Institution: University of Oxford

Unit of Assessment: 12 - Engineering

1. Unit context and structure, research and impact strategy

1.0 Overview and context

This submission comprises the Departments of Engineering Science (DES) and Materials (DoM). Both are within the Mathematical, Physical, and Life Sciences (MPLS) Division, one of four academic divisions in the University. The departments have grown significantly during the REF period through creation of new posts and the integration of two existing research centres into DES. This reflects MPLS strategic objectives to expand engineering as a discipline and energy as a thematic priority.

The departments are distributed over five sites in Oxford, with the main centres co-located in the University Science Area. Both also maintain laboratories at the Oxford Suzhou Centre for Advanced Research (OSCAR) in Suzhou, China (*section 4.1)*.

DES is a general engineering department with 133 academics and senior researchers with a strong commitment to engineering without boundaries between subdisciplines. The Head of Department of DES is supported by a Deputy Head and four Associate Heads (Research, Teaching, Graduates, and Infrastructure), who together with the Head of Finance and Administration form the Senior Management Team (SMT). The Department is organised into nine research subject clusters (*section 1.1.1).* DES also hosts five semi-autonomous research institutes that facilitate research in specific areas (*Fig. 1).* There is overlap between the clusters and institutes, with many academic staff belonging to more than one.

DoM aims to make substantial contributions to agenda-setting research, and to train future leaders in areas spanning theory through to commercial applications of materials. It hosts 37 academic and senior research staff. The SMT consists of two Joint Heads of Department, two Associate Heads (Teaching and Research), the Head of Administration and Finance, and the Director of Studies. Research is grouped and coordinated through five complementary subject clusters (*section 1.2.1)*.

In both DES and DoM, there is minimal hierarchy. The flat management structure ensures equal research opportunities and provision of resources. Each submitted researcher has autonomy in establishing and leading research activities within their group, though larger themes and 'super-groups' emerge in natural response to multi-faceted research challenges. The Associate Heads for Research in each department coordinate larger, strategic goals and liaise with the wider University.

1.1 Research Strategy: Engineering Science

We seek to apply intellectual rigour to challenging engineering problems, ensuring timely and relevant research outcomes that benefit society and foster inter-disciplinarity, where appropriate. Our core belief is that engineering science is rooted in three guiding principles:

1. Engineering excellence rests on a sound mathematical and scientific foundation.
2. Problem-solving and innovation are best achieved by recognising that key concepts and techniques recur across many branches of engineering.
3. Many of today's technological challenges demand an interdisciplinary approach that crosses traditional engineering boundaries.

Alongside traditional engineering disciplines, reflected in our research clusters, we also support broad themes, such as energy, transport, environment, and healthcare. These themes are

deliberately focused on key societal issues where engineering science can have significant impact. The creation and dissemination of new knowledge is paramount. To shepherd research from conception through dissemination, and ultimately through application for societal and economic benefit, is a core part of our mission as a department.

The nine subject clusters (*Fig. 1*) are each overseen by a research committee, aiding the Associate Head (Research), which reports to the termly research meeting of the Departmental Committee. This structure allows us to respond rapidly to opportunities, for example, our recent initiative to set up an Energy Systems Accelerator centre.

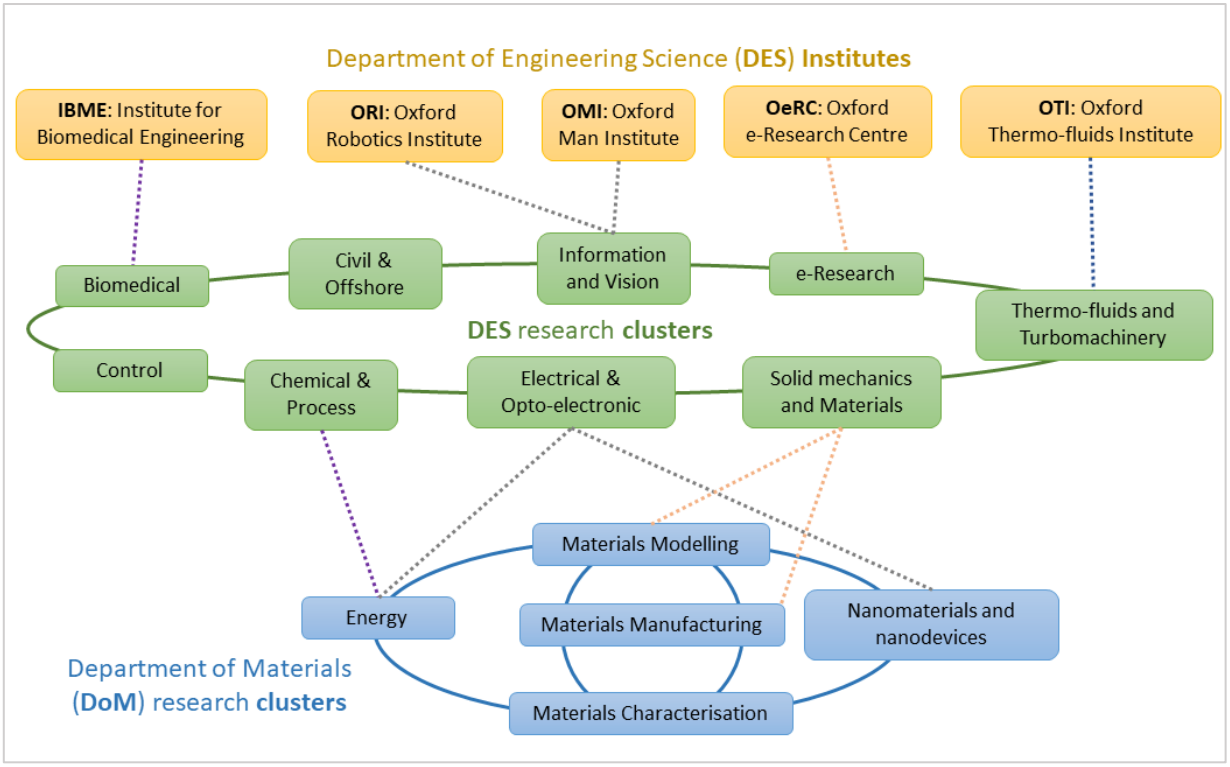

Figure 1: Research Clusters and Institutes

Forging strong relationships to understand end-user needs and uncover new research questions inspired by their requirements is a vital element of DES research. This approach is enabled and supported through strategic partnerships with industry, other external partners, and a strong culture of technology translation.

As part of a strategy to increase research capacity, DES has grown by 41% from 94 to 133 academic staff in the current REF period. Our growth strategy is based both on organic expansion of each research cluster and the creation or assimilation of research institutes with a focus on major opportunities for interdisciplinary activity. A good example is the Oxford Robotics Institute (ORI), which incorporates elements of robotics, machine vision, machine learning, and data science. Since 2017, two existing, stand-alone research units have also become part of DES: the Oxford e-Research Centre (OeRC), and the Oxford-Man Institute of Quantitative Finance (following a strategic change in its research focus into applications of machine learning to finance).

1.1.1 DES Research Clusters: Strategy, objectives, and future plans

The following sections describe the strong collaboration between different areas of the DES research landscape and research in each of the clusters, highlighting their synergistic nature and relationship to DES Institutes.

Biomedical Engineering

The Institute for Biomedical Engineering (IBME) is strategically co-located on the Churchill Hospital site alongside clinicians and medical scientists (including the new NHS Cancer Centre and the Nuffield Orthopaedic Centre). This has been pivotal in delivering our key strategic objectives for this REF period: sustainable expansion, driven by clinical need; and high-impact translation of biomedical engineering research into clinical practice (with 18 clinical trials of IBME technologies). We have maintained the four focus areas from REF2014: non-invasive therapies & drug delivery; biomedical image analysis; regenerative medicine & tissue engineering; biomedical signal processing & e-health. We have also established and grown two new areas, biomaterials and neurotechnology, following the appointments of **Stride** and **Denison** to chairs. Net faculty numbers have increased from 15 to 21 during the period, with each of the six research areas led by senior chairs.

Over the next REF period we will further develop our newer areas of biomaterials and neurotechnology. We also seek to establish a new area, through the establishment of a funded institute in youth sports medicine and technology.

Chemical and Process Engineering

Our research in Chemical Engineering focuses on emerging areas that directly impact human life and society. Since REF2014, we have added four new academics (**Monroe, Kwan, Huang, Yang**) to strengthen our underpinning strategies across biotechnology, synthetic biology, systems engineering, and energy.

In biomedical technology and bioprocessing, we create enabling technologies for regenerative medicine, bioreactor technologies, biomaterial processing, and bio-manufacture.

In synthetic biology and environmental biotechnology, we develop advanced biosensors and research CO_2 biotransformation into high-value products. Biomimetic anaerobic digesters (AD) were developed for biomass conversion to bioenergy and chemicals leading to a 40-fold efficiency improvement.

In environmental and systems engineering, we focus on the human living environment, *i.e.* the integrated design and optimisation of water-food-energy nexus, which includes wastewater treatment, food security, transport systems, and negative emission technologies.

In energy conversion and storage, we develop technologies for harvesting of renewable energy, redox flow batteries, biofuels, green ammonia, and local production systems.

Over the next REF period, we plan to expand research activity in medical and environmental biotechnology, water systems engineering, and energy storage. We also plan to establish a second Chair, the Professor of Process Engineering and Chemical Technology, to strength our links with chemistry.

Civil and Offshore Engineering

This cluster undertakes research in geotechnics, fluid mechanics and structures, including projects with overlapping themes. We have strong links with industry, especially in renewable energy and offshore engineering. Research activities – incorporating both experimental and numerical methods – range from laboratory-scale studies through to large-scale field testing and monitoring programmes. Since REF2014 we added nine new academics (**Acikgoz, McAdam, Nishino, Rossi, Sheil, van den Bremer, Vogel, Adamadis, Smyth**) and one academic (**Byrne**) became a RAEng Research Chair.

We have continued to shift into marine renewables, with significant research on the design and monitoring of foundations for offshore wind turbines, supported by research councils and industry (including Ørsted). Within fluid mechanics, major projects have focused on non-linear wave mechanics including transport of plastic pollutants, wind farm and tidal farm interactional physics, and flows through soft porous media.

During the next period, renewable energy (particularly offshore systems) will continue as a key focus. Laboratory soil element testing is emerging as a new research area, as is large-scale structural testing. Research on construction processes and asset management (*e.g.* tunnels, bridges, and buildings) will remain central to our strategy.

Electrical and Optoelectronic Engineering (EOE)

This cluster combines research in photonics, electronics, energy, communications, metamaterials, and computer engineering. During this REF period, academic and senior research staff numbers have increased from 15 to 20. New appointments have strengthened electrical energy (**Monroe**, **Rogers**), and photonics (**Stavrinou**, plus ECR fellows in diamond technology (**Salter**) and optical fibre sensing (**Fells**)); and have initiated new research themes in computer engineering (**Zilbermann**).

EOE faculty advance battery and energy storage research and social/technical aspects of power grids for the developing world. Our photonics research covers liquid crystals, adaptive optics, microscopy, and laser-based manufacturing; and we continue to lead the Oxford photonics community across the University. We have expanded research in optical communications and networks, computing infrastructure, and metamaterials (supported by an EPSRC Programme Grant and formation of the Oxford Metamaterials Network). We developed electronic and optical technologies for the UK National Quantum Technologies Programme and led the systems engineering effort within the quantum computing (NQIT) Hub. **O'Brien** is Director of the follow-on Quantum Computing and Simulation Hub.

We aim to appoint new chairs in Electrical Engineering and in Photonic Engineering, the latter to support the formation of a Photonics Engineering and Technology Institute. We will expand core expertise in quantum systems engineering through new academic appointments. The Energy Systems Accelerator (TESA), a centre for low carbon energy systems, will consolidate activities and efforts in energy and power systems research across academia, industry, and third sector organisations; a pilot phase will commence in autumn 2021.

Information and Vision Engineering

We explore the development, design, and deployment of the state-of-the-art in computer vision, machine learning, financial modelling, and robotics.

Our primary goals for this period were to expand expertise around key leaders in machine learning, vision, and field robotics, and to grow links with industry. Both have been achieved. We have increased the number of academic and senior research staff from nine to 20. We established the Oxford Robotics Institute (ORI), an integrated group of researchers, engineers and students driven to change what robots can do for society through a diverse portfolio of research interests (led by **Newman** and **Posner**). The Oxford Man Institute (OMI) became part of DES, shifting its primary research focus to machine learning and finance (Director: **Roberts**). Researchers from the cluster have established a wide range of industrial collaborations (*section 4.3.3*); within the Computer Vision group this includes creation of joint positions with DeepMind and Facebook (*section 2.2*).

We shall continue to diversify our work into both the development and wide application of information engineering: the ORI will expand into soft-robotics and autonomous flight; OMI into discrete and continuous probabilistic optimisation; and Vision into simultaneous visual and audio inference, and mobile device graphics.

Control Engineering

We make theoretical contributions to robust and distributed optimisation, predictive control, and data-centric and networked systems. As control engineering is an 'underpinning' technology, this research is interdisciplinary, as illustrated by our applications in biological, transport, energy, autonomy, and machine learning systems.

Since 2014, the cluster has expanded from four to nine full-time academics, and now runs as a separate cluster. New appointments strengthened work on vehicular systems, bringing expertise in vehicle dynamics (**Ober-Blöbaum**), power systems, and hybrid vehicle charging (**Goulart**, **Margellos, Gatsis**), and control in biological systems (**Steel**). In addition, we developed collaborations in areas including building control, distributed optimisation, and energy storage.

During the next REF period, we will refill the vacant chair in Control Engineering. We aim to expand our current areas of research to include applications covered by UKRI Grand Challenges, including smart cities (low carbon transportation, smart infrastructure, and building control), healthcare and life sciences, and energy systems.

Solid Mechanics and Materials Engineering

Research covers all aspects of materials and mechanics: from the nanoscale through to engineering components; and from fundamental analysis and new material development to the practical applications of established materials. Notably, we follow an integrated approach, in which experimental and analytical considerations combine to tackle key engineering challenges.

The cluster has grown during the period from ten to 15 academic staff (including two joint appointments with DoM). New appointments have brought expertise in areas including shock physics (**Eakins**), computational and multiscale mechanics (**Brassart**), nanomaterials, soft solids, metal processing, and materials modelling (**Tarleton**). The Rolls-Royce UTC in Solid Mechanics remains at the centre of our activities (*section 4.3.1*); but researchers also play key roles in other centres, including the Bristol-Oxford Nuclear Research Centre, and the International Brain Mechanics and Trauma Lab. We develop and use state-of-the-art experimental and computational facilities, including *in situ* micro-analysis and multi-beam microscopes, extensive structural impact and shock facilities, a wide range of material synthesis and characterization tools, and computing clusters for cross-scale computation (*section 3.3*).

We shall continue to develop research in aerospace and energy materials and undertake fundamental studies of complex transient processes in hierarchically structured materials and biological tissues. We will pursue a 'Materials by Design' agenda using multi-scale characterisation and modelling approaches. Translation of fundamental research to benefit industrial and clinical applications will remain a key objective.

Thermo-fluids and Turbomachinery Engineering

This cluster now comprises 18 faculty members. Since 2013, we have recruited seven new academics (**Bacic, Rogers, Coull, di Mare, Leach, McGilvray, Williams**) and built new links with two senior researchers from the OeRC (**Wallom, Chen**). Research includes aircraft propulsion, automotive engines, applied thermodynamics, and hypersonics; and we are strongly committed to mitigating the climate impacts caused by propulsion and power generation.

The Oxford Thermo-fluids Institute (OTI) combines analytic/numerical models with experiments and ensures research impact is maximised by partnering world-class companies. It is home to the Rolls-Royce UTC in Heat Transfer and Aerodynamics (*section 4.3.1*); other industry partners include Mitsubishi Heavy Industries, Siemens Energy, and DSTL. Our strategically important research in turbomachinery encompasses jet engine cooling, effects of sand deposition on turbines, and hypersonic flight.

Our Applied Thermodynamics activity, which ranges from novel engines and compressors to solar concentrators, has been supported by sponsors including BP, Siemens, Honeywell Hymatic, and SEA. Activity in thermal propulsion is focused in our 'Centre of Excellence' for combustion engines and its follow-on Prosperity Partnership (*section 4.3.1*).

In the next REF period, new activities will include zero-carbon propulsion, focussing on thermal systems for hydrogen and batteries, with engagement in the National Wind Tunnel 2, the Oxford-Cambridge Arc, Flightzero, and the Aerospace Technologies Institute.

Oxford e-Research Centre (OeRC)

The OeRC is a multidisciplinary applied research cluster, developing and applying innovative computational and information technology in both academic research and industrial applications. Its integration into DES (2017) was a strategic move by the University to ensure the long-term viability of such research as part of a broader engineering programme. Academic and senior research staff numbers expanded from three (REF2014) to ten.

OeRC acts as a hub for interdisciplinary collaborations nationally and internationally, *e.g.* providing data processing expertise for the Square Kilometre Array. A growing focus has been research software engineering (RSE): **Bush** was one of the first EPSRC RSE fellows; and **De Roure** is a Co-I in the Software Sustainability Institute.

Looking ahead, we will appoint a new chair in Interdisciplinary AI and an Associate Professor in Scientific Computing. We will also expand expertise in machine learning through further collaborations and new academic appointments, in coordination with the Information and Vision Engineering cluster.

1.2 Research Strategy: Department of Materials (DoM)

Research is grouped into five broad clusters with individual academics contributing to multiple themes. Strengths in these areas enable coherent identification and response to major intellectual and technological problems at the heart of societal and economic grand challenges. DoM has long-standing expertise in **modelling** and **characterisation**: the application of established techniques is central to work in 'energy', 'manufacturing', and 'nanomaterials and nanodevices', whilst dedicated themes focus on the development of novel methods.

1.2.1 DoM Research Clusters: Strategy, objectives, and future plans

Energy

The strong socioeconomic need makes sustainable and secure energy research our largest theme. During the REF period, we have enhanced existing strengths in nuclear power and established major local and national initiatives in energy storage, while maintaining activity across power generation, solar/PV, and transport.

Eight academics work on materials for nuclear power, collaborating with major industry partners, including Rolls-Royce, Westinghouse, and EDF Energy Plc. We have achieved our REF2014 goal of strengthening strategic relationships with the Culham Centre for Fusion Energy (CCFE) and the National Nuclear User Facility (NNUF). Over ten CCFE staff hold visiting posts in DoM, and we are partners with CCFE in five major grants. The active atom probe for the NNUF is housed by DoM.

In energy storage materials, the appointment of **Bruce** was followed by two further faculty appointments (**Pasta**, **Weatherup**), backed with substantial investment in infrastructure (*section 3.3*). Interactions within and beyond DoM have pulled in expertise in processing, mechanical properties, characterisation, and modelling – generating substantial collaborations with industry.

Over the next period, we will expand research into materials aspects for zero-carbon energy systems. We will continue to pursue new battery technologies with smart processing routes, demonstrating scalability to aid industry translation; and strong interactions with CCFE to support development of fusion power technologies, maintaining international collaborations in existing and genIV fission power.

Nanomaterials and Nanodevices

New nanomaterial technologies, including quantum information processing, are strategic research areas aligned with globally-acknowledged challenges. Activities include fundamental studies of carbon-based nanomaterials, 2D and 1D materials, phase change systems, magnetic nanomaterials, inorganic semi-conductors, photonic materials, and device fabrication for quantum computation, information storage, and biosensing.

Delivering on REF2014 plans, we have invested in infrastructure for quantum and photonic materials (*section 3.3*). The appointments of Royal Society URFs **Bogani** and **Ares** bring expertise in quantum transport, molecular spintronics, nanomagnetism, nanoelectronics, circuit quantum electrodynamics, quantum computing, and machine learning. We have significant programmes on quantum effects in electronic nanodevices (led by **Briggs**), with the potential for low-energy information processing; and via the quantum technology hubs (*section 3.1*).

We will seek new academic recruitments in this important emerging area to maintain strength and address an impending retirement, using this to enhance collaboration with the National Quantum Computing Centre, at Harwell.

Manufacturing

Our strategy in manufacturing combines novel processing routes and materials innovation. Activities span from advancing traditional industries, such as metallurgy, to transformative new areas, like wearable technologies.

Two new appointments since REF2014 support this strategy (**Speller** and **Liotti**). We have invested heavily in advanced manufacturing facilities (*section 3.3*), with significant funding via the Royce Institute and an Eight Great Technologies capital grant. **Grant** contributes to two national Manufacturing Hubs in Metallurgy; **Bhaskaran** leads activities on phase change materials and wearable technologies and holds an EPSRC Manufacturing Fellowship; and **Reed** is founding director of the Hitachi-Metals UTC of Metallurgy (2020). **Speller** and **Grovenor** established the Centre for Applied Superconductivity (*section 4.3.3*) which drives research collaborations with important regional industries.

We will continue to deliver innovative scalable routes to materials and device manufacture across traditional and emerging sectors. Sustainability and reduced environmental impact will be increasingly important foci.

Modelling

Theory and simulation are integral to modern materials engineering and activities using established methods are embedded in all research clusters. We are also committed to development of new theoretical and numerical methods at a variety of time and length scales.

The DoM modelling efforts have expanded since REF2014 through **Nicholls** obtaining an Early Career EPSRC Fellowship to combine theory with experimental characterisation, and the joint appointment with DES of **Tarleton.**

New theory at the electronic structure/atomistic level for prediction and interpretation of NMR and EELS data has been developed and released through the widely-used CASTEP DFT code, effectively bridging modelling with characterisation activities. The open-source Wannier90 DFT

code developed by **Yates** and colleagues supports hundreds of outputs annually, particularly for ferroelectrics, topological insulators, and thermoelectrics.

We will augment existing strength through recruitment of a statutory chair, and subsequently an Associate Professor, in materials modelling. Ahead of this, we have invested in refurbishment of our Materials Modelling Lab space allowing for significant growth.

Characterisation

Materials characterisation is a core strength of DoM, in which we continue to make significant strategic investment. Similar to modelling, characterisation is a key enabler for all materials research clusters, but we also have strength in development of new methodologies.

Since REF2014, **Lozano-Perez** was awarded the title of Professor, and two researchers secured independent fellowships in the area of advanced characterisation of energy materials (**Nicholls, Robertson**).

A strategic priority has been the radical improvement of our nationally-important atom probe tomography (APT) facility (*section 3.3*). We continue to develop our extensive electron microscopy expertise and facilities through relaunching the David Cockayne Centre for Electron Microscopy (DCCEM). This sustainable facility, which has been completely refurbished (~£100k) to create a suitable environment for housing a suite of state-of-the-art equipment and scientific support, facilitates research across the University and externally (*section 3.3*). To complement this strategy, we make significant scientific and leadership contributions to external facilities (*section 4.1*), including the Diamond Light Source (DLS) and the Rosalind Franklin Institute (RFI), in line with our REF2014 strategy of enhancing links to the Harwell Campus. Research groups have access to further characterisation facilities and make extensive use of facilities at DLS and other synchrotron facilities around the globe.

Our strategy to replace instruments at a rate of ~1/year across the DCCEM and APT facilities is required to maintain state-of-the-art capabilities. An analytical (S)TEM is the next target.

1.3 Impact Strategy

We have taken full advantage of the University's strategic initiatives for impact delivery and our impact-oriented activities have thrived in this environment. Our impact strategy is rooted in the concept of translating fundamental understanding, through interdisciplinarity, to practical deployment. Our approach is to provide researchers with the freedom and support needed to build impact activities that best fit their situation. The development of impact is a central mission for all researchers – enabled by dedicating infrastructure, resources, and facilities to transfer science to practice; and by encouraging innovative partnerships with industry (*section 4*). We have significant translation of biomedical technologies through partnership with Oxford Medical Sciences in clinical trials. We provide numerous specialist services to industry (*e.g. section 3.3*). Many of our major research programmes are undertaken jointly with industry, the success of which is evidenced through several of our Impact Case Studies.

Due to the applied nature of activity in this UoA, much of the research is geared towards end-user needs from inception. To maximise the application and impact of research outputs, our researchers are encouraged and supported to make extensive use of Oxford University Innovation (OUI) for IP protection, licensing, and spin-out of their research (*section 4.4*). Commercialisation through all these routes is seen as a core part of our academic activities and is recognised as such in reviews and appraisals. Mechanisms are in place to enable researchers to undertake secondments to external partners, such as spin-outs or other industry, through flexible contractual arrangements (*section 2.2 and 4.4*).

Furthermore, we seek to engage with policy development in the UK and internationally through policy initiatives and participation in advisory bodies, with influence ranging from microplastics

pollution to effects of automation on society (*section 4.4*). This is best illustrated by **Newman's** appointment as a member of the Prime Minister's Council for Science and Technology.

Both departments are successful in obtaining funds from the Oxford EPSRC Impact Acceleration Account, with 20 projects totalling approximately £1.1m. (For illustrative examples see *sections 4.3.2 and 4.4*).

1.4 Open Research

We strive to promote a broader Open Research environment in line with the University Strategic Plan. Both departments encourage the use of the institutional repository, the Oxford Research Archive (ORA) for all types of research output (from journals and conferences to "grey matter", such as pre-prints, theses, book chapters, and figures) and accompanying datasets. We have also deposited over 100 underlying research data sets into ORA-Data, which is curated and preserved, ensuring long-term availability and access. Furthermore, both departments have an established tradition of open-source code and software (*section 1.2.1 Modelling and 4.4 for examples*).

Beyond supporting open research, we are also driving the agenda. In the OeRC, **Sansone**'s team works to transform the data landscape and create an open research environment through Findable, Accessible, Interoperable, and Reusable data for human and machine reading (FAIR) [*see impact case study*]. This includes interoperability standards, educative steps to motivate and encourage researchers to share high-quality data, and data readiness. Whilst being encouraged locally, these FAIR Principles are also finding their way into Government, major funder, and publisher policies to greater support access and preservation of research findings. Sansone's team also designs and develops open-source software to improve collection, representation, sharing, and publication of multi-dimensional data.

1.5 Interdisciplinarity

Much of our research is interdisciplinary by its very nature. We seek to sustain interdisciplinary approaches through a mix of practical arrangements and organisational structures. These include: leadership of/participation in internal and external networks (*sections 4.1, 4.2, 4.5*); co-location (from lab moves or refurbishments designed to cluster cognate research groups together to building the IBME on the medical campus to facilitate clinical collaboration and application); and the use of Institutes as a focus for collaboration (*e.g.* the OMI providing a link between machine learning and finance).

1.6 Research Integrity and Reproducibility

Our commitment to upholding standards of research integrity and reproducibility is guided by the principles and policies outlined in the institutional statement. In addition to the common University approach to research ethics and integrity, there are some areas where bespoke approaches are required. Our biomedical research draws upon ethics procedures in the Medical Sciences Division. For our work in artificial intelligence, we are developing an ethics framework that will draw upon experience in Computer Science.

Furthermore, **De Roure** brings expertise through his involvement in the Steering Group for Reproducible Research Oxford (RROx), a University-wide initiative focused on advancing the open research agenda, open scholarship, and research reproducibility that extends to all disciplines. As an example of where responsible research was a central to a large-scale programme, the Networked Quantum Information Technologies hub ran a theme on responsible research and innovation. Specific training in this area is also provided through the Autonomous Intelligent Machines and Systems (AIMS) CDT, which concentrates on ethical, legal, and societal consequences of the application of artificial intelligence.

2. People

2.1 Academic staff strategy

We believe that delivering and sustaining cutting-edge research depends on the ability to attract, recruit, develop, and retain world-leading staff. During the period, both departments increased their research capacity through new faculty appointments, with 15% growth in DoM and 33% in DES. In DoM, energy storage materials was a key focus for expansion; in DES, the goal was to grow capacity in all research areas, but with higher growth in identified key areas such as Biomedical and Information Engineering. To promote sustainability, our strategy is to create new posts at all career stages, adopting a range of strategies to support critical mass in expanding areas:

- Research fellowship applications are encouraged at all levels to support academic career development [13 new posts in period].
- Academics with strong expanding research portfolios were supported in moving to senior research leadership roles [six posts] and an additional chair was created [one post].
- External funding was obtained to pump-prime new permanent research fellows in key areas for growth [net eight posts].
- The creation of four- or five-year career development positions [net 13 posts].
- Three more traditional academic posts were created.

The success of these strategies is illustrated by the growth in robotics: during the period, a team of two academics has become eight, including a new research leadership post, a fellowship, and three career development positions.

These policies have created demographic shifts towards early-career and research-intensive roles. For example, in DES, junior career development positions now account for 8% of academic roles [2014, 1%], early career research fellows for 5% [2014,0%], senior fellowship positions for 19% [2014, 10%], and senior research leadership roles for 10% [2014, 4%]. Traditional mid-career academic roles now account for only 50% of academic posts [2014, 70%]. This shift supports both current and future management of research and, in particular, has provided the capacity to manage large research portfolios and programme grants.

Academic staff development strategy

New academic appointments have an initial five-year term, with a first formal review after two years and a final review in the fifth year. Both departments operate a mentoring system. Teaching and administration loads are individually tailored to ensure new academic staff gain relevant experience, but also have sufficient time to build a research track record. All academic staff are encouraged to take sabbatical leave, including during their probationary period.

New appointees receive departmental funding to launch their research programmes and support in applications for University funding. Standard start-up funds (£20k for Associate Professors, £10k Departmental Lecturers; and, in DES, funds for a postgraduate scholarship) are augmented for those with major equipment needs. Recent examples include **Monroe, Rossi**, **Maiolino**, **Zilberman, Kwan, Steel** and **Denison** in DES and **Weatherup** in DoM. Across the two departments, over £2.7M has been provided in start-up funds for new hires during the REF period.

New appointees receive graduate supervision training, supplemented by colleagues acting as mentors or co-supervisors. New students are assigned to them wherever feasible, to assist with the growth of their research group. In both departments, the Associate Head (Research) works closely with Research Support teams, who assist with review and preparation of grant proposals, and new academic staff are encouraged to take advice on proposals from colleagues.

Beyond the initial five-year period, continued support is given to staff to develop their careers. Fellowship applications are strongly supported in both departments (*section 3.1*). Systems of self-appraisal and optional one-to-one appraisals with the Head of Department provide an opportunity to reflect on work objectives, achievements, and difficulties; and on any support, career development, or training needs. Discussions cover workload and aspirations for promotion, including internal or external recognition exercises. In the wider University, leadership development and mentoring schemes provide opportunities for staff to develop in roles both within and beyond their home department.

Academic staff recruitment

Across the departments, academic posts are almost exclusively recruited by international open competition. Search committees are tasked to publicise widely. Interview panel chairs undergo recruitment and equality training provided by the University. Selection processes involve thorough engagement with the research proposals. Each stage of the process is subject to review for equality considerations. We usually have exceptional fields of applicants from academia and industry around the world, so recruitment is facilitated through relocation packages. Notable examples where we have successfully attracted academic talent directly from overseas universities and industry include **Monroe** (University of Michigan, USA), **Pasta** (Stanford University, USA), **Brassart** (Monash University, Australia), **Rossi** (KU Leuven, Belgium) and **Denison** (Medtronic PLC, USA). Before **Zilberman's** recent post at Cambridge, she was a senior engineer at Broadcom.

2.2 Recruitment and development strategies – research staff

Recruitment and integration

Appointments for research staff, mostly post-doctoral Research Assistants (PDRAs), are made following an openly-advertised competition. New advertising methods, including field-specific social media, are used to ensure the best possible pool of applicants and to encourage under-represented groups to apply. Chairs and members of recruitment panels are required to complete a recruitment and selection training course. DES recruits to an average of 60 posts per year and DoM 25.

Both departments run activities to help integrate staff into the research culture and ensure they are provided with support to help them thrive. Induction processes and formal probation processes exist for all new research staff. Information is provided about personal development resources (Career Services, Centre for Teaching and Learning, etc.) and University-wide mentoring and networking opportunities. Supervisors receive guidance on management, and all research positions have formal specifications with required tasks set out clearly and transparently. Supervisors undertake annual formal performance reviews. Through informal career development review schemes, PDRAs can discuss career goal planning with a senior academic who is not their supervisor. In DES, a Staff Development Manager has been appointed to strengthen further this support. DoM runs a mentoring scheme on a voluntary basis for interested researchers.

Both departments have committees specifically to look after the interests of research staff, with close engagement from senior departmental leadership. DoM has established the Materials Postdoc Association Committee (MPAC), which is represented on various departmental committees. In DES, there is a Researcher Committee, co-chaired by the Associate Head (Research) and a post-doctoral researcher. It organises an annual Researcher Conference and other events specifically targeted at PDRAs, such as termly welcome lunches.

Training and career development

Both departments implement the Concordat for Contract Research Staff. The entitlement to 10 days per annum for professional development is well-publicised, with researchers directed to courses/workshops provided by the University. These include:

- face-to-face and online learning on leadership, management, and personal effectiveness;
- entrepreneurship, innovation, and intellectual property;
- scientific writing, public engagement, and research management;
- courses, support, and services for teaching;
- IT training courses and advice about educational technology, such as digital whiteboards;
- writing fellowship applications;
- courses and resources for staff who need foreign languages for their research, work, or personal development;
- career discussions and career development workshops.

Researchers are encouraged to undertake teaching to gain experience required for academic posts, with many holding lecturer positions in the University's colleges. DES has introduced Teaching Assistant positions, which allow PDRAs to develop specialist teaching experience through small group tutorials as part of the undergraduate course. In DoM, further support is given through Teaching Skills Workshops on delivering classes and lab demonstrating; these roles are taken up by many research staff.

Destinations

We actively support the career aspirations of our research staff. PDRAs are encouraged to apply for permanent academic posts or personal research fellowships, with departmental training sessions complementing University provision. These sessions have included inviting grant-giving bodies (*e.g.* EPSRC) to run workshops on-site. Senior academics act as fellowship champions and mentors who, together with the Research Support teams, advise on and facilitate applying to the most suitable schemes. More generally, researchers are supported, where possible, in applying for research funding (*section 3.2)*. The opportunity to undertake consultancy work can be used by researchers interested in careers outside academia to explore wider options. Information from exit questionnaires is used to improve the experience of researchers and inform strategy; the establishment of researcher forums and mentoring schemes at DoM are active examples.

All this support facilitates successful research career progression beyond Oxford. Examples include Dr Thomas Morstyn (from a PDRA position to an EPSRC Innovation Fellowship at DES to a Lectureship in Power Electronics and Smart Grids at Edinburgh); and Dr Ramil Nigmatullin (who moved from a PDRA position at DoM to a Lectureship at the University of Sydney).

In the REF period, 46% of leaving PDRAs joined another University (UK or overseas), 23% moved to the private sector, and 5% moved to the public sector (including research institutes).

Recognising and rewarding research and impact

Both departments support the professional development of academic staff and encourage use of the University's career progression structures, including applications for full Professor title under the annual Recognition of Distinction scheme, which recognises strengths in research, teaching, and good academic citizenship. During the period, 27 UoA members were awarded the title. Those who hold such professorships can also apply for merit awards, with salary supplements.

In order to provide incentives, and modest amounts of flexible funding, DES operates a research recognition scheme, where 1% of recovered overheads is returned to the grant holders in the form of an "academic support fund". Over the REF period, this has amounted to over £450k to

support activities such as conference attendance, purchasing small equipment, or short research visits.

Our success in creating a culture of impact and innovation is demonstrated through the recognition of our researchers' activities through prizes and awards, such as those from the MPLS Division. Since 2014, UoA members have won six MPLS Impact Awards and one Public Engagement with Research Award.

2.3 Research students

Recruitment strategies

We recruit PGRs mainly through a central open competition, although there are some project-specific positions that are advertised separately. Our goal is to recruit the best-qualified students whose interests align with our academics' programmes. There is an overall upward trend in applications, offers and places. Intake has increased from 151 in 2013/14 to 220 in 2019/20, with a broadly consistent average of 5 applicants per place.

Approximately 20% of DES's doctoral students are female, mirroring the profile of the undergraduate population. Offer rates for male and female doctoral applicants are identical.

To encourage undergraduates to consider careers in research, both departments support their engagement in research and encourage research group placements during summer vacations. In 2019, DES launched a research internship programme allowing up to 20 2nd/3rd year Oxford MEng students to spend a fully-funded eight-week placement in a research group. Feedback from the initial cohort of students has been very positive.

Funding

A total of 148 studentships were supported through UKRI's competitively-awarded Centres for Doctoral Training (CDTs). The UoA jointly led (*) or contributed to training through the following CDTs (start dates in brackets):

- Autonomous Intelligent Machines and Systems (2014, 2019)*
- Gas Turbine Aerodynamics (2014); Future Propulsion and Power (2019)*
- Renewable Energy Marine Structures (2014); Wind and Marine Energy Systems and Structure (2019)*
- Synthetic Biology (2014)*
- Science and Technology of Fusion Energy (2014)
- Diamond Science and Technology (2014)
- Theory & Modelling in Chemical Sciences (2014)
- Biomedical Imaging (2014)
- Health Data Science (2019)
- Sustainable Approaches to Biomedical Science (2014); SABS:R^3 (2019)

Others are funded through competitive studentships held by the University and its colleges, or from other UKRI sources (including Oxford's EPSRC Doctoral Training Partnership (DTP) grants). During the period, >225 students were wholly or partially funded through these mechanisms, including >60 CASE/iCASE studentships, including via Rolls-Royce (14), UKAEA (6), Jaguar Land Rover (5), and Toshiba (4).

Finally, over 200 students were wholly or partially funded by industry via direct studentships, including from Rolls-Royce, EON, Facebook, and Diamond Light Source.

Most scholarships awarded over the past seven years have been full studentships (covering bursary + fees), although some are either fees-only or bursary-only.

Support, monitoring and career development

All new PGRs receive departmental and group-level inductions and safety training. They are able to attend advanced taught courses given in the undergraduate MEng programmes. PGR supervision is monitored quarterly through online reporting, which includes self-assessment by the student to encourage ownership of performance and project scope. Reports are reviewed by the Director of Graduate Studies. In DoM, each student has an additional advisor who can be approached for support. Where relevant, students are also mentored through their CDTs. PGRs receive formal or informal mentoring through their research group and are supported by advisors in their colleges. Supervision reports also cover training needs; any training undertaken is recorded through this system.

Progress through two stages of independent review is required during research towards a DPhil (PhD) or MSc. These are undertaken by short written reports and interviews with two independent assessors, usually at the end of the first and second years.

PGRs have full access to the University's extensive researcher training programmes, as described in *section 2.2*. Training is also provided to doctoral students who wish to demonstrate, work as teaching assistants in undergraduate classes and tutorials, or assist with open days, access, and outreach programmes. Other departmental training/support includes:

- in DES, a student-led session entitled "Owning a successful DPhil";
- encouragement to explore relevant internships with industry or other organisations;
- conference travel funding.

DES and DoM nourish a culture of collaboration to make students feel integrated and to ensure they are fully engaged with all aspects of research practice. It is common practice at research group level for PGRs to lead seminars, reading, and discussion groups. They are encouraged to use their initiative to create valuable collaboration and networking opportunities through links to other groups and institutions.

PGRs have representation in termly committees in both departments. In DoM, this is a student-led committee consisting of student and staff members that feeds recommendations back to the department. In DES, the graduate student chair attends the Departmental Graduate Studies Committee to represent the views of the community.

Both departments operate *ad-hoc* studentships each year for students with only three years of funding who have experienced delays beyond their control: a 'continuation bursary' provides continued support to complete their studies. On average, from all cohorts expected to submit within the REF period, 90% of our research students successfully completed their doctorate. Moreover, 80% of the latest cohort of students to complete standard DPhil programmes (excluding CDTs) have finished within four years, which shows an upward trend during the REF period [cf. 64% for the first cohort finishing in period].

The quality of the training, support and research environment is reflected in the latest destination survey (2014-17) with a high employment rate (92%), 3% continuing studies, 2.5% seeking employment, and 2.5% not looking for employment.

According to the University's Student Barometer Survey, in 2014 overall satisfaction at PGR level was at 90.4%, rising to 91.2% in 2019. This puts the UoA above the national average satisfaction in the Postgraduate Research Experience Survey (PRES), which was 82% in 2014 and 81% in 2019.

2.4 Research/impact leave and support for external interaction

We reward those who excel in research and aim to provide structures within which their research and its impact can thrive, whilst balancing other responsibilities. This includes sabbatical leave, flexible duties, consultancy, and fixed-term reduction in FTE; a small number of researchers have permanent joint posts with an industry partner.

Sabbatical leave is available to academic staff on permanent contracts, whether full or part-time; taking leave is actively encouraged for staff within their first five years to help consolidate their research programme. In the UoA, 79 academics have taken sabbatical leave during the REF period, equivalent to over 220 terms in total.

In DES, teaching and administration duties are reduced for those with research leadership positions or with more than 40% of their time on awarded grants. The ability of academics to move to research-intensive career roles has helped capitalise upon significant opportunities to expand research activities. For example, **O'Brien** was able to take up directorship of the Quantum Computing and Simulation hub.

All academic and research staff are entitled to up to 30 days of outside work per year: they can use this to support impact through their spin-out companies, or for consultancy with other external organisations.

Staff can apply for a fixed-term reduction in contractual hours (or other arrangements) to support longer-term working with external sectors as a route to impact or to enhance their research. This option was taken up at all faculty levels, from staff within their first 5 years to established chairs. Examples have included one year's full-time leave or a longer period of part-time leave to work for a spin-out, and part-time contract secondments to industry. Eight permanent academic staff in the UoA have used such arrangements with either spin-outs (*e.g.* Oxbotica: **Newman**; Bodle: **Bhaskaran**) or industry partners (including DeepMind: **Mudigonda** and **Zisserman**; Facebook: **Vedaldi**; Niantic: **Prisacariu**). **Allen** and **Korsunsky** have been seconded to senior scientist positions at Diamond Light Source.

Research students have also been supported in taking on secondments and internships. In these circumstances, student status can be suspended so that the time spent with external parties does not affect the completion time for research degrees.

2.5 Equality, Diversity, and Inclusion (ED&I)

Departmental strategies

We seek to create a diverse academic community within a framework and culture of equality, promoting the University's commitments and action plans for race and gender equality and supporting staff and students with disabilities. Both departments have an ED&I Committee to embed equality and diversity within their activities, promote these messages, and measure their progress through data review and staff surveys. Both also hold Athena SWAN bronze awards.

ED&I considerations start from recruitment, with academic positions advertised widely. For example, DES advertises in Women into Science and Engineering, the Association for Black Engineers, and the National Society for Black Engineers. For permanent academic roles, both departments use search committees which are charged with reaching out to a diverse range of candidates. Evidence of the success of this in terms of gender equality was the appointment of ten women candidates to permanent academic roles within the UoA in the REF period (25% of appointments). This extends to PDRA positions as well, with >20% of the new appointments for the last three years being female. Members of recruitment panels attend ED&I training and formal gateways are in place during the recruitment process for permanent academic roles to check that the applicants and shortlist demonstrate diversity.

Both departments have utilised the Vice-Chancellor's diversity fund to benefit staff (*e.g.* to redevelop the DES recruitment website to encourage more diverse applications).

Flexible and remote working

Both departments engage with the University strategy encouraging working pattern flexibility and family support. Department-wide arrangements (*e.g.* ensuring committee timings allow for those with childcare responsibilities to attend), and individual arrangements (such as timetabling of lectures) can be formalised to support individual needs. Part-time working arrangements include reduced hours to support caring responsibilities. For example, in response to a staff survey, the DoM made changes to offer part-time working for PDRAs, where external grant contracts allow (*e.g.* longer platform or programme grants).

Pre-COVID, we supported remote working requests where possible. Examples include supporting a colleague through over a year of remote working for health reasons, and others to support caring responsibilities. During summer months, where possible, DoM offers staff a 9-day fortnight, to allow a day away to help with childcare over school holidays.

Networking, career development, and research leadership roles

Women in Engineering and Women in Materials Science groups were launched in 2012 and 2017, respectively. The groups are open to all genders, staff and students alike, and aim to provide a safe and supportive environment in which to identify and tackle problems facing those who identify as women and to recognise and celebrate their contributions.

UoA members support the University LGBTQ Staff Network, the BME Staff Network, and the BIPOC STEM network. DES has provided financial support to the LGBTQ+STEMinar Conference. Both departments have an EDI Fellow, a staff member representing the department on University groups, helping to raise awareness of EDI issues, and leading on related activities.

The process for promotion to "Professor" takes career breaks into account. In career discussions, staff are encouraged to consider research-related leadership roles. The Oxford Senior Women's Mentoring Network supports women aiming for leadership roles. Over the REF period the departments have seen men and women take on leadership positions within the University, and at national and international bodies. Examples include: **Grobert** (Chair, Young Academy of Europe; Chair, Group of Chief Scientific Advisors to the European Commission; AssocHoD (Research)), **Noble** (Associate Head of MPLS Division (Industry and Innovation); Director of IBME), and **Sansone** (Honorary Academic Editor, Springer Nature Scientific Data).

All academic staff have access to funding to support conference attendance and travel. All research students are guaranteed funding to attend at least one relevant conference during their studies (underwritten by the departments if no grant funding is available).

All academic staff are encouraged to make funding applications to both external and internal funds. Sabbatical leave applies to full-time and part-time academic staff alike. All staff have access to the University's training programmes.

Support for carers, ill health, and those returning from periods of leave

Both departments provide support to those taking parental leave, above contractual and statutory provision. DES recently agreed an extended formal scheme to support academics taking parental leave, providing reductions in teaching and administration alongside funding to support commitments to their research group and their own on-going personal development. In DoM, parental leave, career breaks, and part-time working are considered in reviewing performance, and the focus is upon the quality of research output. Academics returning after maternity leave have no departmental teaching and reduced administrative loading for a year. Ahead of leave, an academic is appointed to maintain continuity of group activity.

Both departments have purchased sponsored priority places at the four University-owned nurseries and offer the "My Family Care" programme to departmental staff.

Four staff members have used the University's Returning Carers Fund to support development of their research following a career break. Small grants financed conference attendance, collaborators visits, technician support, coaching, and support with website design. DES has also hosted two externally-funded Daphne Jackson Fellows, returning to the workplace in part-time contracts after a period of leave.

Support for staff with protected characteristics

Staff and students alike have access to the University's Disability Advisory Service and a range of support and adaptations are available, including alternative software and equipment, support with communication needs, and coaching.

Staff and student wellbeing

Both departments offer a range of wellbeing initiatives, in addition to the substantial University provision. Examples have included providing trained mental health first aiders, additional counselling, arranging for free confidential health checks, and organising well-being training days.

Consideration of equality and diversity in REF preparations

ED&I considerations were thoroughly monitored throughout the UoA REF preparations, according to the institutional code of practice. Our primary criterion for output selection was research quality. To mitigate unconscious bias, an output selection advisory group with diverse representation was convened to define policy for output selection and ensure that processes did not unfairly disadvantage groups within the UoA. Eligible staff were asked to nominate up to five outputs for consideration, which were reviewed internally by at least two academic referees. This process was supported by use of an in-house Excel tool, which worked from anonymised output identifiers and scores, without reference to any protected characteristic. At each stage, the advisory group monitored the distribution of outputs and was able to query any matters of concern. UoA members were able to raise confidentially through the institutional structures any matters that might affect their contributions.

An equality analysis of the resulting distribution shows:

- 14.7% of submitted outputs are attributed to ECRs (average 1.68 per ECR);
- One ECRs was attributed 5 outputs;
- An average of 2.74 outputs have been attributed to male and 1.81 to female staff.

The proportion of eligible staff in the UoA who are female (15%) is closely comparable with the University's average across panel B (17%). Our successful recruitment strategies have contributed to an increase in this figure since REF2014. Consequently, we now have a much higher proportion of female researchers in younger demographics than previously. It is normal for more junior academics to have fewer attributed outputs, which explains the lower average for outputs attributed to female staff. We therefore expect the male/female outputs ratio to improve further over the next REF period.

3. Income, infrastructure, and facilities

3.1 Research Funding

Average annual research income during the current REF period was £49M, more than twice the figure for the REF2014 period (£22.6M). The aggregate split of funding sources over the period is shown in *Fig. 2* below:

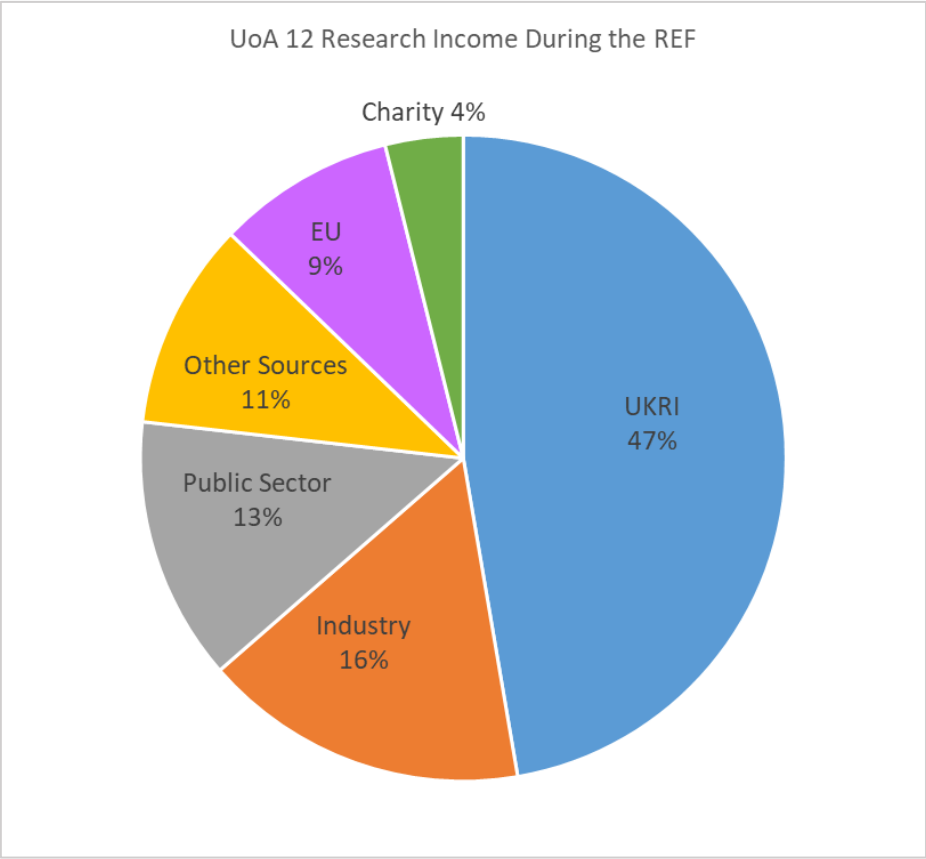

Figure 2: UoA Income profile during the REF period

Reflecting long-term local and institutional strategies, we have diversified the sources of research income to achieve a more balanced, sustainable portfolio. We have also achieved our objective of securing more 'longer, larger' grants, particularly from EPSRC (*see Table 1 below*). We have obtained more than £33M from Innovate UK in the REF period (64 projects) with a strong focus on translational research and hence a faster, or more direct, route to impact.

The strength of our relationship with industry is evidenced by the £56M of industry income during the REF period (£75M of direct funding secured since FY13-14). Much of this activity is housed within Centres of Excellence, set up through industry partnership, or our UTCs (*section 4.3.1*), one of which was established during the REF period.

The UoA boasts upwards of 150 industry sponsors from myriad sectors across the globe. A select list includes Amazon, Facebook, JLR, GSK, Samsung, Continental, Johnson Matthey, Rolls-Royce, Dyson Technology, EDF Energy, Ørsted, and the Man Group.

Major funded strategic initiatives initiated during the REF period include two Prosperity Partnerships (*section 4.3*) and these seven major EPSRC-funded Programme Grants led by the UoA:

Title	*Principal Investigator*	*Value (GBP)*
Hydrogen in metals - from fundamentals to the design of new steels (HEmS)	**Cocks**	5,481,675
Mobile Robotics: Enabling a Pervasive Technology of the Future	**Newman**	4,991,610
OxCD3: Oxford Centre for Drug Delivery Devices	**Coussios**	6,384,336
Seebibyte: Visual Search for the Era of Big Data	**Zisserman**	4,466,184
Transpiration Cooling Systems for Jet Engine Turbines and Hypersonic Flight	**Ireland**	6,136,938
Enabling next generation lithium batteries	**Bruce**	6,799,833
Quantum Effects in Electronic Nanodevices (QuEEN)	**Briggs**	5,296,044
	Total	39,556,620

Table 1: Large programme grants (>£4M) led by the UoA during the REF period

Amongst the many notable outputs and outcomes from these programmes, we highlight:

- **Seebibyte**: has produced over 169 outputs in the field of computer vision, and 81 engagement activities, including workshops, talks, and presentations. The project has created 22 software and technical products, used across disciplines like medicine, zoology, medieval languages, and anthropology to analyse large datasets in a fast and robust manner.

- **Enabling next generation lithium batteries**: The grant had very high impact beyond direct research outputs: it is the progenitor of the Faraday Institution (FI, *section 4.1*) and several investigators became FI founding members. Outputs supported the case to Government that a strong consortium with experts inside and outside battery science is needed to advance lithium battery technology. This led to Faraday Challenge funding of £250M being released, including £80M supporting FI's fundamental battery research.

- **OxCD3:** resulted in three new clinical trials of device-enhanced drug delivery for cancer: TarDox for ultrasound-triggered drug release in liver tumours; PanDox in pancreas, which recently obtained ethical approval to commence; and CEeDD received major NIHR funding to investigate cavitation-enhanced drug delivery in colorectal liver metastases.

The research vision of our academics has been widely recognised and supported through significant personal research grants and fellowships:

- **ERC Grants**: Four Starting (**Bogani**, **Hofmann**, **MacMinn, Vedaldi**), three Consolidator (**Bogani**, **Tan, Warner**), three Advanced (**Booth**, **Noble**, **Torr**), and four Proof of Concept (**Booth, Grobert** x2**, Noble**).
- During the REF period, six senior academics were appointed to **prestigious Research Chairs**:
    - **Zisserman**, Royal Society Research Professor;
    - **Petrinic**, Rolls-Royce/RAEng Professor of Impact Engineering;
    - **Byrne**, Ørsted/RAEng Research Professor in Advanced Geotechnical Design;
    - **Torr**, Five AI/RAEng Research Professor in Computer Vision;
    - **Denison**, RAEng Research Professor in Emerging Technologies;
    - **Roberts**, Man Group/RAEng Professor of Machine Learning.

- The following personal **Research Fellowships** have been held:
    - Ten EPSRC Fellowships (**Bhaskaran, Bush, Salter, Fells**, **Jerusalem**, **Morstyn**, **Nicholls, Papachristodolou**, **Tarleton, Willden)**.
    - Six Royal Academy of Engineering Research Fellowships (**Henriques**, **Namburete**, **Zhu**, **Sheil**, **Van den Bremer, Bonilla**).
    - Six Royal Society URFs (**Castrejon-Pita**, **Fallon**, **Morris, Robertson, Ares, Bogani**) and one Royal Society Industry Fellowship (**Grobert**)
    - Two Royal Commission for the Exhibition of 1851 Fellowships (**Acikgoz, Lui**).
    - One Sir Henry Wellcome Research Fellowship (**Sailem**)

Further notable funded research activity includes the following examples:

- **O'Brien** leads the £24M EPSRC Quantum Computing and Simulation Hub, with **Smith** and **Benjamin** leading workpackages. All three led workpackages in the previous £38M Networked Quantum Information Technologies Hub, also led by Oxford, in which **O'Brien** was Co-Director (Systems Engineering) and **Smith** and **Benjamin** were Associate Directors.

- In geotechnics (Civil Engineering), significant grants totalling over £14M linked to industry include the Carbon Trust/industry (PISA), EPSRC/industry (ALPACA) and Ørsted/RAEng (PICASO) [*see impact case study*]. Major projects in fluid mechanics have included wave transport of plastic pollutants (EPSRC/IFD/RAEng), wind and tidal physics (EPSRC/E.ON), and flows through soft porous media (ERC/EPSRC).

3.2 Research and impact support

The UoA has five full-time professional staff in dedicated Research Offices supporting funding applications. This includes support in finding and applying for funding at all career levels preparing costings, assisting with policy compliance around funding bodies and their publication regulations, ResearchFish, and working with the MPLS Industrial Research Partnerships (IRP) team to increase the volume of industry-funded work.

In DES, 12 project managers support research and impact. In DoM, five project assistants provide equivalent support, along with managers recruited for specific large projects. Project managers work on high-value portfolios and collaborate closely with the Research Offices and the projects/finance teams to ensure seamless support throughout.

Our impact activities have benefitted greatly through extensive interactions with OUI, which advises on intellectual property, commercialisation, and spin-out processes (*section 4.4*). This is facilitated through scheduled workshops, regular on-site "surgery" sessions, and proactive engagement with individual researchers at all levels.

The UoA has dedicated teams to facilitate research impact (including the DES Communications, Events, and Marketing team). They support communication with key audiences (including prospective, partners, collaborators, decision-makers, and industry) about research findings and potential applications, impact, teaching, outreach, and industry collaborations.

3.3 Infrastructure and facilities supporting research and impact

We continue to maintain and expand our array of specialised, often unique facilities. We highlight prominent examples below.

The **civil engineering structures** laboratory's testing capabilities have been substantially enriched over the REF period with new control systems, a biaxial shake table, and a fatigue testing rig (£700k). Numerous systems have also been commissioned to support field testing and structural health monitoring, facilitating links with industrial partners including Network Rail,

Ward & Burke, and Arup. Wave mechanics laboratories have been enhanced through a new current and **wave flume** funded from institutional sources (£300k). A new laboratory for **advanced soil element testing** was established, with £400k of equipment co-funded by Oxford and industry, as part of the PISA project.

At the **OTI**, an Aerospace Technologies Institute infrastructure grant and a large hardware donation from Rolls-Royce enhanced the existing Oxford Turbine Research Facility. £13M of investment enabled a step change in capability for high-temperature and high-pressure turbine research and testing. Our **hypersonic wind tunnels** facilities are the most capable test facilities in the UK after being upgraded as part of a Government investment in aerospace – with research sponsors including ESA, Reaction Engines, DSTL, USA Dept. of Defense, and USAF. The instruments are now part of the National Wind Tunnel Facility.

We have made significant investment in infrastructure for Solid Mechanics and Materials Engineering. The **Laboratory for in-situ Microscopy and Analysis** has been strengthened by the addition of further thermo-mechanical testing apparatus. Mechanical workshop facilities have been significantly enhanced with the addition of eight **CNC or hybrid machines**. Two new **wire EDM machines** are supported by specialist technicians, enabling important capability for evaluation of novel aerospace materials, where specimens are taken from complex components. By closely integrating technical support, we have unique capability to rapidly design and build apparatus for experimental activities, allowing us to address challenging problems with partners across the University and industry, including Rolls-Royce, DSTL, Mitsubishi Heavy Industries, and EDF.

The **David Cockayne Centre for Electron Microscopy (DCCEM)** in DoM provides a facility for materials characterisation, housing three TEMs, seven SEMs, three Ga FIB-SEMs, a Xe plasma FIB-SEM-SIMS, and sample preparation equipment, supported by six instrument scientists and technicians. DCCEM instruments are run as a sustainable facility serving the department, wider University, and external users (including internationally through access schemes such as ESTEEM3). This central facility is complemented at the research group level by an extensive range of cutting-edge electron, X-ray, atomic, and magnetic force microscopes.

A strategic priority has been the radical improvement of DoM's atom probe tomography (APT) facility, the only such capability in the UK. This now consists of three atom probe instruments, one of which was funded by the National Nuclear User Facilities (value £3.9M). This sustainable facility has two staff scientists undertaking studies for many groups spanning multiple departments, universities, and industry. APT research includes superalloys for aerospace applications, structural materials for fusion and fission power, semiconductors, geological, and biological materials.

Delivering on REF2014 plans, DoM invested in infrastructure for **nanomaterials and nanodevices**, expanding the suite of **dilution fridges** to four, with funding in place for two more. We have refurbished three photonics laboratories, two laboratories for Molecular & Quantum Materials, and refreshed clean room facilities by upgrading electron beam lithography instrumentation and investing in new reactive ion etching equipment. The Sir Henry Royce Institute has funded £7.7M of equipment for **battery synthesis, cycling, and characterisation** in DoM, housed in approximately 1,000m^2 of refurbished laboratory space. We have also continued to invest in large facilities based mostly at Begbroke Science Park (details below).

Significant investment (>£1.6M capital) in high performance computing and technical support personnel has been made to support ongoing work in the areas of CFD, biomedical imaging, machine learning, and artificial intelligence. Along with this, novel computing technologies have been purchased to support research ranging from in-network computing to the development of signal processing pipelines for the upcoming Square Kilometre Array.

We have increased our use of the **Small Research Facility** model to facilitate shared access to equipment across projects and research groups. For example, the ultrafast laser fabrication facility in DES, originally set up through **Booth**'s research programmes, now supports the research programmes of two ECRs (**Salter** and **Fells**) and is used by students and researchers from across UoA-12, from other departments, and from industry.

3.4 Building infrastructure

The two departments occupy ~37,000m^2 of space across five main sites. The primary site is the Keble Road Triangle in the University Science Area, where DES and DoM occupy a set of adjacent or shared buildings, creating an excellent environment for networking and interaction. Groups are also co-located on the Begbroke Science Park, five miles north of central Oxford, where the two departments occupy ~4,300 m^2.

Both departments have rolling minor capital programmes to refurbish buildings and enable co-location of groups and activities for synergistic gain. For example, space released by the consolidation of workshops has been repurposed to house growth in quantum technologies research and enable co-location of nano-photonics labs and expanded dilution fridge capacity.

The current period has also seen some larger-scale investments:

- a £2.3M extension to the OTI building provided ~200m^2 additional research space, a new compressor room, and an atrium display space to facilitate public engagement with research (which houses a Trent 1000 engine donated by Rolls-Royce);
- a phased £6.6M programme of refurbishment (including co-funding from the Royce Institute and Wolfson Foundation), plus equipment investment, providing 3,000m^2 of lab and office facilities for an Energy Storage Materials Centre and the Materials Modelling Lab;
- £300k to create new lab facilities housing a new atom probe tomography system, dilution refrigerators, and optical benches.

We are developing long-term plans for the overhaul of UoA-12 space in the Keble Road Triangle. The first step will be construction of a new Information Sciences Building to co-locate Computer Science and Information Engineering, which is currently in the early stages of design (RIBA Stage 0/1).

3.5 Use of Infrastructure and facilities to realise impact

As noted already (*section 3.3*), many of our core research facilities are used by external collaborators and industry partners, either directly (as a service) or through industry-funded research.

Another key asset for supporting impact is the University's Begbroke Science Park. This provides space for University research (primarily from UoA-12) and large-scale research infrastructure (such as aluminium direct-chill casting, metal spray forming facilities, and production-scale web-coater) alongside small-scale industrial units and incubator space. The latter houses a mix of University spin-outs and companies seeking to engage with University expertise, ranging from early-stage start-ups to R&D teams from established multi-nationals. Several spin-outs from UoA-12 (including Opsydia, Bodle Technologies, and Oxford High-Q) are currently based at Begbroke, which enables ongoing collaboration and closer integration of research and development.

The Science Park houses the industry-facing Oxford Materials Characterisation Service (OCMS). This offers a range of characterisation techniques, on a commercial basis, through service work by its own staff, or "supported self-drive". The OCMS team can also facilitate contracts with academic groups who have relevant expertise or equipment not available in the main facility.

A Joint Venture between the University and Legal & General will enable significant expansion of both commercial and research facilities at Begbroke during the next REF period, with a target of up to 10,000m^2 of new development (including upgraded cleanroom facilities) by 2025.

3.6 Collaborative use of infrastructure

UoA researchers (30) have been active users of external major facilities, in many cases making significant contributions to their leadership and development (*section 4.1*). During the period, we benefitted from over £10M of research income-in-kind (a 75% increase on the annual average from the previous REF).

The connections between the departments and Diamond Light Source (DLS), the UK's national synchrotron facility, are evidenced by the >175 projects during the period (*section 4.1*). Solid Mechanics and Materials Engineering maintain strong links with both DLS and ISIS, through involvement with visiting scientists and world-leading engineering instruments (JEEP, ENGIN-X, IMAT).

DoM researchers contributed to establishment and leadership of CCFE's Materials Research Facility and the wider materials-related aspects of the new national STEP programme to develop a small fusion reactor. DoM led, for EPSRC, the bid to BEIS that, in 2018, secured £76M of funding for 15 projects for internationally-significant infrastructure in the National Nuclear User Facility (NNUF) project.

We are one of the six managing consortium universities in SuperSTEM (**Nellist** as Deputy Chair of Consortium Advisory Panel), which with £7.2M renewal funding specialises in high-energy resolution spectroscopy allowing study of vibrational modes.

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

4.1 Collaborations, networks, and partnerships

Our researchers collaborate widely, both nationally and internationally. According to Scopus, between 2014 and June 2020, the UoA produced just under 6,000 outputs. Of these, 71% had external collaborators; 47% were international collaborations. Papers with external collaborators have been cited more than 85,000 times.

Links to External Institutes

In addition to the Quantum Technologies Hubs (*section 3.3)*, staff from the UoA have contributed to several national Institutes that support UK-wide collaboration:

- **Rosalind Franklin Institute**: This new national institute aims to deliver transformative changes in life science through interdisciplinary collaboration, and physical science and engineering technology development. **Roy** and **Kirkland** spearheaded development of two of the five science themes in the case for £103m of government investment. **Kirkland** is now Science Director for Correlated Imaging and leads the £7.8m project to develop an aberration corrected pulsed electron microscope for visualising atomic-scale dynamic events. **Stride** is PI on a Platform Development Project to build the world's most advanced real-time high-speed video camera.
- **Diamond Light Source (DLS)**: The electron Physical Science Imaging Centre (ePSIC) is a national facility for aberration corrected electron microscopy, established as a collaboration between Johnson Matthey, DoM (**Kirkland**, **Kim**), and the DLS to provide access to state-of-the-art transmission electron microscopes with expert support from our scientists. **Hofmann**, **Tan** and **Korsunsky** co-supervise joint doctoral projects at DLS, where **Korsunsky** also leads a group and champions the upgrade (OCTOPI) of I13 Imaging beamline. **Kawal Sawhney**, head of Optics and Metrology at DLS, is Visiting

Professor in DES. **Goulart** and **Duncan** are designing the control system for the main electron ring at Diamond-II.

- **The Faraday Institution (FI)**: Also with an HQ on the Harwell Campus, the FI is the UK's independent institute for electrochemical energy storage science and technology, supporting research, training, and analysis. It was co-founded (in 2017) by **Bruce**, who led the case for government investment and is now its Chief Scientist. **Pasta** is project lead for the SOLBAT consortium project (an £11M partnership between 6 HEIs and industry); and **Grant** is PI for NEXTRODE (a £12M, six-partner project investigating next-generation battery electrode structures); groups from the Chemistry and Process Engineering and EOE clusters are also partners in FI programmes; whilst **Weatherup** is PI for a battery characterisation project (with Manchester).
- **Oxford Suzhou Centre for Advanced Research (OSCAR)**: opened in 2018, this collaborative research facility is Oxford's first overseas centre devoted to physical sciences and engineering. Seven UoA-12 PIs are establishing labs there and building research networks throughout China and Asia. Examples of ongoing collaborations include: fetal ECG screening with Wuhan Children Hospital; and Raman detection of antibiotic-producing strains, with the Soil institute, Chinese Academy of Sciences. OSCAR labs played a critical role in development of a rapid COVID-19 test (*see impact case study*).
- **Sir Henry Royce Institute**: We are a partner in this national collaboration and the lead for energy storage materials. Specialist facilities in our Energy Storage Materials Centre – along with some atom probe, and electron microscopy instruments – are available and promoted to the wider materials community through Royce.
- **Alan Turing Institute**: The University is a founding member of this national institute for data science and artificial intelligence. Six of our PIs had formal associations with the institute through fellowships and faculty member positions during the REF period.

4.2 Other Major Collaborative Networks and Initiatives

Our researchers participate in a myriad of national and international research networks, including numerous formal collaborative projects. Illustrative examples include:

- **Stride, Roy, Coussios,** and **Cleveland** are central players in the Therapeutic Ultrasound Network for Drug Delivery and Ablation Network (ThUNDDAR), a national network of multi-disciplinary therapeutic ultrasound experts whose aim is to promote clinical use of therapeutic ultrasound.
- Eight DES academics are charter members of the new European Laboratory for Learning and Intelligent Systems (ELLIS), a network of leading academics working closely with industry researchers on artificial intelligence.
- **Reed** directs the Next Generation Tatara Co-Creation Centre, Shimane, Japan**,** a manufacturing base for next-generation materials for electric vehicles and aircraft engines.
- **Yang** and **Ng** led the international knowledge exchange platforms SYNERGORS and CRES, promoting system thinking and circular economy, such as enhancing the reuse and recycling of resources in industrial and waste management systems.
- **Booth, Fells, Morris,** and **O'Brien** bring expertise in 'Quantum Computing and Technologies' and 'Optical Engineering and Communications' to the European Space Agency Lab@Oxford collaboration with groups across other departments.
- As inaugural members of the Bristol-Oxford Nuclear Research Centre, we provide innovative research to support the safe operation of current and future generation nuclear systems. Research has been supported through two large EPSRC multi-institutional research grants, and direct support from EDF Energy and AWE. **Grovenor** (to 2019) then **Marrow** are co-directors. The centre houses 60 full-time researchers, demonstrating commitment to training a new generation of nuclear scientists and engineers.

Members of the UoA also lead or play prominent roles in networks across the University and associated bodies. These include the Oxford Optics and Photonics Network, Oxford Metamaterials, and Oxford Energy.

4.3 Relationships with key users and external audiences

We interact with industry through multiple mechanisms, tailored to different situations; these range from long-term 'institutional' partnerships (*e.g.* with Rolls-Royce) to more recent relationships developed from individual research connections. Activities include service contracts (for immediate practical application of specialist knowledge and facilities) and collaborative research programmes (with open or closed outcomes depending on the nature of the contract). Where possible, we seek to leverage government and industry funds to amplify the activity and the impact (*e.g.* we are involved in three EPSRC Prosperity Partnerships, large-scale industry-led collaborations with public and industry funding). Contract support is provided by the University Research Services and Legal Services teams. Examples during the period include:

4.3.1 Long term partnerships with Industry

University Technology Centres

UTC work by **Bacic**, who holds a joint Oxford/Rolls-Royce position, led to a Civil Aerospace Best Patent award (2015). One prominent example of impact arose from joint research since 2014 by **Ireland**, **Gillespie**, **Bacic**, and others into heat transfer management in new turbine designed to operate at high firing temperatures and minimise fuel burn and CO_2 emissions. Their research led to new technology for controlling rotor leakage flows and hence turbine losses: the technology was integrated into the Rolls-Royce Trent XWB engine used in the Airbus A350 (317 aircraft across 31 operators).

The UTC model is well-suited to interactions with well-established industrial partners, where stability of a long-term relationship is beneficial to both parties, allowing the UTC to develop facilities and expertise, to contribute to technology road-mapping, and to apply research outcomes more quickly through established pipelines.

As noted in *section 1.1.1*, we host two of the longest-established Rolls-Royce UTCs. In Aug 2013, the Heat Transfer and Aerodynamics UTC became the first of 31 UTCs to achieve ISO9001 compliance, providing reliability to Rolls-Royce. UTC facilities have enriched the research environment, underpinning new research into jet engine cooling and hypersonic flight, and the effects of sand deposition on turbines, attracting significant UKRI and industry funding.

Through the UTC in Solid Mechanics, we engage with a worldwide network of research supporting the aircraft propulsion industry. During the REF period, investment in state-of-the-art facilities for impact and high strain-rate testing of materials and components has enabled us to tackle new technical challenges, including a paradigm shift in the use of new materials for large aviation gas turbine engines.

In January 2020, we launched the Hitachi Metals-Oxford UTC of Metallurgy, cementing a long-term collaboration between DoM and Hitachi Metals. The initial focus will exploit expertise on advanced superalloy development for aerospace applications and amorphous ferrous ribbon processing as crucial technology for improved electric motors for the automotive industry.

Centre of Excellence for Compression Ignition Engine Combustion Research

From 2014–19, DES hosted the Oxford/Jaguar Land Rover (JLR) Centre of Excellence for Compression Ignition Engine Combustion Research. This supported work with a strong focus on improving efficiency and emissions in next-generation engines. Our state-of-the-art engine test facility, developed in partnership with JLR, supported JLR diesel research.

The collaboration will be continued with a five-year EPSRC Prosperity Partnership between DES, JLR, University of Bath, and Siemens Digital Industries. The expanded centre will develop hybrid propulsion systems and examine low-carbon fuels in highly efficient thermal propulsion systems and electric motors, while minimising demand on the electricity grid and preparing for future fuels.

4.3.2 Strategic partnerships in key areas

Offshore renewables

Building on a decade of collaboration – including the highly-successful Pile Soil Analysis (PISA) project, which involved 11 of Europe's main offshore windfarm developers responsible for 75% of offshore wind capacity – we established a five-year research framework with Ørsted. Improved geotechnical designs are already reducing the costs of offshore wind (*see impact case study*), with findings being incorporated into international standards for all future developments. **Byrne** and **Willden** co-direct EPSRC's £9M Supergen Offshore Renewable Energy Hub, which has resulted in 22 funded research projects and provided opportunities for 157 ECRs, who are now a part of the network.

Computational research infrastructure

The OeRC has undertaken extensive work on computational research infrastructure, with industrial collaborators Intel, ARM, and Atos. It has hosted an NVIDIA CUDA Centre of Excellence and formed an Enterprise Innovation Centre with Lenovo. Activity has also covered biomedical work with Roche and Springer Nature, and energy and climate work with the National Trust and Marks and Spencer.

Nanomaterials

The EPSRC IAA-funded project *Special nanomaterials for ultra-performance heat exchangers in motor and aerospace industries* involved development of heat exchangers that led on to work on thermal management module manufacture with Williams Advanced Engineering. This link developed into a Royal Society Industry Fellowship for **Grobert**.

4.3.3 Other partnership enablers

Centre for Advanced Superconductivity

Established in 2015 using Local Growth Funding, the centre enables collaboration with an important regional cluster of industries to whom superconducting materials are vital. This includes Siemens Magnet Technology, Oxford Instruments, Element6, and a growing number of SMEs (*e.g.* Tokamak Energy and MRsolutions).

Oxford Robotics Institute (ORI) Membership

The ORI has an extensive network of industry collaborators, supporting symbiotic interactions and a user-led research agenda in large-scale mobile autonomy. The membership scheme enables deep immersion within the ORI portfolio. Companies can embed employees within the institute with access to data, software, hardware, and facilities, as well as seminars, trials, and workshops. The scheme accelerates and catalyses knowledge transfer from the ORI to its industrial members.

ORI employs a diverse set of over 20 robots: rovers, cars, drones, handheld sensor platforms and quadrupeds. With experience in a wide range of robotic systems as well as excellent fundamentals in robotics, ORI's team of in-house professional engineers are instrumental in making the membership programme a success.

Consultancy

As explained in *section 2.4,* we encourage staff to undertake up to 30 days of consultancy per year, as this is an effective way both to deliver expertise to industry and to identify user needs. Support is available through OUI, which identifies opportunities, negotiates terms, manages consultancies, and provides professional indemnity cover. This is a highly effective model that has delivered robust growth in activity. Across the REF period, our researchers held an annual average of 116 outside appointment activities, such as consultancy, voluntary work, or company directorships.

4.4 Wider evidence of impact

Commercialisation

During the period, the two departments generated 265 priority patent filings; and OUI completed 134 licensing agreements arising from UoA projects. The establishment of Oxford Sciences Innovation plc (OSI) has driven an increase in spin-out activity: 34 companies were spun-out from DES and DoM in the REF period, in areas ranging from healthcare products to AI business solutions.

Notable spin-out examples not covered by *Impact Case Studies* include:

- *6D.ai* exploits research from the Active Vision Lab (DES) to develop unique imaging software, designed to enhance augmented reality (AR) applications and help them interact with the world in a natural and realistic way. In 2020, *6D.ai* was acquired by Niantic Labs.
- *OxMet Technologies* builds on decades of research and experience with alloys and alloy processes at Oxford. Founded in 2017, it developed the Alloy-by-Design (ABD®) rapid alloy design and optimisation software which is used to develop, license, and manufacture proprietary alloys, alloy powders, and components for the aerospace, automotive, industrial, and biomedical markets.
- *Mindfoundry* has developed a collaborative, accessible AI platform, allowing application of machine learning to solve real-world problems encountered by business, and employs over 30 people. The platform enabled a measurement instrument manufacturer to predict and categorize equipment failures, saving months of work. Its services are extensively used in the finance industry, deployed to optimise existing algorithmic solutions and generate new ones, helping drive down losses across several use cases.

Other illustrative examples of impact and technology transfer

Researchers in Control Engineering have led a collaboration with Stanford, Princeton, and ETH Zurich to develop open-source software for large-scale optimisation (www.osqp.org), which has been downloaded 2.5M times and is used by organisations including Google, Blackrock, and Lyft. **Papachristodoulou** and **Steel** have created open-source hardware for biological science research (www.chi.bio), which is being used in industry and academia (Microsoft, Vow Foods, Caltech). In materials modelling, **Yates** has projects supporting industrial take-up in screening new pharmaceutical compounds, (bio)minerals and glasses, with users including AstraZeneca and Johnson Matthey.

The EPSRC IAA-funded project *Crowdsourced Map Building for Disaster Response* (led by **Reece**) developed rapid delivery of information to disaster responders using satellite imaging combined with machine learning and crowdsourced technologies. This has been used by numerous agencies for improved recovery times following major hurricanes.

Further prominent examples of policy and industrial impact:

Building upon her expertise in nanomaterials, **Grobert** has influenced policy serving as a Chief Scientific Advisor to the European Commission. This has led to agenda-setting reports on microplastics that have directly impacted policy making in various international contexts: including influencing the Commission's agenda and policies concerning microplastics pollution and biodegradability of plastics in the open environment, as well as enabling international collaborations between the G7 countries on the prevention of microplastics pollution.

Leach and **Stone**'s vehicle emission research and manufacturer collaboration led to the adoption of a metric (the PN index) that links fuel composition and particulate emissions from gasoline direct injection (GDI) engines (today's dominant engine technology). The PN index and its associated study were provided to the European Commission to inform the fuel composition standards in the current Euro 6 legislation. This work has directly improved the practice of their industrial partners, particularly JLR. Bosch and BMW have cited the Oxford PN index in their publications. Furthermore, improvements in practice arising from this work have positive implications for public health through reductions in particulate emissions.

Research in the UoA has also led to significant public policy impacts, several of which are described in our *impact case studies* (see: *Informing policy by raising awareness of the societal and economic effects of automation; Oxbotica – Creating Universal Autonomy for Vehicles*; and *The FAIR Principles and FAIRsharing: Transforming Data Policies, Supporting Reproducibility and Reusability World-Wide*).

4.5 Wider community engagement

Public Engagement with Research (PER)

Both departments take an active role in high-quality, innovative public engagement activities to enrich research and society via radio interviews, television/YouTube appearance, podcasts, and workshops. Notable PER examples include:

- **Page** was a part of the *Digital Delius* project, which won a VC Public Engagement with Research award. Working with the British Library, this collaborative team of Oxford academics from DES and Music created a permanent digital exhibition, supported by workshops for young people in Oxfordshire to enable a wider understanding and appreciation of musical sources.
- OeRC invests significant effort in public engagement, such as performances at the Barbican of music written by AI as a tribute to Ada Lovelace. As part of the PRiSM collaboration, **De Roure** provided the dataset for the AI used to write the musical score.
- *Making Materials Matter* is an ongoing annual collaborative project which began in 2016. Over 100 Year 8 students have engaged, carrying out student-led research investigations culminating in a Student Conference. The scheme enriches the curriculum and increases awareness of materials science. Originally a joint Oxford-Cambridge initiative, partners now include Imperial College and Sheffield University.
- ORI researchers ran *Betty the Robot at Blenheim Palace* and gave many public lectures (*e.g.* Royal Society Milner Lecture and the UCL Milldner Lecture). ORI has also been involved in major public demonstrations to improve public perceptions of autonomous vehicles, including the Lutz, Autodrive, and DRIVEN projects.
- UoA members participated in more than ten podcasts or animations designed for the public via *Oxford Sparks*, the University's online science engagement portal. These range from Lefferts' work on chemiresistive sensors being explored to match that of sniffer dogs, to Posner and Ashton discussing what Hollywood gets wrong or right in science fiction.

Interdisciplinary research

Our many notable advances in interdisciplinary research have been mentioned throughout this environment statement and a visual representation of this breadth can be seen in *Fig. 3*.

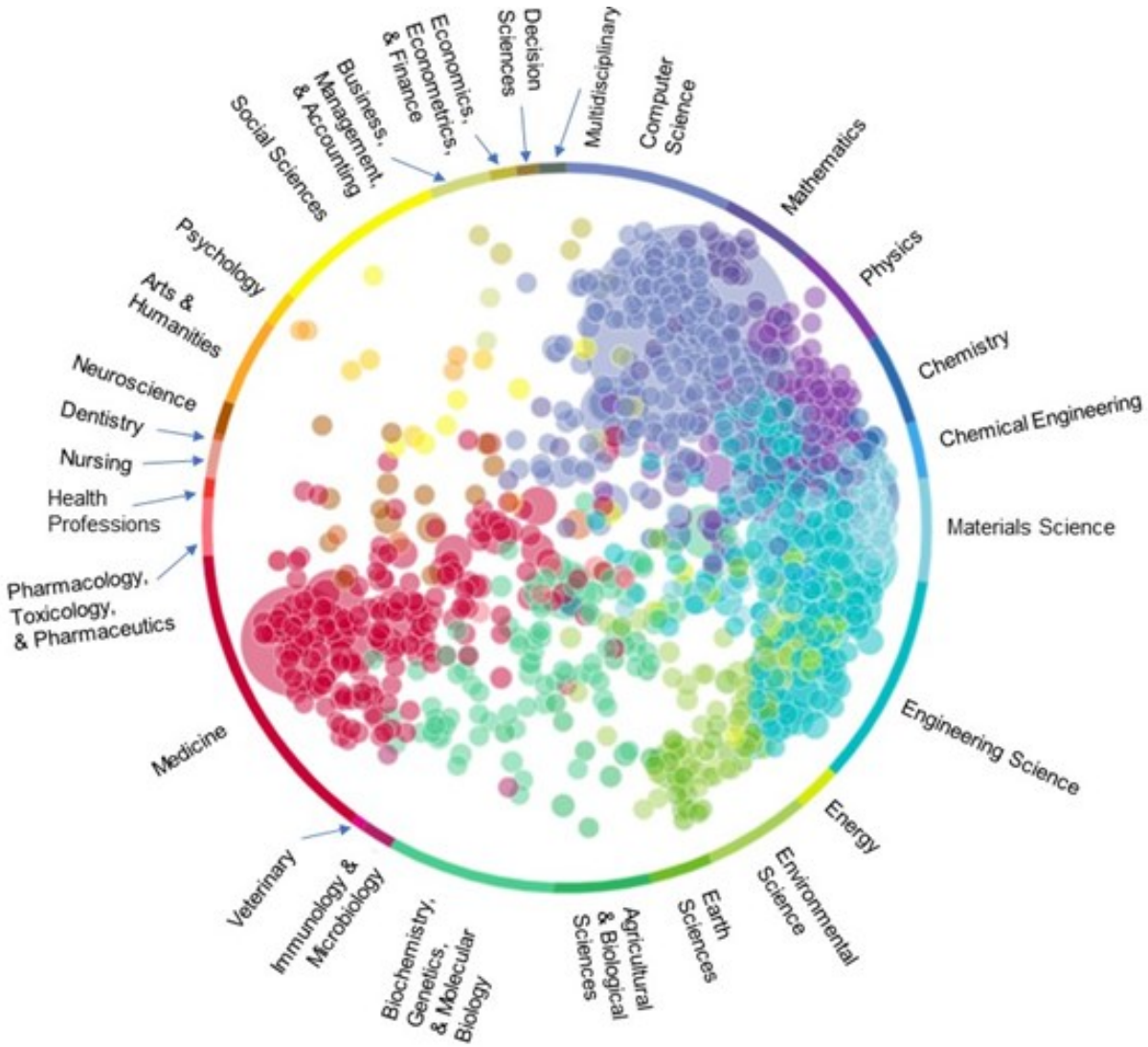

Figure 3: Scholarly outputs by topic, 2014-20, illustrating the interdisciplinary reach of the UoA's research (data source: Scopus).

For brevity, we highlight again just the two major areas of Biomedical and Information engineering.

The IBME's location on a medical campus has facilitated collaboration between engineering researchers and clinicians from a broad range of disciplines, including radiology, oncology, cardiovascular medicine, obstetrics, and gerontology. During the REF period, 18 clinical trials of novel technologies developed within the IBME have been conducted, reported in major journals including *Nature*, *Lancet Oncology*, and *JAMA Cardiology*. The IBME's contributions to medical technology innovation and clinical translation for societal benefit were recognized by the award of the 2015 Queen's Anniversary Prize.

Research in Information Engineering is inherently interdisciplinary, working within the University with Materials, Anthropology, and Zoology. More widely, we have collaborated with MIT and Universidad Carlos III de Madrid on the Atlas of Inequality Project, and in the Data for Refugees

Challenge with higher education institutes worldwide. A unique collaboration with the Man Group has continued in this REF period through OMI, where pioneering research into quantitative finance using machine learning techniques and data analytics is conducted. This in turn has led to the spin-out *Mindfoundry* (*section 4.4*). Similarly, experts in computer vision worked with the Nuffield Department of Clinical Medicine to create a wearable technology to assist those with near blindness to regain freedom. This was subsequently spun out into the company *OxSight* (*see impact case study*).

Responsiveness to national/international priorities

The UoA's strategies for expansion in particular areas have enhanced its ability to respond to national and international priorities. Evidence for this in areas including turbomachinery and robotics has already been detailed in *section 4.3*. Further clear examples of this arose on separate fronts in Biomedical Engineering during the COVID-19 pandemic:

- **Cui** and **Huang** led development of rapid COVID-19 tests that are being widely deployed (*see impact case study*).
- The *OxVent* initiative was launched, with significant input by DES researchers and pump-priming funds from the department, in response to the UK Government's ventilator challenge in March 2020. Within ten weeks, *OxVent* created a simple, scalable design, based on off-the-shelf components with one moving part. A single manufacturing line can output 5,000 units/week at around £1,000/unit, making it suitable not only for rapid response during a pandemic, but also for increasing routine critical care capacity and access to emergency surgery in lower-middle income countries.
- The *SEND* (*System for Electronic Notification & Documentation*) in-hospital vital-sign monitoring system helped to support the management of COVID-19 patients in Intensive Care Units (ICU). This system, developed by **Tarassenko**'s group and clinical collaborators, was deployed throughout the Oxford hospitals and contributed to a reduced ICU mortality rate of 15% in these hospitals, compared to the national average rate of 40% ICU mortality rate in the first wave of the pandemic in 2020.

At national level, the UoA has engaged with societal and business challenges including through several Industrial Strategy Challenge Fund projects. We highlight three notable examples:

- **Clean growth**: The UoA participates in two regional ambitious projects: Local Energy Oxfordshire (LEO), trialling intelligent local grids to balance power generation and demand; and Energy Superhub Oxford (ESO), building a rapid charging network for big vehicle fleets.
- **Future of mobility**: Further to the close work with the Faraday Institution and its battery challenges (*section 4.1*), we are also part of consortia which focus on exploring how robots can make a safer world (RAIN: advanced robotics in nuclear operations, and ORCA: AI for offshore energy management). We are also at the forefront of self-driven vehicles (*see impact case study*).
- **AI and data**: The JADE 2 consortium and facility is a collaboration with Maths and Biochemistry. Bringing together 19 universities, JADE is a unique national resource, providing state-of-the-art GPU compute for research in areas including artificial intelligence, machine learning and molecular dynamics.

Our ongoing strategic support and development plans for these and other research areas (as detailed in *section 1*) mean that we will be in a strong position to respond to future emerging priorities.

4.6 Indicators of recognition, external influence and esteem

Below, we provide highlights of the wide range of activities we have undertaken, and accolades we have received, which demonstrate and recognise our researchers' wider influence beyond the University, their contributions to the vitality and sustainability of the discipline, and leadership roles.

Journal Editorships

48% of our academic staff have at least one editorial role in scientific journals (78 editorships in total). To highlight this, we list here those who hold (or have held since 2014) senior Editor-in-Chief or equivalent positions:

- **Booth**: Optics Communications.
- **Chen**: IEEE Transactions on Visualization and Computer Graphics; Wiley Computer Graphics Forum.
- **Hankins**: Journal of Water Process Engineering.
- **Hills**: International Journal of Solids and Structures.
- **Jerusalem**: Brain Multiphysics.
- **Kirkland**: Ultramicroscopy.
- **Korsunsky**: Materials & Design.
- **Nellist**: Journal of Microscopy.
- **Sansone**: Springer-Nature Scientific Data.
- **Smith**: Materials for Quantum Technology.
- **Stone**: Proc IMechE Part A, Journal of Power and Energy.
- **Todd:** Journal of the European Ceramic Society; Journal of Wuhan University of Technology: Materials Science.
- **Wallom**: SoftwareX.
- **Wilson**: Journal of Microscopy.

Services to Funding Bodies

Academic members of DES and DoM contribute regularly as reviewers for funding bodies and over 40% have served on research council or other funding committees, including EPSRC, the Royal Society, and several others. Of particular note are the following:

- **Briggs**: Principal Advisor for the Power of Information initiative; directs services provided by the University of Oxford for Templeton World Charity Foundation.
- **Denison**: Royal Society Working Group in Neurotechnology 2018-19; NIH (U.S.) Director's working group, BRAIN Initiative 2.0, 2018-19.
- **Grant*:*** 2011-17 EPSRC Strategic Advisory Network; 2010-15 EPSRC Manufacturing the Future Strategic Advisory Team.
- **Grobert**: served on ten research council committees or similar bodies.
- **Grovenor**: leads the NNUF Management Group.
- **Houlsby**: member, RAEng Research Fellowship selection committees.

Prizes and Awards

UoA members have collectively been awarded over 80 academic prizes since 2014. Selected highlights include:

- **Armstrong**: IoM3, Grunfeld Award & Medal (2016)
- **Bacic**: Royal Academy of Engineering, Silver Medal (2020)
- **Booth**: International Commission for Optics Prize (2014).

- **Bruce**: Royal Society of Chemistry, Liversidge Award (2016); Royal Society, Hughes Medal (2017).
- **Byrne, MacAdam, and others**: British Geotechnical Association, Fleming Award (2017).
- **Kirkland**: Harald Rose Distinguished Lecture Award (2015); European Microscopy Society, Quadrennial Prize (2016), Royal Microscopical Society, Alan Agar Medal (2017).
- **McCulloch**: Gusi Peace Prize (2018).
- **Nellist**: European Microscopy Society, Outstanding Paper Award in Materials Science
- **Newman**: Royal Academy of Engineering, Silver Medal; Inst Measurement and Control, Sir Harold Hartley Medal.
- **Siviour**: Society of Experimental Mechanics, JSA Young Investigator Award.
- **Stride**: Institute of Engineering and Technology, AF Harvey Prize (2014).
- **Todd**: European Ceramic Society, Stuijts Award (2019).
- **Zisserman:** Royal Society, Milner Award (2017).

Learned Societies

The following have been elected to fellowships of national learned societies during this REF period:

- **Nellist, Noble**: Fellow of the Royal Society.
- **Nellist**: Honorary Fellow, Royal Microscopical Society
- **Coussios, Cocks, Ireland, Reed, Roberts, Stride, Torr, Trefethen**: Fellow of the Royal Academy of Engineering.
- **Bruce, Grobert**: Members of Academia Europaea

Honorary and Visiting Professorships

- **Booth**: Visiting Professor, SAOT, University of Erlangen-Nürnberg, Germany.
- **De Roure**: Honorary Visiting Professor, Royal Northern College of Music.
- **Grobert**: Visiting Professor, Toyo University, Kawagoe, Japan
- **Kirkland:** Honorary Professor, Nelson Mandela University; Distinguished Honorary Visiting Professor, Shanghai Technical University.
- **Roy**: Honorary Professor, Hong Kong Polytechnic University
- **Wilson:** 2013-2020 Thousand Talents Professor, Harbin Institute of Technology.

Significant training roles

- **Morris:** Academic Director for CPD programmes in Electronics, Engineering, and Telecommunications at Oxford's Department for Continuing Education.
- **Smith**: Associate Director (Skills and Training), Networked Quantum Information Technologies Hub (NQIT) (2014-19).

Prominent Lectures

Our academics have collectively given around 1,000 invited lectures at conferences and other events. Particularly prominent highlights include:

- **Booth:** Ernst Abbe Lecture, International Commission for Optics Congress, 2017.
- **Houlsby:** 54th "Rankine Lecture" (given 25 times), Institute of Advanced Studies Distinguished Visiting Fellow Lecture, Osterberg Lecture, Jack W. Hilf Memorial Lecture, "Cross-Canada Lecture Tour" (10x lectures).
- **Zisserman:** KCIS Distinguished Lecture; Royal Society Milner lecture; British Machine Vision Conference (BMVC) keynote 2013.

Other Notable Service

- **Bruce**: Physical Secretary, Royal Society, from November 2018.
- **De Roure**: Gave oral evidence to three Select Committee Inquiries; Member of Government Office for Science Blackett Review of Internet of Things (2014); Expert on EC Foresight on Key Long-term Transformations in Research, Innovation and Higher Education (2014-15); Member of the Executive of the UK Computing Research Committee.
- **Denison**: Graham Clarke Orator, Melbourne Australia (2019) (Oration, School Outreach, and Neurotech conference).
- **Grant**: Board member, Oxfordshire Local Enterprise Partnership (OXLEP, 2018); Appointed by Minister for Universities, Science and Cities to the Advanced Materials Leadership Council (2014-16); Non-executive director, Oxford University Innovation (2015-).
- **Grobert**: Group of Chief Scientific Advisors to the European Commission (member since May 2018; chair from November 2020); Chair, Young Academy of Europe (2015-16).
- **Houlsby:** Member, search committee for 2019 Queen Elizabeth Prize for Engineering. Will be Vice-chair, then Chair in the coming biennial rounds.
- **Marrow**: Independent advisor to the UK nuclear regulator (ONR).
- **Nellist**: President, Royal Microscopical Society (2013-16).
- **Noble**: Member, Government Blackett Review Panel (2016-17); Chair, Royal Society Policy Working Group: Privacy Enhancing Technologies (2017-19); Member, Royal Academy of Engineering (RAEng): Capturing Value Steering Group (2017-19); Member, RAEng External Affairs Committee (2013-15).
- **Roy:** Acoustical Society of America: various positions, including Vice President (2016-17).
- **Wilson**: Master, Worshipful Company of Scientific Instrument Makers (2014-15).