awarded NSF IRES funding for 2020-2022 (delayed to 2021 due to COVID 19) to continue supporting students to come to Nottingham. This relationship has enabled 73 joint publications. Other North America relationships include those in the EPSRC Composite Hub and EPSRC Programme Grant in Next Generation Additive Manufacturing (section 1.3.1).

Rest of the World. Through British Council (£1.2M) and Royal Society (£0.9M) funding we collaborate through international mobility and exchange grants and joint PGRs (e.g. **Columbia** *([Lester] £109k)*; **Egypt** (*[Everitt] £73k; [Benson, Sewell, Morgan, Vukovic, Seddon, Korposh] £234k; [Riffat, Omer] £184k*); **Indonesia** *([Ahmed] £80k*) and **Malaysia** (*[MacKenzie, Grant] £119k*)). Our links with **Chile** include MoUs with 12 institutions and MoAs including Universidad de Chile, resulting in >20 academic and research exchanges; four Nottingham PEMC alumni (PhD) in Chilean Academic posts; >25 jointly funded research projects since 1990; PhD student mobility including dual degree awards with funding available for up to two years from the Chilean Government. The UoN-Chile Foundation was launched on 10th July 2018 at the British Ambassador's Residence, Santiago. In 2018, [*Muljadi*] established our Indonesian Doctoral Training Partnerships with 8 PhD students sponsored through joint funding with Indonesian government agencies. This has led to projects with **Indonesia** through Newton Institutional links programme (e.g., Establishing Affordable Healthcare in Indonesia *(British Council-2019 – 2317013 [Ahmed] £80k)* IPB University, Indonesia). Our work in energy, [*Grant, Walker*] have collaborated with partners in **India** (Indian Institute of Technology, Madras; Visva-Bharati University, Santiniketan; PSG College of Technology) and **China** (Chinese Academy of Science).

4.2 Key research users, beneficiaries or audiences

FoE organised 49 **International conferences** since 2014 including: International Conference on Sustainable Energy Technologies, in collaboration with the World Society of Sustainable Energy Technologies, led by *[Riffat]* with 350 delegates worldwide. FoE also hosted the International Conference on Disability, Virtual Reality & Associated Technologies (ICDVRAT) 2018 in association with the International Society for Virtual Rehabilitation *[Cobb]* 150 delegates.

Knowledge Transfer Partnerships (KTPs) are supported by 1.0 FTE dedicated administrative staff and are a key tool for collaboration; UoN are 3rd in the UK for our number of these partnerships involving 53 of our staff and 40 companies across a range of sectors: e.g., Tioga Ltd, Attenborough Dental Ltd, Hitachi ICSE Ltd, Polypipe Ltd, BPB Saint-Gobain, A.T. Kearney Ltd, Footfalls and Heartbeats, Sprint Electric Ltd, Teledyne e2v (UK) Ltd, and Siemens plc (Siemens Managed Services). KTP awards total £1.7M and industrial investment of £1.2M and have led to follow-up projects (e.g., IUK SPRINT; Footfalls) and supplemented relationships with companies (e.g., Teledyne e2v).

Industrial relationships

Our strategic partnerships have strengthened over the period. We have worked with 225 partners across the world. Highlights of these include: Rolls-Royce, projects worth £12.5M in a range of technology sectors. Our 12-year relationship with Teledyne e2v is formalised through direct investment (£3.2M of funding within this period (third renewal) in the Centre for Industrial Microwave Processing),which extends across a range of technologies and engineering disciplines, including microwave technology [*Kingman, Dodds*], power electronics [*Clare, Watson*] and geospatial sensing

[*Marsh*]. This exceptional collaboration was recognised through the joint award of the RAEng Sir Colin Campbell Mitchell Award (2018) (section 4.3). [*Kingman*] has also led projects valued over £11.5M on the use of microwave processing for novel mineral extraction.

Research supported by defence companies such as BAE Systems ranges from computational modelling [*Benson, Vukovic and Sewell*] to manufacturing [*Ratchev*]. BAE have supported a total of 9 projects with direct funding ~£1.27M since 2014. BAE are partners on larger UKRI investments such as our Future Manufacturing Composites Hub and Prosperity Partnerships *(EP/S03661X/1, [Tuck] £0.8M).* Funding from AWE Plc totals over £1.1M since 2014 for work in a range of additive manufacturing techniques and materials, including metal jetting and novel silicone material constructs. Further, direct awards from Airbus totals over £1.95M in the area of manufacturing and supply chains; and we work across the sector, e.g., Boeing Company (5 projects, [*De Focatiis, Empringham, Harper, Johnson, Pickering, Warrior*] £2.7M); Goodrich Actuation and Control Systems Ltd *([Gerada, Vakil], £2M)*. Our aerospace portfolio is further augmented through China, e.g., AECC commercial Aircraft, AVIC Aircraft Strength Research Institute, Commercial Aircraft Engine Company Ltd, Xi'an Aircraft Design and Research Institute and Flight Automatic Control (Total £1M). Siemens are also a key strategic partner directly investing in projects for future hybrid Aircrafts (*[Gerada] £312k);* a 4 MW Generator Drive *([Gerada]* £3.7M) and the new Power Electronics Building (2021).

Jaguar Land Rover, where our research in connected and autonomous vehicles has supported projects >£1M to develop novel techniques for understanding and exploiting the effects of these disruptive technologies in the automotive industry; has resulted in our ICS in human machine interfaces. Network Rail (total £1.7M) are a long-standing supporter of our research, with work around suicide prevention and the use of automated technology on rail infrastructure [*Ryan*] and infrastructure and resilience engineering [*Andrews*] coupled with Lloyds Register.

In energy generation, we have long-standing relationships with Alstom *([Clare, Costabeber, Large, Johnson, McCartney, Snape, Sun, Watson, Wheeler] £1.34M)* and E.ON *([Eastwick Gillott, Grant, Johnson, Riffat, Snape, Sumner, Sun, Walker] £1.96M).*

In GeoSpatial engineering, GRACE has had impact on over 211 businesses, including the creation of 42 new jobs, the safeguarding of an additional 21 and the creation of 14 new start-ups. For example, Geomatic Ventures Limited (GVL) was formed by GRACE after winning first place in the 2014 Copernicus Masters competition where UoN patent-pending technology was exploited to create a first-of-a-kind land deformation map of the UK. Furthermore, GRACE has provided industrial training to 361 people through the delivery of 15 multi-day training courses. GRACE has facilitated new UK satellite navigation receiver manufacturing capability and capacity in the UK in partnership with Rockwell Collins.

4.3 Wider activities and contributions to the research base, economy and society

175 of our people are **Fellows** of 58 learned societies and professional institutes, including: 4 Fellows of the Royal Academy of Engineering (FREng) *[Long, Benson, Somekh and Kirk]*. Staff have held the role as **President or Vice President** of a variety of societies. These include: Chartered Institute of Ergonomics and Human Factors *[Sharples];* Institution of Engineering Designers *[Kirk];* International Academy of Engineering and Technology *[Leach];* International Society for Computing in Civil and Building Engineering *[Tiziani];* International Society for Virtual Rehabilitation *[Cobb];* Royal Institute of Navigation *[Moore*]; Optics within the Life Sciences Society *[Morgan];* and UK Society for Biomaterials *[Scotchford].* **Contributions to UKRI Research Council committees:** *[Conradie]* is Senior Scientist on BBSRC Council and *[Sharples]* sits on EPSRC Council as an Advisor, as well as the Science Advisory Council for the Department of Transport. We have 38 full members and 25 associate members of the **EPSRC Review College**.

We **contribute to policy-making,** e.g.
[*Turnbull*] was visiting scientist at the Woods Hole Oceanographic Institute in 2018, 2019 (2020 COVID 19 curtailed) with invited contributions at the American Geophysical Union in 2019.

[*Moore*] was appointed (2019) to US Government's PNT (Space-based Positioning, Navigation and Timing) Advisory Board. [*Moore*] is the only academic on the PNT Cabinet Office Technical Group implementing the Blackett Review on Critical Infrastructure dependence upon GNSS.

The UK Parliament Parliamentary Office for Science and Technology (POST) briefing on Environmental Earth Observation includes contributions from [*Grebby and Marsh*]. [*Mackenzie*] is on part-time secondment to POST writing a data analysis tool to analyse MP's tweets and publish on-line.

[*Morgan*] works with regulatory bodies including National Institute for Clinical Excellence (NICE) on monitoring burn wounds.

Work by [*Snape and Meredith*] has supported and influenced policy on the profile of shale gas and its prevalence in the UK and forms part of our ICS "HYPY".

Work by [*Large*], supported by Scottish Natural Heritage, has led to the Scottish Government's commitment to invest £250M over 10 years to support climate change monitoring on the use of peatland and water.

[*Walker*] contributes to Energy Policy as a UK expert for the International Energy Agency's Tasks 17 and 22 (hydrogen storage materials).

Evidence to the inquiry in "Active Travel" was provided by [*Moore, Airey and Hughes*].

Evidence to the House of Lords on connected and autonomous vehicles was given in 2016 [*Sharples*].

We contribute to international and national standards committees (~12, e.g. ASTM F42 committee [*Tuck*]; the British Standards Institute (BSI) Committees [*Craven, Leach*]*:* the Food Standards Agency [*Watson*]*; and* Institute for Electrical and Electronic Engineers Standards committee [*Thomas*])*.*

Our **awards and prizes** demonstrate the impact of our research. In both 2018 and 2019 we were recipients of the **Royal Academy of Engineering Colin Campbell Mitchell Award** given annually to engineers who have made an outstanding contribution to the advancement of any field of UK engineering. These were awarded to [*Kingman and Dodds*] with Teledyne e2v in 2018 for Microhammer, a revolutionary process for extracting copper from its ore using microwave technology. In 2019 [*Hayes-Gill and Crowe*] won the same award for development of the world's first wireless fetal monitor, the Monica Novii system. Monica Novii was presented with the Healthcare Technology award by the Institution of Engineering and Technology (IET) in 2019. The Institute of Physics business awards recognised Promethean Particles [*Lester*] for solving the key fluid mechanics problem that held back the use of supercritical fluids in the production of nanomaterials.

In 2020 [*Gomes*] and [*Liu*] were listed in the "Top 50 Women in Engineering" by the Women's Engineering Society for contributions to water reuse and treatment and nano-materials for hydrogen storage respectively. The Institute of Materials, Minerals and Mining awarded (2020) the Leslie Holliday Prize to [*Long*] for work on advanced, lightweight composite material over the last three decades. The US Institute of Navigation awarded *[Moore]* the Johannes Kepler Award in 2017 for outstanding contributions to the development of satellite navigation, only the second Briton to win the award. Institute of Measurement and Control awarded [*Leach*] the Finkelstein Medal for notable contributions to measurement internationally in 2019. [*Clare J*] was awarded the Royal Society Wolfson Research Merit Award in 2016 for outstanding achievement and potential to Power Electronics.

At The Engineer's "Collaborate to Innovate" awards (2019), FoE won with Project SCENe (Sustainable Community Energy Networks) [*Gillott*]; and SHYMAN (Sustainable Hydrothermal Manufacturing of Nanomaterials) [*Lester*]. This follows previous success in 2018 in the Defence,

Security & Aerospace category [*Axinte*] with Rolls-Royce plc for their work on remote keyhole surgery for jet engines.

At the NHS England Healthcare Science Awards (2018) [*Morgan et al*] won the Developing Partnerships to Improve Outcomes Award with the Centre for Healthcare Technologies. SurePulse Medical Ltd [*Hayes-Gill and Morgan*] won the Start-Up award at the Medilink East Midlands Business Awards (2018), following 2017 success by [*Lester*] who won the Outstanding Achievement Award at the Medilink East Midlands Business Awards.

Our research and people have been shortlisted for numerous awards including: Times Higher Education (THE) Awards 2018, [*Irvine and Morgan (School of Pharmacy)*] were shortlisted for Most Innovative Contribution to Business-University Collaboration with Camstent, a Cambridge biotechnology company, for their work on bacteria-resistant plastics. [*Hayes Gill and Crowe*] were shortlisted for IET Technological Innovation of the Year with Monica Healthcare Ltd in 2019. At the IChemE Global Awards in 2017, [*Kingman and Dodds*], Teledyne e2v and Jenike & Johanson were commended for large scale microwave pre-treatment of ores in both Research Project and Team Awards. [*Wang*] received the Judges' Special Award at the Regional Heritage Awards 2019 for the Dinosaurs of China exhibition. The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) awarded [*Ghiassi*] the Gustavo Colonnetti Medal in 2019. Further, in 2019 [*Sewell and Vukovic*] were awarded the BAE Systems, Europe and International, Bronze Chairman's Award for their work in "Predicting the Effects of the Lightning".

Public engagement occurs through a range of events. For example, our research has been showcased at the Royal Society Summer Science Exhibitions. In 2016, [*DeFocatis*] supported work around the exhibition: 'Plastics inside us'. In 2019, the exhibition centred on "Super biomaterials to fight super bugs". This cross disciplinary exhibition with colleagues in the Faculty of Science involved engineers in the design and delivery: [*Irvine*], [*Lester*], [*Wildman*], Research Fellows [*Dundas*], PGR [*Crucitti, Conta*]. In 2020, the theme was to be "Personalised Printing of Pills" [*Hague, Wildman, Tuck, Irvine*] a collaboration between Additive Manufacturing and School of Pharmacy [*Rose, Alexander, Roberts*] (now COVID-19 curtailed to 2021). This builds on mass public engagement at the Science Museum (London) on 3D Printing the Future where CfAM helped curate the exhibition and online content, which transferred to the Science and Industry Museum (MoSI) in 2015 [*Hague, Wildman, Ashcroft, Tuck, Goodridge*].

[*Wang and Hale*] as part of their research into museum architecture enabled **a world-exclusive exhibition** at Wollaton Hall (2017), that brought Chinese dinosaurs, never-before seen outside of Asia, to the City of Nottingham. This research resulted in the "excellence in exhibitions" award and much interest in the national and popular press (e.g., The Guardian, The Times, New Scientist, BBC World Service). The exhibition, working with Nottingham City Council Museums had more than 130,000 visitors in four months with an accompanying engagement programme, which included science lectures and Q&A sessions at UoN's Lakeside Museum. This saw 28,000 participants, including 75 schools, in activities designed to inspire an interest in science and scientific research.