

Institution: University of Southampton

Unit of Assessment: 12 Engineering

1. UNIT CONTEXT AND STRUCTURE, RESEARCH AND IMPACT STRATEGY

1.1 Overview and Structure

1.1.1 Overview

The Unit covers a wide range of engineering and applied science disciplines, encompassing traditional application areas such as aerospace, civil, electrical, electronic, and mechanical engineering; enabling technologies such as computation, imaging, materials, optoelectronics, and photonics; and future-facing applications such as biomedical, communications, cyber, and sustainability. We have a strong emphasis on the interactions between engineering, the environment and people; and on the complex systems that characterise and describe them.

The Unit comprises the School of Engineering (**SoE**); engineering disciplines of the School of Electronics and Computer Science (**ECS**); and staff within the Zepler Institute of Photonics and Nanoelectronics which includes the recently established Centre for Electronic Frontiers and the long-established Optoelectronics Research Centre (**ORC**). Over the current assessment period, we have built on the strong separate submissions in REF2014 by:

- Increasing average per capita annual research grant and contract income by >52%, from £108k to £166k
- Winning 7 new EPSRC Programme Grants (value £38.4M) to Southampton PIs, in addition to the 4 already running at the start, and participation in 6 further Programme Grants (value £33.7M) led from other universities
- Attracting capital grants and other third-party investment that has funded a complete new £170M engineering campus and £25M of major equipment
- Improving the diversity of our staff - for example, numbers of Category A BAME staff have increased from 49 to 62, and non-UK staff from 100 to 110; and of 26 Early Career Fellowships, 6 were won by women

1.1.2 Structure

SoE, **ECS** and **ORC** all sit within the Faculty of Engineering and Physical Sciences (FEPS), which oversees common structures and procedures for administrative, staff, and student support. All are research-intensive; **SoE** and **ECS** have vibrant undergraduate and postgraduate teaching programmes, while **ORC** teaches only at postgraduate level. In this narrative, all three sub-units are referred to as “schools”. Descriptions are given by individual school or for the whole Unit, as appropriate.

Figure 1.1: Unit Category A staff by School

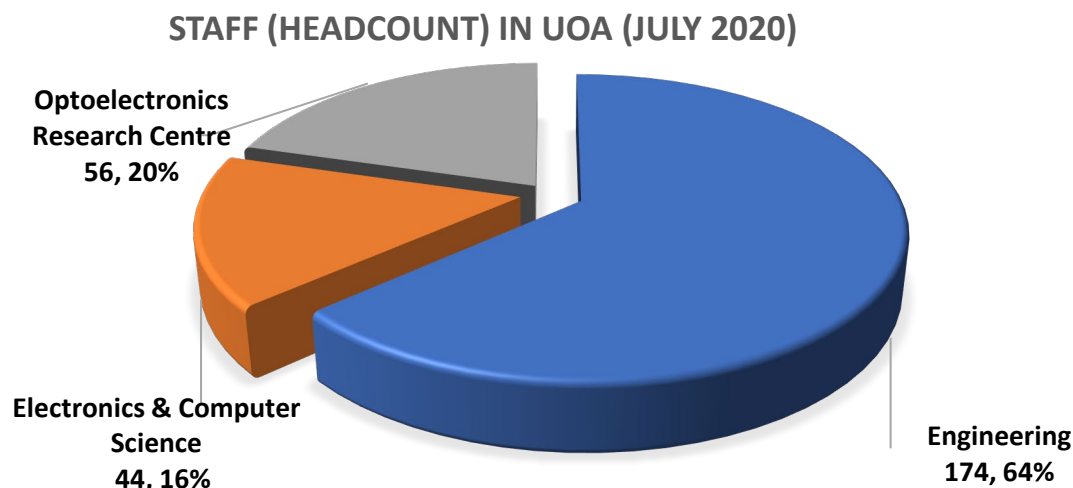


Table 1.1: Summary of Unit Staff and Research Income for the final year of the REF period (2019/20)

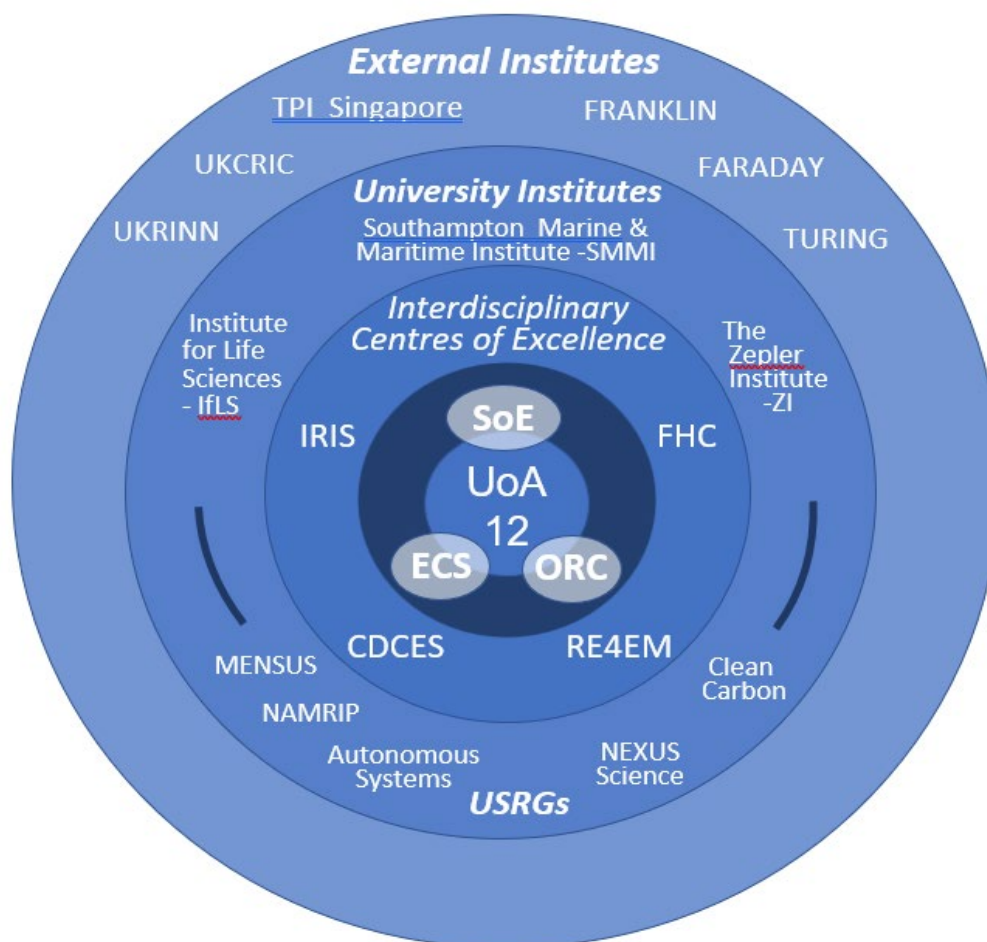
	Cat A REF submitted staff Headcount	Cat A REF submitted staff FTE	PDR Fellows	In-year Doctoral awards	Research Grant Income £M
Total	273	261	271	136	39.0

Solving societal, system-scale problems requires a flexible organizational structure enabling engineers to work together with other disciplines in responsive and changing collaborations, whereas people management requires stability and consistency. To provide that stability, each member of staff belongs to a research group within an academic department. Academic staff are line managed by their group or department head. Research projects and teams are organised more flexibly, to encourage work across traditional discipline boundaries.

Interdisciplinary and cross-school research is further promoted through University-level Institutes, collaborative research funding, Centres for Doctoral Training (§4.5) and interdisciplinary Centres of Excellence (§3.2).

The *Interdisciplinary Centres of Excellence* are Continuous Digital Chemical Engineering Science; Future of Human Communication; Health Technologies; In-situ and Remote Intelligent Sensing; Internet of Things and Pervasive Systems; Machine Intelligence; and Re-engineering for Electric Mobility (§3.2). *USRGs* are University Strategic Research Groups (§1.4).

Figure 1.2: Engagement of the Unit and Schools with internal and external cross-disciplinary groups.



SoE comprises four departments, with constituent management groups as follows.

- **Aeronautics, Astronautics and Computational Engineering (AACE):** Astronautics; Aerodynamics & Flight Mechanics; Computational Engineering & Design.
- **Civil, Maritime and Environmental Engineering (CMEE):** Energy and Climate Change; Maritime Engineering; Infrastructure; Transportation; Water and Environmental Engineering.
- **Mechanical Engineering (ME):** Bioengineering; Energy Technology; Engineering Materials; Mechatronics; National Centre for Advanced Tribology.
- **Institute for Sound and Vibration Research (ISVR):** Dynamics; Acoustics; Signal Processing, Audio and Hearing.

In addition to these established engineering areas, **SoE** works at the interfaces between engineering and complex biological systems; for example in environmental and ecosystem management, bioengineering, human factors, and performance sport. Our research addresses key challenges facing society in areas including sustainable energy, green transport, resource efficiency, resilient infrastructure, and cities, mitigating and adapting to climate and environmental change. Research projects and teams are therefore organised more flexibly (as is teaching), transcending the traditional disciplines of aeronautical, civil, environmental, maritime, and mechanical engineering, around themes of:

- Acoustics
- Autonomous Systems
- Bioengineering
- Computational Engineering
- Energy and Climate Change
- Fluid Dynamics
- Infrastructure
- Materials, Solid Mechanics and Surface Engineering
- Transportation
- Water and Environmental Engineering

These themes reflect and are supported by major laboratories and facilities, as described in §3.5. They have been developed and refined over the assessment period to enable us to respond to key international and UK research priorities, as described in §4.4.

ECS comprises one large integrated school spanning the spectrum of Computer Science (UoA 11) and Electrical and Electronic Engineering. It is organised into management groups clustered around research themes. Following a strategic review in 2016 these groups were reorganised to reflect the interdisciplinary nature of our research, new research challenges, and opportunities. The groups relevant to this UoA are:

- Biomedical Electronics
- Cyber Physical Systems
- Electrical Power Engineering
- Next Generation Wireless
- Smart Electronic Materials and Systems
- Sustainable Electronic Technologies
- Vision Learning and Control

Research groups include staff from both computer science and electronics facilitating cross-disciplinary research, for example between software and computer hardware. The groups' research covers a wide range of areas e.g. nanotechnology and nanoelectronics, electronics hardware (power, processing and reliability), wireless communications, power generation/distribution, materials, and medical technologies. Cross-cutting research is further facilitated through interdisciplinary initiatives, which bring together staff with complementary skills to address specific challenges in Machine Intelligence (CMI); Health Technologies (CHT); and Internet of Things and Pervasive Systems (CIoT). These new initiatives sit alongside the *Arm-*

ECS Centre for research in advanced design methods, architectures, and validation for dependable and energy-efficient multi-core processor systems (§4.2.1).

ORC has been at the forefront of photonics technology for more than 30 years and is organised into four broad research areas:

- Electronic Materials and Devices
- Fibres and Lasers
- Nanophotonics
- Photonic Systems, Circuits and Sensors

ORC's mission is to combine focused, application-led research, with fundamental studies into the generation, transmission, and control of light, with a particular emphasis on lasers, nonlinear optics, telecommunications, nanophotonics, bio-photonics, and the photonics/electronics interface. **ORC** has developed important new lasers, fibre-lasers and new fibre components, producing major impact in the fields of telecommunications and materials processing. It developed the erbium-doped fibre amplifier (EDFA) which powers the internet, and has a long track record of trialling and commercialising the technology it develops, which since 2000 has led to 13 photonics spin-out companies employing >600 people.

1.2 Research Strategy

Although submitted for REF2014 in two different UoAs, the research objectives of all three Schools for the period 2014-2020 were broadly comparable, focusing around:

1.2.1 Staff recruitment and development

We have recruited a total of 59 Category A academic staff, supervised 1069 PhD students to successful completion and won 41 flagship fellowships funded by bodies such as the RAEng, the Royal Society, ERC, and UKRI (§Table 4.10). We have promoted 36 (6F,30M) and externally recruited 9 (1F,8M) staff to professorial chairs.

1.2.2 Facilitating collaboration and teamwork

During the assessment period, all three Schools have reviewed, refreshed and refocused their research organizational structures (groups, themes or centres) to better address societal needs and research challenges, and to facilitate interdisciplinary working including:

- Growing silicon photonics following the recruitment of **Reed** and his team in 2012. Activities expanded into nanoelectronics through **Prodromakis**.
- Strengthening ocean and offshore engineering through external appointments **Gourvenec**, **White** and **Thornton** and their subsequent engagement with Oceanography, Computer Science, Archaeology, and Law through *Southampton Marine and Maritime Institute (SMMI)*(§1.4)
- Committing >£0.5M annually from 2017 in start-up funding and PhD studentships to create 7 new interdisciplinary Centres of Excellence in areas including healthcare, sensing and security, transport, and AI; to enhance industry engagement, provide a forum for seminars, and deliver impact (§3.2).

We have continued to lead and participate in internal and external collaborations within and across disciplines, addressing national and global research grand challenges. Specific examples include leading roles in the *UK Collaboratorium for Research in Infrastructure and Cities (UKCRIC)*, **Powrie** is Convenor, **Richards** Director of Strategy); the *UK Rail Research and Innovation Network (UKRRIN)*, in which we lead the *Infrastructure Centre of Excellence*; and the *Faraday Institution (Cruden and Spearing)*. We are major partners in the *National Wind Tunnel Facility* consortium (NWTF; **Ganapathasubramani**). **Sandham** led the *UK Turbulence Consortium* (to 2018). We are a founding member of the *National Dark Fibre Facility (NDFF)*: a collaboration between the Universities of Bristol, Cambridge, Southampton, and UCL) and host one of its nodes.

UKCRIC, *NWTF* and *NDFF* offer our researchers the opportunity to experiment and collaborate using test apparatus, wind tunnels, and flumes at other institutions, and a unique research facility

for emulating real-world communication networks. We also have a formal collaboration agreement with Diamond Light source, giving our researchers beamtime access for a range of collaborative projects.

1.2.3 Developing and exploiting our world-class facilities

A notable, once in a generation, achievement has been the completion of the new Boldrewood Innovation Campus (BIC). This £170M investment in teaching space, staff/student offices, and laboratories was funded largely from sources external to the University, including Lloyds Register (who relocated their *Global Maritime Centre of Excellence* to Southampton), South East England Development Agency, and UK Research Partner Investment Fund. New facilities include a fluid dynamics laboratory with a 138m long towing tank and unique anechoic wind tunnel (supported by Airbus); simulation and autonomous systems laboratories; and the new National Infrastructure Laboratory (NIL) funded by the £26M UKCRIC grant from Department of Business, Energy and Industrial Strategy (BEIS), which houses a large structures testing laboratory with a 15m x 30m strongfloor, a world-leading geotechnical testing laboratory, and a 3m radius geotechnical centrifuge (§3.5).

The Photonics Institute (TPI) at Nanyang Technological University (NTU), Singapore has been developed since 2014 as a strategic collaboration between University of Southampton (UoS) and NTU and represents the next phase of the trend for globalised research. TPI facilities span five Centres that extend the capabilities available at Southampton and provide specialist infrastructure in the areas of semiconductor lighting and displays, and biophotonics. These TPI Centres comprise 220 faculty and research staff with a combined grant portfolio of £65M (not included in REF4c and not otherwise part of this REF return). Leading professors from the **ORC (Payne, Zheludev, Reed)** have helped TPI colleagues to establish new research directions in fibre technology, metamaterials, quantum and topological nanophotonics, and silicon photonics. This has resulted in an influx of photonics funding to TPI from the Government of Singapore. Southampton academics have been involved in several large multi-million research programmes in Singapore, totalling more than £38M. The collaboration between the TPI and the **ORC** has resulted in numerous joint publications (241 over the REF period, journals and conferences, co-authors **Zheludev, Reed, Payne**), as well as joint patents.

In addition to these entirely new campuses, we have continued to develop and exploit our existing world-leading facilities, including the Zepler Institute Cleanroom Complex, as described in (§3.5a-p).

1.2.4 Growing research partnerships to produce world-leading research

Establishing and sustaining long-term partnerships with industry and other key external organisations was identified as a vital component of our strategy in REF2014. Links and interactions have been facilitated in a number of ways including RAEng Industry Fellowships, Knowledge Transfer Partnerships (KTPs), secondments (§2.2), consultancy, Industry Days, and industrial engagement. The Unit has provided consultancy to over 150 companies/government bodies, held 11 KTPs (§3, Table 3.3) and organised over 122 events of industrial engagement (§4.2.2 & §4.2.3).

We have established new or renewed key partnerships with major UK and international companies including Airbus, ARM, BAE Systems, English Institute of Sport, Huawei, Lumenisity, Microsoft, National Grid plc, Network Rail, Rockley, Rolls Royce, Shell, SPI Lasers, and Thales. These partnerships and income from other major industry collaborators, are summarised in (§3, Tables 3.1 & 3.2.)

1.2.5 Increasing engagement with Industry

A key stated objective in REF2014 was to broaden our funding base and grow industrial funding. All Schools now have a significant and diverse funding portfolio encompassing not only EPSRC and EU but also MRC and NIHR, reflecting the breadth and depth of interdisciplinary research activities. Many staff have long-standing research collaborations with industry as summarised above and in §3.1. We have been very successful in securing long-term research funding underpinned by large grants having a value of >£70M, detailed in §4, Table 4.2.

1.2.6 Objectives 2021-2025

We will continue to sustain and grow research excellence in line with the University's strategy (REF5a) and mission to change the world for the better, and in support of UN sustainable development goals, UK Government grand challenges and industry sector strategies, and UK/regional economies, by:

- Recruiting and developing staff to reinforce, complement, and broaden our key areas of activity, with a particular emphasis on improving our (gender) diversity
- Recruiting, training, and developing the next generation of world-leading researchers, again with a focus on improving diversity
- Leading and supporting major, externally-funded research programmes
- Being agile in research, including diversity of funding sources and the ability to form teams rapidly
- Exploiting and developing our facilities
- Establishing and growing partnerships with industry, users, and other researchers.

We will maintain the health and currency of our fundamental engineering disciplines, and through our research enhance social equity and inclusion, environmental protection, and sustainability. In that context, we will invest and encourage growth in the following inter and multi-disciplinary research areas.

a) Healthcare and medicine

Digital healthcare: diagnostic systems including real-time (bio)chemical analysis, fusion of machine learning, wearable technologies, energy harvesting, extended lifetime, and manufacturability of next generation digital healthcare platforms.

Advanced prosthetics and orthotics: body interface sensors, AI evaluation, IoT, computational modelling, and musculoskeletal biomechanics to enable digitisation and evidence-based rehabilitation.

b) Manufacturing and materials of the future

Novel semiconductor materials: development and characterisation of new group VI compounds including 2-D materials, thermo-electric and topological insulators, phase change memory, ovonic threshold switch, radiation hardened SOI CMOS, memory technology (including silicon carbide for harsh environments).

Advanced manufacturing: 3D printing of complex metal alloys and composites; non-destructive material analysis using advanced X-ray imaging (μ -VIS lab); ultrafast image capture to explore mechanical properties in-operando regime; material design using predictive multiscale simulations combined with machine learning algorithms.

c) Energy technologies

Sustainable and resilient power systems: cost-effective integration of renewable energy generation, management of ageing assets through innovation in new insulation materials, first generation digital twins for electrical assets.

Clean energy technologies: energy storage (e.g. safer Li-ion batteries and next-generation Al-ion battery technology); hydrogen for heating; high power density cryogenic and superconducting electric machines and very high strength (>20T) magnets.

Solar photovoltaics (PV): simulation of large power production in cities utilising built infrastructure (roofs of buildings etc) coupled with energy storage informing policy; investment to support announced city climate targets.

Energy Efficiency: city-wide simulation of interventions (insulation, CHP, heat pumps etc) in buildings supported by large scale consumption monitoring, creating understanding for net-zero targets.

Offshore renewable energy: novel foundation systems including tethered buoyant structures; upscaling of offshore wind, wave and tidal energy through new technologies for

fixed and floating station-keeping, seabed surveys and coupled system modelling, drawing on Machine Learning and AI to better quantify risk and reliability; new cable-seabed interaction modelling to increase power transmission; regional modelling of offshore wind energy resources to inform policy.

Energy for development: solar PV driven mini grids to provide electricity access for hard-to-reach rural communities in developing countries.

d) Robotics and autonomous systems

Control engineering: modelling and control of networked systems in e.g. IoT, power generation and distribution; robotic swarms; parsimonious models describing only the variables of interest with minimum complexity; modularity; hierarchical modelling.

Unmanned autonomous vehicle technology to facilitate rapid disaster relief, seabed surveying and aged population mobility.

e) Sustainable infrastructure and cities

Healthy and sustainable housing: housing that is dry, energy efficient and affordable in neighbourhoods that promote wellbeing.

Mitigating the impacts of climate change: resilience in infrastructure systems including earthwork slopes and railways.

Co-existing with biodiversity: the role of green and blue infrastructure

Sustainable infrastructure systems: decarbonisation of infrastructure through improved materials and design; better understanding of material and system behaviour, deterioration and life cycle performance/analysis; railway electrification infrastructure; high-intensity use railway track systems; very light rail.

Sustainable mobility: making cycling and walking safe and attractive; decarbonisation of transport; integrating electrified road, aerospace, maritime and rail propulsion technology to support delivery of net carbon zero by 2050.

Environmental assessment of cities: assessment of city environmental footprint based on 5 city-wide criteria - energy, transport, air quality, waste management & natural environment - providing feedback for improvement and annual progress tracking.

f) Transformative digital technologies

Cyber hardware: hardware-based solutions for side channel attacks on cryptographic hardware; smart card security; physical unclonable functions (PUFs); hardware-based monitors for anomaly/intrusion detection; vulnerabilities in co-processors; device fingerprinting.

Embedded hardware systems: green mobile and embedded devices (energy-efficient or environmentally-powered); safe and intelligent devices.

Quantum Communications: 6G systems and standards; topological quantum codes (correcting for quantum bit errors imposed by quantum decoherence).

Computing System Engineering: high performance computing using (millions of) low-performance compute elements, embedded in a parallel bespoke communications fabric (input formalisms and command, control, internal visibility and debug tools); photonics for computing (imaging, programmable photonics) and hardware-enabled AI.

1.3 Impact Strategy

As engineers, our *raison d'être* is to carry out research that solves practical problems through the application of fundamental science. Achieving impact is crucial and underpins our philosophy. Within the University framework summarised in REF5a, our impact strategy – which builds on and exploits key research strengths – has four pillars:

- Engagement with industry on research ranging from individual undergraduate projects through to major UKRI-funded programme grants.
- Enterprise units, which provide specialist commercial services that build on our research strengths and industry access to our key research facilities (§1.3.2).

- Entrepreneurship (consultancy, patents and spin-out companies).
- Long-term, strategic partnerships with key companies and industry organisations.

1.3.1 Engagement with industry

Over 90% of our research grants have strong industry support, and many of our PhD student projects are undertaken in collaboration with industry. Most of our major grants have their own industry advisory groups, which in addition to helping define and steer the research, facilitate the early uptake and impact of research results. The value placed by companies on engaging with us in this way is illustrated by the seniority of their representation, e.g. the Director of Systems Engineering, Network Rail; Head of Track, Network Rail High Speed; Chief of Technology System Design, Rolls Royce; Acoustics Domain Technical Advisor, Airbus; Technical Competence Leader in Aerodynamics, Airbus. New and renewed long-term strategic industry partnerships were summarised in §1.2.4 & §3 Tables 3.1 & 3.2.

Our selected impact case studies are in areas of established research strength, and involve companies with whom we have long-standing partnerships or are spin-outs from the Unit. This relationship is illustrated in Table 1.2.

Table 1.2: Areas of research strength, facilities and company links in relation to selected Impact Case Studies

ICS #	Area of Research Strength	Previous and current major grant funding	Key facilities (and predecessors)	Company strategic partnerships
12-01	Energy Harvesting	EP/G067740; EP/H013458	PEM lab	Perpetuum
12-02	Signal processing algorithms / hardware acceleration implementation for 5G wireless communication	EP/L010550; EP/P034284; Innovate UK 133560; Innovate UK 900037	IRIDIS super computers	AccelerComm
12-05	Engineered non-linear materials	GR/S50700; UK Quantum Technology Hub - EP/M013294	Zepler clean rooms	Covesion
12-06	High-powered Fibre Lasers	EP/M020770; EP/P027644	Zepler clean rooms	SPI Lasers
12-08	Silicon Photonics	EP/M009416; EP/L00044X; EP/L021129; EP/R003076	Zepler clean rooms	Rockley Photonics
12-12	Hollow Core Fibres	EP/I01196X; EP/H02607X	Zepler clean rooms	Lumenisity
12-16	Aircraft design- cleaner, quieter more efficient	CompUTC; ANTC; NoiseUTC	Acoustics laboratories, Wind tunnels; IRIDIS super computers	Rolls Royce; Airbus
12-17	Transportation infrastructure	RRUK (GR/S12784 EP/D080207); Track21 (EP/H044949); Track to the Future (EP/M025276)	Infrastructure and Geomechanics laboratories	Network Rail, HS1

12-19	Ecological engineering and ecohydraulics.	EU Horizon 2020 AMBER	Large scale ecohydraulics laboratories and flumes.	Environment Agency
12-25	Signal processing for sound and vibration	EPSRC Prosperity Partnership- BAE EP/S03661X; EP/L000539	Acoustics, signal processing and Active control laboratories	ClanTect, BBC,
12-28	Micro-technologies for medical applications	EPSRC, NIHR	Centre for Hybrid Bio-devices	Vivoplex, Sharp
12-29	Cleaner, safer, smarter maritime	EPSRC Prosperity Partnership- BAE EPSRC Grant	Fluid dynamics and Water/ environment Laboratories	Shell, Lloyds Register, RNLI, CJR Propulsion.

Examples of impact not included in the Impact Case Studies are given in §4.2.1 (Table 4.4).

1.3.2 Enterprise Units

Operating as small, embedded, financially self-sustaining business units with dedicated staff, each has their own business plans with agreed financial and non-financial key performance indicators. In addition to facilitating and generating external income (£10.4M over the REF period), enterprise units contribute through internal spend and reputational enhancement. Each has its own head, reporting formally to the Associate Dean Enterprise (**Williams**). Enterprise units operate in areas of research strength and expertise, often related to a major experimental facility, as follows:

- a) *ISVR Consulting*: consultancy and applied research in noise, vibration and acoustics.
- b) *The Wolfson Unit for Marine Technology and Industrial Aerodynamics (WUMTIA)*: hydrodynamic, aerodynamic and naval architecture/engineering consultancy to an international client base of designers, builders and regulatory bodies. *WUMTIA* specialises in small to medium size fast power craft and sailing yachts, experimental hydrodynamic and aerodynamic testing and computational fluid dynamics.
- c) *University of Southampton Auditory Implant Service (USAIS)*: specialised assessment, treatment and rehabilitation of deaf and hearing-impaired people across the South of England and beyond. It carries out cochlear and other types of auditory implant assessment and implantation for National Health Service (NHS) England.
- d) *nC²*: expert consultancy in tribology, corrosion and forensic materials engineering.
- e) *ECS Partners Ltd*: set up to establish and sustain links with industry, including through consultancy and providing access to fabrication and characterisation facilities, reducing risk and cost for fabless start-ups needing small prototype runs.

1.3.3 Entrepreneurship

Academic staff are encouraged to achieve impact for their research through appropriately high-level consultancy. Typical consultancy commissions include developing new codes of practice, establishing design principles for a new class of structure or artefact for which no code of practice currently exists, high profile legal or expert witness advice, and specialist investigation using unique or bespoke equipment only available at the Unit. Academic consultancy is typically provided to public, private, charitable or voluntary sector clients by individuals or groups of academics responding to an approach or tender. Consultancy is undertaken through *ECS Partners Ltd*. and its counterpart for the School of Engineering, *Engineering and Environment Partners*. Consultancy income generated across the Unit amounts to ~30% of the University total (£10M of £33M, 2019/20). Examples of significant, high profile consultancies are given in §4.3.1, and contributions to codes and standards in §4.3.2.

In addition to *iCURE*, *SetSquared* and the *Science Park Catalyst* as outlined in REF5a, start-up and spin-out companies are encouraged and facilitated through the *Future Worlds Innovation Hub* (§4.3.3). This is a unique on-campus start-up accelerator, which nurtures aspiring entrepreneurs and cutting-edge technologies through one-to-one support and a network of seasoned founders, investors and millionaire entrepreneurs. Since its foundation in 2015, over 3000 students and staff have engaged with its programme of events; and over 100 start-up / spin-out ideas have been accelerated through its network of 80 mentors, investors and senior executives, including directors of *Apple* and *Salesforce* and the founder of *Arieso*.

Future Worlds can host up to 15 resident start-ups in its six-month accelerator programme. It has raised the profile of the University through its presence at the Las Vegas Consumer Electronics Show (unique among UK universities), and partnerships with *SkyDeck Incubator* (University of California, Berkeley). §4.3.3 lists some successful spin-outs that have benefitted from *Future Worlds*.

IP protection and commercialisation within the Unit has been vibrant and over the assessment period, the Unit has filed 345 patent applications (figure is for all applications in different geographical regions). In the same period 134 patents were granted. The total royalty income received by the University, derived from licensing of IP from the Unit, is £1,056,170

1.3.4 Supporting the vitality and sustainability of our impact

Generation of impact is a key element of the Unit's activity. The associated industry/user engagement is a double benefit in that it generates new research ideas; in our field, industry need is as likely to push the boundaries of human knowledge as pure research. The four pillars of our impact strategy have been hugely beneficial to all concerned, and will therefore continue to form the basis of our future impact and industry engagement strategy. With the anticipated continuing pressures on the economy, it is likely that enterprise will become increasingly important in terms of both University funding and in realising the UK's industrial strategy.

We will reinforce and grow current success and strength by:

- a) Continuing to improve the visibility and recognition of enterprise and industry engagement activities and career progression for staff involved, especially women and BAME staff.
- b) Shaping the development of a refreshed University Enterprise strategy for 2021 and beyond.
- c) Ensuring we have the resource to support industry engagement and enterprise activities in a timely manner, including assisting in the UK's recovery from Covid-19.
- d) Increasing the number of high-level, strategic partnerships with major companies.
- e) Exploiting more proactively our unique, world-leading research facilities in acoustics, aero- and hydro-dynamics, the Zepler cleanroom complex, geomechanics, high voltage, imaging, infrastructure, materials and nanofabrication.
- f) Shaping forward-looking research roadmaps and research outputs to align with Government strategies including the Industrial Strategy Challenge Fund (ISCF) and the Global Challenges Research Fund.
- g) Further developing interdisciplinary research as outlined below.

1.4 Interdisciplinary Research

The University, FEPS and its Schools actively encourage and facilitate cross-disciplinary research (Figure 1.2). We provide leadership across the University in interdisciplinary research in life sciences, through the University *Institute for Life Sciences (IfLS)*, and in marine and maritime studies, through the *Southampton Marine and Maritime Institute (SMMI)*.

IfLS (Deputy Director **Morgan**) draws together expertise in science and engineering to address research challenges and opportunities in the life sciences. *IfLS* has fostered strong links between Engineering, the National Oceanography Centre Southampton (NOCS) and Southampton University Hospital Trust (SUHT), including access to state-of-the-art imaging, bioinformatics, proteomics and lipidomics facilities and expertise. *IfLS* runs the *FortisNet* network; an interdisciplinary hub of expertise in regenerative medicine, orthopaedics, prosthetics and assistive

technologies that develops products and processes to improve lives by connecting clinicians, enterprise and engineers.

SMMI (Deputy Director **Gourvenec**, Founding Director **Shenoi**) covers a unique cross-disciplinary spectrum encompassing humanities, natural, physical, and social sciences, engineering, and law, where knowledge is acquired and applied in a collaborative manner with business and civic and industrial societies to reach common objectives.

A new group (2019) in the *Alan Turing Institute* led by **Weymouth** and **Sobey** has established marine and maritime data-centric engineering research, with funding of £800k to address fundamental AI and data analytics issues and provide a roadmap for applications in the marine industry.

The University Strategic Research Group in *Nexus Science* brings people from across the University to work on interactions between water, energy and food. Projects have included the multi-partner EPSRC Vaccinating the Nexus programme (£1.6M) and a British Council-funded initiative to develop sustainable hydropower in Brazil.

Global NAMRIP (Global Network for Anti-Microbial Resistance (AMR) and Infection Prevention: Chair Leighton, steering group including **Eason, Hill**) was established in 2015 to address the global problem and cost of anti-microbial resistance. The network crosses 4 continents, includes 200 academics in the UK, conducting research with translational emphasis on infection prevention and vaccination. Established with an EPSRC grant (*NAMRA* £0.87M, 2015-2017) it has pump-primed 39 projects, which have generated 23 follow-on awards, 9 prizes and awards, 12 patents, and one spin-out company.

Autonomous systems research, led by **Scanlan**, aims to ensure a sustainable, critical mass of cross-disciplinary excellence; provide continuity of funding for world class science and research in the area of autonomous systems, sensing, computing, communications and platforms; provide world class, cost effective facilities and capabilities for scientists and other users and allow society, through this technology, to develop and maintain a low carbon economy, respond to climate change and conduct earth science research whether sub-sea, surface, land, air or space

River, estuary and coastal research led by **Nicholls** (to 2019) and **Kemp** in collaboration with colleagues in Natural and Environmental, Human and Social Sciences addresses mitigating environmental impacts of river engineering, coastal morphodynamics, flooding, and the future evolution of delta areas (which provide homes to 500M people worldwide). Major funding over the assessment period came from EUH2020 (*AMBER*, total 6.2M Euro) to develop adaptive management strategies for barriers in European rivers, the results of which have fed directly into the 2030 Biodiversity Strategy to set a clear target of reconnecting at least 25,000km of Europe's rivers by 2030; NERC (*iCOASST*, £2.9M) for research in collaboration with the Environment Agency on coastal erosion and accretion to support flood risk management; and the £3.8M *ESPA Deltas* project analysing coastal Bangladesh, the results of which are being used by the Planning Commission for Bangladesh in its new 100 year Delta Plan. This research has formed the nucleus of the new *Future Towns Innovation Hub*, funded through awards of £3M from the EM3 Local Enterprise Partnership and £1.5M from Research England.

Looking to the future, we have identified key areas of future interdisciplinary research, to which the expertise and contribution of early career researchers (ECRs) will be essential. These have been formalised by the establishment of 7 Interdisciplinary Centres of Excellence (CoE), in *Continuous Digital Chemical Engineering Science*; *Future of Human Communication*; *Health Technologies*; *In situ and Remote Intelligent Sensing*; *Internet of Things and Pervasive Systems*; *Machine Intelligence*; and *Re-Engineering for Electric Mobility* (Figure 1.2 & §3.2).

In addition, the Faculty runs cross-disciplinary community building workshops such as the *IoT for smart infrastructure* event, combining our strengths in sensing, optical fibres, big data and infrastructure, and utilising opportunities presented by the National Infrastructure Laboratory and our nanofabrication/clean rooms complex.

Interdisciplinary research is further actively supported through pump-priming small projects and equipment, creation of new cross-theme interdisciplinary groups and joint appointments across research groups.

1.5 Open Access

Staff are encouraged to make their research outputs as widely and freely available as possible. Institutional funding to cover the costs of gold open access is available for key papers resulting from UKRI research; it is a University requirement that a pre-publication “author-accepted-typescript”, along with relevant datasets, are uploaded to the institutional repository, ePrints. This is the world’s leading open-source digital repository platform, developed by ECS 20 years ago it has now been adopted by 675+ institutional and subject repositories world-wide. Managed through ECS partners (§1.2.4 & §3.4) its success contributes to our enterprise economy. Approximately 33% of our journal papers have been published with gold open access.

Recent examples of our progress in encouraging an open access research environment beyond REF policy requirements are:

- **CORNERSTONE**; an open access service fabricating silicon photonics devices for researchers around the world. In contrast to the conventional licensing model in this field, **CORNERSTONE** shares its fabrication processes, its process design kit and a library of commonly-used components openly and freely via its website. Entry for researchers who do not have access to their own fabrication facilities is facilitated by the removal of legal barriers and complex license agreements.
- **PeRSo**, a personal respirator for healthcare professionals treating COVID-19, which illustrates our ability to react quickly to a world-wide crisis in terms of sharing results and data. Two open-access papers (along with datasets, CAD files and assembly instructions) were published on 6/4/20, three weeks after the project started, and to date have been downloaded >2400 times. The project had >18,000 hits on social media (Twitter @PeRSoPPE); over 5000 first tweets with the dataset. A **PeRSo-Developing World** website led to 96 contacts in 28 locations, raised awareness of the technology and enabled dissemination of development material. Teams in Colombia (Universidad Los Andes), Ethiopia (University of Bahir Dar), Bangladesh, East Africa, South Africa and India have manufacture prototypes based on the **PeRSo** Specification.

1.6 Research Integrity

The University is a signatory to the *Concordat for Research Integrity* and has robust policies to ensure we maintain the highest standards in research. The *Research Integrity and Governance Committee (RIG)* is responsible for developing and fostering a culture of research integrity, and promoting responsible research conduct and governance amongst the University academic community.

Each School has a Concordat representative (ECS **Torah**, ENG **Kaparias**, ORC **MacDonald**) reporting to School management meetings bi-annually or where new policies or changes in governance are discussed. The Faculty RIG champion chairs the *Ethics Committee* and sits on the *Information Governance Group* and the *Data Protection Impact Assessment Panel*, ensuring continuity in the standard and exchange of information in the Faculty and Schools.

Within the structure outlined in REF5a, the *Faculty Research and Ethics Committee (FREC)*, chaired by an experienced academic, comprises representatives from each school, a student and a lay member. **FREC** meets twice annually to review the ethical implications of all research studies involving human subjects or participants, and ensure that such projects adhere to both Faculty and University ethics policies and procedures. Complaints and potential research integrity issues are also considered and addressed. As part of the Unit’s induction programme, all new staff and PGRs are introduced to the University and Unit culture regarding research integrity, ethics and ethical approval, and the basis of responsible research through two online training courses in research integrity and ethics. Guidance developed by the Unit (e.g. a checklist for supervisors; secondary data analysis) is available on the Unit’s SharePoint site. There is also the opportunity via the Faculty staff website to review policies and undertake further training if required.

2. People

2.1 Staffing strategy

The University, Faculty and Schools are committed to research excellence. We aim to sustain and improve research performance by attracting, nurturing, developing and retaining high-achieving staff; and to grow and develop our strengths, ensuring critical mass in key research areas. New appointments are planned at School level with reference to local requirements and internal/external opportunities (including succession planning, availability of research facilities, the funding landscape, and our current and future ability to address societal challenges); and approved by the University through an annual strategic planning and business review. We are committed to research-led teaching; the size and diversity of the UoA allows us to make research-led appointments, while ensuring good disciplinary coverage of the core subject areas of the undergraduate curriculum and our many specialist masters programmes. The quality of the research undertaken by an individual is paramount; all appointees must either already be performing at an international level or have the potential to do so. We expect staff to apply their skills to solving problems that are intellectually challenging and important to society, and to develop new skills through action learning and formal training. Our aim is to seek and attract the best talent worldwide, from a diversity of background, gender and ethnicity, and develop it into tomorrow's research leadership.

Over the REF period, we have appointed 59 new external Category A members of academic staff, and internally promoted 98 (L6 & L7). Some leavers have moved on to positions of national responsibility, e.g. Nichols (Director of the Tyndall Centre for Climate Change) and Thomsen (NCC Chair in Composites Manufacturing and Design); or to industry, e.g. Saito (Hitachi, Japan). International and sectorial visibility and mobility is further demonstrated by the appointments we have made from non-UK universities and industry. New appointees may either **reinforce**, or **complement** and enhance areas of research strength, or enable us to **broaden** into new but related areas of strategic research opportunity, as summarised below:

- Appointments to **reinforce** existing areas of research strength ensure their vibrancy and continuing development, reflect resource availability and exploit our major experimental and computational facilities. Examples include **Mak** (2015, cyber physical systems); **Gauthier** (2015, energy technology/buildings); **Deiterding** (2015, computational aerodynamics); **Yan** (2016, distributed sensor technology/Si MEMS); **Afshan** (2019, infrastructure); **Bailey** (2019, energy technology/cryogenics).
- Appointments made to **complement** and bridge existing research strengths, generating new multidisciplinary activities and thereby opening up new areas of strategic importance, include **Downes** (2014, structures/autonomy); **Hovorka** (2014, computational modelling linking with physics and maths); **Schneider** (2014, biomedical imaging); **De Almeida** (2014, hydrodynamics); **Spencer** (2016, biomedical electronics, to drive the interdisciplinary health care technology agenda); **Thornton** (2016, hydrodynamics/autonomy); **Kashani** (2017, infrastructure/earthquake resilience); **Huang** (2018, to drive cross-disciplinary research linking to Centre for IoT); **Heydari** (2018, transport); **Singh** (2019, electrical power engineering/system control).
- Appointments made to **broaden** our research base generally involve attracting proven research leaders to Southampton to grow our expertise and inspire new research areas. They include: **Lot** (2014-20, automotive); **Ryan** (2015), **Kim** (2016) and **Wittig** (2017), computational space propulsion and orbital mechanics); **Wilson** (2016, computational aeroacoustics, Rolls Royce UTC); **Gourvenec** (2017, infrastructure/offshore geotechnics); **White** (2017, infrastructure/offshore geotechnics); **Turner** (2020, cyber physical security/control systems).

Appointments made through these three routes align with our research vision and future strategic directions, enabling the development of future research leaders and the exploitation of our experimental and computational facilities, and enhancing our ability to address societal challenges.

The Unit has implemented a range of initiatives to address gender imbalance in both recruitment and promotion, including using gender-neutral language in our advertisements, marketing materials and job descriptions; proactively approaching potential applicants with protected characteristics; and ensuring panels contain a mix of genders. An on-line tool (<http://gender-decoder.katmatfield.com/>) is used to ensure we use terms and descriptors that encourage applications from women and BAME candidates. Advertisements include information about our family-friendly policies and flexible/part-time working. We proactively contact potential female candidates to encourage them to apply. Shortlisting and interview panels are mixed gender, including at least two women. Panel membership is prescribed by role within the University and may include colleagues from other Schools to ensure balance. Panel members undergo training to ensure there is no unconscious bias against protected characteristics and internal candidates.

The proportion of female Category A academic staff across the Unit has remained steady at about 11.0%. While progress has been made (the proportion of women at L6&7 has increased slightly from 5.7% in 2013/14 to 7.6% in 2019/20), there is much more to do regarding our gender balance. BAME Category A staff numbers have increased (from 49/292 in 2013/14 to 62/273 in 2019/20); and non-UK Category A staff (from 100/292 in 2013/14 to 110/273 in 2019/20).

2.2 Staff development

We run coherent programmes for inducting and mentoring new staff, and well-established processes for annual appraisal and promotions including:

Induction: All new staff are assigned a line manager, who coordinates their induction and oversees the two-year probation period (one year for PDRs). Our induction highlights University policies on diversity, discrimination, and dignity at work, and online training that all new staff must take, including in ED&I, ethics, safeguarding, data management and health and safety. New staff are made aware of university-wide mentoring schemes, the *WISSET* network and the *Springboard* development programme for women, which is funded by the Unit. We also have local school induction policies; the Head of School welcome letter emphasises our commitment to diversity and encourages uptake of University ED&I training, which is monitored to ensure that all new staff undertake it promptly.

Mentoring: All new staff have a named mentor, who is not their line manager. Our mentoring scheme aims to help new staff settle in, and to provide a supportive environment for personal development. Mentors provide advice and support both in their own area of expertise and more generally, in areas ranging across education, enterprise, fellowships, finance, life transitions, outreach, grant funding, research supervision and management. Mentoring is a confidential process, separate from regular managerial support and induction. It is available and relevant to all individuals within the Schools, irrespective of their level of seniority or job family.

Appraisal: Following probation, all staff have annual appraisal meetings with their line managers (a member of staff can request a change of line manager). Appraisal training, which covers unconscious bias and managing diversity, is mandatory for line managers. Appraisal via an on-line system ensures transparency. Objectives, achievements, training undertaken and required, and long-term ambitions and aspirations are discussed and recorded, and a performance descriptor is agreed. Discussion of research plans forms a key component.

Staff workloads are managed with reference to School norms. The balance between research, teaching and leadership may vary between individuals, but the expected overall contribution is consistent for staff at a given level.

Applications for **promotion** are considered annually. University-wide information events outline the process and key milestones. Line managers are proactive in encouraging applications, especially from groups under-represented at more senior levels. Potential applications are initially discussed informally, and applicants are supported in presenting their case by their line manager and through professionally-run workshops. Applications are considered by a School, then a Faculty panel, and for promotion to full professor by a University panel. Interviews are conducted at levels 6 & 7 (Associate and full Professor), for which the University offers day-long interview training. The panels at all levels are mixed gender and constructed in a manner to

ensure there is no unconscious bias against protected characteristics. The application form includes space to comment in-confidence on individual circumstances such as career breaks, and periods of maternity/paternity leave.

The recruitment, induction, appraisal and promotions processes all provide for the candidates / appraisees to give and receive feedback at each stage. This may be in writing or in person. For professorial applications it will cover the interview and include suggestions/advice in support of specific future plans and career path.

We strongly encourage sabbatical leave where the scope supports our research strategy and the expected outcomes meet our aspirations in terms of quality and impact. Staff are encouraged to apply for external funding to support study leave – also an indicator of relevance and quality. The policy for study leave and sabbaticals is described in REF5a, §3.2.

Secondment to and buy-out by business, industry, public and third sector bodies is encouraged where appropriate to the career development of staff and the Unit's research strategy. Such secondments and buy-outs are often funded by the collaborating organization, and sometimes through an EPSRC or RAEng Industry Fellowship. At least 11 academic staff have been seconded or bought out by international and national companies including AccelerComm, Hitachi, Lumenisity, Proctor & Gamble and SPI Lasers, for periods ranging from 3 months to 4 years. These have usually been linked to the development or transfer of specific products or technology. For example **Mauder's** secondment as CTO of AccelerComm (80% FTE since April 2019) was instrumental in securing £8.8M investment, growing the company to 33 employees. It filed 35 patents, sold 58 licences and developed 27 products in 4G and 5G encoders and decoders. **Morgan's** 20% FTE, 2-year secondment to Vivoplex Ltd led to 9 patent applications in biomedical sensors. **Nelson** was seconded to EPSRC as CEO for 4.5 years. Enterprise and impact activities carried out on secondment or through partial buy-out are recognised for promotion purposes including to professorial level (Level 7).

2.3 Equality, Diversity and Inclusion (ED&I)

All Schools within the Unit are fully committed to ED&I: details of some of our procedures and process, together with evidence of their success, have been given earlier in this section. All three Schools currently hold Bronze Athena SWAN awards, alongside the University's Silver award. Each School has an ED&I committee and ED&I is a standing item at all management meetings. The chair of each school ED&I committee sits on the University ED&I Committee with membership from all faculties, professional services, staff and students. Chaired by the Vice President Research and Enterprise, it reports to the University's Executive Board and recommends annual objectives. The schools follow University policies on *Equal Opportunities*, *Gender Identity*, *Dignity at Work & Study*, *Religion & Belief* and *Reasonable Adjustments*.

Within the Unit an extensive network of groups meets regularly to share good practice and collaborate on initiatives regarding protected characteristics. These include the BAME, LGBT and Parents' and Carers' Networks. Active student societies span LGBT, Feminism, Religious and International remits. Support networks for women include *Theano*, *WiSET* and *Empower*. *Theano*, founded in the 1990s, is a networking group that brings together women and is open to all female students and academic staff across the University. *WiSET*, founded in 2002, helps shape the policies and culture of our University for women in science, engineering and technology. *WiSET* hosts the prestigious annual Campbell lecture and helps to develop school ECR mentoring programmes.

The Faculty sets aside funding to cover maternity/paternity/adoption payments to fixed-term contract staff where the funding body does not do so. We provide the same level of return-to-work assistance (e.g. flexible return, managed transition, mentoring, partner support) to staff on fixed-term contracts as staff on open-ended contracts. All PGRs are covered by a Faculty parental leave and sickness leave policy that mirrors staff provision. Since 2014, there have been 10 periods of maternity leave and 33 periods of (2 week) paternity leave across the Unit. Other initiatives include suitably-configured private rooms for nursing mothers, well-being counselling and support, and a fund to cover additional carer costs associated with elective attendance at extracurricular conferences and similar events.

Further evidence of our commitment to equality and diversity, for example in the recruitment and support of staff and research students, is given in §2.5.

2.4 Supporting and developing ECRs (new academic staff and Postdoctoral Researchers)

Staff induction tailored for **Early Career Researchers (ECRs)** appointed as academic staff covers research finance and funding, REF, grants, studentships, internships, fellowships, research facilities and research governance, in addition to compulsory on-line training in research integrity, ethics, intellectual property (IP) and ED&I.

New academic staff are supported by their line manager and mentor in the supervision of PGRs, teaching, research and the development of grant applications. A personal development plan is drawn up, and followed with the benefit of internal and externally-provided training. New lecturer teaching increases gradually from 40% of a normal workload over three years, recognising the need to prepare new material and undertake formal training. Academic staff ECRs may apply for internal funds for pump priming, impact acceleration, feasibility or collaboration purposes. Research groups offer peer review and guidance for these and external research grant applications. Senior colleagues in other research areas or schools provide mentoring for academic staff ECRs through career guidance, review of long-term objectives and general confidential advice. ECRs participate in *Fellowship Programme* training modules on leadership, negotiation and presentation skills. Specific workshops and training include: Fellowships - a beginner's guide; How to talk about yourself and your skillset; Pathways to Impact; and Meet the Fellows.

Postdoctoral Researchers (PDRs) are essential to the vibrancy, breadth and freshness of our research ecosystem. Hence their effective integration into our research community is paramount. They are encouraged to join PhD supervision teams; experienced PDRs can be main supervisors, and apply for research contracts and lead projects in their own right. PDRs often have specialist expertise (for example, in relation to a particular apparatus, facility or technique); mentoring and training is geared to helping PDRs transition towards senior research posts.

The Faculty runs an annual Research Week for all staff. Sessions focused on ECRs and PDRs cover topics including securing first grants (new investigator grants and early career fellowships), proposal writing, large proposals, fellowships, PI replies, mock panels, impact and industrial engagement, community building, motivational talks, networking and sessions with external funders. Staff diaries are cleared of meetings during that week and it is run out of term-time so staff can engage with research support events and devote a block of time to developing or refining a research proposal.

Our *Fellowship Programme*, led by **Roose** and supported in each school by a fellowship champion, was established to identify and nurture outstanding junior academics and post-doctoral researchers, and to support them in securing prestigious externally-funded fellowships and permanent academic posts in our own or other universities. The *Fellowship Programme* arranges workshops in each school to advertise the various funding streams available. The Unit has won 26 early career fellowships (Table 2.3).

Table 2.3: ECR Fellowships awarded.

Funding body	F	M
EPSRC- Early Career Researcher & Innovation	2	3
Future Leaders Fellowship	1	0
NERC Fellowship	0	1
RAEng Research Fellow, Industrial Fellow	1	7
Royal Society	1	2
European Research Commission	0	1
Others (e.g. Marie Curie, Leverhulme)	1	6
Total	6	20

ECRs may also benefit from the Faculty *Fast Track* programme which supports responsive mode applications with timelines, regular one-to-one mentoring sessions to discuss progress and support from the Research and Innovation Services (RIS) team. For high performing ECRs, an agreed focus on research may be accompanied by a corresponding reduction in teaching load. ECRs may be employed on Innovate UK projects, giving them the opportunity to spend periods of time with SMEs, to undertake consultancy or to contribution to our outreach programme. We provide matched equipment funding for research grant applications; a Faculty strategic fund supports large-scale bids including laboratory/workshop refurbishment; and the University Multi-user Large Scale Equipment for Research (MuLSER) fund provides institutional support to multiuser equipment bids such as EPSRC strategic equipment funding (§3.3).

2.5 Postgraduate Researcher recruitment, training and support

All postgraduate researchers are supported by the *Faculty Graduate School (FGS)*, a team of academic staff and administrators with an overarching responsibility to ensure that University quality frameworks and regulations are applied rigorously. *FGS* monitors progression, training, supervision and registration status and receives and acts on student feedback. *FGS* Board meets quarterly, and the PGR Student-Staff Liaison Committee three times annually. Membership includes the Faculty Director of the Graduate School (**McAlpine**), PGR student representatives and doctoral programme directors from each school.

Table 2.4: Unit Doctoral awards

Year	13/14	14/15	15/16	16/17	17/18	18/19	19/20	Total
PhD	133	142	171	186	145	156	136	1069

PGR recruitment and admissions are led at a School level by senior admission tutors and representatives from research groups. Multiple funding routes include EPSRC DTP and CDT, iCASE, industry, the Faculty or University and the students themselves (e.g. government sponsorship of international students). Funding for any particular student can be made up from a combination of sources to broaden access. We seek to attract the best students through funded scholarships for international and EU students, and enhanced stipends for UK students. PhD scholarships are allocated competitively with panels judging applicants on academic quality and strategic importance, for example:

- **Developing people:** early career academics, or a change in research direction
- **Interdisciplinarity:** alignment with a recognised *USRG* or University Institute (§1.1)
- **Sustainability:** leverage of additional income/matched funding or developing/sustaining a strategically important area of research
- **Excellence:** outstanding quality of the project or the student
- **Enterprise:** collaboration with a strategic partner or likely to lead to strong impact, spin-out, commercialisation etc.

ED&I principles are embedded into our PGR recruitment and admissions processes. At PhD recruitment events we emphasize our commitment to providing a supportive and inclusive environment for all. We highlight the active involvement of our staff and students in groups such as *WiSET+* and *Theano*, which support and encourage women in engineering. We proactively ask our high-performing female undergraduates if they would like to consider applying for PhDs in engineering, emphasizing the real-world impacts of our research and its positive effect on people. Our websites profile some of our successful PhD alumni, with examples chosen to provide a balance across different gender and ethnic groups. We ensure there is no unconscious bias in our studentship allocation procedures by redacting names and indications of gender or ethnicity from applications prior to ranking. We monitor attendance and gender balance at PGR recruitment events and activities.

Research students are supported throughout their period of study, through formal and informal mechanisms and processes as follows:

Induction: The University provides students with a high-level perspective, while Faculty and School inductions explain the stages of progression to successful completion and the compulsory and optional training opportunities. School-based local induction (a two-day tailored programme) provides in-depth guidance, for example on subject-specific training through an Academic Needs Analysis. Throughout the induction period there is a programme of faculty, school and research group social meetings, at which the students get to know each other, co-workers and staff.

Supervision: Each PhD student has a supervisory team of at least two members of academic staff with a clear primary supervisor. At least one member of the team must have prior experience of PhD supervision to successful completion, enabling new academics to be mentored in supervision. Mentoring is also available to the students should they wish it. All new PhD supervisors are required to attend a Graduate School training workshop.

Progress Monitoring: FGS has pioneered a web-based system, *PGR Tracker*, which supports progression monitoring and records all the training activities undertaken by each student. This system prompts students, supervisors and examiners when tasks are due for completion. Students submit reports through *PGR Tracker* and supervisors/examiners give feedback on the reports and any subsequent viva. This ensures that a permanent, personalised and easily accessible record of the progress of every student is maintained. *PGR Tracker* also automatically records training activities undertaken at the University and allows the student to enter any additional training or other activities that they wish to note, so as to maintain a record of their personal professional development. Following its success within FEPS, *PGR Tracker* has now been implemented across the University and an enhanced second generation system is being procured.

Professional Skills Training and Support: FGS provides a broad range of courses to enhance research-centred learning and transferable skills training to optimise the development of postgraduate students. Personal development planning provides each student with a structured and supported process for reflecting on their own learning and achievements, and planning their personal, educational and career development. Subject-specific training delivered at Faculty, School and research group levels includes formal lecture courses, seminar programmes, methods training etc. Each PGR student irrespective of funding source has a personal research training support grant of up to £1200 p.a. conditional on progression, which provides funds to present papers at conferences and attend summer Schools.

Career Development: Engagement with employers is an essential part of PGR career development. Nearly all of our PGR students are working on topics that are highly relevant to industry, and in collaboration with industrial partners. Students frequently attend conferences incorporating large industry exhibitions, and industry-based engineers are regularly invited to Southampton to give seminars. All PGR students are encouraged to participate in widening participation, through leading activities and mentoring young students to consider university study. Examples include robot building, creating and delivering research talks to sixth forms, summer Schools, and mentoring school students in extended project qualifications (EPQ). PGRs are also encouraged and trained to take part in undergraduate teaching, mainly through laboratory demonstration and providing tutorial support.

Outside a student's doctoral research, **PGR internships** provide experiential learning opportunities in which individual students contribute to the delivery of a project and/or the strategic direction of a host organisation. Student interns reflect on their experience and undertake a skills audit to assist in their personal development. These internships are optional and are flexibly negotiated with a range of organisations throughout the year. The Global Research Initiator scheme offers PGRs and ECRs the opportunity to visit one of our international partners to establish and cultivate research links at an institutional and individual level. Since 2018 our records shown that 7 awards have been made to Unit staff and PGR students.

The *University Career and Employability Service* includes dedicated PGR and international student web areas. It holds careers fairs and events, provides training on CVs, applications and interviews, and helps with work placements. The service also arranges for alumni to act as careers contacts. Within the Unit, the *ECS Careers Hub* plays a vigorous role in building relationships with leading companies that bring benefits to research and education programmes across FEPS. Each year, the Hub supports a full programme of employer visits, sponsored events and activities, ensuring that our students are aware and informed of the opportunities available to them. Annually, we have interactions with around 300 companies, with many of which we have long-standing partnership relationships and advertise over 400 technology positions directly to our students and alumni.

Future Worlds (§1.3.3, §4.3.3) leads the development of entrepreneurial skills in our students, it nurtures aspiring PGR entrepreneurs through one-to-one support along with its network of seasoned founders, investors and millionaire entrepreneurs. Martinho-Corbishley and Lomeli established a start-up based on their PhD research, securing £100k seed investment for retail customer tracking technology. Raddi Devices (Founder PhD Steer, RAEng Enterprise Fellowship in 2019) is a spin-out using software to improve prosthetic limb design. ArchA1 (Founder PhD Iris Kramer) uses the power of AI to the construction industry to deliver rapid results and improved outcomes by automatically detecting archaeological sites on earth observation data.

FGS oversees new initiatives, such as establishing quality frameworks and regulations for collaborative research supervision and joint PhD programmes e.g. King Abdulaziz University, Saudi Arabia, Nanyang Technical University, National University of Singapore, University of Aachen, Germany and University of Padova, Italy.

Papers co-authored by students and supervisors, based on or including the student's doctoral research, have been awarded 41 "best paper" type prizes from journals, publishing houses and conferences. Other prestigious prizes include the 2015 IET Control and Automation Doctoral Dissertation Prize (Mayo Maldonado); a Gold Medal for Excellence in Engineering by a Young Engineer, STEM for Britain 2017 (Miguel Xavier), and Silver in 2020 (Davide Zilli); and Gold at Malaysia's Innovation Technology Expo 2016 (Sei Ping Lau).

2.6 Equality and diversity issues in the construction of the REF submission

An initial Equality Impact Assessment (EIA) undertaken in July 2019 was widely discussed within FEPS and a number of interventions made, including:

- Carefully considering the key equality, diversity and inclusion issues in selecting both internal and external reviewers for REF 2021 outputs, including ensuring an appropriate balance of seniority, disciplines, gender and ethnicity amongst reviewers
- Reminding assessors of the possibility of unconscious bias and that outputs should be reviewed purely on the basis of the quality of the work
- A review of all output scores to ensure consistency and fairness between the different Schools in the Unit
- Discussing the findings at school meetings.

Allocating outputs to staff in accordance with the REF guidance and ED&I criteria is challenging for very large submissions (273 staff in UOA12). As described in the University's Code of Practice (Part 4), we made significant use of a software tool that is blind to the protected characteristics of staff and their outputs, and also ensured that the gender balance for selected outputs matched that of the overall population of researchers.

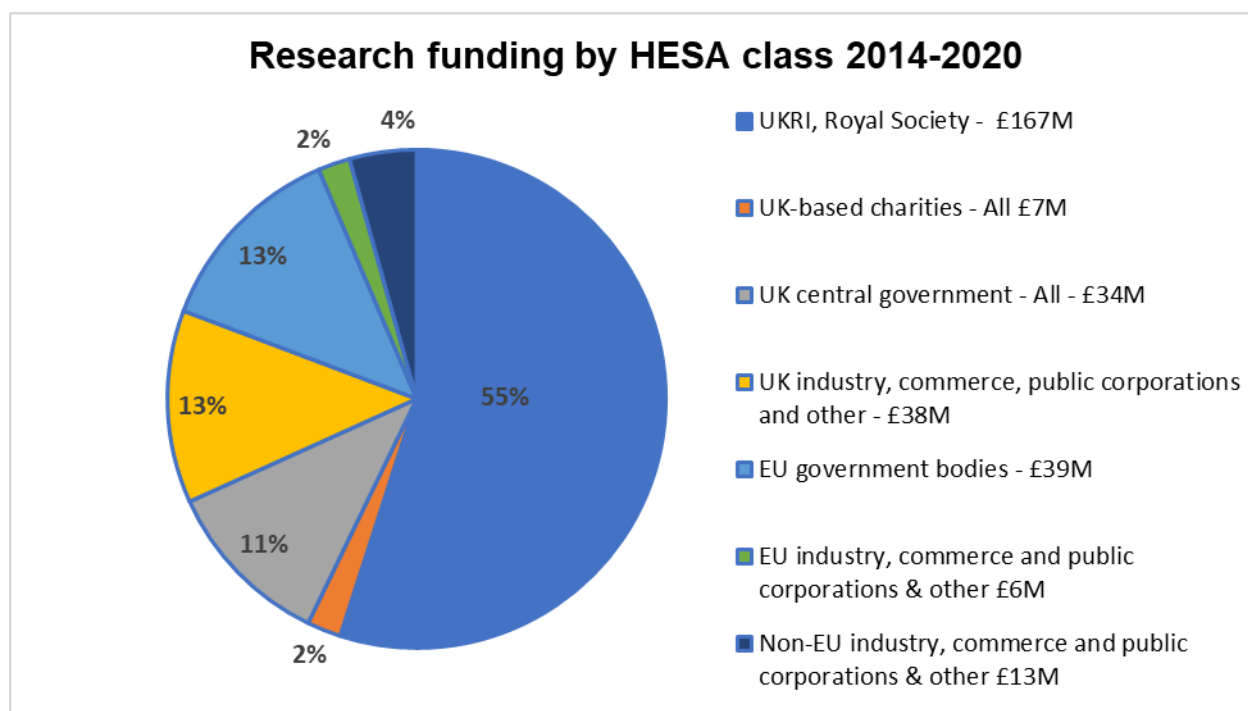
3. Income, infrastructure and facilities

3.1 Strategy for generating research income

The Unit has a policy of securing strategic large grant funding via EPSRC programme grants (Unit PIs currently hold 7, refer §4.1 Table 4.2), and other multi-£M funding routes, balanced with shorter-term responsive mode grants and funding via industrial collaborators ranging from long-term corporate partnerships to shorter project-based support.

The Unit has maintained an average annual research economy of ~£45M over the REF period. UKRI (notably EPSRC) is consistently the single biggest sponsor, accounting for about 55% of the Unit's research income. 13% is from UK industry, reflecting our strong links with major high-impact collaborators including Airbus, BAE, Network Rail and Rolls-Royce. A full breakdown is given in Figure 3.1.

Figure 3.1: Research funding by HESA class



Total research income over the REF period was £304M, equating to ~£166k per FTE p.a. for each of the 261FTE staff returned in UoA12 (an increase of >52%, from £108k in REF2014).

The Unit's researchers derive tremendous benefit from access to world-class facilities and infrastructure both within the Unit and University, and at other institutions around the world via collaborative research projects. Within the Unit, facilities are operated in clusters (by theme) at School level, rather than individually by departments or groups, to maximise the benefit of multi-application disciplines such as acoustics, computing, materials, structures or photonics. Activities are further supported by teams specialising in the delivery of research impact, often (co-) funded by grant income from agencies and sponsors as shown in Figure 3.1. Many of the larger activities run annual competitions (typically £100k per call) for seed-corn stimulus funding to support new initiatives and early-stage feasibility studies; projects funded in this way often utilise the Unit's wide range of experimental and computational facilities. (§3.5)

Full lists of Programme Grants and other large scale (multi-£M) funding are given in §4.1 Table 4.2 for Unit PIs, and §4.1 Table 4.3 for Unit Co-Is with a PI elsewhere. The respective totals of >£70.3M and £277.6M indicate a considerable and consistent level of research funding.

In addition, the Unit has benefitted significantly from EPSRC Prosperity Partnerships leveraging matched funding from partnering organisation(s); equipment funding; KTPs; and framework agreement / strategic partnership / University Technology Centre (UTCs) type funding from industry. Details of these are provided here rather than in §4, reflecting the strategic nature of

such funding streams in terms of the joint benefits of the research undertaken, partnership development, and routes to impact – for example, as evidenced by the Impact Case Studies.

Table 3.1: Prosperity Partnerships, framework agreements, UK Capability and Equipment grants

Scheme	PI	Dates	Funder and key partners	Total Funding £M
Prosperity Partnership	Reed	2017-23	EPSRC Rockley Photonics	4.2
Prosperity Partnership	Daley	2018-23	BAE Systems	6.0
Strategic Partnership / Framework agreement	Powrie	2013-24	Network Rail	3.3
Framework agreement	Hudson	2014-23	Shell	2.5
Framework agreement	Turnock	2014-18	English Institute of Sport	1.0
Strategic Partnership	Powrie	2014-20	China Railway Rolling Stock Corporation	0.3
UK Capability: Cornerstone	Reed	2014-20	EPSRC + 13 partners	3.1
UK Capability: Cornerstone 2	Reed	2020-22	EPSRC + 49 partners	1.5
Equipment grant: Structures 2025	Barton	2017-21	EPSRC + 16 partners	1.1
Future Towns Innovation Hub	Kemp	2019-	EM3 LEP, Research England	4.5
Totals				£27.5M

Table 3.2: University Technology Centres

Scheme	PI	Partner	Name	Dates	Direct funding £M
UTC	Angland	Airbus	Airbus Noise Technology Centre	2014-present	1.1
UTC	Keane	Rolls Royce	Computational Aerodynamics	2014-present	1.1
UTC	Wilson	Rolls Royce	Propulsion Systems Noise	2014-present	1.9

Table 3.3: Knowledge Transfer Partnerships (KTPs)

PI	Partner	Date	Status
Ferguson/Waters	Controlled Power Technologies	2014	Completed
Gawith /Gates	Covesion 2	2014	Completed
Kim/ Joseph	Vesta Wind Tunnels	2014	Completed
Hill/ Newton	Merck Chemicals	2016	Completed
Brocklesby/Frey	LMC Environmental	2016	Completed
Byfield/Kashani	Dawson Construction Plant	2017	Completed
Gawith /Carpenter	Covesion 3	2018	Completed
Zwolinski/Halak	PragmatlC	2018	Ends 4/21

Yang/Mak	AccelerComm	2018	Ends 1/21
Jiang/Badar	Blatchford	2018	Ends 2022
Sobey/Hudson	Silverstream technologies Ltd	2020	Ends 2022

3.2 Areas of strategic investment

One of the key Faculty strategies is to support and actively encourage interdisciplinary research. To this end, over the REF period we have launched 7 new interdisciplinary Centres of Excellence. Each centre has a director, and is supported by Faculty and RIS staff and cross-disciplinary PhD studentships.

Continuous Digital Chemical Engineering Science (CDCES) is developing smarter, greener and more efficient processes for the discovery and manufacture of new chemicals and materials, the building blocks of future technological and scientific advances.

Future of Human Communication (FHC) is developing digital technologies that will help people to communicate better. Research focuses on accessible devices and systems to improve healthcare and wellbeing, and enhance the way we learn, work and enjoy entertainment and culture.

Health Technologies facilitates coordination between academics and practitioners in the health domain, including e-health, healthcare technologies, wellbeing and rehabilitation.

In-situ and Remote Intelligent Sensing (IRIS) is the world's only research hub dedicated to developing intelligent, connected, self-powered sensing systems to operate in some of Earth's most remote, harshest environments; providing a better understanding of the world around us and helping to tackle some of the most pressing environmental and societal challenges we face today.

IoT and Pervasive Systems covers the full IoT system stack, from underpinning semiconductor and sensor devices through to machine intelligence and data science.

Machine Intelligence includes academics involved in fundamental research as well as those using AI and robotics in novel applications. An £11.8M grant for research in this area – the *Trustworthy Autonomous Systems Hub* – was announced in June 2020.

Re-engineering for Electric Mobility (RE4EM) is accelerating the development of sustainable, interconnected electric transport systems, the re-engineering of existing infrastructure and vehicles; through advances in energy storage technology, the use of digital tribology to optimise components and redesigning the human-machine interface.

3.3 Organisational infrastructure, operational and scholarly support for research and impact

The Unit benefits from a raft of research support activities provided by the University centrally through Research and Innovation Services (RIS), the Faculty and at school level.

University central support: RIS oversee almost every aspect of the research funding lifecycle from initial advertising of calls through to impact, REF and licencing/spin-out activity. This includes:

- Advertising calls and alerting staff to funding opportunities
- Reviewing and providing feedback on draft proposals, including advice on costing (supported by the finance hub)
- Arranging mock interviews where relevant (e.g. EPSRC, RAEng, Royal Society, European Research Council proposals)
- Brokering engagement with funders via team visits, panels, and expert advice from specific staff who are fully focussed on a particular funder
- Negotiating contracts, including non-disclosure, confidentiality and licensing agreements
- Overseeing REF processes via a central planning section
- Assisting spin-out activities including technology transfer, licensing deals etc
- Running the Impact Acceleration Account, including funding, to maximise its effectiveness

Unit (Faculty/school)-level support includes:

- Marketing and research highlights dissemination activities
- Enterprise-related activities including *Future Worlds* meetings and events
- Local IT and HR management for our engineering-intensive Faculty
- A network to promote the fellowship culture within the Unit
- Support for proposals in terms of institutional and match funding
- A Patent Panel, which oversees the patent submission and filing process for developing impact
- Local support staff, often co-funded via large grant funding, who are specialists in particular areas of engineering, electronics, photonics.
- Fellowship champions, who provide support and feedback for staff engaging in fellowship applications
- Proposal review teams, who provide timely feedback on draft proposals

Operational support is provided at University, Faculty and school level through various mechanisms and funding streams:

Technical support: The University Estates and Facilities (E&F) team is responsible for day-to-day operation and maintenance, and its Project Management Unit for major new construction such as the Boldrewood Innovation Campus and the Zepler Institute cleanroom complex. Local enhancements are managed by E&F to the requirements of the Faculty/Unit. Technical support totalling >100 staff and £4M p.a. is controlled by Schools, funded by devolved budget allocations from the University and grants from research councils, through infrastructure, pool or dedicated technical posts.

IT equipment: Funding and management depends on scale and user group/need. Central funding covers institutional provision including the *IRIDIS4* and *IRIDIS5* super-computers. *IRIDIS* remains one of the largest computational facilities in the UK. The 20,000-core *IRIDIS5*, >4× more powerful than its predecessor, has a peak performance of 1.3 Petaflops. It entered the list of the 500 most powerful super-computer systems in the world in November 2017. *IRIDIS6* is now in the planning stage. We host the Spitfire cluster, which has a total of 864 cores, a peak performance of ~20Tflops, 4Tbytes of RAM and 30Tbytes of (RAW) disk storage. These facilities underpin the Rolls Royce UTC in computational engineering and are used in research across the Unit. Most other local IT, including lab-based PCs, are provided and maintained by central IT, via Unit technical support.

Large-scale equipment: Major investment in new equipment is supported by the Faculty or the University centrally (e.g. through *MuLSER*; Template 5a), subject to a sound business case aligning with institutional strategy. For major equipment purchased via grant funding, the Faculty meets the usual 50% matching requirement following approval from the Associate Dean Research (**Wood**).

Facilities management: Large-scale facilities operate as cost centres in the Faculty financial model, and are managed at University level *TRAC* small research facilities. They are credited with income earned from research and teaching, from which the day-to-day running costs are met including consumables, routine equipment purchase, maintenance, and technical support. The Area Academic Lead is responsible for keeping the facility up to date with state-of-the art equipment, and ensuring it is efficiently utilized with a user consultative group and fair access for all. The Area Technical lead is responsible for the day-to-day safe and efficient running of the facility, with the Area Safety Officer, reporting to central H&S team, having an oversight and advisory role.

3.4 Infrastructure, facilities and expertise in relation to impact activities

Impact activities are facilitated and promoted via four main routes focusing on the use of University facilities for newly created spin-outs, external commercial contract use, consultancy work, and ongoing collaborations with major companies.

New spin-outs have benefitted from the use of the Zepler Cleanroom Complex (e.g. Lumenisity Ltd using ORC fibre drawing towers), the Printed Electronics and Materials Lab (Smart Fabric

Inks Ltd, who develop specialised printable inks), and bio-lab facilities (Vivoplex Ltd, developing implantable wireless sensors). Access agreements enable the use of facilities by spin-outs prior to securing seed funding.

External commercial use involves agreed access to facilities as part of planned (usually joint) research programmes. Examples include *Cornerstone* (EPSRC EP/L021129) and *Cornerstone2* (EPSRC EP/T019697), which provides silicon photonics foundry services to external UK users; the rolling contract with IQE for LED fabrication using cleanroom facilities; and the Tony Davies High Voltage Laboratory, which supports testing and development of novel dielectric materials for cable insulation for manufacturers, leading to reduced material usage and costs and improved performance. Electrical equipment manufacturers such as AP Sensing, Brecknell Willis, Nexans, Power CSL, TE Connectivity and Vestas; infrastructure businesses Balfour Beatty, National Grid, Network Rail and Scottish Power Energy Networks; and telecommunications businesses A2Sea Solutions and Global Marine Systems have used the facility over the REF period.

Consultancies via *ECS Partners*, *E&E Partners* and our enterprise units (§1.3.2 and §4.3.1) provide access to the cleanroom complex and other specialist facilities for commercial income generation.

Ongoing collaborations with major corporates and industries: the National Infrastructure Laboratory (NIL: EPSRC EP/P013627) was funded to provide targeted investment in capital equipment to address near-term issues including the resilience of railways and roads in the face of climate change, flood and water management. The proposal was supported by Network Rail, who are now funding work in the facility as part of their ongoing research partnership with the Unit. Lloyds Register has invested in laboratory facilities and has ongoing research collaboration elsewhere on the Boldrewood Innovation Campus, while Airbus supported and use the new aeroacoustic wind tunnel. Our wind tunnels, hydrodynamics facilities and simulators underpin our framework agreement with the English Institute of Sport, and have contributed significantly to national sporting success in cycling, sailing and winter skeleton (sled) events.

3.5 Specialist research infrastructure and facilities

The Unit has extensive established and new facilities, housed in 20 buildings (many purpose-built) across three campuses. Over the REF period we have received over £250M investment in major new facilities and upgrades from UKRI, industry and the University. Each facility has designated Academic and Technical Leads and is supported by technical staff (§3.3).

(a) The *Boldrewood Innovation Campus (BIC)* is the stand-out achievement of the last six years. It represents an investment of £170M funded largely from outside the University by bodies such as Lloyds Register, Department for Business, Energy and Industrial Strategy (BEIS) and South East England Development Agency (SEEDA), recognising the strength and quality of Engineering at Southampton. The campus was officially opened in 2015 by HRH the Princess Royal. Home to *Southampton Marine and Maritime Institute (SMMI)* and Lloyd's Register's Global Technology Centre, it is the UK's largest University-business partnership and represents the next stage of a >40 year partnership between the University and Lloyds Register in marine engineering research.

BIC encompasses state-of-the-art facilities for teaching, research and enterprise including a fluids laboratory, autonomous vehicle research laboratories, a driving simulator sponsored by Jaguar Land Rover, a performance sports laboratory, a large design studio, lecture and seminar spaces, and the new UKCRIC National Infrastructure Laboratory (NIL), completed and opened in 2019 by the CEO of Network Rail.

- The ***UKCRIC National Infrastructure Laboratory (NIL)*** represents a £48M investment as part of the UK's Collaboratorium for Research on Infrastructure and Cities (UKCRIC) including funding from the Department for Business, Energy and Industry Strategy (BEIS), the Engineering and Physical Sciences Research Council (EPSRC £26M EP/P013627) and project partners. The laboratory houses teaching and research laboratories for geomechanics, large structures, environmental and infrastructure engineering (§1.2.3), used

to develop new understandings of the behaviour of large structures and structural components, with an emphasis on the infrastructure, rail and maritime sectors.

- The **Fluid Dynamics Research Laboratory** incorporates a 138m towing tank and advanced wind tunnels complementing existing facilities. The towing tank, built with the most advanced instrumentation including a wave maker, will be used to investigate the power requirements of high speed vessels, safe limits in extreme waves, marine renewables, fluid-structure interactions of moorings for offshore structures, and the energy efficiency of hull designs. It also houses a unique aeroacoustic wind tunnel used in our research on aircraft noise reduction. A recirculating wind tunnel is used for environmental research including atmospheric boundary layers. These facilities complement our established RJ Mitchell wind tunnel, used extensively for research into vehicle and Olympic-level cycling aerodynamics – as well as by Chris Froome prior to his 2016 *Tour de France* victory, to perfect posture and maximise speed/performance.

The Unit's other key specialist facilities are listed below, in alphabetical order by research area or theme.

b) Our Acoustics Laboratories are amongst Europe's most comprehensive. They include large ($55\text{m}^2/348\text{m}^3$) and small ($32\text{m}^2/131\text{m}^3$) reverberant chambers, a large anechoic chamber (54m^2), the Doak laboratory (anechoic down to 400Hz, with microphone arrays to give complete 3D maps of jet and valve noise), and the AB Wood $8\text{m}\times 8\text{m}\times 5\text{m}$ deepwater tank (with hydrophone and sources). These support our pioneering research in sound and vibration, including Rolls Royce and Airbus UTCs in aircraft noise. The deepwater tank has been used by DSTL (target detection), Statoil (gas pipe leakage), MOD/Red-Scientific/BAeSystems (TWIPS sonar, BAe-funded patent, all inventors being University of Southampton), and €2.5M Horizon2020 research quantifying leakage from North Sea Carbon Capture and Storage facilities. An audio laboratory with a 40-loudspeaker array and RME DAC/ADC units for 3D audio-reproduction underpins research into active noise/vibration control (which has attracted >£6M from the Home Office and BAE Systems for border security and maritime applications since 2015) and 3D/personal-audio research (£6M, including >£3M from Huawei and the S3A EPSRC Programme Grant with BBC).

c) The Advanced Packaging Laboratory was established in 2017 to enable placement and connection to wafer-scale packaged components and LEDs, utilising processing equipment donated by IQE Ltd.

d) Autonomous systems facilities for maritime robotics include: a 300kg autonomous surface vehicle with expanded payload capabilities and both subsea and surface communication, and a fleet of 6, medium (20-50kg) and small (<10kg) autonomous underwater vehicles capable of operating at depths of up to 500m. Of total value ~£250k, these form a basis for both fundamental (control, sensing, intelligence and swarm behaviour) and applied (environmental monitoring, infrastructure inspection) research at the University, and are compatible with mobile autonomous systems control centres to support operations at sea. We are one of the largest operators of drones in the UK, with ~100 platforms in extensive use in the UK and internationally. We have considerable experience of beyond visible line of sight (BVLOS) operation and were the first non-military organisation in the UK to gain CAA permission for a >25kg platform (in 2012). Field operations are supported by two ~£1M mobile laboratories.

e) Bioengineering and human factors facilities include: a wet-biolab with microbiological safety cabinets; cell culture; a tissue testing suite housing multiaxial servo-hydraulic and electromechanical test machines; and microscopy. Human Factors facilities include an extensive hearing and balance laboratory suite (for researching human responses to vibration), a 6-axis motion simulator; 12m, 6m and 1m horizontal shakers; a 1m vertical shaker; oscillatory and yaw simulation; and an instrumented treadmill system for gait analysis.

f) Energy and climate change facilities include: one stand-alone and two building-integrated instrumented photovoltaic arrays of 7.2 kW peak (kWp) and 12.5kWp; laboratory testing of solar home systems (batteries, lighting, fans, TVs, fridges etc.); environmental monitoring systems; thermal cameras; and tidal/wave energy device testing facilities (housed in the Fluid Dynamics Research Laboratory).

g) The Centre for Hybrid Biodevices (CHB) is located within the *Institute for Life Sciences* and supports interdisciplinary research across the University. The laboratories are biosafety category 2, facilitating research using hazardous biological material. They host a wide range of rapid prototyping and analytical equipment. The facility is widely used by researchers from Southampton University Hospital Trust, industry and start-ups.

h) Infrastructure engineering facilities within the NIL include: the 15m×30m strongfloor and a smaller testing laboratory equipped with a range of computer-controlled, servo-hydraulic testing machines ranging from 1kN to 2.5MN in capacity, able to reproduce complex dynamic loading signatures; a 100kN high strain rate test machine; and bi-and tri-axial loading machines supported by *UKCRIC*, *UKRRIN* and *Structures 2025*. Facilities for stress analysis and crack/damage monitoring include ultrasonic scanning, and a suite of CCD and high-speed infrared cameras with associated image-based strain measurement software. Composite fabrication and processing facilities include vacuum assisted resin infusion and an autoclave (1m dia. × 1.5m long). Our new geotechnical laboratory is equipped with resonant column, cyclic triaxial, hollow cylinder and cyclic simple shear apparatus; a low temperature/high pressure rig for testing gas hydrate bearing sediments; consolidating anaerobic reactors used to investigate waste compression and degradation, on which similar equipment around the world is based; in-house digital image analysis-based strain measurement equipment; and a 3m radius geotechnical centrifuge. The geomechanics laboratory and our associated field measuring expertise supports work in geotechnical transport infrastructure (co-funded by EPSRC, Network Rail and HS1) and environmental geotechnics (we are a partner in the Dutch Accelerated landfill Remediation Trial). We also have access to an environmental analytical suite and a 36m full-scale railway test track.

i) Materials, solid mechanics and surface engineering facilities have benefitted from continuing investments associated with the μ -VIS Computed Tomography Centre and *nCATS*, the *National Centre for Advanced Tribology at Southampton*. Equipment in μ -VIS includes 9 CT scanners and associated analysis suites, a Jeol JSM-6500F field emission scanning electron microscope; and micro powder processing and microfabrication facilities. Equipment in *nCATS* includes 3D contacting and non-contacting profilometry; a range of optical microscopes and associated metallography equipment; nanomechanical and nanotribological test facilities; pin-on-disc and twin disc tribometers; a full-scale train bearing and various wear, abrasion, corrosion and erosion test rigs. This is used to support themes across engineering, from geomechanics (characterizing the behaviour of plant roots in shearing soils, EP/M020355) through sustainable energy to bioengineering (prosthetic joint wear and dental tribology). μ -VIS will play a leading role in the recently-announced National Research Facility (NRF) in Lab-based X-ray Computed Tomography (XCT), commissioning what will be the largest engineering XCT capability in UK universities and leading on biomedical applications of XCT in collaboration with the Faculty of Medicine and Southampton University Hospital Trust.

j) The Measurement Laboratory supports a wide level of electrical, optical, magnetic, structural and thermoelectric characterisation techniques. It has a 200mm wafer semi-automatic probe-station with 67 GHz network analyser, two variable temperature spintronic systems (prober with 1T in plane field, and 9T cryostat), and a triple wavelength tip-enhanced Raman system. The facility is funded by Research Councils, EU Horizon 2020 and industry.

k) The Printed Electronics and Materials (PEM) laboratory houses equipment to enable the printing and deposition of solution-processed functional materials, for example polymer-based low temperature materials for flexible electronics and e-textiles. Processes include screen, dispenser and inkjet printing, doctor blading and spray coating enabling the deposition of film thicknesses ranging from a few nanometres to hundreds of microns. The laboratory supports a wide range of research activities including flexible electronic circuit fabrication, thin film organic electronic devices and e-textiles for wearable applications.

l) The Tony Davies High Voltage Laboratory (TDHVL) supports research into dielectric materials and insulation systems, as well as high voltage and related phenomena. The laboratory houses state-of-the-art facilities and is supported by a specialist engineering team. An EP large vacuum chamber with two 4800l/s maglev turbo pumps makes this a unique test facility

in the UK. The TDHVL is also a commercial testing house and offers consultancy service. It is one of only a handful of facilities in Europe and has established itself as leading institution in high voltage research. The TDHVL is audited annually, and offers a certified service to ISO9001:2015, ISO14001:2015 and OHSAS18001:2007. The value of commercial activities undertaken through TDHVL is approximately £200k p.a. for clients including Morgan Sindall, Offshore Renewable Energy Catapult, QinetiQ, RINA Consulting and Transmission Excellence.

m) The *TRUMPF/ORC Advanced Laser Laboratory (ALL)* is a jointly managed dedicated research facility geared towards providing concept phase technology typically linked to the company's product road map. Deliverables are specific fibre, components, laser design concepts and early concept prototype lasers. ALL is staffed by both ORC and visiting TRUMPF Laser UK personnel and currently contributes ~£250k/year to costs, amounting to a total of £2M since its inception. In addition, the ALL is involved in preparing bids for larger UK/EU research initiatives, such as Innovate UK, EPSRC and EU H2020 and has contributed to an impact case study submitted for UoA 12.

n) *Transportation* facilities include the Southampton University Driving Simulator (SUDS), comprising a Land Rover Discovery and Triumph motorcycle linked to AV Simulation's SCANeR Studio simulation software. Three projectors provide a 135° forward field of view, door mirrors are simulated using mini-LCD monitors, and a rear projection screen allows natural usage of the vehicle's rear-view mirror. In-vehicle information can be provided through the vehicle's original instrument cluster, or through a bespoke, reconfigurable, touchscreen display. The car's audio system delivers simulation sounds, and all vehicle controls are fully functional. Our on-road instrumented vehicle, a Toyota Prius plug-In hybrid, was acquired in 2020 and is equipped with a Race-logic Video VBOX Pro system combining 32 CAN data input channels with four high-definition video feeds, two microphones, and a GPS antenna. The system records data at 20Hz with a velocity accuracy of 0.1km/h, acceleration accuracy of 0.5%, and distance accuracy of 0.05%. We have recently developed an instrumented bicycle (*iBike*) for on-road trials and behavioural studies. *ComTET* is a 10-workstation similar of the command room of an Astute-class submarine, with a custom-built simulation engine using Dangerous Waters software. For transportation data analysis, we have a range of planning and modelling software, traffic data collection and processing equipment.

o) *Water and environmental engineering* facilities comprise bioreactor laboratories used in the development of novel environmental technologies for water, waste and wastewater treatment and bioenergy production from prototype to commercially viable application; an analytical suite (shared by all groups) housing a range of equipment including gas and ion chromatographs, atomic absorption and near infrared spectrophotometers, carbon and elemental analysers and calorimeters); 24m and 16m tilting flumes; 60m outdoor ecohydraulics flumes; 8m and 12.5m wave basins; a semi-anechoic ecosystem tank; and field equipment including boat-based acoustic Doppler current profilers and 3-D acoustic telemetry for ecohydraulics research.

p) *Zepler Institute Cleanroom Complex* is a state-of-the-art 1780m² multidisciplinary centre for materials and device research in photonics (silica, glass and silicon technologies), electronics and nanotechnology. Our cleanrooms house the best set of photonics and nanoelectronics fabrication capabilities in the UK University sector. Facilities include: silica fibre fabrication with four fibre drawing towers, nanofabrication, novel and compound glass, silicon and integrated photonics facilities, and FHD, SEM and FIB suites. The complex was established in 2008 at a cost of £120M including building and equipment, and offers a unique mix of expertise in established and cutting-edge technologies. Integrated with specialist application development laboratories in areas such as communications, lasers, sensors and biotechnology and advanced characterisation facilities across the University, the Zepler Institute is able to address every aspect of the discipline.

3.6 Benefits-in-kind

The Unit has strong working relationships with industry and alumni, resulting in benefits-in-kind having a total value of > £3.84M over the REF period (Table 3.4), in addition to those already mentioned.

Table 3.4: Major benefits-in-kind and other contributions

Sponsor	Relationship	Benefit	Value £k
Intel	Corporate	Equipment: stepper/scanner	1400
NERC	Research Council	Use of facilities: ship time	225
Lumenisity	Spin-out	Equipment: fibre draw tower upgrade	200
Huawei	Corporate	Donation to fund research	200
Dr KV Reddy	Personal	Sir David Payne Student Scholarship	100
Central Laser Facility	Research Council	Use of facilities	284
National Institute for Health Research	Department of Health and Social Care	Use of Facilities: Diamond Light Source beam time	1643
ISIS Neutron and Muon Source	Research Council	Use of facilities	270
Dr A Grudinin	Alumnus	Postgraduate bursary	50
Total			£4372k

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

4.1 Support for Unit research collaborations, networks and partnerships

The University supports the Unit's research collaborations, networks and partnerships through centralised functions for Research and Innovation Services (RIS), Finance, Estates and Facilities (E&F) and HR, as described in §3.3. The Office of Development and Alumni Relations (ODAR) develops mutually beneficial, lifelong relationships with key constituents to increase philanthropic support for the University. Fellowship networks, overseen by the Faculty, but managed at school level, have been running within the Unit for >10 years, brokering all aspects of fellowship submission, management, mentoring and focussed events. All these activities are overseen at University level by the Research & Enterprise Executive Group (REEG) which manages and maximises the delivery of research under the University strategic plan.

As evidence of the Unit's success, we summarise our major research collaborations, networks and partnerships below.

Major non-UKRI collaborations involve: Airbus, ARM, AWE, BAE, Boeing, DSTL, European Space Agency, Huawei, IBM, Lloyds Register, National Grid, Northrop Grumman, Rolls Royce, Thales, Siemens, Schaeffler, Shell and the Home Office. Individual collaborations with an income >£1M are listed in Table 4.1.

Table 4.1: Non-UKRI research income >£1M during REF period (rounded)

Funder	£M
BAE Systems	5.4
Rolls Royce	5.3
DSTL	3.6
National Grid	3.1
Rockley Photonics	2.6
Huawei	2.1

Microsoft	1.9
Lumenisity (spin-out)	1.7
SPI lasers (spin-out)	1.3
Hi-Silicon	1.2
Airbus	1.1
Network Rail	1.0
Total	£30.3M

Further funding totaling >£4M has been received from AP Sensing, AWE, BP, De Puy, European Space Agency, GE Aviation, Honeywell, IBM, Jaguar Land Rover, QinetiQ, Schlumberger, Southampton City Council, TWI, and others. Additional examples of major collaborative research via a research framework or similar strategic agreement with industry, including University Technology Centres, are given in §3.1 (Table 3.2).

The Unit's success in achieving its key REF2014 objective of research partnerships with industry and other academic institutions is detailed below.

Large research collaborations funded through Programme and similar grants led by Unit staff over the assessment period are shown in Table 4.2. This includes 7 active EPSRC Programme grants (PG) totaling £37.4M and four other grants worth £32.9M, together involving more than 30 HEIs and over 100 industry partners. 4 further Programme grants of total value £16M, not included in Table 4.2, were awarded prior to 2013 and ran for >3 years within the assessment period.

Table 4.2: Grants >£2M led by a Unit PI awarded during the REF period ("PG)" after the name of the PI denotes a Programme grant.

PI	Title	Dates	£M	HEI Partners	Industry Partners
Richards	UKCRIC National Infrastructure Laboratory	4/2016 - 5/2017	26	N/A	N/A
Prodromakis(PG)	FORTE	4/2018 - 9/2023	6.3	Imperial, Manchester	11 including ARM, Lloyd's Register, NMI, NXP Semiconductor UK, Thales
Richardson(PG)	Airguide Photonics	6/2017- 5/2023	6.1	Aston, Bristol, Cambridge, Liverpool, Sheffield, Surrey, UCL	18 including BT, CIP Technologies, JPL, Microsoft, NPL, Oclaro, Qinetiq, SPI Lasers, Toshiba
Reed(PG)	Silicon photonics for future systems	12/2013- 3/2021	6.0	KAIST, MIT, Paris South, Tokyo,	8 including Intel, Oclaro
Powrie(PG)	Track to the Future	6/2015 - 5/2021	5.2	Birmingham, Huddersfield, Nottingham	10 including HS2, London Underground, Network Rail, Tata Steel UK

Brown(PG)	PoETS	5/2016-11/2022	5.0	Cambridge, Hong Kong, Imperial, Newcastle	5 including UKAEA, NMI, Imagination Technologies
Zheludev(PG)	The Physics and Technology of Photonic Metadevices and Metasystems	10/2015-9/2021	4.4	Glasgow, Nanyang and Taiwan TU	4 BAE systems, DSTL, Ilika, Oclaro
Scanlan(PG)	CASCADE (Autonomous aircraft systems)	2/2018-1/2023	4.4	Bristol, Cranfield	26 including Babcock, BAE, BP, DSTL, Met Office, Network Rail, Ordnance survey, Thales
Hewak	Manufacture and application of next generation chalcogenides	2/2015-1/2021	2.5	Cambridge, Exeter, Oxford	16 including DSTL, NPL, Samsung, Seagate technology
Reed	Cornerstone	9/2014-6/2020	2.2	Bristol, Cardiff, Heriot-Watt, Leeds, Nottingham, Strathclyde, St Andrews, UCL, York	2 Rockley UK, Filarette Foundation
Beeby	Novel manufacturing methods for functional electronic textiles	3/2015-6/2019	2.2	none	9 including DSTL
Totals			£70.3M	31	109

Grants with PIs at other institutions but on which Unit staff are Co-Is total >£251M; these include 1 collaboratorium, 4 technology hubs and 6 Programme grants involving >25 HEIs and >200 industry partners. These are summarized in Table 4.3.

Table 4.3: Grants >£2M involving Unit Co-Is

Co-I	Title	Dates	Amount /£M	Co-I HEIs/ partners	Industry Partners
31 (Convenor), Richards (Director of Strategy)	UKCRIC: UK Collaboratorium for research in infrastructure and cities	4/2016-5/2017	110* excludes amount in Table 4.2	Bristol, Birmingham, Cambridge, Cranfield, ICL, Leeds, Loughborough Manchester, Newcastle, Oxford, Sheffield, UCL	>50 in the original submission to BEIS, including Catapults, Network Rail, Highways Agency, National Nuclear Laboratory, Scottish Water, Northumbrian Water, Laing

					O'Rourke, Arup, Costain, Mott MacDonald, Siemens, and city councils e.g. Manchester, Bristol, Newcastle
Smith, Horak	UK Quantum Technology Hub (NQIT)	12/2014-3/2020	38	Bath, Cambridge, Edinburgh, Oxford, Strathclyde, Sussex, Warwick	22 including AWE, DSTL, GCHQ, Google, Lockheed Martin, NPL, NIST, Raytheon, Toshiba
Smith, Gawith, Horak	UK Quantum Technology Hub for sensors and metrology	12/2014-11/2019	35.5	Birmingham, Bradford, Glasgow, Lancaster, Nottingham, Strathclyde, Sussex	51 including AWE, BAE, BP, DSTL, IBM, NPL, NIST, Thales
Smith, Gawith	<i>QuantIC</i> : The UK Quantum Technology Hub in quantum imaging	12/2019-11/2024	21.6	Bristol, Edinburgh, Exeter, Glasgow, Heriot-Watt, Imperial, Strathclyde	30 including Airbus, BAE, DSTL, Leonardo, NPL, Qinetiq, Thales, Toshiba
Payne, Reed, Zheludev	National Hub in high value photonic manufacturing	1/2016-12/2022	10.2	Sheffield	39 including AWE, BAE, CIP, DSTL, IQE, NPL, Plessey, Qinetiq, Renishaw, Sharp, Xyratex
De Groot (PG)	ADEPT: Advanced devices by electroplating	7/2016-7/2022	6.3	Southampton (Chemistry PI)	4 including European Thermodynamics Ltd, Johnson Matthey, STFC
Sandham, Dieterding (PG)	Transpiration cooling systems for jet engine turbines and hypersonic flight	8/2016-8/2021	6.1	Bangor, Birmingham, Imperial, Oxford	9 including DSTL, ESA, Lockheed Martin, Rolls-Royce
Richardson (PG)	Lighting the way to a healthy nation:	6/2020-5/2025	5.6	Edinburgh, Nottingham	2 DSTL, SPI Lasers UK
Preston, Blainey, Powrie, (PG)	MISTRAL: Multi-scale Infrastructure systems analytics	2/2016-2/2021	5.4	Cambridge, Cardiff, East Anglia, Newcastle, Oxford, UCL	52 including Arup, BP, KPMG, Lloyd's register, Shell, National Grid, Siemens, Transport for London

Nelson Fazi (PG)	S3A: Future spatial audio for an immersive listener experience at home	12/2013-6/2019	5.4	Salford, Surrey	9 including Bang & Olufson, BBC, Sony Europe
Powrie, Smethurst, Preston (PG)	ACHILLES - Assessment, costing and enhancement of long life, long linear assets	7/2018-12/2022	4.9	Bath, Durham, Leeds, Loughborough, Newcastle, Strathclyde	11 including Arup, HS2 Ltd, Network Rail, Highways England
Powrie, Richards	UKCRIC Coordination Node	10/2017-3/2021	2.6	Birmingham, Cranfield, UCL	
Total			£251.6M	>25	>200

4.2 Relationship development with key beneficiaries.

In addition to the formal corporate level research partnerships listed above, mechanisms by which users inform our research agenda and benefit from our research include collaboration on individual projects including through EngD/PhD/CDT student sponsorship and KTPs; industry/user advisory boards at project, programme and strategic level; industry days, innovation meetings, exhibitions and showcases. These routes to engagement and development are described below, with evidence and examples given in each case to illustrate the mechanisms and the impact delivered.

4.2.1 Interaction with key research users: collaborators, partners and industry

Some typical cases from many possible examples are summarised below.

The **Arm-ECS** partnership celebrated its 10th anniversary in 2018. It is the largest university research collaboration supported by Arm in the UK and in 2015 won the title *University Research Group of the Year* from the UK technology industry body, National Microelectronics Institute. This collaboration has been cited as an example of a highly successful industry-academic research by Arm and EPSRC and contributed to the information-gathering stage of the Dowling Review of Business-University Research Collaborations. The collaboration, led by **Merrett**, involves 13 academics and research staff from Southampton and 18 engineers from Arm, and has resulted in the fabrication of 13 new test chips, 46 co-authored papers, 10 co-supervised PhD graduates, 28 internships with Arm, 12 patents, and 5 open-source simulation tools.

Shell Shipping established a Research Framework agreement in September 2014, through a deed of gift to the University of ~£1M over 5 years to fund **Hudson** as *Shell Chair of Ship Safety and Efficiency* and related research activity. The deed was renewed in 2019 (£1.5M to 2024), to support 3 research staff. It is managed and stewarded by Office of Development and Alumni Relations at corporate level.

We have had a Strategic University Partnership (£1.25M), and subsequently a Research Framework Agreement (>£2M) in infrastructure systems with **Network Rail** since 2013 (academic lead: **Powrie**). Within the REF period, this has supported research projects to a value of £2.2M and 11 PhD students; contributed to £6.9M of EPSRC grants; facilitated impact through rapid uptake of research results; and enabled staff and students to collaborate in EU projects *Shift2Rail* and *In2Rail*.

The EPSRC-funded **National Hub in High Value Photonic Manufacturing** (£10.4M, 39 project partners, 2016-2022) addresses the grand challenge of optimising multiple cross-disciplinary photonic platform technologies to enable integration through developing low-cost fabrication processes. This theme addresses the collective requirements of the UK photonics (and photonics enabled) industry; its £1M short term (<1 year) research project budget has to date funded 9 projects having a total value of £506k.

Examples of impact arising from interactions and engagement with key research users, in addition to the Impact Case studies, are summarised in Table 4.4.

Table 4.4: Examples of impact in addition to the ICS

Lead investigator(s)	Nature/area of research	Impact / Metrics
Vershuur, Cullington	Cochlear Implants	Changes in NHS candidacy guidelines for cochlear implantation
Yang	Long-standing research collaboration with CERN though applied Superconductivity and Cryogenics.	Part of the UK contribution to the High Luminosity Upgrade (HL-LHC) to the Large Hadron collider (LHC) at CERN. Total funding of £2.2M from STFC, matched by £2M from CERN, will bring major commercial opportunities for the UK cryogenics engineering industry.
Charlton	Harnessing the capability of photonic crystals to improve the light efficiency of light emitting diodes (LEDs).	Energy Savings estimated at 0.3GWh p.a. Spin-out IQE and other economic growth.
Preston	Methods have been developed to design, monitor and evaluate policy interventions that promote local sustainable passenger and freight transport.	In partnership with Hampshire CC and Southampton CC, this research informed future clean air policy for Southampton and identified areas where improvements could be made. This work also attracted >£22M in investment to the local economy.
Kazansky	5D optical storage a joint venture with Microsoft, a method for modifying glass on the nanoscale for permanently recording digital data in inert, stable silica glass using an ultrafast laser writing process.	Economic impact investment and new jobs at Microsoft. 5D technology used to digitally record and preserve national historic archives including Magna Carta.
Turnock	Research for English Institute of Sport for Team GB	1 Gold and 2 bronze medals (50% of all skeleton medals) at the 2018 Winter Olympics
Niu	Environmental sensors and wearable healthcare sensors for continuous monitoring of chemical and biological biomarkers in situ	Commercialisation through spin-out SouthWestSensor Ltd. 8 employees.

4.2.2 Industry and Academia: industry-focused days

Since 2014, the Unit has run over 211 events and industry-focused days, often with our strategic or industry partners but also with international government bodies such as the US Army. Examples of notable, large events with totals of attendees and exhibitors (in brackets) are:

- ChAMP - Chalcogenide Advanced Manufacturing Partnerships – 2014 (263)
- Industry showcase with Sharp Labs Europe – 2014 (>100)
- Parliamentary Outreach Event – 2014 (50)
- UK-Japan Silicon Nanoelectronics & Nanotechnology Symposium – 2016 (75)

- The Future Photonics Hub – 2016, 2018 (387)
- Industry days in Autonomous Shipping – 2016, 2017 (~50)
- Innovative Future Sensors: in partnership with JEMI – 2016 (50)
- 3D imaging for life sciences – organised by μ -vis – 2018 (~100)
- Altera and Huawei engagement day – 2018 (55)
- UK-Japan Ballasted Railway Track Workshop – 11/2018 (36)
- Rail Safety and Standards Board (RSSB) Infrastructure Standards Committee 2-day event – 1/2019 (25)
- Working together in Silicon Photonics – 2019- (70)
- Rail Industries Association (RIA) Infrastructure Technical Interest Group – 9/2019 (50)
- NIL showcase and official opening – 9/2019 (160)
- Rail Industries Association (RIA) Unlocking Innovation (MADE in Britain) Infrastructure showcase – 2/2020 (130)

4.2.3. Exhibitions and PR events

Part of our engagement strategy, events and exhibitions enable us to open up discussions on specific industry needs and sector-wide challenges in engineering, manufacturing, and developing technologies, providing an opportunity for researchers to demonstrate our capabilities directly to industry. Examples include:

FortisNet: a collaborative, interdisciplinary network in musculoskeletal health research bringing together expertise from clinical, academic, stakeholder and enterprise partners, led by the *Institute for Life Sciences (IfLS)*. Since its launch in 2016, 5 annual *FortisNet* network meetings have taken place involving 237 individual participants representing 95 organisations (15 academic, 49 industry, 14 clinical and 17 stakeholder partners). Collaborative projects initiated at the network meetings and supported by *IfLS* pump priming funds have returned 18x the investment in new research income.

Between 2016 and 2019, we showcased our photonics research at >90 conferences, trade shows and networking meetings across the UK and in six countries from North America, Europe and Asia. A media highlight from 2018 was *The Secret Story of Stuff: Materials of the Modern Age*, broadcast to 2M viewers on 31 October; 12 minutes of the hour-long programme was dedicated to photonics research. In 2019, 17 press releases were published to academic and scientific media outlets, and a feature in the *Telegraph* named Southampton as a “hotspot” for innovation.

4.3 Wider contributions to the economy and society

Members of the Unit contribute broadly to the economy and society by providing expert advice/consultancy on specific projects/issues (§4.3.1), sometimes as expert witnesses; contributing to codes of practice and industry guidance (§4.3.2); and establishing start-up and spin-out companies (§4.3.3).

4.3.1 Consultancy

Engagement with users to develop impact is facilitated by the collaborative nature of our research. As part of that engagement, staff are encouraged to provide consultancy that involves exploitation of their research or the generation of new research ideas, usually through one of the vehicles (enterprise units, or ECS/E&E Partners: §1.3.2 and §1.3.3) we have established for this purpose.

37% of our Category A academic staff have engaged in 184 separate consultancy commissions, working not only with large corporations but also charitable institutions and smaller companies in the UK, Europe, USA, Japan and China. Significant consultancies in which staff have utilized knowledge/expertise gained from their research include:

- Work for the Carbon Trust Offshore Wind Accelerator on optimizing the rating of their array and export cables, which identified cost reductions of £1/MWhr on the levelised cost of energy and was subsequently included in Best Practice Guidance to the wind farm industry (**Pilgrim**)

- Chairing the Pilot Study Earthworks design review panels for HS2 (2018-19), which realised estimated savings of ~£100M; and membership (one of three) of the Company Chair's 2019 review team (**Powrie**)

Other consultancies have been carried out for companies including A2Sea Solutions, Arup, BAE Systems, Balfour Beatty, Bombadier, BP, China Southern Power Grid, CYME International Ltd, Daido Metals Ltd, DONG Energy, DSTL, Dyson, Elnk, Equitix, Fugro, GKN Aerospace, Global Marine Systems, Hellenic Cables, Honeywell, Huawei, Ilika, Kelda Technology, Merck, Power CSL, Rapiscan Systems, Reynolds, Rolls Royce, Samsung, Sharp Labs, Shell, TE Connectivity, Teledyne SSE and Woodside.

4.3.2 Codes of practice and industry guidance

10% of our academic staff work closely with industry/government bodies to define standards and publish technical guidance. This work results in monetary savings, reduced pollution/carbon omissions and improved future sustainability. Examples include:

Chen contributed to Cigre D1.23 (brochure No.636, 2015); Cigre A2/D1.43 (brochure No.646, 2016); and IEEE DEIS HVDC cables working group position paper and IEEE standard (IEEE Std 1732-2017), 2017.

Pilgrim is the UK representative on IEC TC20 Working Group 19, which maintains the IEC 60228, 60287, 60853 and 60949 standards. He is also the UK member of a number of Cigre working groups, delivering internationally used best practice guides, including: Cigre B1.35, Technical Brochure "A Guide for Rating Calculations of Insulated Cables" in 2015; Cigre B1.50, Technical Brochure on Sheath Voltage Limiters and Bonding Systems in 2019; Cigre B1.56, Technical Brochure on Current Rating Verification in 2019.

Gourvenec is Convenor of ISO/TC67/SC7/WG10, responsible for development of three international standards for offshore structures; a member of API committee SC2/RG7, developing mirror standards for the US offshore market (API RP2GEO); a member of the SC7 committee responsible for ISO standards across all aspects of offshore structures; and UK expert on offshore geotechnics for BSI B-525-12, *Design of Offshore Structures*.

Hanzo and his team are frequent contributors to the ongoing P1913 IEEE Quantum Comm standardization efforts.

Maunder participated in the 3GPP TS38.212 New Radio channel coding standardization and published an improvement of the ratified standard with **Hanzo** and **Shao**.

Powrie is co-author of Construction Industry Research and Information Association (CIRIA) reports C750 *Groundwater control design and practice* (2nd edition) and C760 *Guidance on embedded wall design*.

Richards and **Powrie** contributed to the new Network Rail Overline Electrification Equipment (OLE) standard PAN101.

White is a member of the ISO/TC67/SC7/WG7 Foundations Panel (ISO19905: Site-specific assessment of jack-up units), the ISO/TC67/SC4/WG6 Task Group on Risers and Flowlines (API RP 2RD/ISO13628: Design and operation of subsea production systems), and the drafting committee for BS10009 Stability design of cables on rocky seabeds.

4.3.3 Startups and spin-outs

Future Worlds (§1.3.3) has helped many start-ups and spin-outs to raise capital and launch during the REF period. Since its formation in 2015, 32 start-ups and spin-outs have been launched, and venture capital investment totalling £7M raised. In many cases, the underpinning technologies were developed through EPSRC funding.

Staff have also engaged with the *iCURE* programme managed by the *SETsquared* enterprise partnership (REF5a). *iCURE* enables researchers with commercially promising ideas to engage with end-users to build their business canvas and identify commercial opportunities for their research. AccelerComm and Highfield Diagnostics have benefitted from the programme though

awards of £50k each, enabling them to meet and interview >100 potential licensees and develop formal business plans.

Spin-outs incorporated or active during the REF period include: Adaptive Audio (**Elliott, Nelson**); AccelerComm (5G mobile; **Maunder**); Arc Instruments (**Prodromakis**); Audio Scenic (3D audio; **Fazi**); Carena Healthcare (stents; **Bressloff**); CHG (**Hewak**); Covesion (**Smith, Gawith**); Cuesta (**Shrimpton**); Dynamics Modelling (**Keane**); e-sens (**Prodromakis**); HiT systems (**Sharkh**); Lumenisity (**Richardson, Poletti**); Opsodis (**Nelson, Elliott**); Pointcloud (**Reed, Thomson**); Radii Devices (prosthetics; **Dickinson**); Smart Fabric Inks (**Beeby, Tudor, Yang**); SouthWestSensor (sensing; **Niu**) and Vivoplex, (digital health; **Morgan**).

4.4 Contribution to sustainability of the discipline and Interdisciplinary research

Unit staff contribute to the sustainability of the discipline through leadership and participation in collaborative research programmes as listed in §4.1; working with government and other agencies in the UK and abroad, and contributing to collegial scholarly activity through journal editorship, review, committee and conference organisation activities, as summarised in §4.6.

In addition to contributions to major national projects such as HS2, three examples of our links with government and our responsiveness to national/international priorities/initiatives are:

a) The **SUSCABLE II** project, which took concepts developed in earlier EPSRC Supergen and Technology Strategy Board (TSB) projects to prototype stage. **SUSCABLE II** showed how low Technology Readiness Level (TRL), EPSRC-funded work could be developed through proof-of-concept to scale-up and prototype development, fully funded by industry. The consortium included two major multi-national cable makers (General Cable, Nexans) and one SME (Gnosys Global). The final stage involved the production of tons of a new thermoplastic insulation and the manufacture of kilometre lengths of a typical medium voltage cable core using industrial manufacturing facilities.

b) The Tony Davies High Voltage Laboratory, which has undertaken Network Innovation Allowance research projects for **National Grid** throughout the REF period. Working with colleagues in Chemistry and Mathematics, major projects include *Condition and climatic environment for power transformers* (£928k), *Liquids for cable sealing ends* (£702k), *Transformer oil passivation and impact of corrosive sulphur* (£545k) and *Economic ageing of transformers* (£447k).

c) The *Britain is GREAT campaign*: Working with UK Trade and Industry and the Foreign and Commonwealth Office, an iconic poster was produced promoting UK photonics manufacturing capability and encouraging people to visit, do business, invest and study in the UK. The poster was selected as the flagship image for the UK Pavilion at Photonics West in San Francisco, and for a UK Trade & Investment (UKTI) social media campaign to promote UK photonics capability worldwide.

This complements our involvement in TPI (Singapore; §1.2.3) and (with the EPSRC National Epitaxy Facility, Sheffield) in the *Future Photonics Hub (FPH)*. The *FPH* aims to secure the UK's position as a leading innovator in the high value global photonics market by transferring new, practical and commercial process technologies to industry and between 2016-2019 has generated £15M in industrial income, funding 72 research projects across 9 key industry sectors, bringing new photonics technologies to market. We contribute to the All-Party Parliamentary Group (APPG) on Photonics, and the recent report *Future Horizons for photonics research 2030 and beyond*, published by *Innovate UK*, the Photonics Knowledge Transfer Network (KTN) and the Photonics Leadership Group (PLG), featured the expert views of **Payne** and **Reed** together with 24 other UK photonics experts.

4.5 Wider contributions to and recognition by the research base

The following lists provide quantitative evidence of the Unit's wider contributions to and recognition by the research base, through journal and book editorships (Table 4.5); leadership of grant-awarding committees (Table 4.6) and membership of Research Council and similar national/international committees (Table 4.7); fellowships (Tables 4.8 and 4.9); prizes; and invited keynote lectures etc (Table 4.10).

Table 4.5 Journal editorships

Editorial Role Held	Number of staff	Additional commentary
1. Editor-in-Chief	12	Including managing editor, deputy editor-in-chief, founding editor and deputy editor roles
2. Editor	56	Including associate editor and assistant editor roles
3. Topic Editor	67	Including series editor, subject editor, guest editor and consulting editor roles
4. Other editorial board member	24	
Total	159	

Note: journals specify their editorial roles in different terminology, so the editorial roles in Table 4.5 have been grouped into categories (1-4) indicating levels of seniority.

Table 4.6: Leadership of grant-awarding committees

Academic	Research Council or Industry	Role held
Nelson	EPSRC UKRI RCUK RAEng	Member of Council 2014-2018 Member of Executive Committee 2018 Member of Executive Group 2014-2018, Chair 2015-2018 Research Fellowships Committee Chair 2018-
Powrie	RAEng Cross Academies (Academy of Medicine/British Academy/Royal Academy of Engineering/Royal Society)	Newton Fund Steering Committee Chair 2014-2016 Lloyds Register Foundation "Engineering X" Safer End of Engineered Life Programme Board Chair 2018- Frontiers Group Chair 2019-
Prodromakis	Lloyds Register Foundation.	Director of ICoN Programme
Spearing	Singapore National Research Foundation	Fellowship Evaluation Panel 2012- date

In addition to these high-level roles, Table 4.7 summarises shorter term membership of research council and similar grant committees in the UK, EU and overseas.

Table 4.7: Membership of Research Council and similar national/international committees

Location	Body	Instances	Additional commentary
UK	EPSRC	62	College member, Panel/committee chair/member
UK	Other Research Councils and charitable trusts	21	Including Royal Society, UKRI (FLF), BBSRC, NERC, ESRC, STFC, MRC, Innovate UK, Leverhulme, Diamond, Wellcome, Daphne Jackson Trust
EU	National councils, ESF	188	Including associated states
EU	Commission	28	Including H2020 and ERC fellowship panels
Overseas	National councils	71	Including for the US Army (2), American Association for the Advancement of Science (1), National Science Foundation China (3), the China Scholarship Committee; and FCT Portugal (5)

As well as grants, all of the Unit's Category A staff and many of our researchers regularly review papers submitted for publication in journals and academic conferences. We do not formally record this, but estimate we have contributed a total of at least 3,500 reviews over the assessment period.

Fellowships of prestigious professional and learned societies, current and awarded during the Ref period, are summarised in Table 4.8.

Table 4.8: Fellowships (by election) of major professional and learned societies

Fellows of professional & learned societies	Before REF period	During REF period
Fellow of the Royal Society (FRS)	Payne	Leighton, Richardson, Zheludev
Fellow of the Royal Academy of Engineering (FREng)	Elliott, Hanzo, Leighton, Keane, Langdon, Nelson, Payne, Powrie Richardson	Chen, Reed, White, Wood
Royal Academy of Medical Sciences		Leighton
Fellow of the Learned Society of Wales		Morgan
Foreign Member of US National Academy of Engineering		Zheludev
Fellow of the American Physical Society		Zheludev
Fellow of the Acoustical Society of America	Nelson	Elliott
EPSRC RISE Fellow		Payne

In addition, Unit staff hold 102 fellowships of other relevant professional and learned society institutions (Table 4.9):

Table 4.9: Fellowships of relevant professional and society institutions

Post-nominal letters	Name of Institute	Number of staff
FIET	Institution of Engineering and Technology	19
FIMECHE	Institution of Mechanical Engineers	9
FIOP	Institute of Physics	9
FHEA	Higher Education Academy	9
FOSA	Optical Society of America	7
FIOA	Institute of Acoustics	5
FIEEE	Institution of Electrical and Electronic Engineers	5
FICE	Institution of Civil Engineers	5
FRINA	Royal Institution of Naval Architects	4
FBCS	British Computer Society	3
FRAeS	Royal Aeronautical Society	3
FIEAust	Institution of Engineers Australia	2
SPIE	International Society of Optics and Photonics	2
FRSC	Royal Society of Chemistry	2
FIOM3	Institute of Materials, Minerals and Mining	2

Plus 1 fellow in each of: FRSS (Royal Statistical Society), FSEM (Society of Experimental Mechanics), FIMA (Institute of Mathematics and its Applications), FBPS (British Psychological Society), FCIBSE (Chartered Institute of Building Services Engineers), FIEH (Institute of Ergonomics and Human Factors), FISCM (International Society for Condition Monitoring), FGS (Geological Society), FRMS (Royal Mathematical Society), FICorr (Institute of Corrosion), FRGS (Royal Geographical Society), FPWI (Permanent Way Institution), FRMS (Royal Meteorological Society), FCIHT (Chartered Institution of Highways and Transportation), Foreign Fellow of the Indian National Science Academy (only 9 Foreign Fellows), Foreign Fellow of the Indian National Academy of Engineering.

Over 40 funded Research Fellowships have been awarded by research councils, learned societies and other bodies in the UK and EU as summarised in Table 4.10. In addition, **Hanzo, Morgan, Pierron, Reed** and **Richardson** have been supported by Royal Society Wolfson Merit Awards for at least part of the REF period.

Table 4.10: Research Fellowships awarded during the REF period

	Funder	Name of fellowship awardee
UK	EPSRC Early Career Researcher (ECR)	Mills, Peacock, Glynne-Jones
	EPSRC Innovation fellowship (ECR)	Yang, Thornton
	EPSRC Established	Smith, Pierron
	EPSRC Manufacturing	Saito (left 2020)
	Royal Society, URF (ECR)	Thomson, Wheeler, Thompson,
	Royal Society Industrial fellowship	Prodromakis
	RAEng fellowship (ECR)	Beresna, Jasion, Fokoua, Nedeljkovic, Dickinson, Paruchuri
	RAEng Industrial fellowship (ECR)	El-Hajjar, Heaven,
	RAEng Senior Research fellowship	Gawith, Slavik
	RAEng Chair in Emerging Technologies	Gourvenec, Prodromakis
	RAEng Research Chair	Zervas
	NERC Industrial Fellowship (ECR)	Nightingale
	Leverhulme (ECR)	Fletcher, Davis
	British Council Commonwealth Rutherford Fellowship	Reed
	FLF(ECR)	Vanderwel
EU	Marie Skłodowska-Curie (ECR)	Anderson, Lawson, Sun, Tzouvadaki, Lou
	ERC Starting grant (ECR)	Guasoni
	ERC Consolidator grant	Poletti, Roose
	ERC Advanced grant	Hanzo, Kazansky, Zheludev
	Total	41

High level prizes and awards: In 2017, the ORC was awarded a Queen's Anniversary Prize for Higher and Further Education. CBEs were awarded in 2018 to **Nelson**, for services to UK engineering and science, and Al-Hashimi (left 2020), for services to academia and industry.

Named awards, medals and prizes awarded to Unit staff include (in alphabetical order of awardee):

Institute of Acoustics Tyndall medal 2018 **Fazi**

Leverhulme Philip Trust prize 2014 **Ganapathasubramani**

RM Quigley Award (Canada) 2014 **Gourvenec**

Royal Institution of Naval Architects Ian Telfer Prize 2014 **Hudson**

IEEE Comsoc Education award 2018 **Hanzo**

EURASIP Papoulis award 2018 **Hanzo**

IEEE Radio Communications Committee award 2014 **Hanzo**

Piotr Laszczak-IET William James Prize 2015 **Jiang**

Rayleigh Medal of the Institute of Acoustics 2018 **Leighton**

Clifford Paterson Medal of the Royal Society 2018 **Leighton**

British Geotechnical Association Medal 2017 **LePen, Powrie, Zervos**

RAEng President's Special Award for Pandemic Service 2020 **Morgan**

IEEE/RSE Wolfson James Clerk Maxwell Award 2014 **Payne**

BJ Lazan award 2017 **Pierron**

SEM M.Hetenyi Award 2017 **Pierron**

Zeng Gui-Xi Prize (China) 2016 **Powrie**

RM Quigley Honourable Mention (Canada) 2017 **Powrie, Le Pen**

PWI Arthur Maber Award 2017 **Powrie, Le Pen, Thompson**

Rees Jeffreys Prize 2016 **Preston**

William W Millar Prize 2017 **Preston**

Individual Contributor PIC award 2019 **Reed**

IET Crompton Medal for Achievement in Energy 2014 **Reed**

Institution of Civil Engineers, Bill Curtin Medal 2016 **Richards**

Breaking the Optical Communications Barrier EU Horizon 2020 Prize 2016 **Richardson**

Institute of Ergonomics and Human Factors, President's Medal 2018 **Stanton**

Institute of Ergonomics and Human Factors, William Floyd Medal 2019 **Stanton**

Institute of Acoustics Rayleigh Medal 2018 **Thompson**

COSPAR Outstanding Paper Award 2016 **Walker**

Institution of Civil Engineers Telford Premium 2017 **White**

ASTM CA Hogentogler award 2017 **White**

RM Quigley Award (Canada) 2014 **White**

Tribology Trust Silver Medal 2018 **Wood**

RAEng ERA Foundation Award 2016 **Yang**

ICE Baker Medal 2017 **Zervos**

IoP Thomas Young Medal and Prize 2015 **Zheludev**

There were an additional 53 other (unnamed) prizes and awards, including "best young researcher" and "top 100 downloaded paper" from journals, conferences and societies.

Table 4.11 shows the number of plenary and keynote talks, and conference chairs in the UK, EU and overseas.

Table 4.11: Invited plenary/keynote lectures, conference chair and committee membership roles

Description	Number	Commentary
Plenary talks	157	Including plenary session chair; total for UK, EU, Overseas
Keynote talks	147	Including lecture series, named and medal lectures
Conference Chair and committee membership	337	

Unit staff hold **visiting academic positions** (adjunct, visiting, guest and honorary professor) at 3 universities in the UK, 9 in Europe and 50 elsewhere (of which 20 are in China, 6 in Japan, 4 in the USA and 6 in Singapore).

Co-operation and collaborative arrangements for PGR training: The Unit hosts or participates in a number of Centres for Doctoral Training (CDT), usually in collaboration with other disciplines and/or HEIs, as follows.

- EPSRC CDT in Next Generation Computational Modelling (**Horak, Kramer, Richardson**; 2014-2022) was established to train future leaders in computational modelling, to form the core of a community of computational modellers crossing disciplinary boundaries, transferring computational advances to relevant application fields.
- EPSRC CDT in Energy Storage and its Applications (**Cruden**; 2014-2022) is jointly run between Sheffield and Southampton. It opened in October 2014 and has recruited 53 PhD students.
- EPSRC CDT in Sustainable Infrastructure Systems, (**Powrie, Preston, Kemp**; 2014-2022), focusing on energy, water, and transport in the priority areas of national infrastructure systems, sustainable built environment and water. From 2019, new students have been recruited into a successor CDT in Sustainable Infrastructure and Cities as part of a UKCRIC initiative.
- EPSRC CDT in New and Sustainable Photovoltaics (**Boden**; 2014-2023), led by the University Liverpool with Southampton, Bath, Cambridge, Loughborough, Oxford and Sheffield.
- EPSRC CDT in Prosthetics and Orthotics (**Jiang**; 2019-2027), led by the University of Salford with Southampton, Imperial and Strathclyde.
- Awarded in 2019, the EPSRC CDT in Machine Intelligence for Nano-Electronic Devices and Systems (**Prodromakis, Norman**) will develop and nurture the next generation of technology pioneers who will have the skills, assets and network to innovate at the artificial intelligence/electronics interface to enable systems with beneficial human impact.
- EPSRC mobility DTP in Defence and Security (~£1.5M) (**Wood, Downes**; Awarded June 2020) is training grant aiming to reskill/upskill industrial staff and offer research projects across AI/drones/cybersecurity/autonomous systems etc to D&S industry such as DSTL, Thales, BAES, Boeing, Institute of Naval Medicine etc.