Institution: Cardiff University

Unit of Assessment 12: Engineering

1. Unit context and structure, research and impact strategy

1.1 Context and structure

The School of Engineering (ENGIN) is the largest School within Cardiff University's College of Physical Sciences and Engineering with a headcount of 115 academic, 213 research and professional service staff and 207 registered postgraduate-research students. We are a thriving, supportive and inclusive international centre of scholarly excellence and impact with deep-rooted industrial links, focusing on five interdisciplinary priority research areas (in alphabetical order): **Advanced Manufacturing, Civil Infrastructure, Compound Semiconductors and Applications, Engineering for Health** and **Sustainable Energy**. Our success since REF2014 is reflected in significant cross-disciplinary and collaborative expansion, new appointments and major investments in facilities and infrastructure.

During the REF assessment period, we **increased category-A staff numbers by 23%** (from 88.2 to 108.8 FTE), **ECR staff by 31%** (from 19 to 25 FTE) and **research staff by 22%** (from 76.9 to 94 FTE, see Section 2), and secured 639 research awards representing **£97M**, an increase of 102% compared to REF2014. **Research income**(REF4b) increased from £44M in the previous REF (£8M p/a) to £79.6M over the current period (£11.4M p/a), with over double the number of PhD completions (416 compared to 205). We have **published 2,132 peer-reviewed journal papers** and our eight impact case studies, aligned with our interdisciplinary priority research areas, reflect our international reach and extensive business collaborations. These were supported by a new dedicated **Business Interface** (Section 3.3), which further facilitated over 197 commercial research projects for business in the period (totalling £14.3M), as well as 116 service or consultancy projects (£1.1M) and 118 PhD projects with external partners.

1.1.1 School structure

The School is organised into three departments with associated Research Groups. This structure ensures that we maintain the strength and health of our disciplinary expertise, allowing researchers to collaborate in communities to develop and sustain disciplinary knowledge. For efficiency and reliable service provision, administrative and technical facilities are shared (Section 3).

Architectural, Civil and Environmental Engineering (ACE, led by *Cleall*) - 24.2 FTE with five research groups: Applied and Computational Mechanics (ACM), the BRE Trust for Sustainable Engineering, Materials for Life (M4L), with the Geoenvironmental Research Centre (GRC) and the Hydro-Environmental Research Centre (HRC).

Electrical and Electronic Engineering (EEE, led by *Lees*) - 34 FTE with four research groups: Magnetics and Materials (M&M), the Centre for High Frequency Engineering (CHFE), the Centre for Integrated Renewable Energy Generation and Supply (CIREGS) and the Advanced High Voltage Engineering Research Centre (AHIVE).

Mechanical and Medical Engineering (MMM, led by *Pullin*) - 39.2 FTE with three research groups: High Value Manufacturing (HVM), Tribology and Performance of Machines, Structures and Materials (TPMSM) and the Centre for Research into Energy, Waste and the Environment (CREWE), with Medical Engineering (MED) spanning both EEE and MMM departments.

1.1.2 Priority areas

Since REF2014, **five interdisciplinary priority research areas** were developed, allowing us to better target investment and provide an environment where wide-ranging expertise is brought together to tackle important interdisciplinary research challenges. This is supported by considerable investment in major infrastructure (Section 3) and a focus on developing a new generation of research leaders (Section 2). Our focus on priority areas reflects our commitment to ensuring an inclusive, open and collaborative environment that promotes internal and external interdisciplinarity. This was highly successful; for example, we collaborated with 19 out of 24 Cardiff University Schools during the REF period.

Advanced Manufacturing (31.45 FTE) Research leaders: *Clarke, Featherston, Holford, Liu, Pullin* and *Setchi*. With 20 PDRAs and 66 PhD students on the census date (119 graduated over the REF period), this priority area achieved 908 publications, including 602 journal papers and 136 grants (£15.1M) during the REF period. **Highlights:** the formation of the Centre for Artificial Intelligence, Robotics and Human-Machine Systems (IROHMS), a £4.6M project led by ENGIN (*Setchi*), involving the Schools of Computer Science (*Allen*) and Psychology (*Jones*), advancing how humans and robots collaborate to accelerate digital manufacturing. £1.8M was invested into the Autonomous Systems and Robotics, Human-Robot Interaction, the Renishaw Digital Manufacturing and Metal Additive Manufacturing Laboratories with 274m^2 experimental space, which enabled advanced tribology solutions for frigates, helicopters and aeroplanes (impact case study - *Evans H.P.).*

Civil Infrastructure (19.1 FTE) Research leaders: *Cleall, Jefferson, Pan, Sapsford* and *Thomas*. With 16 PDRAs and 25 PhD students (67 graduated), this priority area achieved 392 publications, including 307 journal papers and 96 grants (£15.2M) over the REF period. **Highlights:** the M4L research group leading the £4.8M EPSRC Resilient Materials for Life (RM4L) programme grant with Bath, Cambridge and Bradford Universities, pioneering self-diagnosing and self-healing concrete (*Jefferson*). With £400,000 investment into the concrete, light-structures, building and infrastructure information modelling and hydraulics laboratories and 1,800m^2 of experimental space, the area supports two Centres for Doctoral Training (CDTs), the EPSRC Water Informatics Science and Engineering (WISE) and NERC GW4 FRESH, resulting in three impact case studies (*Jefferson, Ahmadian, Rezgui*).

Compound Semiconductors and Applications (12.08 FTE) Research leaders: *Bennett, Elgaid, Lees, Quaglia, Tasker* and *Wallis*. With nine PDRAs and 11 PhD students (32 graduated), the area achieved 249 publications, including 129 journal papers and 60 grants (£21.2M) over the REF period. **Highlights:** a partnership with Cardiff School of Physics and Astronomy in the £10M EPSRC Future Compound Semiconductor Manufacturing Hub (*Tasker, Elgaid*) and a £4M EPSRC Programme Grant on Integrating Gallium Nitride (GaN)-on-Diamond Microwave electronics (*Tasker*), the £5.2M GaNforCS project (ERDF, *Lees*) and the £77M University investment in the Institute for Compound Semiconductors (ICS, ENGIN and School of Physics), part of the £131M Translational Research Hub (TRH) on the University's new £300M Innovation Campus development. This priority area partners the £6.5M EPSRC Compound Semiconductor Manufacturing CDT (with Cardiff Physics, Manchester, Sheffield, UCL) with £3.2M in contributions from 23 industrial partners including Airbus, Hitachi, IQE, and Huawei.

Engineering for Health (13.6 FTE) Research leaders: *Barrow, Evans S., Holt, Porch* and *Spezi*. With 11 PDRAs and 27 PhD students (56 graduated), the area generated 428 publications, including 308 journal papers and 118 grants (£11.4M) over the REF period. **Highlights:** the £5M Musculoskeletal and Biomechanics Research Facility (MSKBRF) and £1.2M EPSRC Osteoarthritis Technology NetworkPlus (OATech+) (*Holt*), with an associated 600m^2 state-of-the-art research space (Section 1.4), and an ongoing collaboration between Velindre NHS Trust and the Cancer Imaging and the Data Analytics team (CIDA, *Spezi*) leading to the PET-based Adaptive Radiotherapy Clinical Trial (PEARL)with Swansea, Bristol, and Guy's and St Thomas NHS Trusts, and evaluation agreements with MIM Software (Cleveland, Ohio) and Varian Medical Systems (Palo-Alto, California), as well as collaborations with Intel-UK on AI for image segmentation.

Sustainable Energy (33.65 FTE) Research leaders: *Bowen, Cipcigan, Haddad, Jenkins, Liang, Rezgui, Thomas, and Wu J*. With 40 PDRAs and 78 PhD students (142 graduated), the area generated 1,254 publications over the REF period, including 786 journal papers and 229 grants (£34.2M). **Highlights:** the £24M FLEXIS programme on flexible energy, a collaboration led by ACE (*Thomas*), EEE (*Jenkins, Haddad*) and MMM (*Bowen*), involving six Cardiff University Schools. This project includes a large-scale demonstration area in Port Talbot to support prototype systems-scale experimentation and deployment of resilient, affordable and secure energy. Complementary to this are the £18M UK Energy Research Centre (UKERC-4) and £5.3M Supergen Energy Network Hub projects, co-led by (*Wu J.*), with the £1M EPSRC Network+ Decarbonising Transport Through Electrification (DTE, *Cipcigan*) project. £7M was invested into the High Voltage and Lightning Laboratories with 280m^2 of experimental space, £500k into the 1,300m^2 Gas Turbine Research Centre (GTRC) test facility and a further £500k into Power

Electronics Laboratories. The priority area is a partner in the EPSRC CDT for Resilient Decarbonised Fuel Energy Systems and delivered four impact case studies (*Bowen, Crayford, Haddad, Ugalde-Loo)*.

1.2 Research and impact strategy

Our strategy is steered, approved and implemented by School Board, chaired by Head of School (HoS, *Wu J.*), in consultation with the Research Committee, chaired by Director of Research (S*etchi*), attended by the Director of PGR Studies (DPGR, *Grosvenor*), Heads of Department (HoD) and Research Group Leaders. Working closely with staff, the Research Committee supports and promotes best practice for a vibrant research environment. We developed our own online research grant pipeline support tool, managed by the Research Office and overseen by the Research Committee, allowing us to nurture long-term bid development and provide support for feasibility studies, peer review and analysis of application outcomes.

Since REF2014, our strategy focussed on key objectives to further support our capabilities.

i) **Strengthen our academic base.** By recruiting both outstanding established and early-career researchers, we have improved our long-term sustainability. Since REF2014, we recruited 142 researchers and 39 academic staff across all our departments, with notable appointments including *Elgaid, Bennett* and *Wallis* to the Compound Semiconductors and Applications priority area; *Ji* from Dyson and *Hernandez Vega* from Apple into full lectureship positions supporting robotics and Advanced Manufacturing; as well as *Quaglia* and *Morini* from MSCA Fellowships into full lectureship positions that support high-frequency electronics and solid mechanics.

ii) **Expand and improve our postgraduate research student provision.** We added two new CDTs in Compound Semiconductor Manufacturing (ENGIN and School of Physics) and Resilient Decarbonised Fuel Energy Systems (led by Nottingham in collaboration with Sheffield). These complement the existing WISE CDT run in collaboration with Exeter, Bath and Bristol. We lead the Cardiff Sustainable Transport Doctoral Training hub (*Cipcigan, Featherston*) supported by EPSRC Doctoral Training Partnership (DTP), and a new Marie Skłodowska-Curie Actions (MSCA) Initial Training Network (ITN) on Innovative Tools for Offshore Wind and DC Grids (INNODC) (*Liang*) and participate in a further three ITNs (Section 4.1).

iii) **Collaborate with the best researchers globally.** We have enhanced and developed our global links, including 54 projects (£10M) funded from European funding schemes (Horizon2020, MSCA, Research Fund for Coal and Steel) and more than 40 collaborative projects with international partners through funders, including the EPSRC/Natural Science Foundation of China, EPSRC/Fonds National de la Recherche Luxembourg, RAEng, British Council, Newton Fund and the GCRF. We have built relationships with international industry partners; for example, securing over £1.4M from China Communications Construction Company to support building information modelling research and application.

iv) **Establish influence through internationally leading research roles** (see Section 4)**.** Staff expertise is widely recognised through policy advice to UK/EU governments, with examples including British Standard Institution committees (BSI) PEL37/1, PEL37/2, PEL42, and GEL81 International Standard Committees of International Electrotechnical Commission (*Haddad*); National Flood Resilience Science Advisory Group to UK Government, Hinkley Point C Stakeholder Reference Group to Welsh Government (*Falconer*); Russell Group Post-18 review advisory group; Welsh Government Women in STEM Industry Sub-Committee, Non-Executive Director UKRI STFC Council, including membership of the Finance and Governance Committee and STFC/Innovate UK Joint Forum (*Holford*).

v) **Strengthen collaboration with industry and invest strategically in our research and innovation infrastructure** (see Section 3). Facilitated by our new business interface, we strengthened business collaborations with commercial research awards totalling £14.3M. Strategic collaborations and major investments have accelerated our research; for example, through close working with Compound Semiconductor Cluster partners (IQE, SPTS Technologies, Newport Wafer Fab and the CSA Catapult), with the new £131M TRH, placing

semiconductor electronics research at the centre of Cardiff's new £300M Innovation Campus. Similarly, £3M investment by National Grid and Airbus enabled innovative research into damage to carbon composite panels during lightning strikes.

Our strategy is further guided and co-developed by our **Industrial Advisory Board** (IAB), with over 40 members from Airbus, National Instruments, and GE; Welsh Government; UK Government; and other research user organisations such as Natural Resources Wales. The Board's industrial chair (*Rolley*) holds formal quarterly meetings, with sub-groups tasked with advising on topics aligned with our research priorities, including, for example, future energy systems and low carbon manufacturing for the net-zero agenda, and applications of compound semiconductors. Public engagement has remained an important aspect of our strategy, with a dedicated public engagement officer supporting funding applications, training, and engagement with wider audiences reaching approximately 8,000 people annually (see Section 4.3 for examples).

Over **the next five years**, we will:

- Continue to **build depth, capacity and critical mass in our five interdisciplinary priority areas** enabling large-scale collaborative projects that deliver a wide range of impact. For example, we will make investments to support major compound semiconductor projects, forging deeper collaboration with the School of Physics and partners clustered around the CSA Catapult (IQE, Newport Wafer Fab, SPTS Technologies and Microchip). We will shape the research agenda in Sustainable Energy in collaboration with industrial, policy and academic partners (e.g. National Grid plc, Wales and West Utilities, Welsh Government, and the GW4 Alliance) building a solid intellectual foundation for growth and new landmark projects, particularly concerning future energy infrastructure and the circular economy for Net Zero.
- **Prioritise our Equality, Diversity and Inclusion strategy (Section 2), which is central to supporting untapped potential and removing barriers to success** for existing staff and staff recruitment. Our priority areas and cross-cutting themes (CCTs) will support our ECRs and other staff in undertaking further interdisciplinary and challenge-based research, helping their transition to future research leaders. This will be supported through mentoring, encouraging ambitious career goals and leadership opportunities, coupled with the University's wider comprehensive support for career development (Section 2; also REF5a).
- Continue to **attract the highest quality staff and research students into our priority areas**, with strategic recruitment targeting complementary expertise to support major challenges; for example, The Circular Economy and Net Zero, as well as enhancement to support discipline strengthening; for example, in Compound Semiconductor and Civil Infrastructure priority areas. New staff will receive mentorship, training and support aligned to future research leadership, in close collaboration with our industrial and international partners. Exploiting our three existing CDTs and internal investment, we will increase numbers of high-quality research students by aligning our future CDT proposals with our five interdisciplinary priority areas.
- Target **strategic collaborations with industry** to develop and exploit innovation in our priority areas, with compound semiconductor electronics, energy, transportation, AI and robotics as our initial focus. We will further enrich these collaborations by hosting additional senior visiting academics and industrialists to reaffirm our innovation-led culture.
- Through the GW4 Alliance (REF5a), we will **seek complementary expertise to develop research communities and flagship centres with cutting-edge equipment and facilities**. This approach will reflect successes initiated at Cardiff University, such as GW4 Centre of Excellence in the Built Environment (*Rezgui*), Composites for Enhanced Lightning Performance (*Haddad*), Unlocking the Science for an Autonomous Structural Health Monitoring System (Featherston) and AVaRICE-Algal Valorisation and Remediation of Metal Ion Contaminated Effluents (*Sapsford*).
- Building upon successes, we will **significantly extend and deepen our interdisciplinary and interinstitutional collaborations** to address Net Zero challenges and industrial strengths in Wales and the UK. This will build on our strategic collaborations with the South Wales Industrial Cluster, the Compound Semiconductor Cluster, the Welsh Government Smart Living Initiative

and the GW4 Alliance. We will target the UKRI Strength in Places Fund and the Levelling Up agenda of the UK Government. We will further catalyse significant research and development within Wales and contribute to its green recovery and clean growth agendas, maximising the quality, impact and societal benefits of our research.

1.3 Research impact

We are committed to maximising the impact of our research by working to solve industry-identified challenges (Section 3), using impact acceleration, Knowledge Transfer Partnerships (KTPs) and support for staff to achieve impact. We ensure our research activities align with the most pressing global challenges and societal needs, reflected by our interdisciplinary priority areas, staff interests and capabilities (Section 1.1.2). Impact is embedded within our culture, supported by our personal development review and training processes (Section 2). Impact is supported by the Business Interface team, who promote technology transfer through regular drop-in sessions and attendance at research group, departmental and other meetings. We support and enhance impact in each of our priority areas, including the exploitation of data and AI for advanced manufacturing, advanced modelling capabilities and materials for civil infrastructure, exploitation of compound semiconductor technologies, devices to support and promote health, and developments for clean and resilient integrated energy systems.

To achieve this, we value the following mechanisms:

Partnerships and collaborations. Highlights in the REF period include the Compound Semiconductor Cluster, a major industry-led initiative based in South Wales attracting over £600M investment, with £76.5M attributable to ENGIN in the form of infrastructure, equipment and grants (*Tasker, Elgaid, Wallis, Bennett* and *Lees*), with collaborations enabling the formation of the new Compound Semiconductor Manufacturing CDT. Further examples include Magnetic Materials and Applications (MAGMA), a European Regional Development Fund (ERDF) supported collaboration between Cardiff University and Tata Steel (£2.1M, *Evans S., Anderson*) delivering technology change in manufacturing of magnetic materials, National Grid supporting AHIVE investing over £2M to extend experimental capabilities (impact case study - *Haddad*) and Atkins Global supporting BRE's work into urban sustainability (impact case study - *Rezgui*).

The majority of our **impact case studies** arose from collaborative research projects: a waste energy recovery strategy for Tata Steel in Port Talbot, saving over £44M energy costs (*Bowen);* best practice for measuring aircraft engine particulates, adopted by the UN as a global standard and saving Rolls-Royce over £15M (£5M p/a ongoing, *Crayford*); algorithms underpinning LUSAS concrete modelling software, used across the world in construction (*Jefferson*); energy optimisation methods for buildings deployed internationally by Schneider Electric (Rezgui); influence of National Grid policy and saving Tata Steel over £5M (*Haddad*); tribology used in the design of propulsion of new frigates and aircraft bearings with DBS, Rolls-Royce and SKF (*Evans H.P.*); Europe's first MVdc connection (ANGLE-DC) between Anglesey and Bangor, saving SP Energy Networks over £10M (*Ugalde-Loo*).

Industry research funding and consultancy. We secured joint research projects with industry, attracting over £14M in direct industrial funding from major UK and international businesses (including Airbus, Huawei, National Grid, Renishaw and Rolls Royce), regional employers or SMEs. We have attracted £2.4M funding from InnovateUK, including 11 KTPs with businesses to exchange knowledge, drive innovation and develop graduate employees. Many of our industrial links generated ongoing collaborations and multiple impacts; for example, during the current REF period, two KTPs were secured with SRS Works developing a new photo-voltaic invertor, leading to an academic staff appointment (*Wang*) and extending a city-wide district cooling scheme, whilst a third involved the design, manufacture and test of a domestic thermal battery.

We have a strong portfolio of service and consultancy projects with 124 awards over the REF period (£1.1M), utilising our staff expertise and facilities to support commercial or regulatory activity, including Buru Happold, Haydale, MBDA, Costain, Mouchel, Oxford Instruments, SAS International, SEG Automotive, Semtech, Sony, Tesla and TWI. Through our collaboration with the NHS Cedar Healthcare Technology Centre, we support research and evaluation of e-medical devices and diagnostics.

Industrial-funded studentships. Industry funding supported 118 studentships over the REF period, including 43 part-funded from EPSRC sources: Industrial CASE, CASE conversion, NPIF, and DTP. Key partners include Airbus, Ampleon, Alstom, Arup, Aston Martin, BRE, Charles Owen, Costain, Ferrovial, Infineon, Mercedes-AMG Petronas F1 Team, Merck Group, National Grid, Renishaw, Rolls Royce, RWE Energy, SKF, Tata Steel and Toshiba.

Policy advice and international standards. Reflecting our expertise, Unit staff provided extensive consultation to policy makers and government over the REF period; for example, with UK Government, we advised the BEIS Panel on Electricity Market Reform (*Jenkins*) and the National Flood Resilience Science Advisory Group (*Falconer*). In the built environment, we advised the BRE (Building Research Establishment) UK digitalisation agenda, through a BRE funded Chair (*Rezgui*), leading to the BIM and Digital Built Britain initiatives. For Welsh Government, we advised the TechValleys Strategy Group (*Setchi*), the 5G Expert Group (*Tasker*), and the Flood and Coastal Erosion Committee (*Wilson*), with further examples provided in Section 4.5.

Public engagement and outreach. We engaged with over 43,000 people over the REF period through festivals, workshops and other activities. A dedicated member of support staff facilitates STEM and public engagement, supplemented with training from specialist organisations such as Science Made Simple. We prioritise working with under-represented groups and their influencers; for example, since 2017, our annual open-to-all Museum After Dark event attracts parents with primary age children from diverse backgrounds. In 2019, over 1,000 people attended the event, supported by Kirsty Williams MS, the Welsh Government Minister for Education. Through our RAEng Ingenious grant, we work with the Go Girl Academy to embed gender inclusive practice into our training for outreach volunteers and with Girlguiding to develop a new badge in electromagnetism. We co-lead the STEMlive event, an immersive STEM experience for secondary pupils, solving engineering challenges related to living on Mars.

Working with over 40 partners through public engagement activities, we have built relationships and raised our profile with industry, the public and third sector. Celebrating the breadth of STEM in Wales, we partnered with Amgueddfa Cymru National Museum Wales, First Campus, Techniquest, See-Science, Cardiff Science Festival, Rudry Festival, the Worshipful Company of Wales and Central South Consortium. We contributed to Cardiff Council's 'Cardiff Commitment', linking local schools and industry, stimulating early years awareness of engineering. In the UK context, we partnered the Smallpeice Trust, the IMechE, the IOP, the IET, the Royal Society of Chemistry, and the ICE to deliver engineering events and activities targeting young people and their families.

1.4 Interdisciplinary research

Promoting interdisciplinary research was a core objective in this REF period, aligned to the introduction of priority areas (Section 1.1.2), with ENGIN academics co-authoring research outputs with 19 of the University's 24 Schools and 25% of outputs in our submission categorised as interdisciplinary.

Our researchers are fully benefiting from key interdisciplinary entities on the University's £300M Innovation Campus (REF5a), including the Cardiff University Brain Research and Imaging Centre (CUBRIC; *Holt, Whatling, Gallichan* and *Evans S.*), a £44M investment with four MRI scanners (MEG, EEG and TMS) providing state of the art imaging and other facilities with some of the very best equipment in Europe, and supporting cross-disciplinary collaborations in a wide range of subjects, including radiation oncology (Velindre Cancer Centre, *Spezi*), medical image analysis and big data.

Our longstanding involvement with the Cardiff Institute for Tissue Engineering and Repair led to the establishment of the £2M Biomechanics and Bioengineering Centre (ARUK, now Versus Arthritis), a collaboration with Cardiff Schools of Biosciences, Healthcare Sciences, Medicine, Dentistry and Pharmacy, which delivered over £25M research funding and >300 journal papers. The Musculoskeletal and Biomechanics Research Facility (MSKBRF, £5M) established in 2015, led by *Holt*, is an interdisciplinary research facility providing state-of-the-art motion capture, biplanar video fluoroscopy and other capabilities and supports an NHS clinical service. The MSKBRF leads the multidisciplinary OATech+ (£1.2M, EPSRC, *Holt*). Our partnership with the

CEDAR NHS-Academic evaluation centre continues to support the NICE Medical Technologies Evaluation Programme (*Evans S.*, £1.1M).

We lead IROHMS (£4.6M, ERDF, *Setchi*) targeting emerging interdisciplinary opportunities at the intersection of AI, robotics and human-machine systems, involving the Schools of Computer Science and Psychology, and with strong industrial support from 60 partners, including Airbus, Aston Martin, and Dyson, the Centre generated £4.6M research funding. We also lead MAGMA (£2.1M, ERDF, *Evans S., Anderson*) with the Schools of Physics and Chemistry, building capacity in magnetic materials research, developing and testing materials for motors and other electrical machines critical in the development of electric vehicles. We are partners in ASTUTE 2020 (£8.9M, ERDF, *Setchi*) supporting manufacturing companies across Wales, collaborating with Cardiff Business School and the School of Medicine.

We lead the Cardiff Materials Research Network (CMRN, *Evans S.*), involving over 180 academic staff from 22 of 24 Cardiff Schools. The Network secured >£1.5m in new research funding during its first 18 months. The Cardiff Transport Futures Research Network (*Cipcigan*) developed successful new cross-disciplinary research perspectives, bringing together 60 academics across six Schools and all three Colleges to examine the nature and impacts of new and emerging transport technologies. These include electric vehicles, autonomous vehicles, mobility as a service, all underpinning our EPSRC DTE Network+ award (£1M) as well as the establishment of a Cardiff University Interdisciplinary Doctoral Training Hub in Sustainable Transport (EPSRC-DTP).

We co-lead the Energy Systems Research Institute (*Bowen, Jenkins, Wu, Haddad, Rezgui, O'Doherty*), tackling the global challenges of how we continue to generate, distribute and utilise energy through an interdisciplinary systems-based research culture. This encompasses physical and social sciences, drawing on research excellence from ten Schools across the University. We play a significant leadership role in other University Research Institutes (REF5a), including the Water Research Institute (*Rezgui, Sapsford, Bray*), addressing the grand challenge of sustainable water management for people and ecosystems in a changing world; Data Innovation Research Institute (*Setchi, Beach, Liu, Holt*), which conducts fundamental research in managing, analysing and interpreting massive volumes of textual and numerical information and the Sustainable Places Research Institute (*Rezgui*) which studies the complex interrelations between, ecology, society and economy, looking at how cities and regions can develop sustainable spatial strategies.

1.5 Research ethics, integrity and open research

Cardiff University is a signatory of the **San Francisco Declaration on Research Assessment** (DORA) and we are committed to the fair assessment of research based on its intrinsic value when considering applications for employment, promotion and internal funding. We are fully committed to responsible research, aligned to the University's commitment to research integrity (REF5a). For research involving human participation, we comply with all University research ethics procedures; our Research Ethics Committee Chair (*Spezi*) is responsible for assessing and managing research ethics applications, overseen by the Cardiff University Open Research Integrity and Ethics Committee. Projects adhere to the University's Human Tissue Act, with such activities overseen by a Human Tissue Officer (*Spezi*) who works closely with University teams to ensure compliance.

In line with University policy, mandatory online Research Integrity Training ensures all research staff and students understand and discharge their responsibilities. We are committed to an **open research environment** that promotes access to scientific knowledge free of charge to all. Our Open Access Co-ordinator (OAC, *Whyte*) manages compliance, produces guidance, oversees training and reports to the Research Committee. The OAC ensures that post-print files and bibliographic details for publications are available in Cardiff's digital publications repository in accordance with Institutional and funder requirements (3,184 outputs in the period).

We require and assist all staff and PGR students to register with ORCID. We fully support the 2016 Concordat on Open Data; all projects have a data management plan with research data made openly available and reproducible (subject to relevant regulatory considerations) via our University research portal (uniquely identifiable via DOI), funder, project or subject/generic repositories (e.g. British Geological Society, Zenodo).

2. People

2.1 Staffing strategy

We focus on recruiting, developing and retaining outstanding research staff in priority and emerging research areas, whilst providing a supportive and inclusive research environment that promotes excellence. Our staffing strategy extends to all and is based on trust and integrity, allowing staff to thrive whilst prioritising their health and wellbeing.

Figure 1 - Key elements of our Staffing Strategy

Our approach, outlined in Figure 1, is guided by three key values:

- **Equality, diversity & inclusion (EDI)** - enabling an open, inclusive and collaborative research environment, recruiting students and staff from underrepresented groups and ensuring we are inclusive in developing, applying and embedding our research and impact strategies.
- Developing **connected communities** to support our priority research areas, enabling and supporting interdisciplinary research, building networks across ENGIN, the University and beyond.
- Promoting a **vibrant culture** through our staff, enhancing creativity in our research and teaching and engendering a sense of belonging where all staff feel involved and valued.

These values are supported and guided by the **Concordat to Support the Career Development of Researchers** (REF5a) which underpins all our staffing and development activities, together with a **commitment to ensure the wellbeing of research staff and students**.

2.2 Staff and ECR recruitment

In line with our research strategy, we focussed on **strategic recruitment to strengthen and increase capacity within our five priority areas** (Section 1.1.2) as well as to improve the

diversity of our staff. Since REF2014, we appointed 41 new academic staff members, including 36 lecturers (19 ECRs), two readers and three professors.

	2014	2021	% increase
REF eligible staff	88.2 FTE (count 91)	108.76 FTE (count 116)	23
ECR	19 FTE (count 19)	25 FTE (count 24)	31
Research Staff	76.9 FTE (count 81)	94 FTE (count 96)	22

ECR recruitment and development is central to our strategy. For example, in our Advanced Manufacturing priority area, we recruited *Xie* in fluid mechanics, who co-leads the Multiphysics and Mechanics CCT; *Ji* in robotics, who co-leads the AI and Robotics CCT and *Petri* for smart engineering infrastructures. To strengthen our Sustainable Energy priority area, we recruited *Ming* to lead on power electronics, through a Smart Grids Fellowship and a five-year secondment to the CSA Catapult, and *Li*, leading on energy materials, through a Sêr Cymru II Research Fellowship. To strengthen our other priority areas, we recruited *Morini* into Civil Infrastructure to lead on solid mechanics, through a Marie Curie COFUND Fellowship, *Slocombe* and *Quaglia* (MSCA Fellow, now lecturer) into Compound Semiconductor and Applications, and *Gallichan* (CUBRIC) into Engineering for Health.

We recruited **specialised senior staff to underpin core capabilities and provide research leadership**, for example, *Elgaid* from Glasgow with expertise in GaN technology for high frequency devices; *Wallis* from Cambridge with expertise in epitaxial growth; and *Bennett*, a photonics expert from Toshiba, are strategic recruitments into the Compound Semiconductor and Applications priority area. *Gei,* with expertise in applied computational mechanics, was recruited to strengthen the Civil Infrastructure priority area.

We actively recruit staff from under-represented groups and diverse backgrounds with BAME staff, increasing from 16% (2013/14) to 30% (2018/19). A proactive approach to encourage staff to update personal details led to a positive trend in disclosure of ethnicity details (70% in 2013/14 to 90% in 2018/19)[1].

Senior promotions include *Holford* to Deputy Vice-Chancellor (2017), *Evans S.* to Head of School (2015), *Benedikt* to Deputy Director for International (2016) and *Cleall*, *Pullin* and *Wu J.* to Heads of ACE, MMM, EEE Departments (2018) respectively.

2.3 Staff development and ECR support

Our **staff development strategy supports all staff, regardless of grade or career pathway**, with all staff assigned a mentor to support the transition to a new workplace and new starters receiving the 'Your first 90 days' pack providing key information and advice in building confidence and research networks. All new starters are supported to participate in their research groups, and the seven challenge-driven and cross-disciplinary research **CCTs**. These themes are typically led by ECRs and **facilitate the ability of junior researchers to cross disciplines and collaborate in new networks** (AI and Robotics, Future Materials, Healthy Living, Multiphysics Mechanics, Nanoengineering, Sustainable Transport and Urban Intelligence).

All staff benefit from an annual personal development review (PDR), with a 100% completion rate since REF2014. This review identifies future goals, potential research impact, promotion and training and development needs. Working through line managers, we identify help where needed with bespoke support plans that include workload review or periods of study leave. Over the last three years, we provided external coaching on four occasions; two to support career development and two to support those identified with a disability to help them develop career strategies. During the REF period, we implemented mechanisms and commitments to **support all staff** including:

- A robust and objective procedure for agreeing reasonable adjustments to workload, with discussions led by line managers with the Head of Teaching (HoT) for teaching-related duties,

[1] Copyright Higher Education Statistics Agency Limited 2020. HESA cannot accept responsibility for any inferences or conclusions derived by third parties from its data.

the Head of Department (HoD) for any departmental duties and the Head of School (HoS) for School-wide duties. Academic staff on Teaching and Research contracts are allocated 400 hours dedicated research time in the workload model (or pro rata for part-time staff).

- Encouraging, promoting and providing the infrastructure to enable flexible working arrangements, such as supply of appropriate IT and accommodating staff preference for teaching times.
- Providing support for staff and research students with caring responsibilities; for example, we provide a room with specialised storage facilities for breastfeeding mothers returning to work. We were early adopters of the Returners Support Scheme (REF5a, section 3.2.2), providing adjustments to workloads for staff returning from long-term absence, parental leave and those managing long-term illness.
- Supporting the University Dignity at Work and Study Policy, where we recruited five new Dignity at Work contacts and publicised them widely across ENGIN (Section 2.5). We also implemented review procedures to ensure that research funding applications embed EDI within their management and monitoring plans.
- A protected annual budget of £25k for external courses for staff to address their current and future training needs, identified through probation, the PDR process and discussions with line managers.
- Mandatory line manager training covering recruitment and contract management, managing and supporting staff and promoting wellbeing, developed in response to staff survey feedback.
- Supporting development of effective collaborations; for example, encouraging staff to secure complementary positions overseas; *Lin*, Tsinghua University; *Bordas*, University of Luxembourg; *De Angelis*, University of Bologna; *Kerfriden*, Paris Mines and *Gei*, University of Trieste.

2.3.1 Supporting Early Career Researchers

Supporting and developing ECRs is central to our research and impact strategy, allowing us to build depth and capacity in our five interdisciplinary priority areas and enabling large-scale collaborative projects that will deliver a wide range of impact.

During the REF period, we supported fellowship applications in strategically relevant priority areas as a way of both attracting future research leaders and supporting their transition to permanent academic and leadership posts. Since REF2014, we are delighted to have secured 24 ECR fellowships as a result of our focus, a significant increase on REF2014 (two ECR fellowships) and clearly evidencing depth and quality of our future research leadership. These include EPSRC Fellows (*Kim, Bennett, Qadrdan*), EU-MSCA Fellows (*Simonovic, Theodoridou, Cernescu, Follett, Moreno Rubio, Quaglia, Mu*), Sêr Cymru-National Research Network Fellows (*Choi, Williams, Li Z., Claus*) Sêr Cymru Industrial Fellows (*Kundu, Steer, Hirshy*), MSCA COFUND (*Morini, Perepelkin, Noorikalkhoran, L*i), and Royal Academy of Engineering (RAEng) Fellows (*Zabek, Follett*, *Kundu*). Many staff defined as ECRs at the beginning of the REF period now lead substantial projects within our priority research areas. In Sustainable Energy, *Anderson* leads MAGMA (£2.1M, ERDF); *Sapsford* heads In-Situ Recovery of Resources from Waste Repositories (INSPIRE, £722k, NERC,); and *Valera Medina* leads Storage of Ammonia for Energy (£1.5M, EPSRC). For Compound Semiconductors and Applications, *Lees* leads GaNforCS (£5.2M, ERDF) and in Advanced Manufacturing, *Pullin* secured three KTPs (£1M, InnovateUK).

We develop future research leaders through various mechanisms, such as mentoring and encouragement to play leading roles in committees, as well as leadership of CCTs. For example, *Garcia Rocha* co-led the Future Materials CCT and was a member of the CMRN Steering Group is now a Ramón y Cajal Senior Research Fellow at Instituto Nacional del Carbón, Spain (2020).

Two ECR networks support our staff; one at College level to enhance collaboration, and another at School level organised and managed by the Research Staff Coordinator (*Albano*). These provide support, for example, in preparing new investigator awards. Seedcorn funding (£10kp/a) is ringfenced and allocated competitively, and was used to support various activities, including preparing a first grant proposal by *Xie* on a feasibility study investigating turbulence in hydraulic

jumps over rough riverbeds; for *Petri*, proof of concept research on an edge-cloud environment for smart buildings; and for cohort activities such as carbon literacy training.

The University's Commercial Development Team (REF5a, Section 4.4) provides bespoke support to staff, including ECRs, through one-to-one training and drop-in sessions. ECRs are encouraged to lead on EPSRC Impact Acceleration Account (IAA) proposals, and five of the ten ENGIN ECRs that led proposals in 2019/20 successfully secured funding.

We recognise that post-doctoral researchers and ECRs need opportunity, encouragement, support and development at the start of their academic careers. During probation, ECRs undertake Academic Practice training supported by a dedicated mentor leading to Fellowship of the HEA. Since its inception in 2015, 14 staff completed Academic Practice, of which eight are now Fellows, and six are working towards this goal. In 2019, we introduced the Trevithick Rising Stars pilot scheme within the EEE department, providing an opportunity for PDRs and ECRs to work closely with a senior colleague to experience teaching in a positive and managed way, gaining key pedagogical perspective and developing skills through teaching and producing modular content. This is now being extended across ENGIN. We encourage and support all ECRs to participate in University development schemes (REF5a), including The Cardiff Academic, The Cardiff Researcher and Cardiff Futures. 11 staff have benefited over the REF period, including *Wu J.* (HoS), *Slocombe* (HoT-EEE) and *Marsh* (HoT-MMM). Beyond the University, other programmes include the GW4 Crucible promoting interdisciplinary research approaches (*Choi, Barba, Xie*), GW4 Mock-Panel Training (*Garcia Rocha*) and Welsh Crucible (*Ayre, Eaton, Liang, Pearson, Theobald* and *Williams*).

2.3.2 Dedicated research leave programmes

In addition to the University's Research Leave Fellowship Scheme (REF5a, Section 2.1.5), we run biannual research leave calls open to all academic staff. Since 2015, 15 academic staff (33% female) were supported to deliver new research opportunities, including *Setchi* (2017-18) who secured a £4.6M ERDF award to establish IROHMS, conducting research in additive manufacturing with Airbus, Sandvik Osprey and Continental Teves; and *Lees* (2018-19) who established a £5.2M GaNforCS ERDF project to create a supply chain for GaN transistors in the UK, involving ten industrial partners, the CSA Catapult and Welsh Government. The University's Disglair Lectureship Scheme (REF5a), enabled *O'Doherty* and *Jefferson* to accelerate research in the Civil Infrastructure priority area, with ECR's *Allmark* and *Novelli* appointed to their first academic post as a result.

2.4 Research students

Our substantial, diverse and vibrant PGR community grew by 8%, from 191.75 registered FTE in 2013 to 207.5 FTE in 2020, 44% home and 56% overseas. The PGR Tutors Committee comprising the Director of Postgraduate Research (DPGR) and departmental PGR Tutors manage all aspects of the PGR experience, supported by our PGR Admin Team (4.2FTE) and PGR Student Staff Panel.

EDI considerations permeate our PGR practices, informed by UKRI expectations, the University's Strategic Equality Plan and our EDI Committee. Aligned to our commitment to grow the diversity of the discipline, we seek to recruit high quality candidates using selection processes that clearly emphasise our commitment to EDI. Although much remains to be done, the proportion of female PGR engineers is increasing; for example, 12.5% on EPSRC studentships (current three-year average) compared to 7% in REF2014.

Since REF2014, we supported 244 funded studentships, 95 full or part funded by EPSRC (including 21 industrial case awards) and 118 including collaborative partner contributions from, for example, Airbus, Aston Martin, Cancer Research Wales, Huawei, Mercedes-AMG Petronas F1 Team, National Grid, Renishaw, Rolls Royce, Toshiba, Costain and Lusas. We used our own and College funds to support interdisciplinary studentships with partner Schools, including Biosciences, Business, Chemistry, Computer Science, Dentistry, Earth and Environmental Sciences, Healthcare Sciences, Mathematics, Medicine, and Physics.

Since REF2014, we increased our participation in ESPRC CDTs and MSCA ITNs, working with partner universities and industry to deliver cohort-based development and training, including:

- WISE CDT in the Civil Infrastructure priority area with GW4 partners Exeter, Bath and Bristol and 20 studentships in Cardiff.
- Compound Semiconductor Manufacturing CDT led by Cardiff University with Manchester, Sheffield and UCL and 26 studentships shared with the School of Physics.
- Resilient Decarbonised Fuel Energy Systems CDT in the Sustainable Energy priority area, with Nottingham and Sheffield starting in October 2019 with at least 17 studentships allocated to us.
- Leadership of two MSCA ITNs in the Sustainable Energy priority area, INNODC and Multi-Terminal DC Grids for Offshore Wind (MEDOW) and with eight studentships in Cardiff. We are a partner in a further three ITNs, facilitating recruitment and mobility of high-quality PGR students.
- Further CDTs including ESF-supported Knowledge Economy Skills Scholarships (six studentships), NERC Freshwater Biosciences and Sustainability CDT and NERC GW4+ DTP (one studentship each).

In 2019, the University approved the establishment of five Interdisciplinary Training Hubs (EPSRC DTP funded) to further develop cohort-based researcher training, with ENGIN leading the Sustainable Transport Hub (*Featherston, Cipcigan*) and partnering with the Sustainable Plastics and Biosensors and Diagnostics Hubs (led by Chemistry). These form a catalyst for development of innovative cohort training plans designed to increase numbers of high-quality research students through alignment of CDT proposals with our five interdisciplinary priority areas (Section 2.1, 'The next five years').

PGR monitoring and support mechanisms are overseen by the DPGR, PGR Tutors and Academic Supervisors (minimum of two for all students) with support from the PGR Office. All supervisors undertake formal training by the University every three years. A revised online progress monitoring system was introduced in 2017 to allow regular feedback and a clear path for identifying and rectifying concerns. Progression milestones include an initial three-month report, followed by annual and interim reviews. Annual reviews include the submission of written work and a mini-viva chaired by an independent academic.

All PGRs are allocated office space, appropriate laboratory facilities and integrated within a research group. PGR Tutors and the DPGR provide academic support routes outside of the supervisory team, whilst the PGR Staff Student Panel, chaired by a student representative, promotes informal support mechanisms and social activities.

PGR skills development and career progression extends Doctoral Academy provision (REF5a, 3.4) to focus on subject specific activities and enhancing our PGR community. Structured around the University's transition, acquisition, completion and employability (TACE) framework, support includes ENGIN induction, health and safety, laboratory training, sustaining momentum and completing, and commercialisation workshops. We host an annual three-day postgraduate research conference in Gregynog, mid-Wales, and a one-day conference organised by PGR students. Students are allocated a £2.4k research account to support research training and networking over the studentship duration independent of their research projects, often supplemented with Research Training Support Grants, bench fees, partner or other contributions. Our PGR International Experience fund of typically £12k p/a is competitively awarded, supporting up to six visits to internationally renowned universities or research facilities, with examples including Canada, China, Germany, France, Japan, Mexico, New Zealand and the USA (University of Chicago, Duke University, University of Illinois, Mississippi State University, Berkeley CA, Stanford and Texas A&M). Most industrial studentships include a partner-placement, and we encourage and facilitate other types of placements, including UKRI Policy Internships; for example, Government Office for Science (*Leech*) providing PGR students with opportunities to work within highly influential policy organisations (section 4.4).

2.5 Equality, diversity and inclusion

EDI is central to our culture, and in 2019 we were re-accredited with an Athena Swan Bronze Award. Meeting six times a year, our EDI Committee provides strategic direction, embedding EDI through a diverse membership, including students and staff at all career stages as well as support from senior management. The Committee recognises the need to move beyond gender diversity to a wider brief for all protected characteristics and actively engages with the University's BAME+ Staff Network. Three ENGIN staff are members of the Race Equality Supervisory Panel (RESP), which was recently recognised for best practice at a national level in the published Equality and Human Rights Commission report, 'Tackling Racial Harassment: Universities Challenged'.

We support staff with protected characteristics, identifying and implementing reasonable adjustments. For example, following a staff member's dyslexia diagnosis, we implemented recommended adjustments utilising Access to Work funding. We actively engage with Access to Work to support staff with disabilities, providing physical as well as coaching support. In response to Covid-19, we supported three staff members through the University's Covid-19 flexible working scheme, adjusting their working arrangements to align with caring responsibilities. Further, 22 academic staff members currently benefit from formal flexible working arrangements, with many others using informal arrangements, across all career pathways. We ensure diverse interview panels that include female and BAME staff whenever possible. There have been 23 BAME staff promotions compared to nine over the last REF period, and senior promotions for women include *Featherston* (2015) and *Setchi* (2018) to Deputy Head of School and Director for Research and Innovation respectively, and *Holford*, Deputy Vice-Chancellor (2017), who received a CBE for services to engineering and the advancement of women in engineering (2018).

To ensure that wellbeing of staff and research students is embedded within our Staffing Strategy, we formed a Wellbeing Group to catalyse wellbeing activities suggested by staff and research students, including a book club, museum tours, board games and table tennis facilities. We established Dignity and Wellbeing Contacts trained to offer confidential advice and support to people facing issues with harassment or bullying, with contacts from all career pathways: *Holt, Kennedy, Keenan, Trowbridge* and *Qadrdan.* This initiative was later adopted at College level and implemented across the University.

We are an international school attracting the best staff from across the globe, and currently 20% of academic staff originate from non-EU countries. We support and promote the Trevithick Women in STEM group (TWISTEM), a grassroots group open to staff from across the University. TWISTEM holds monthly events supporting all who identify as female, additionally working to recognise the critical contributions of men in driving gender equality. ENGIN support for TWISTEM includes providing networking lunches, Q&A sessions on women in STEM and the University (*Holford*), as well as organisational support.

3. Income, infrastructure and facilities

3.1 Research funding

During the REF period, we secured 639 research awards (337 in REF2014), representing an award value of **£97M**. This is a **102% increase** compared to the previous REF period (£48M), and as a result, research income spend (REF4b) substantially increased from £44M in the previous REF period (£8M p/a) to £79.6M over the current period (£11.4M p/a). Funders include UKRI (ESRC, EPSRC, MRC, NERC, STFC, InnovateUK), UK Government departments, Welsh Government, the NHS, charities (including RAEng, Royal Society, Alzheimer's Society, Versus Arthritis, Bill and Melinda Gates Foundation, British Council, Cancer Research Wales, Leverhulme Trust Wellcome Trust), Europe, and industry. This success has given us a diverse and balanced portfolio of awards in support of our strategic aims across all our priority areas

Over the REF period, we **focussed on securing larger grants alongside fellowships as a means of attracting and developing world-class researchers to increase our capacity**. We secured **13 grants each worth over £1M** (compared to three in REF2014) and were **awarded 26 externally funded Fellowships** from the EPSRC, RAEng and European sources (Sections 2.3 and 4.5). To support this, we strategically used small grants **(340 awards <£50k)** to help initiate new research ideas, support researcher mobility (GCRF, Newton Fund), develop ECR track-

records (e.g. EPSRC IAA and Royal Society Small Equipment Grants), and establish new research partnerships and industry collaborations (InnovateUK/Small Business Research Initiative) feasibility studies, as well as applied research with local SMEs. This was invaluable in supporting larger research grant applications aligned with our five priority areas (Section 1.1.2).

We have focussed on supporting researchers during the grant application process, with particular emphasis on ECRs, through interaction with line managers, mentors and dedicated support activities (Section 2.3.1). The ENGIN Research Office (applications and awards support), Business Interface (impact, knowledge exchange and commercialisation) and Public Engagement Officer (communication and outreach) provide professional support to all aspects of grant capture and delivery.

In our **Advanced Manufacturing** priority area, we secured 136 grants (£15.1M) across six research groups (Section 1.1.1). Highlights include: ACM secured 12 awards with a focus on staff mobility and exchange, including a RAEng Industrial Fellowship with Airbus (*Kundu*) applying industrial mathematics to develop aircraft wing designs using machine learning, Sêr Cymru-MSCA Co-funded Fellowships (*Morini, Noorikalkhoran,* and *Li*) and a RAEng Distinguished Visiting Fellowship (*Dorfmann*, Tufts University). HVM secured 54 awards, including ASTUTE 2020 and leadership of IROHMS (*Setchi*). M&M (21 awards) were awarded MAGMA (*Anderson*), while TPMSM successful secured 47 awards, including EPSRC Fellowship (*Kim*) and MSCA Fellowships (*Cernescu, Perepelkin,* and *Li*).

Our **Civil Infrastructure** priority area secured 96 grants (£15.2M) across three research groups. The GRC secured 54 awards, with highlights including the NERC-UKRI funded INSPIRE (*Sapsford*) creating new in-situ technologies to harness waste for economic and environmental gain. Our HRC obtained 35 awards, including an MSCA Fellowship considering sediment dynamics of instream wood-jams and managed installations (*Follett*). M4L secured seven grants and lead an EPSRC Programme Grant RM4L (*Jefferson*) developing biomimetic construction materials.

In our **Compound Semiconductors and Applications** priority area, we secured 60 grants (£21.2M) across three research groups. CHFE highlights include GaNforCS ERDF (*Lees*) bringing together a complete supply chain for high-frequency transistor manufacture in South Wales; an EPSRC Manufacturing Fellowship (*Wallis*) developing GaN-based optoelectronics; and a novel millimetre-wave on-Wafer Characterisation Facility (*Taske*r). CIREGS obtained a CSA Catapult Industry Fellowship (*Ming*), and M&M an EPSRC Manufacturing Fellowship (*Bennett)* with membership of the EPSRC Hub in Quantum Computing and Simulation.

Our **Engineering for Health** priority area secured 118 grants (£11.4M) involving three active research groups. MED obtained 80 awards with highlights including the MSKBRF and OATech+ (section 1.4). CHFE were awarded 28 awards, including a large H2020 grant - Artificial Cells with Distributed Cores to Decipher Protein Function *(Barrow),* and microwave-enabled, non-invasive blood glucose sensors (*Porch*). M&M secured nine awards, including NIHR - Generation and Evaluation of Hand Therapy Devices for Epidermolysis Bullosa (*Meydan*).

In our **Sustainable Energy** priority area, we secured 229 grants (£34.2M). CIREGS obtained 90 awards, with a strong EPSRC track record (35 awards) on smart grids and multi-vector energy systems (SUPERGEN Hubs, *Jenkins* and *Wu J.*) including integrated decarbonised electricity (MEDOW, *Jenkins* and *Liang*), gas (EPSRC Fellowship, *Qadrdan*), heat (UKERC-4, *Wu J.*) and electrified transport (DTE Network, *Cipcigan*). AHIVE obtained 40 awards focusing on high voltage electrical network infrastructure, with contributions from industrial partners, including Airbus and National Grid (*Haddad*). GRC leads FLEXIS (*Thomas*) building flexible energy systems, while the BRE Trust for Sustainable Engineering secured 40 awards, with a strong track record of participation in Horizon2020 on building and district energy management (12 projects, *Rezgui*). CREWE obtained 55 awards focussing on flexible power generation, zero carbon fuels and industrial waste heat and gas utilisation (impact case study - *Bowen*), as well as low-emission transport (impact case study - *Crayford*).

3.2 Operational and scholarly infrastructure including specialist equipment

While predominantly based in the University's Queen's Buildings, the University is providing critical new investment for ENGIN at Cardiff's new £300M Innovation Campus and unique offsite industrial facilities are available for researchers: The Gas Turbine Research Centre in Neath Port Talbot and the Morgan-Botti Lightning Laboratory in Cardiff. Since REF2014, £33M has been invested from a range of sources to enhance our research laboratories and associated space, aligned to enhancing research advances in our priority areas (Section 1).

We continually work to make infrastructure and facilities accessible to all, and in line with our commitment to EDI, we have modified laboratories to improve accessibility: the Musculoskeletal and Biomechanics Research Facility, for example, has accessibility designed in, with ground floor access, disabled toilets and changing rooms, broad corridors and direct access to parking.

3.2.1 Investments into facilities

Investments from diverse sources have been targeted to ensure strategic priority areas reach their full potential and are internationally competitive. For example, growth in compound semiconductor research is being transformed through a £77M University capital investment into the Institute for Compound Semiconductors (ICS), part of £131M Translational Research Hub (TRH) within the University's Innovation Campus development due to open Spring 2022. The TRH will accommodate a total of 329 staff, including 49 research-active academic staff from ENGIN, Physics and Chemistry, together with 51 post-doctoral research staff and up to 180 PGR students. The ICS will occupy two floors of the TRH, with one floor dedicated to ENGIN, providing **1,500m^2** of specialist cleanroom facilities. This unique environment strengthens our cross-disciplinary collaboration with Physics, specifically around compound semiconductor applications. Investment into the ICS was backed by a £17.3M UK Research Partnership Investment Fund award from UKRI and Welsh Government, driving the fabrication, testing and development of ground-breaking compound semiconductor technologies. We are a partner in the Compound Semiconductor Centre, a joint venture between IQE and Cardiff University (£24M from Cardiff University), ensuring research at ICS is commercialised into new technologies and applications.

At a School level, during the REF period, **over £33M** has been invested strategically into our priority areas aligned to our research strategy (see Section 1.2):

Compound Semiconductor and Applications (£15.8M): a £12M Welsh Government Award (including £5M for molecular beam epitaxy and metal organic chemical vapour deposition facilities located in ENGIN); £13M from ERDF (awards split 50/50 between ENGIN and the School of Physics) plus a £2M (£500k to ENGIN) Compound Semiconductor Underpinning Equipment Grant (*Thomas*, EP/P030556/1); a GaN materials characterisation facility (£100k, *Wallis*) for measurement of large diameter wafer-bow; a new Quantum Technology Laboratory (£760k, *Bennett*) in the ICS supporting research in quantum technologies; a new characterisation facility (£1.5M EPSRC Equipment Grant, *Tasker*) extending capabilities to mm-wave frequencies. In terms of **enhancements to existing facilities**, the cleanroom in Queen's Buildings was upgraded (£450k) to support ICS development and the new EPSRC Compound Semiconductor CDT.

Advanced Manufacturing (£3.5M): a spark plasma sintering (SPS) system (£240k, *Garcia Rocha*) and measurement equipment (£300k, *Prickett*) to refurbish the Renishaw Metrology Laboratory; a new acoustic camera (£202k, *Pearson*) led to a project with Airbus considering the entire lifecycle of aerospace structures using structural health monitoring; two new robotics laboratories (The Autonomous Systems and Robotics Laboratory, £350k, and the Human-Robot Interactions Laboratory, £420k, *Setchi*), together with the Metal Additive Manufacturing facility (£600k, *Setchi, Prickett*) supported by Renishaw; a Mazak VCS430 Vertical Machining Centre was purchased by Renishaw (£350k) and ENGIN (£100k) in 2015 (*Setchi, Prickett*), enabling work in smart manufacturing and advanced nanocomposites. For existing facilities, our Micro/Nano Manufacturing capability was enhanced (£155k) by investment in transmission electron microscopy and our Structural Performance and Tribology Laboratories benefited from a 3D-laser scanning vibrometer (£500k) and new controllers (£145k).

Engineering for Health (£5.2M): the new 6,000m^2 MSKBRF (£5M, *Holt*) provides state-of-the-art research access to patients and clinicians. Capabilities include a teaching laboratory, full motion

analysis to clinical standards, micro-CT scanner, DEXA scan and fluoroscopy laboratory with dynamic biplanar fluoroscopy (dynamic 3D x-ray imagery, unique in Europe). As part of enhancements to existing facilities, our Medical Diagnostic Laboratory, through our research partnership with Cardiff and Vale UHB, now provides MRI, X-ray, ultrasound, and whole-body radiation counter facilities. The Medical Ultrasound and Sensor Laboratory received investment (£50k) for new ultrasound equipment. The Human Factors Technology Laboratory was upgraded (£150k) with motion capture and other multimedia equipment.

Sustainable Energy (£8.6M): a new Medium Voltage Direct Current Laboratory (£300k, donated by Windsun Ltd.), sponsored by SP Energy Networks (£200k), was successfully applied in the £15M ANGLE-DC project realising a medium voltage direct current link between Anglesey and North Wales, a national flagship Electricity Network Innovation Competition demonstration project funded by Ofgem (impact case study - *Ugalde-Loo*). For existing facilities, the National Grid strategic partnership continued to support AHIVE through a £2M investment, supporting increased experimental capacities and securing staff positions. University investment of £1M allowed the relocation of laboratories to a new, dedicated facility in 2016/17; subsequently, grant funding of £4M (National Grid and EPSRC) allowed the installation of 300kV transformer and a 400kV gas insulated demonstrator test rig. Facilities in the CIREGS Power Electronics Laboratory were enhanced (£500k) to include real-time simulators (RTDS and Opal RT). A Medium Voltage Direct Current simulator was commissioned, as well as a new laboratory for interdisciplinary energy research on gas/electricity systems (£100k). The Gas Turbine Research Centre facility was significantly enhanced since REF2014 with investment (£200k) in low carbon technology to reduce facility operating costs and carbon footprint. A further £300k was invested in advanced optical diagnostic equipment, enabling new research into the zero-carbon fuels hydrogen and ammonia.

Civil Infrastructure (£430k): our Hydraulics Laboratory was upgraded with new flumes (£24k) and a full range of state-of-the-art instrumentation for measuring flows (£85k), while our Geotechnical Laboratories were refurbished and updated (£170k). Our Building Information Modelling Laboratory was enhanced with a new visualisation and high-performance computing facility for architectural building modelling (£150k). The Materials Characterisation and Construction Materials Research Laboratories were refurbished, and equipment installed to allow characterisation of self-healing cementitious materials.

All facilities are supported by a team of technical and professional services staff; since REF2014 we increased our research technical support by five FTE. A pool of infrastructure technicians (33 FTE) supports the general operation and upkeep of the research laboratories, with dedicated technicians (4.5 FTE) supporting specialist laboratories. Fully equipped mechanical and electronic workshops provide bespoke manufacturing and specialised maintenance. We promote technical staff representation on key committees; Health and Safety and ENGIN Operations Group (*Hunt)*, and in 2019, the annual Technicians Conference was organised jointly between ENGIN and Physics and hosted on site. We also promote the Technical Commitment (REF5a) and support our staff to become accredited.

3.3 Infrastructure and expertise contributing to impact

The Business Interface (Section 1.3) is central to our current and future strategy, focussed on knowledge transfer and maximising the impact of our activities. Our School Research Office, meanwhile, ensures that grant applications include appropriately designed and resourced impact generating activities while advising on impact focussed schemes (e.g. EPSRC IAA, GCRF, H2020 Proof of Concept funding). The Interface hosts Technology Transfer Officers (TTO) from the University Commercial Development Team (REF5a, section 4.4); for example, supporting the SETSquared Scale-up Programme, helping academics and high growth potential SMEs connect (*Beach*, 'digitisation of construction regulations' via the Construction Innovation Hub, £430k), or working with researchers developing a non-invasive blood glucose monitor (led by *Porch*) to devise a commercialisation strategy and support initial clinical trials. Cardiff Partnership seed funding (£99k) was used to underpin IP and optimise the sensor, leading to a Wellcome Trust grant (£1.1M, *Porch*) for prototype development and clinical studies. A licence agreement was concluded in June 2019 for commercialisation which included a £250k development project and a royalty return to the University.

ENGIN facilities, including laboratories and equipment, are accessible to SMEs and other collaborators to test or develop new materials, processes and products. Large industrial partners, such as Airbus, National Grid and Tata Steel, value access to our major facilities with unique capabilities, including the GTRC, the Morgan-Botti Lightning Laboratory (MBLL) and the GRC's Characterisation Laboratories for Environmental Engineering Research (CLEER) facility (see Section 1.3 for scale of engagement).

We actively engage with the Cardiff University Innovation Network (REF5a) with success in several University Innovation and Impact Awards: *Valera Medina* and Siemens, Sustainable Innovation Award (2019); *Pullin* and Microsemi, Business Innovation Award (2018); *Lees* and Flintec, Business Innovation Award (2017).

3.4 Major benefits-in-kind

Project partners play an integral role in our research, providing direct cash and in-kind support including expertise, staff time, access to facilities and test sites or provision of materials and equipment. UKRI grants secured during the REF period included £4.5M of in-kind contributions, (e.g. Resilient Materials for Life (RM4L), including £400k in-kind contribution to demonstration and site trials from Costain, or Accelerated Supergene Processes in Repository Engineering (ASPIRE), 17 project partners, including donations of equipment, public engagement expertise and samples). Major ERDF funding also included significant match, for example, GaNforCS SMART Expertise, with over £2.8M in-kind funding from industrial partners, including Newport Wafer Fab, IQE and SPTS Technologies/Orbotech, who provided technical staff, equipment and cleanroom access. MAGMA received £750k match in the form of staff secondments and equipment.

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

4.1 Research collaborations, networks and partnerships

The breadth and international profile of our research collaboration can be evidenced through co-authorship: **65%** of our REF2021 papers (176/272) include joint authors (278 different Institutions), with 45% (122) involving authors from outside of the UK (39 unique countries) and 11% including end-user or industry authors; whilst 78% (499/639) of grants secured in the REF period involved collaborative research with partners or users.

International collaborations extend across all priority areas and resulted in 36 H2020 projects (£7.3M) including: MSCA ITN **INNODC** (£765k), led by *Liang*, with partners Politecnica Catalunya, U.Porto, DTU, KU Leuven and six international industries, training European leaders in renewable smart energy and tackling climate change; **pISCES, THERMOSS, PENTAGON** (£1M total), led by the BRE Trust for Sustainable Engineering, which were H2020 companion projects, reducing energy use and tackling fuel poverty by enhancing urban energy efficiency with partners from Italy, Germany, Spain, France, Switzerland, Belgium, Czech Republic and Ireland; and **COST**, a 28 partner European Co-operation in Science and Technology (chaired by *Pullin*), considering the optimisation of design for inspection to maximise the full benefit of in-service, continual monitoring of aerospace structures for cleaner and safer skies.

We hosted 147 visiting academics and 74 visiting researchers during the period including RAEng Distinguished Visiting Fellows *Beroual* (Lyon); *Thompson* (Mississippi State); *Dorfman* (Tufts); *Sklonlewski* (Maryland) plus RAEng Visiting Professors *Edwards* (Culham Science Centre) with a focus on nuclear engineering and *Yang*, (Olympus Surgical Technology Europe), focussing on Medical Device Design. GCRF/Newton Fund awards developed new links and joint research with Bangladesh, Brazil, China, Columbia, Egypt, India, Jordan, Malaysia, Senegal and Vietnam.

Visits have facilitated mutually beneficial outcomes, e.g. a paper generated by a visiting PhD student won the 13th European Microwave Integrated Circuits Conference Young Engineer Prize; multiple co-authored papers (including in our submission, e.g. 10.1088/1741-2552/ab0328; 10.1007/s10915-017-0392-0); or grant awards, e.g. *Valera-Medina* being invited to join the €12M H2020 FLEXnCONFU consortium.

National collaborations delivered 122 new UKRI awards (£32M to ENGIN), with our researchers leading 34. Notable examples of national project leadership include the following, as well as examples provided in Sections 1 and 3:

- The EPSRC Programme Grant **RM4L** (*Jefferson*), with Bath, Bradford and Cambridge (£4.8M).
- The **Future Compound Semiconductor Manufacturing Hub** (£10.3M, £1.5M to ENGIN) - a major collaborative initiative led by the School of Physics, with academic partners including Sheffield, UCL and Manchester, with 23 industrial partners.
- The EPSRC Network+ **OATech+** (£1.2M, *Holt*) with Imperial College, Royal Veterinary College, Leeds and Strathclyde developing a multidisciplinary approach to the prevention and treatment of osteoarthritis.
- The EPSRC **DTE** Network+ (£1M, *Cipcigan*) with partners including Cranfield, Birmingham, Bristol and Southampton Universities, along with Aston Martin, Ricardo Group, National Grid, Transport for London, Transport for Wales, Welsh Government, the IEEE and others.

Regional and Welsh collaborations saw major developments through the formation of the Compound Semiconductor Cluster (Section 1.3) involving five international companies: IQE, Newport Wafer Fab, SPTS Technologies, Microchip with Swansea University and the CSA Catapult. We are a key partner of the **GW4 Alliance** (REF5a) and lead a large portfolio of collaborative grants funded by the Welsh Government designed to promote strategic cooperation within Wales. **FLEXIS** (led by *Thomas, Haddad, Jenkins, Bowen*) is a £24M research programme conducted in consortium with Cardiff, Swansea, University of South Wales, Neath-Port Talbot County Borough Council and Tata Steel to achieve a resilient, affordable, secure energy system across Wales with potential for global application. **MAGMA** is a £2.1M project (*Evans S., Anderson*), in which ENGIN, the School of Chemistry and Tata Steel are delivering technology change in processing, characterisation, manufacturing and recycling of magnetic materials.

4.2 Engaging with key research users, beneficiaries and audiences

In addition to editorial and advisory roles and leadership in national and international research communities, learned societies and professional bodies (Section 4.5), examples of engagement across all priority areas include delivery of over 200 industrial collaborative research projects with partners including Airbus, Arup, China Communication Construction, Cogent Power, GE Healthcare, GlaxoSmithKline, Huawei, IQE, Mercedes-Benz, NASA, National Grid, Olympus, Tata Steel and Toshiba. Working with Rolls-Royce, we defined best practice for measuring aircraft engine particulates, now adopted by the UN as a global standard (impact case study - *Crayford*), as well as applied Cardiff tribology research in the design of propulsion of new frigates and aircraft bearings (impact case study - *Evans H.P.*).

Our **international reach** extends through our European links and strategic international collaborations to over 40 joint externally funded projects, 36 H2020 projects, with examples including the MSCA ITN **INNODC** engaging with six international industrial partners and strengthening Europe's position of leadership in renewable smart energy (others in Section 4.1). We provide international policy advice; for example, International Standard Committees of International Electrotechnical Commission (*Haddad*) and Foreign Membership of the Chinese Academy of Engineering (*Falconer*, Section 4.5).

Successful **strategic engagements with industry** led to longstanding relationships and partnerships, including Tata Steel, recovering heat waste and significantly reducing energy costs and CO_2 emissions (impact case studies, *Bowen, Haddad*). The MBLL (*Haddad*) engages in research with the Airbus, HEXCEL and the National Composite Centre through the PROTEST project (£2.6M), investigating ways of protecting aircraft from lightning strikes. Collaborations also led directly to RAEng Industrial Fellowships (*Cipcigan, Kundu*) at National Grid and Airbus.

A strategic engagement with Renishaw in the **Advanced Manufacturing** priority area delivered five EPSRC iCASE PhD studentships and, spanning MMM and EEE departments, resulted in the development of novel RF and microwave techniques to assist in additive manufacturing, leading to the filing of several patents (e.g., EP3200942A1, 2017). We also have a well-established track-record of KTPs with 15 awards since REF2014 including wireless, autonomous weight-measuring

load-cells (Innovate UK KTP with *Lees* and Flintec UK, Feb 2014-Sep 2015, £128k) which won a CUIN Business Innovation Award.

Aligned with our **Engineering for Health** priority area, and through our collaboration with the NHS CEDAR Healthcare Technology Centre, we support research and evaluation of medical devices and diagnostics. CEDAR is one of four centres supporting UK healthcare through the Medical Technologies Evaluation Programme (NICE, £1.1M funding to ENGIN).

School members are active in global networking and dissemination via conferences, including 950 presentations openly available via our online repository. We organised and hosted six major conferences aligned with our priority areas, including the 24th Conference of Computational Mechanics ACME-UK (2016), Recent Appointees in Materials Science RAMS2018, 30th British Machine Vision Conference at Cardiff BMVC 2019, the International Workshop on Integrated Nonlinear Microwave and Millimetre-wave Circuits (INNMIC2020), the UK Nitrides Consortium conference in 2020 and the 9th International Conference on Applied Energy (2017), with over 700 delegates, including the Chief Scientific Advisor to BEIS, John Loughhead, as a keynote speaker.

4.3 Engaging with Diverse Communities and the Public

Our Public Engagement Officer coordinates our engagement and outreach programme, reaching approximately 8,000 people a year. We run regular staff training on best practice and public engagement techniques, and we focus on building long-term relationships with primary and secondary schools leading to visits, workshops and teacher CPD. Our Tidal Power project with Radnor Primary School provided support to design turbines for the Bristol Channel and was highly commended in the Young Innovator category of The Engineer's Collaborate to Innovate Awards. Our Cardiff Marine Energy Research Group (part of CREWE) supported the creation of GCSE resources, including lesson plans, for the National STEM Learning Centre. We work with diverse communities, such as Willows High School, where 44% of pupils are eligible for free school meals, and 68% of pupils live in the 20% most deprived areas in Wales. Students from Willows Year 7 join us annually for hands-on interaction with projects in our laboratories, while students from Ninian Park Primary, with a similar dependency on free school meals and with 84% of students with English as an additional language, performed their own Science Magic Show in ENGIN.

Following a review of activities and best practice (2016), we established a new evidence-based strategy for public engagement focussing on ensuring our activities and actions are gender neutral. This includes emphasising how engineers help people, choosing universal themes such as health and sustainability, replacing competition with collaboration as an engagement tool. In 2019, we received an Ingenious grant from the RAEng to work with Go Girl Academy and Girlguiding. We trialled resources and provided training to engineers in inclusive practice, ran engineering workshops at school holiday clubs for girls and developed an electromagnetics Girlguiding challenge badge.

Our researchers engage at public events such as the National Eisteddfod (recognised as the most important Welsh cultural event, attracting many thousands of visitors over a week), the Green Man music festival, Rudry Music Festival (engaging with 150 families in 'motor madness' and robotic hands activities, *Lees*), Edinburgh Science Festival - How to start an electric car and Cardiff Science Festival (*Cipcigan*). We lead several interdisciplinary University events, such as the annual STEM live: Mission to Mars, a one-day immersive experience involving 12 secondary schools and approximately 150 12- to 13-year-olds participating in a range of interactive STEM activities themed around a voyage to live on another planet. The aim of these events is to showcase the vital importance of engineering, maths and science to a wide audience.

Examples of wider contributions to economy and society include the FIFA-accredited Medical Centre of Excellence (*Nokes*), a joint facility with Cardiff Metropolitan University and the Football Association of Wales, focussed on providing the best medical care to all those participating in football, irrespective of age or gender. We also collaborate with the School of Earth and Environmental Sciences developing 'CryoEgg', a system for exploring radio propagation through glacial ice in North East Greenland (*Lees*). This work attracted significant attention in national media and was nominated for 'The Engineer' Collaborate to Innovate award in 2019.

4.4 Contribution to the sustainability of engineering

During the period, 416 students received research degrees and are now applying their skills globally, for example, as academics in the UK (including, at Cardiff, Allmark, Barba, Wyatt) or worldwide (e.g. China, India, Iraq, Libya, Malaysia, Netherlands, Norway, Saudi Arabia, Spain) as postdoctoral researchers, or in industry and the public sector (e.g. Atkins, BEIS, Carbon Trust, EA Technologies, Google, HR Wallingford, Intertek, National HVDC Centre, STFC, Tata, Welsh Water, ONS), contributing to the sustainability of the sector. To help promote the sustainability of the discipline, *Holford* sits on the Russell Group Post-18 review advisory group, co-chaired the Welsh Government Talented Women for a Successful Wales report and is Non-Executive Director of the UKRI STFC Council, including membership of Finance and Governance Committee and STFC/Innovate UK joint forum. *Falconer* is the Foreign Member of the Chinese Academy of Engineering and the National Flood Resilience Science Advisory Group to UK Government and Hinkley Point-C Stakeholder Reference Group to Welsh Government.

We develop future research leaders through various mechanisms (Section 2.3), such as mentoring and encouraging ECRs to play leading roles in our committees and CCTs. Many staff, including ECRs, promote discipline sustainability through membership of national committees and standards bodies, including BSI GEL/081 Protection against lightning (*Robson*), IEEE MTT Technical Committee 5 High Power Amplifiers (*Quaglia*), Royal Society Policy Briefing on Ammonia (*Valera Medina*), Welsh Government's Flood and Coastal Erosion Committee (*Wilson*) and the IET Power Academy (*Robson*), Vice-Chair and Secretary of SAE-31 international technical committee for particulate matter emissions (*Crayford*).

All academic staff are expected to contribute to the fundamental process of peer review for journals and further contribute to the discipline by acting as external examiners and reviewers. Academic staff have authored, edited or contributed to 88 books and monographs, extending the underpinning knowledge base of the discipline.

Our staff provide informed and impartial assessments supporting the allocation of research funds, e.g. BBSRC, EPSRC (25 Full and 23 Associate Peer Review College Members), NERC, MRC, Leverhulme Trust, Royal Academy of Engineering, Innovate UK, Royal Society, Wellcome Trust; at the European level as expert evaluators for H2020, MCSA, ERC, European Science Foundation; and with National Research Councils, including Australia, Austria, Belgium, Canada, Denmark, Chile, China, Cyprus, Czech Republic, Finland, France, Ireland, Italy, Israel, Kazakhstan, Lithuania, Mexico, the Netherlands, Qatar, Singapore, Slovenia, South Africa, Spain, Switzerland, UAE and USA, reflecting our international engagement, reach and reputation.

4.5 Indicators of wider influence of the research base

Many staff are, or have been **Editors-in-Chief, editors or associate editors of international journals**. With the IEEE, *Cripps* on Microwave and Components Letters; *Haddad* with Transactions on Dielectrics and Electric Insulation; *Melikhov* and Transactions on Magnetics; *Setchi* on Access; and *Liu* Transactions on Automation Science and Engineering. For the IET, *Wu J.* on the Journal of Smart Grids and is Deputy Editor-in-Chief of the Journal on Energy System Integration. Other positions reflect our breadth of expertise: *Cipcigan,* Smart Grids and Power Systems and Renewable and Sustainable Energy Reviews; *Jefferson,* European Journal of Civil Engineering; *Bordas,* Advances in Applied Mechanics; *Brousseau* Manufacturing Letters; *Valera Medina* Journal of Thermal Science; *Mourshed,* PLoS One; *O'Doherty,* International Marine Energy; *Jenkins* former Chair ICE Energy; *Benedikt,* Microwave and Optical Technology Letters; *Liu* ASME Journal of Computing and Information Science in Engineering, Journal of Industrial and Production Engineering, Autonomous Intelligent Systems and CCF Transactions on Pervasive Computing and Interaction; and *Tripathy* Canadian Geotechnical Journal.

We dedicate significant time and expertise advising professional bodies, **standard committees and in expert advisory roles**. Representing our Sustainable Energy priority area, *Liang* is a member of five CIGRE Working Groups (B4.58, B4.60, B4.62, B4.72, B4/C6-37) and the China Electric Power Technology Collaboration. With the British Standard Institution Committees (BSI) *Haddad* is involved with PEL37/1, PEL37/2, PEL42, and GEL81 International Standard Committees of International Electrotechnical Commission; *Cipcigan* is on the Technical Committee ESL/120 Electrical Energy Storage; *Robson* on the GEL/081 Protection Against Lightning. *Valera Medina* participated in a Royal Society Policy Briefing and *Robson* is involved

with the IET Power Academy. *Li* is a Standards Committee Technical Executive of buildingSMART (producing BIM ISO standards) and leads the development of IFC ISO 16739-1:2018 extension - IFC Ports and Waterways (IFC4.3).

In our Advanced Manufacturing and Engineering for Health priority areas, *Evans S.* supported the Canadian Standards Agency Z325 Committee and NHS Wales Evidence Based Purchasing Board; *Setchi* worked with the European Institute of Innovation and Technology and Tech Valleys Strategic Advisory Group; *Haddad* on the Technical Advisory Board for National Grid Advisory; *Pullin* on the RILEM Technical Committee; and *Holt* with the IMechE Biomedical Board. Other priority areas include *Mourshed, Wilson,* and *Cipcigan* advising Welsh Government Committees; *Quaglia* on the IEEE MTT Technical Committee 5; *Tasker* with the Wales 5G Expert Group; *Davies* on the Industry Innovation Platform-Infrastructures Technical Standard and *Rezgui* advising the Digital Built Britain initiative.

Prizes, awards and other distinctions received by our academics include *Holford* as Fellow of the RAEng and CBE for services to engineering and for the advancement of women in engineering; *Thomas* awarded CBE for outstanding contribution to academic research and services to higher education, as well as President of the Learned Society of Wales; and *Falconer* recognised as Fellow of the European Academy of Sciences, Honorary Member of the International Association for Hydro-Environment Engineering and Research, Foreign Member of the Chinese Academy of Engineering for distinguished contributions to hydraulic engineering and to the promotion of China-UK exchanges and cooperation in the field.

Tasker and *Ekanayake* became IEEE Fellows and *Li* was elected to the Royal Society of Chemistry. Awards include *Cripps* with the best annual paper in Microwave Theory and Techniques and the MWCL Tatsuo Itoh Award for best paper published in the IEEE Microwave and Wireless Component Letters; *Ming* won the IET Control and Automation PhD Prize; *Steer* was awarded the IoM3 Adrian Normanton Medal for best technical paper on steelmaking or casting; and *Stoesser* won the ICE George Stephenson Medal. *McWhirter* was included in the Science Council's list of 100 Leading UK Practising Scientists.

Staff in all our priority areas deliver many **keynote lectures in international conferences.** For example, in our Advanced Manufacturing priority area, highlights include *Borodich* at 9th and 10th European Solid Mechanics Conferences EUROMECH, as well as EUROMECH Colloquium 574, Anadolu University, Turkey; *Setchi* for the 19th International Conference on Knowledge-Based and Intelligent Information and Engineering Systems, 7th International Symposium for Sustainability by Engineering, 16th Global Conference on Sustainable Manufacturing, as well as KES International Conference on Smart Sustainable Technologies. For the Civil Infrastructure priority area, *Falconer* in 21st International Association for Hydro-Environment Engineering and Research (IAHR) Asia Pacific Division Congress and 37th IAHR World Congress; *Jefferson* at the joint 6th European Conference on Computational Mechanics and 7th European Conference on Computational Dynamics Glasgow, Concrete Solutions International Conference on Concrete Repair Cluj, as well as Durable Concrete for Infrastructure under Severe Conditions Ghent 2019; and *Tripathy* at the International Conference on Soil and Environment 2016. In the Sustainable Energy priority area, *Min* for the European Conference on Thermoelectrics; *O'Doherty* at the International Conference on Renewable Energy 2019; *Valera Medina* for 14th Clean Air Conference 2019 and *Wu J.* in the Global Engineering Conference, London, 2018, and the China International Electrical and Energy Conference, Beijing, China, 2017.

Our staff have been **invited guest speakers** at many prestigious institutions. In the UK, highlights include *Porch* and *Gei* spoke at the University of Oxford; *Garcia Rocha* and *Xie* at the University of Cambridge; *Gei* at UCL; and *Bennett, Garcia Rocha, Whatling* and *Xie* at Imperial College London. *Gei, Liang* and *Evans S.* have spoken at KU Leuven, one of the University's partner institutions. Within Europe, talks include *Bennett* Technical University of Munich, *Haddad* ETH Zurich; *Gei* Tufts University; *Gallichan* Max Planck Institute-Tuebingen; *Kerfriden* Delft University of Technology; *Kennedy* Politecnico di Torino; and *Quaglia* Politecnico di Milano. Further afield, *Gei* spoke at Harvard University; *Setchi* the Georgia Institute of Technology and Nanyang Technological University; *Xie* Tsinghua University and University of Tokyo; *Tripathy* IIT Bombay; *Borodich* Russian Academy of Science; *Cleall* University of New South Wales, *Pan* University of Wollongong and University of Sydney.