

Institution: Bangor University (10007857)
Unit of Assessment: Engineering
<p>1. Unit context and structure, research, and impact strategy</p> <p>1.1 Structure and Context</p> <p>Engineering research at Bangor University is led by the School of Computer Science and Electronic Engineering (CSEE), one of three sub-units of the College of Environmental Sciences and Engineering. The School was formed in 2017 from the strategic merger of the Schools of Computer Science and of Electronic Engineering, thereby increasing the cohesion, critical mass, and interdisciplinary opportunities in these areas of historic strength and recent growth. Bangor's Engineering research is focussed around three main themes. Reflecting our intrinsic commitment to interdisciplinary working, many of our researchers work across these theme boundaries. The three themes are also aligned with local industrial sectors of international significance, fostering research translation and relevance.</p> <p>1) Photonics and Communications (Chen, Giddings, Hong, Kettle, Nezhad, Ritsos, Shore, Spencer, Tang, Wang, Yue)</p> <p>This theme has roots in the School's extended track-record in fundamental research in photonics and electromagnetics, specifically nanoscale light sources, integrated photonics, and super-resolution imaging, as well as critical applied research areas of optical communications and GPS technologies (the latter underpinning one of our impact case studies [REF3_03]). Since REF2014 Bangor's position has strengthened and expanded from device level into new sub-systems areas such as nanophotonic MEMS (micro-electro-mechanical systems), micro-robotics, and the associated laser materials-processing techniques. Bangor's microfabrication facility underpins much of the group's research, which has been complemented by the installation of new facilities (see Section 3.2) and benefited from access to laboratories at Manchester's National Graphene Institute.</p> <p>Research highlights include: 1) Real-time orthogonal frequency-division multiplexing transceiver technology capable of 20 Gb/s utilised by Tang and Giddings together with other DSP-based techniques for optical communications systems, which are being commercialised via a series of awarded grants (GBP7,100,000; funding figures throughout this document reflect award value to Bangor unless otherwise stated) with 27 industrial partners including BT, Vodafone, Keysight and VPI; 2) Development of an optical 'Superlens' by Wang capable of imaging features as small as 40 nm using conventional microscopes, interdisciplinary research through collaboration with Oxford's Biological Sciences that received media attention for the use of spider silk in nanoscale imaging; 3) Advanced microlaser and nanolaser theoretical and experimental research led by Shore and Hong leading to an EPSRC grant (GBP390,000) in collaboration with the III-V centre at Sheffield University; and 4) Integrated photonic chip technology for infrared applications developed using advanced materials such as nanocrystalline diamond by Nezhad, which led to EPSRC funding (GBP680,000) and international patent filing.</p> <p>Bangor's Digital Signal Processing Centre of Excellence (DSP) led by Tang was established following a GBP6,000,000 (2019-2023) investment from the European Regional Development Fund. The Centre, hosted at Bangor University's new GBP20,000,000 Menai Science Park (M-SParc), focuses on highly specialised research into digital communication systems such as 5G networks and ecosystems. Key projects are focused on: real-time algorithm design, optimisation and implementation; flexible transceivers and networking devices; optical and wireless transmission system convergence; cloud network architecture; software-defined networking; and 5G testbed establishment and field trials. Expansion of this work is a key part of the UK/Welsh Governments' North Wales Growth Deal, which will see a further GBP3,000,000 invested in the centre to accelerate commercialisation.</p>

The **Centre for Photonics Excellence (CPE)**, supported by Welsh Government and EU funds, GBP800,000 (2019-2022), is centred around supporting the regionally important photonics cluster and is a collaboration with industry partners and other universities to assist with translation of new processing techniques and optical coatings used in imaging systems and satellites. **Wang's** group's research on both imaging and laser micromachining is aiding the development of new imaging systems.

2) Energy, Environmental- and Bio-Sensing (Chen, Dahlfors, Hancock, Kettle, Lee, Lewis, Mabrook, Middleburgh, Neill, Nezhad, Palego, Rushton, Spencer, Wang)

Bangor's work in this theme takes a holistic 'systems' approach, with a special focus on a range of Low Carbon Energy activities including nuclear and marine energy systems and sensor technologies relevant to these areas. Bangor's research in this area is heavily focused on enhancing the readiness of new technologies, strengthened through significant academic and industrial partnerships (Section 4).

Highlights include: 1) Development by **Lee** and colleagues of a suite of molten-Pb testing facilities to support Westinghouse Electric and National Nuclear Laboratory research into their lead-fast reactor (GBP450,000) as part of the BEIS-funded Advanced Modular Reactor competition (Phase 2) and the Nuclear Innovation Programme. The facility will act as a national centre for high-temperature lead testing, enabling international collaboration with leading organisations (including SCK-CEN, Belgium; ENEA, Italy; Los Alamos National Laboratory, USA); 2) Research in Bangor's School of Ocean Sciences (**Neill** and **Lewis**) on the monitoring and modelling of new renewable and low carbon energy systems, in particular solar and marine, to guide best practice in quantifying energy generation potential. With GBP5,500,000 of grant income, Bangor's simulation and modelling approach has been adopted globally, creating new research fields in the understanding of real-life system performance and forming the basis of one of our **impact case studies (REF3_02)**; 3) Interdisciplinary sensing research by **Palego**, using a new approach for near-real-time detection of cancer stem cells using ultra-wide broadband radiation, as part of the H2020 Future and Emerging Technologies programme (SUMCASTEC; GBP682,000 to Bangor, total project GBP3,400,000).

Bangor's **Nuclear Futures Institute (NFI)** (launched in 2017 with funding from the Welsh Government (WG), EPSRC, and the European Regional Development Fund, GBP6,500,000) includes extraordinary facilities that are being used by researchers and leading industry stakeholders to aid nuclear technology development. The Institute is led by **Lee**, a world expert in nuclear energy and materials, who was recruited to Bangor in 2016 as part of WG's prestigious Sêr Cymru (Stars of Wales) innovation and science funding scheme. (Sêr Cymru, overseen by the Chief Scientific Officer for Wales, attracts to Wales world-leading researchers and their groups with the potential for high research impact.) The Institute includes a materials manufacture, processing/testing and characterisation facility (funded through NFI and grants won from EPSRC and WG) to enable research on radioactive materials, a unique infrastructure in Wales. This facility is efficiently coupled with computational analysis capabilities that support nuclear energy applications and other low-CO₂ technologies. The NFI has established (in 2020) a reactor modelling group to build reactor physics and thermal hydraulics capability, in support of the UK Government's intentions, set out through the Nuclear Sector Deal, to site a National Thermal Hydraulics Facility in North Wales. Finally, the NFI is developing new areas of speciality research including accident-tolerant fuels, nuclear forensics, and advanced nuclear waste-form design.

Bangor's **Smart Efficient Energy Centre (SEEC)** (European Regional Development Fund, GBP4,600,000) led by **Neill** works across three low carbon energy sectors: ocean energy, nuclear energy, and energy efficient structures, interconnected by a common cyberinfrastructure hub. The project will lead innovation on how advanced engineering, computer science and modelling can be applied most effectively to increase the sustainability of energy supply and utilization, while minimizing negative environmental impacts, in particular net carbon emissions.

3) Visualisation, Data Modelling and Graphics (Ap Cenydd, Kuncheva, Lim, Mansoor, Ritsos, Roberts, Teahan, Vidal)

Bangor's research in this theme has built on its longstanding strengths in machine learning and pattern recognition and has expanded its impacts into Analytics and Virtual Reality (VR). Highlights include: 1) New Principal Component Analysis feature extraction techniques developed by **Kuncheva**, supported by the Leverhulme Trust (GBP226,000), which have been used by the England Cricket Board to identify predictors of elite performance; 2) Development by **Ritsos** of the first open-standards, web-based Immersive VR Analytics framework to standardise the way that data-driven VR experiences are created and deployed on the web; 3) Novel use of procedural animation agents and computer graphics by **ap Cenydd** and **Teahan** enabling commercialisation of 'Ocean Rift', one of the leading VR experiences for a plethora of VR platforms with over 12,000 downloads, described in **impact case study REF3_01**.

This group has considerable interdisciplinary research activity with impacts both locally and internationally. **Vidal's** work on radiography imaging resulted in the development of an open-source software suite that is being adopted in Spain as a tool for formal training for radiography health care workers. The code is hosted on the Simulation Open Framework Architecture site – a prominent library for physics-based medical simulations. The national Supercomputing Wales platform provides access to high-performance computing facilities enabling interactions between **Vidal** and **Ritsos** and the Nuclear Futures Institute around visualisation and high-performance computing expertise.

1.2 Strategic aims for this assessment period

Research strategy is led by the College and School Research Committees, the latter (previously chaired by **Kettle** and now by **Nezhad**) consisting of representatives of the three themes, together with **Spencer** in his role as University Pro-Vice Chancellor Research and Innovation. Under their direction in this REF period, Engineering research at Bangor University has focused on responding to major government strategic drivers, such as the UK's Industrial Strategy, the Welsh Government's Prosperity for All strategy, and the Higher Education Funding Council for Wales's Research & Innovation Vision for Wales. The merger of Electronic Engineering with Computer Science has enabled CSEE to focus on research strengths related to these drivers, in order to grow into strategically targeted sectors. This has enabled us to meet Bangor's commitments in our REF2014 returns (to UoAs 11 and 13) through expansion in the fields of low-carbon electronics and energy, and in medical imaging technologies. Through the School merger and interdisciplinary research opportunities provided by CSEE, we have developed **new research directions** in low carbon energy, digital communications, laser manufacture and emerging medical applications that are globally significant in terms of their industrial and societal impact.

This strategic realignment has enabled us to deliver on Bangor's REF2014 commitment to provide the scientific and engineering research capacity required for regional economic growth. Bangor has delivered this through our investment to meet the needs of regionally important industrial sectors of low carbon energy (NFI, SEEC) and high-value manufacturing (DSP, CPE, The Centre for Lifetime and Reliability Testing [CLARET]). We have secured core funding from the Welsh Government's Sêr Cymru Research programme and European Union to deliver our strategic aims of developing four new facilities (material fabrication and testing lab, lifetime and reliability lab, optical communications/5G lab, and laser micromachining lab) and recruitment of new research staff.

A welcome outcome of Bangor's intense collaboration with companies has been an increase in in-kind company support with staff time, equipment and consumables. While this increased engagement with industry has helped project delivery and research output, it has also generated employment opportunities for our postgraduate researchers. A good example is Creo Medical

(AIM listed), who sponsored five PhD students at Bangor, all subsequently recruited upon graduating.

Our strategy has resulted in a significant strengthening of Engineering research at Bangor during the current REF period. **External research grant expenditure has risen by over 140% per annum per FTE** relative to Bangor's REF2014 combined returns to UoA11 and UoA13 (the two previous units now returned together to UoA12 in REF2021), as a result of increased capture of funding from UKRI and EU sources, and increasingly fruitful partnerships with new and emergent companies. **Research doctoral degrees awarded have grown by over 80% per annum per FTE** compared with Bangor's REF2014 returns, with continued growth expected as a result of Bangor's membership of three doctoral training networks and other similar programmes that are highlighted in Section 2.

1.3 Achievement of impact arising from research

In this REF period, Bangor's Engineering researchers have been intensely focused on conducting research that generates impacts of reach and significance. This agenda has been facilitated since the formation of CSEE by the development of a new impact strategy, led by an academic Impact Director (**Roberts**) who is further supported in this mission by research support staff. We have achieved our impact goals via national and international engagement with industry, academic, and government partners, supported by external funds and building on Bangor's physical facilities.

Industry engagement is illustrated by links from our Centres and Institutes to the spectrum of partners from international conglomerates, to regional SMEs and micro-businesses. For example, the DSP Centre has worked with both multinationals (e.g., BT, Effect Photonics and Vodafone) and SMEs at the centre of the nationwide 5G roll-out. Facilitation by the Welsh Optoelectronics Forum enabled Bangor researchers in the pan-Wales Centre for Photonics Expertise to provide supported access to our state-of-the-art facilities for industry partners. The establishment of the Nuclear Futures Institute has enabled extensive links to industry (Westinghouse, Tokamak Energy, Jacobs etc.) and government (e.g. UK Atomic Energy Authority, National Nuclear Laboratory, Atomic Weapons Establishment and BEIS) partners, and its facilities for on-site uranium testing have provided a framework for industry/academic collaborations that has attracted >GBP1,000,000 of external funding since 2019. CLARET (2014-2019) executed industrially funded research projects on failure analysis/predictive ageing with the photonics and electronics sectors. For example, CLARET supported the anchor tenant (IQE plc) of the internationally important compound semiconductor cluster in South Wales with characterisation and analysis of both wafers and devices (**Spencer, Kettle**).

Our impact-focused collaborations with industrial and academic partners have attracted significant external funding support. For example, applied research funding has been secured from UK national programmes such as UKRI/InnovateUK via Knowledge Transfer Partnership grants (**Taylor, Kettle**), the Royal Society (**Kettle**), the RAEng (**Kettle**), and the Welsh Government's 'Smart Expertise' scheme enabling knowledge transfer to major local companies including Qioptiq and IQE (**Yue, Kettle**). Exploitation funding from UKRI includes the EPSRC Manufacturing the Future seed grant awarded to **Nezhad** (with Cardiff and Southampton University partners) for developing infrared photonic chips using industrially-grown diamond. **Vidal, Ritsos** and **Roberts** are co-investigators on an Oxford-led project that answered a call in May 2020 for visualisation experts to support modelling scientists and epidemiologists in the Scottish COVID-19 Response Consortium (SCRC), and was one of three consortia in the Royal Society's Rapid Assistance in Modelling the Pandemic initiative. The Nuclear Futures Institute has been awarded funding to enable industry/academic collaboration that addresses identified industrial needs: THOR (Thermal Hydraulics Open Access Research facility, GBP338,000, **Dahlfors**), a thermal analysis materials laboratory (GBP110,000, **Middleburgh**) and a strategic partner accelerator grant with Los Alamos National Laboratory (GBP60,000, **Rushton**).

Key tangible indicators of Bangor's success at generating impact from our research are the development of patents, licensing, knowledge exchange, and spinouts. A number of patent portfolios are being developed around: 'Super-lens' imaging (**Wang**); microwave-based cosmetic and skin cancer treatments (**Hancock**); a radiotherapy software suite (**Vidal**); a flexible photonic MEMS platform (**Nezhad**); a miniature RF tracking system that can be fitted to flying insects (**Palego's** interdisciplinary collaboration with colleagues in UoA7); and a suite of patents with Westinghouse Electric (Sweden/USA) and Tokamak Energy (UK) related to nuclear materials and component inventions (**Middleburgh**). Licensing of antimicrobial films to Biolase Ltd/UPS2 Ltd has also been agreed (**Kettle**).

The appointment of **Hancock**, the CTO and founder of Creo Medical plc, to a Chair at Bangor University has helped the company grow from a micro-SME in Bath (2003) to an AIM-listed plc (2018) with a listing of GBP330,000,000 and a manufacturing base, part-funded by Finance Wales. A recently awarded Royal Academy of Engineering Visiting Chair appointment will see a further strengthening of the relationship, with the former CEO of Creo Medical joining Bangor in 2021. Two spinout companies, Laser Micromachining Ltd (the subject of a Bangor REF2014 Impact Case Study) and IDB Systems Ltd (established 2014), continue to flourish and have increased staff headcount by 50% in this REF period.

The preceding examples illustrate how Bangor's strategy for collaboration with industry, academic and government partners has borne fruit with demonstrable impact on both start-ups and multi-national companies. The potential for further acceleration of regional impact from Bangor's engineering research was highlighted in two BEIS Science and Innovation Audits, the North West Nuclear Arc and the North West Coastal Arc Partnership for Clean and Sustainable Growth. This will be delivered through the North Wales Growth Deal (GBP27,000,000 for all three Bangor University projects, led by **Spencer**) targeted at delivering benefits from research to local industry and attracting inward investment to the region.

1.4 Progress toward an open research environment

Since 2014, Bangor has supported an online open-access platform for publications, datasets and software. Data curation and storage processes are in place to ensure compliance with both funder and legal requirements. Policies and procedures are overseen by the University's Digital Strategy group and the central compliance unit, supported by external audits initiated by the University and research funders. Open access funds were made available to authors to enable compliance and dissemination of outputs.

Bangor researchers have used European Regional Development Funds (GBP1,500,000) to create an open-research resource, the iMarDis system, a data portal that streamlines access to our marine and oceanographic data and models for our research collaborators and end-user partners in the commercial and private sectors; it is a core component of Bangor's Smart Efficient Energy Centre. This system was established as a solution to the unmet industrial demand for data; currently 70% of the registered users are government agencies or industry.

1.5 Support for a culture of research integrity

Bangor's research governance and integrity policies and procedures adhere to Universities UK's Concordat to Support Research Integrity (2012; revised 2019). The College ethics committee, comprising representatives from across disciplines and career stages, takes responsibility for ensuring that ethical issues raised by our research are properly understood, considered and addressed. The committee provides training on research integrity and research ethics for new staff, and organises research ethics seminars where current issues are shared and discussed. More granular decisions regarding research ethics and integrity are presented and resolved in the School's Research Committee.

Some of the work undertaken by the Nuclear Futures Institute requires notification to the UK's Office for Nuclear Regulation, a process that is overseen by the University Radiation Health and Safety sub-committee, with operational oversight undertaken at School level. Some Nuclear Futures Institute staff also have high-level security clearance, but no sensitive nuclear data is held at Bangor. Some of the interdisciplinary work undertaken with colleagues in biological and marine sciences requires research governance oversight to ensure compliance with the necessary legislation and ethical issues. This is addressed via the College Health and Safety and Ethics Committees and the University level equivalents, which in turn report to University Executive and Council.

The University has policies and procedures in place that address wider research governance and integrity issues with clear reporting processes for 'whistle-blowers' and misconduct concerns. Induction training and awareness raising seminars are run by Bangor's Human Resources Department and Governance Office.

2. People

2.1 Staffing Strategy and Staff Development

Bangor University develops, supports and rewards the research excellence of all research staff. Continuing the successful strategy employed in REF2014, we have: appointed and promoted academic staff with high potential to deliver excellence in research or who already are research leaders; focused appointments where they can grow capacity in the School's priority research areas; and encouraged research-led incoming and outgoing secondments with world-leading universities and major national/international companies. We have rewarded excellence through promotion: in this REF period, five staff members to Professor/Reader and another five to Senior Lecturer, including four who were early career researchers submitted to REF2014.

We place special emphasis on providing early career researchers with a mature but flexible structure to flourish within. In this REF period, we have recruited promising early career researcher (ECR) staff (**Dahlfors, Lewis, Middleburgh, Rushton, Yue**) who we are developing into research leaders through mentoring by senior, established academic staff (further supported by Bangor University's academic mentoring scheme). For example, during this REF period, Dahlfors, Lewis, Middleburgh and Rushton have all succeeded in capturing substantial external grant funding. Former ECRs have been inducted into positions of responsibility, supporting succession planning and sustainability of Engineering at Bangor (e.g., **Nezhad** to School Director of Research and **Ritsos** to Director of External Engagement). Of those staff submitted as ECRs to REF2014, 75% have captured at least one major research grant >GBP350,000 in this REF period.

Funding applications are reviewed by the School and College Research Committees or other experienced staff mentors, with particular attention paid to those aimed at UKRI, and those prepared by ECRs. The same colleagues also offer support in responding to grant application reviews and comments. The Research Committees coordinate Bangor's response to cross-disciplinary opportunities. Practice and feedback are provided for interviews: for example, **Nezhad's** successful EPSRC Innovation Fellowship (GBP630,000) was supported by a mock panel of colleagues from CSEE and other Bangor Schools. The University's research office also provides central support for research contracts (UK and international), knowledge-transfer, and IP support.

The University's workload allocation model balances research, teaching and administration, with significant research commitments matched by reduced teaching and administration. New staff are allocated reduced teaching loads during their first three years to allow them to establish their research programmes. Staff participate in the annual Performance Development Review process, providing an opportunity to discuss expectations, training needs and career development.

Bangor supports its engineering researchers by providing 'pump-priming' funding, on the condition that this results in research grant submissions, for: laboratory provision, small items of equipment/consumables, attendance at conferences and visiting academic/industrial partners, and support for patenting and providing open-access to research outputs.

2.2. Commitment to equality and diversity

We value the talents and skills of all staff and seek to ensure our working environment, and opportunities for career progression, are fully inclusive. Bangor University's commitment to gender equality is captured by our institutional **Athena Swan Bronze Award**, initially won in 2011, renewed in 2014 and in 2018 (valid until 2023). Bangor is also recognised for its support of women in the traditionally male-dominated field of Engineering by **CSEE being awarded a Bronze Athena SWAN Award in 2020**, which includes a 4-year action plan to promote change that feeds into School and University strategy. Delivery of the plan is the responsibility of the Head of School, supported by a task and end group. Opportunities are made open to all by transparent processes for recruitment, promotion, appointment to school positions, and allocation of duties. We strive to improve gender balance through enhancing recruitment and promotion processes. CSEE invests significant staff time in an extensive schools' outreach programme (Technocamps) that seeks to raise awareness and address diversity issues by highlighting STEM careers to school children, their parents and other influencers.

Our colleagues are active in Bangor's LGBTQ Network and support is provided to meet the needs identified by the Equality and Diversity self-assessment teams. Measures such as the scheduling of meetings and seminars in core business hours to assist those with caring responsibilities, and the provision of funding for staff, PDRA and PGR development needs (including conference attendance) have been in place throughout the REF period. The Head of School has overall responsibility for ensuring all Equality and Diversity policies and procedures are followed, and is aided by the support of a designated contact in Human Resources.

2.3 Post-doctoral progression – Research Associates

All postdoctoral researchers and fellows are offered training in research, teaching (PGCertHE), career management, personnel management, and research ethics. This is in addition to the technical training and mentoring such researchers receive in the laboratory setting as part of their research projects. Opportunities to assist in teaching activities (e.g., guest lecturing) are offered regularly. Our postdoctoral alumni have gone into academic and industrial positions, such as Senior Researcher at **ADVA Optical Networking**, Senior Project manager at **Huawei Research** (Munich), Senior Process engineer at **Smartkem**, Multiphysics Engineer at **Effect Photonics** (Netherlands), and Senior Lecturer at the **University of Lincoln**. Several former Bangor postdocs have joined CSEE as permanent staff via open competition (**Ritsos, Hong and Vidal**).

2.4 Post-Graduate Research students (PGRs)

The number of doctoral degrees awarded in Engineering at Bangor has risen by over 80% on a per FTE per annum basis in this REF period, compared to Bangor's REF2014 combined returns to UoA11 and UoA13. A major factor in this success is that, since 2014, Bangor has won funding for **three prestigious UKRI doctoral training networks**: (1) the EPSRC Centre for Doctoral Training in Nuclear Energy Futures (in partnership with Imperial College, University of Cambridge, and Open University) established in 2019; (2) the UKRI Centre for Doctoral Training in Artificial Intelligence, Machine Learning & Advanced Computing (with Swansea, Bristol, Cardiff and Aberystwyth Universities) also established in 2019; (3) the NERC Envision Doctoral Training Programme (with Lancaster and Nottingham Universities), which was recently renewed. Further PhD studentships have been awarded by the Fujitsu High Performance Computing

Wales project associated with Supercomputing Wales; EPSRC CASE partnerships (e.g. with Merck) and international government scholarships. The CDTs and DTP provide high quality programmes of structured training for each student cohort across the partner institutions, based on their excellence in engineering and related sciences.

The Sêr Cymru National Research Network in Advanced Engineering and Materials (2012-2018), a major GBP7,000,000 Welsh-Government funded initiative, has seen Bangor secure GBP1,800,000 via competitive externally reviewed process, which has provided an important source of PGR funding for ECR staff with 6 studentships awarded. The network was key to collaboration with major engineering centres across Wales, including the Institute of Energy and the Compound Semiconductor Centre at Cardiff University, Solar Research and Active Buildings and the Centre for Nanohealth at Swansea University, and The Welding Institute (TWI), enabling PGR access to specialist equipment not readily available in Bangor. The DSP Centre of Excellence has recruited 8 PGRs during the REF period. Finally, a large cohort of PGRs (16 PhD, 3 MRes) has been recruited to Engineering at Bangor through the Knowledge Economy Skills Scholarships (KESS) scheme. This pan-Wales initiative, led by Bangor, is supported by European Social Funds (2015-2023, GBP56,000,000) to link industrial partners with Welsh universities for collaborative PhD or Research Master's projects.

PhD progress is monitored by the University's Doctoral School, which also provides training and social activities. All PhD students have a supervisory committee and a personal tutor. The Doctoral School, as well as CSEE, have mechanisms in place to support students having health or wellbeing issues. PGRs are **embedded in areas of research strength** via the three research themes and associated centres that create supportive cohorts, and are provided with transferrable skills training by the Bangor Doctoral School (e.g. in research management, presentation skills, writing, and interview skills). The College organises a weekly seminar series and three post-graduate research conferences per year. At the latter our PGRs present a poster (2nd year) or talk (3rd year) to a wide cohort of fellow PGRs and staff, allowing them to develop their presentation skills and multidisciplinary contacts.

We place great emphasis on PGR students visiting partner institutions, enabling them to gain skills and promote their research, and to initiate collaborations and information exchange that will last beyond their projects. In 2019, **Middleburgh** and **Rushton**, 2 PGRs and a PDRA travelled to Sweden to work with KTH University and Westinghouse Electric (funding through the Supporting Collaborative Research and innovation in Europe - Wales scheme). **Palego** and **Kettle** have enabled students to visit MIT and Harvard as part of their PhD studies using funding from the University's Wynn Humphrey Fund, supported by the Drapers Livery Company. Other internal funding schemes (e.g. Santander travel bursaries) have enabled PGRs to visit Ben Gurion University (Israel), MCAST (Malta), URJC (Spain), Analog Devices (Ireland) and NUT (Taiwan). **Rushton** acquired a GBP60,000 Sêr Cymru Partnership Accelerator Award for Nuclear Futures Institute PGRs to spend extended periods at Los Alamos National Laboratory (USA). Long-term visits have enabled PGRs to perform Small- and Wide-angle X-ray Scattering measurements at the National Synchrotron Radiation Research Center (Taiwan) and at Brookhaven National Laboratory (USA).

2.5 Incoming and external appointments

Visiting and Honorary appointments closely link each theme to key academic and user communities, thus promoting the delivery of research impact. Examples include: the Chief Scientist at the National Nuclear Laboratory, who works closely with Bangor's Nuclear Futures Institute on structural integrity in nuclear technologies, and the Chair of the Snowdonia Enterprise Zone, who links us to community programmes, researchers and engineers. Amongst local industrial leaders, the CEO of Comtek, Askar Sheibani (Honorary Entrepreneurial Fellow), who chairs the industrial panel of the North Wales Economic Ambition Board, has become a close collaborator with Bangor via the DSP centre. Professor Terry Hewitt (EDS/Hewlett Packard) works with researchers in our Visualization, Data, Modelling and Graphics theme to

support the high-performance computing provision in the University and secure funding for the Supercomputing Wales project.

Outgoing appointments are encouraged to secure additional funding sources or significantly enhance the quality of research outputs. Examples include: **Palego**, Adjunct Professor, Lehigh University, USA; **Kettle**, Institute of Catalan Nanotechnology, Barcelona; **Nezhad**, National Graphene Institute, University of Manchester. **Rushton** was seconded to Los Alamos National Laboratory, USA for 5 weeks to build a collaboration for modelling radiation damage in sensing materials, which led to a GBP60,000 Sêr Cymru Partnership Accelerator Award.

3. Income, infrastructure, and facilities

3.1 Research funding portfolio and future plans

Total external research grant expenditure for Bangor Engineering over the REF2021 period was more than GBP16,000,000. Of this, over GBP2,250,000 was from UKRI or equivalent status funders, equating to an increase of 58% on a per annum per FTE basis over Bangor's REF2014 combined returns to UoA11 and UoA13.

Bangor was a partner in the pan-Wales GBP7,000,000 Sêr Cymru National Research Network in Advanced Engineering and Materials (NRN-AEM; Welsh Government, 2012-2018) securing GBP1,800,000 for Bangor projects. Bangor led the NRN in Low Carbon, Energy and Environment (NRN-LCEE; Welsh Government, with a total budget of GBP7,000,000, 2012-2019). The success of Bangor's roles in these networks paved the way for the Welsh Government's funding to establish the **Nuclear Futures Institute**. The NRN's promote collaborative and interdisciplinary research within Wales, providing seed funding to Bangor ECR staff, and enabling impact from our research collaborations with science end-users by involving them from the outset of project planning. Examples include **Nezhad's** collaborations via NRN-AEM with Cardiff University, leading to his UKRI Innovation Fellowship award on 'Optically Actuated Microrobots' (GBP630,000), which aims to realise sub-millimetre, light-powered robotic structures. The research of **Shore** and **Hong**, who continued theoretical and experimental work on nanolasers, and which was subsequently supported by EPSRC (Ultrastable High-Performance Nanolasers, GBP390,000) was in part aimed at producing light sources for applications such as Nezhad's Microrobots.

Neill led the NRN-LCEE cluster 'Quantification, Optimisation, and Environmental Impacts of Marine Renewable Energy' (GBP400,000), which led to an EPSRC project grant on tidal energy (GBP1,389,372) and the EPSRC Fellowship to **Lewis** (2019; GBP287,382). **Rushton** leveraged Sêr Cymru funding to win the EPSRC Centre for Doctoral Training in Nuclear Energy Futures (2019-2028).

Support from the Welsh Government directly facilitated funding from the European Regional Development Fund, which has supported the establishment of Bangor's DSP Centre, Smart Efficient Energy Centre (SEEC), and Centre for Photonics Expertise (all 2019-22; total GBP11,400,000). These centres have allowed us to expand our cutting-edge research into industrially relevant areas and enable us to link our science directly to end-user industry partners. Importantly, they were often used to leverage UKRI and European grants; examples include **Kettle's** DEPICT project funded by InnovateUK (GBP498,000, 2018-2019, led by IQE plc).

Looking ahead, we recognise the need to adapt and diversify to remain resilient in the changing funding landscape. Our aim is to grow our areas of research excellence and prioritize activity that has the potential for transformative societal and economic impact of international significance. This approach aligns us with the policy and funding mechanisms of the Welsh and UK Governments, and positions us to benefit from the 'Levelling-up' agenda. Structural changes that are needed to enable this ambition are already either in place or at an advanced stage of planning. The formation of the new College of Environment Sciences and Engineering sought to

increase interdisciplinary working, already leading to fruitful collaborations such as SEEC, the insect-tracking work of **Palego**, and the bio-inspired work of **Wang**. Support for a further step-change increase in interdisciplinary working will be driven by Bangor's new ten-year research strategy, supported by transformative improvements in the physical estate and overseen via the annual strategic planning round.

European Investment Bank and North Wales Growth Deal funding will be used to co-locate Engineering and Computer Science within a refurbished Science campus, along with the majority of the rest of the College. Expansion of Bangor's DSP Centre has been initiated; formal recognition as a 5G Centre of Excellence by the UK Government's Department for Digital, Culture, Media and Sport is being sought with the support of Welsh Government. The DSP Centre will also work with colleagues in the Compound Semiconductor Centre in South Wales to develop sub-systems to help meet the UK requirement for locally sourced telecoms equipment. This movement up the supply chain from III-V wafer to devices and now on to sub-systems will be aided by the planned expansion of our cleanroom facilities. Investments in state-of-the-art nanofabrication capabilities will enable us to assist the development of SMEs in the electronics, photonics and bioengineering domains.

We also seek to capitalise on the materials science expertise of the Nuclear Future Institute by growing the analytic facilities at Bangor through a centralised Materials Analysis Laboratory that will be catalytic for other research groups and accessible to local businesses. NFI also seeks to become an integral partner in the UK's medical isotope research network. In particular, with support from Welsh and UK Governments, there is the potential for a Medical Isotopes Research Reactor to be sited on the local decommissioned nuclear site at Trawsfynydd.

Via collaboration with key stakeholders, such as the Welsh Government and the Betsi Cadwaladr University Health Board, the University aims to expand its current medical and clinical training to a full North Wales Health and Medical School. The School's interdisciplinary research would incorporate existing Bangor expertise in medical devices (**Hancock, Palego, Chen**), virtual training (**Vidal, Panos**) and emerging excellence in digital systems that support health care provision in geographically dispersed communities (**Tang, Giddings**). The appointment of at least 4 new Early Career Researchers through the Sêr Cymru scheme, in emerging multidisciplinary theme areas such as Control and Instrumentation; Medical Isotopes and Nuclear Medicine; Nuclear Co-Generation; and Functional Sensor Materials has already commenced.

We recognise the need for an agile approach to research planning that ensures alignment with emerging opportunities and mitigates risks. Research partnerships with a carefully selected set of institutions offer an important risk-mitigation strategy and will be an essential consortium-building tool needed to address the 'Levelling-up' agenda: MoUs have been signed with key stakeholders both within the UK and overseas (Section 3.3). Regular information sessions are held at various levels with relevant civil servants, politicians, funding agencies and industrial trade bodies, such as the CBI and the Federation of Small Businesses, to raise awareness of research projects that have the potential for mutually significant translational impact. Increased research through these partnerships requires access to a highly skilled researcher base in North Wales and we are putting in place pathways to attract, develop and retain high quality researchers, particularly ECRs. Increased research translation and company interaction will be sought by increasing professional doctorates, especially where there are important regional opportunities in sectors seeking to move to a zero carbon footprint (Aerospace, Automotive, Energy and Photonics).

3.2 Infrastructure and facilities

Bangor University has substantially invested in Engineering research infrastructure over the REF2021 period across our three research themes areas, to a total of GBP3,860,000 on laboratories and equipment, as described below.

Within the **Energy, Environmental-, and Bio-sensing** theme, **marine energy and ocean engineering** are of particular local significance, given the proximity of tidal energy sites around Anglesey, including the West Anglesey Tidal Demonstration Zone. The University's shelf sea 35-m research vessel, the **RV Prince Madog**, provides infrastructure for ocean energy research, supported by a team of electronics technicians and a range of instrumentation. This vessel is capable of hosting 10 scientists continuously at sea for up to 10 days, which facilitates collaboration with numerous UK research institutions and government partners. During this REF period the Prince Madog was equipped with a **new multibeam seabed mapping system** (GBP250,000) enhancing both mapping resolution and spatial scale. This makes Bangor one of the best-equipped UK universities for offshore energy resource assessment and characterization. These facilities are complemented by the iMarDis system, a data portal that streamlines our data acquisition and storage, and three Coastal Observatories (GBP450,000) that house 18 different oceanographic sensors and feed real-time data to iMarDis, providing some of the highest temporal resolution data available for marine energy research and increasing the spatial scale we can cover during surveys. Bangor's investment in the Prince Madog has led to grants of GBP1,200,000 (2014-20) for ocean renewable energy surveys, which link closely with our **data modelling** research.

Other investments in the Energy and Environment theme include the Nuclear Futures Institute's 4 new purpose-built laboratories (GBP700,000), which include **active materials manufacture and characterisation** laboratories with a new scanning electron microscope, Raman and X-ray diffraction. Sub-kilogram scales of uranium can be handled for fuel development investigations. These facilities support industrial projects and enable further inward funding (e.g. through the Sêr Cymru II infrastructure accelerator grant (GBP110,000) for thermal analysis equipment and a number of research projects totalling >GBP1,000,000). The Welsh Government recently funded the Thermal Hydraulics Open-access Research facility (GBP350,000) to provide initial research and develop the skills base for the GBP60,000,000 National Thermal Hydraulics Facility planned to be located in North Wales, a critical capability to support next-generation nuclear energy, as highlighted in the UK Government's Nuclear Industry Sector Deal. These will provide sustainable research projects for new nuclear reactor designs and propel the University to a world-leading position in this field.

Additionally, Bangor's **reliability testing facilities** were expanded via the Academic Expertise for Business (A4B) CLARET project (GBP500,000) enabling highly accelerated life testing/stress screening, thermal humidity and thermal cycle testing. Further enhancement of the facilities has been achieved through individual grants: UKRI KTP funding has been used to install new electrical test equipment for reliability; SPARC II, a European-funded collaboration with Swansea and Aberystwyth Universities (2017-2023), has enabled new accelerated UV-testing stability chambers to be commissioned; and private funding from Landis+Gyr has been used to install a new salt-spray fog environmental chamber. This set of energy-related facilities has been designed to meet the need for integration of research, innovation and industrially-funded work in the energy sector. It now acts as a hub and infrastructure centre for numerous interdisciplinary projects across the College.

The consistent growth of the **Photonics and Communications** theme over the REF period has been enabled by strategic investments in staff and infrastructure, resulting in further grant capture and expansion of our research facilities. The DSP Centre alone has commissioned high-speed waveform generators, oscilloscope, optical spectrum analyser and vector network analyser (GBP1,500,000). Expanded surface metrology equipment, including a laser confocal microscope, was funded by Welsh Government. Our laser processing facilities have been greatly expanded by **Wang and Chen**, with six new laser processing systems giving a total of eight spanning a wide range of wavelength (355 nm – 10.6 μm) and temporal ranges (femtosecond – CW), including nanosecond lasers (GuoKe 355nm UV, 1064 nm fiber laser), femtosecond laser (Tropical, Spectra Physics) and CO₂ laser systems (Trotec Rayjet, Speedy 300W, 400W, 500W). **Nezhad's** EPSRC Fellowship has provided state-of-the-art photonic chip

testing, including high resolution L+C band spectral sweeping and an integrated nanomechanical testing capability.

Bangor opened the GBP20,000,000 **Menai Science Parc** in 2018 with major investments from Welsh Government and EU sources. M-SParc is focused on exploiting and commercialising Bangor's research to realise benefits for the local economy, with a focus on low-carbon energy and digital sectors. It is sited within Anglesey's Low Carbon Energy Enterprise Zone. M-SParc now houses the DSP Centre's commercial exploitation work and the THOR experimental facility of the Nuclear Futures Institute.

3.3 Collaborative use of research infrastructure

Engineering at Bangor follows a culture of equipment and infrastructure sharing, both internally and also with external users and facilities. As a result, cross-collaborations are common and follow both themes/centres, and organic collaborations between individual PIs. The CSEE Research Committee has an ethos of facilitating Bangor's Engineering researchers. It plans research directions, infrastructure needs, and collaborations, deciding on priorities and providing guidance. Specific investment proposals are considered and decided based on expert consensus among staff stakeholders. This co-ordinated approach has already enabled a significant shift towards both industry collaboration and successful UKRI funding.

Collaboration with strategic partner research groups and industry has been set up through formal memoranda of understanding and research agreements with, for example, Imperial College, University of New Brunswick (Canada), Nuclear Advanced Manufacturing Research Centre, the UK National Nuclear Laboratory, Siemens (Germany), Thales (France), Hitachi-GE (Japan), Westinghouse Electric Company (USA, Sweden and the UK). The longer-term impact of these partnerships is to support the development of high-value supply chain clusters in the North Wales region's key export sectors (aerospace, automotive, photonics and renewable energy) and emerging new sectors (next generation nuclear, environment, 5G, medical devices and microrobotics), providing high value jobs and sustainability to the region.

In addition to informal collaboration arrangements between PIs and research centres for sharing laboratory setups and test equipment, CSEE also operates several large infrastructure items that operate on a shared infrastructure basis (e.g., the microfabrication cleanroom and the laser processing lab). These are open to both School staff and external users (fee-based for the latter). Access to the cleanroom is governed by a dedicated equipment reservation calendar and a robust training and qualification process is in place for rapid induction of users. The success of these policies has led to them being adopted widely across the University (for example in NFI's new materials characterisation facility). Direct access or secondments of external staff to undertake research in our cleanroom, material, reliability and device characterisation labs has generated external income of nearly GBP200,000 since 2014.

Our researchers also make use of major external facilities. **Nezhad** has been a visiting researcher at the National Graphene Institute (University of Manchester) since 2017, enabling use of cleanroom infrastructure and equipment, and sharing of technical knowledge with the Institute team. Other examples include the Nuclear Future Institute's access to the National Nuclear Users Facilities (including the Dalton Nuclear Institute's Cumbria [irradiation] Facility and UK Atomic Energy Authority Materials Research Facility at Culham), **Vidal's** use of the Diamond Light Source synchrotron and **Roberts'** role as Bangor's lead in Supercomputing Wales.

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

4.1 Collaborations and interdisciplinary research

Bangor University has a long track record of national and international collaborations in engineering. Internal support is provided to enhance success with international grant

applications such as the Newton fund, which has led to collaborative projects with University Londrina (Brazil), Vietnam Academy of Science and Technology, and University of Sao Paulo (Brazil). Other significant interdisciplinary and/or international grants include those from EU sources such as the H2020 “Future and Emerging Technologies” projects: SUMCASTEC (led by Limoges and Bangor Universities (**Palego**)), SteelPV (**Kettle**) and Marie Curie networks (**Chen**). The SUMCASTEC collaboration of engineers and biologists has resulted in novel bio-electric experimental techniques for studying cancerous brain cells. EPSRC seed funding and NRN-AEM grants have enabled new collaborations on silicon and diamond integrated photonics between **Nezhad** and Cardiff and Southampton Universities.

Interdisciplinarity is a defining feature of our research that has been significantly facilitated by the establishment of CSEE during this REF period. Outputs submitted to REF2021 include 52 publications (81% of total) co-authored with collaborators from other institutions, including UK and international research leaders in physics, ocean science, bio- and environmental sciences, chemistry, economics, mathematics and medicine. Exemplars include published work on microwave medical equipment (**Hancock/Palego**) co-authored with two consultant gastroenterologists. Two PhD students have been funded by KESS2 to research bee telemetry, with co-supervision between UoA12 engineering (**Palego**) and UoA7 environmental science staff, and close collaboration with Agritech industry to develop technology for monitoring pollinators. Other funded interdisciplinary collaborations have been with environmental and Agritech researchers in the Institute of Biological, Environmental and Rural Sciences at Aberystwyth University to develop low-cost and printed methane sensors for monitoring greenhouse gas emissions (**Kettle**).

4.2 Industrial collaborators

A range of projects have been supported by industrial collaborators. Industry-facing centres have been established as part of the CLARET project led by **Kettle** through industrially-funded projects on reliability engineering with around 15 companies, which generated significant repeat business, leading to KTP projects and InnovateUK funding. The DSP Centre’s 27 industrial partners provide in-kind support. Additional work by **Kettle** includes expert advice to Walker Morris LLP for quality investigation of electronic products. Other technology transfer saw GBP285,000 secured by via two KTP projects with Smartkem, and direct cash contributions to undertake collaborative research, and a further successful KTP with PolarOLED. In the renewable energy sector, the research of **Neill** and **Lewis** has supported research projects with industrial partners Minesto, Morlais, Nova Innovation, SIMEC Atlantis, Nortek, Deltares, and SBS International Ltd, and The Met Office. **Middleburgh** has an ongoing industrial collaboration with Westinghouse Electric including membership of the GBP10,000,000 consortium (funded by BEIS) to work on their lead-cooled advanced modular reactor (GBP300,000 supporting Bangor University). The Virtual Reality research of **Ap Cenydd** informs an ongoing collaboration since 2013 with a range of international companies, such as Facebook/Samsung/Xiaomi. Industrial projects have also been a useful funding source for many of our PhD students. The EPSRC CDT in Nuclear Energy Futures is supported by most major nuclear companies in the UK who provide GBP5,200,000 of in-kind support to the whole network. The KESS II PhD programme has supported 15 industrial-focused PhD students, including with Westinghouse, AstralDynamics and Qioptiq.

In addition to direct research collaboration with individual companies, Bangor staff also sit on advisory boards. For example, **Lee** serves on the Technical Advisory Board for several companies: the National Nuclear Laboratory, the Royal United Services Institute, Morgan Advanced Materials plc, Tokamak Energy plc and RHI-Magnesita plc. **Rushton** sits on the Nuclear Academic and Industry Liaison Sub-committee of the Nuclear Institute, which provides a key interface between academia and the nuclear industry. **Kettle** was the Vice-chair in the COST Action Performance and Reliability of Photovoltaic Systems, involving 37 countries, with the aim of improving the energy performance and reliability of photovoltaic (PV) solar energy systems in Europe.

4.3 Contribution to society

We disseminate our engineering research in a tailored way appropriate to the intended audience and objective. Our secondary schools and FE outreach has sought to highlight the opportunities of a STEM career in a way that addresses diversity issues and raises aspiration of pupils by using role models that they can relate to. In Bangor's North Wales context, that means being sensitive to the bilingual nature of the local community. Bangor's role in the Wales-wide Technocamps project (supported by EU and Welsh Government funds of GBP1,100,000) has led to children from over 100 local schools being introduced to coding, robotics and control electronic research, utilizing relevant research from our **Visualisation** theme. CSEE is also home to the 'Photonics Academy for Wales @Bangor', which enables photonics research projects to be undertaken by high school students. Both of these programmes have also sought to inform and educate parents and other influencers who have a significant impact on children in their formative years. Capacity for societal outreach from our research is greatly enhanced by Bangor University's GBP51,000,000 Pontio Arts and Innovation Centre, which opened in 2015 and includes a business development hub with an MIT-accredited 'Fab-lab' that provides a venue for local users to develop and exploit innovative ideas at different scales. Science discovery sessions are incorporated into Pontio's Arts programme, and CSEE hosted an 'Artist in Residence'. Bangor's engineers also worked with the theatre group Acrojou on a production exploring chaotic dynamics.

We have also extensively used more familiar methods of dissemination, including presentations at major national/international events and coverage in national media. **Shore** led events in Wales for the 2015 UN International Year of Light and was Chair, Science and Technology Committee, National Eisteddfod of Wales 2017, which attracted 25,000 visitors to the Science and Technology Pavilion. **ap Cenydd** organised an underwater VR exhibit at the American Museum of Natural History, New York (2017) and exhibited at National Eisteddfod (2017), M-SParc (2018), local schools (2016-Present), the Bangor Science Festival (2014-2018), and the House of Commons (2019). **Kettle, ap Cenydd, Wang, Palego, Lee, Rushton** and **Middleburgh** have been interviewed on BBC Wales and **Roberts** on ITV to communicate and promote their research. Our staff are encouraged to publicise their research using the University's press office and media such as *The Conversation*; examples include "*Researchers invent device that generates light from the cold night sky*" (**Kettle**), which attracted 60,000 views. The University also introduced a social and digital media strategy to promote research in this REF period, which greatly benefited dissemination of **Wang's** research; his 'spider silk' microscope reached >15,700 web pages with 110,000 views since publication.

4.4 Other esteem indicators

Examples of instances demonstrating esteem during the assessment period are:

- **Lee** served on the US National Academies of Sciences, Engineering and Medicine Committee for Independent Assessment of Science and Technology, for the Department of Energy's Defense Environmental Cleanup Programme. He was the only non-USA member and the committee reported direct to US Congress. He was also a member of the UK Government Nuclear Innovation and Research Advisory Board (2014-17), the Royal Society Policy Briefing Committee on Nuclear Co-Generation and the Global Challenges Research Fund Networking Grants scheme Awards panel, an Evaluator for the EC H2020 Widespread programme Teaming Phase 2, and on the External Advisory Board of a multi-member US consortium Center for Performance and Design of Nuclear Waste Forms and Containers hosted by Ohio State University.
- **Middleburgh** is a member of the team working with the Foreign Office, Ministry of Defence and Counter Proliferation & Arms Control Centre as an expert on nuclear fuel

manufacture and behaviour for the UK's commitment to the Joint Comprehensive Plan of Action (colloquially called the Iran Nuclear Deal, 2018-2020). **Rushton** and **Middleburgh** are members of the EPSRC UK-Japan panel for civil nuclear research funding.

- **Neill** was a steering committee member of a US Department of Energy SNL "Early market Hotspot" project (2017-2019).
- **Kettle** was a member of the Advisory Board to BEIS on future of Research Fund for Coal and Steel.
- **Lee, Shore, Giddings, Ritsos, Roberts** and **Nezhad** are full members of the EPSRC Peer Review College. **Kettle** and **Hong** are associate EPSRC Peer-Review College members and **Neill** a NERC Peer-Review College member.
- **Roberts** was Chair of an ICT, EPSRC prioritisation panel. **Neill** is an assessment panel member of the EPSRC UK/China offshore renewable energy call.
- **Nezhad** was invited as a 'Silicon Photonics Champion' by the University of Southampton to assist in preparing their 2020 bid for a Silicon Photonics National Research Facility.
- **Hancock** received the **IOP Katharine Burr Blodgett Medal** for designing and patenting an electro-surgery platform to treat lesions in the gastrointestinal tract.

4.5. Fellowship/leadership of significant societies

Our staff have achieved national and international recognition in multiple diverse areas. Examples during the REF201 period are:

- **Shore** is the General Secretary and Council member of the Learned Society of Wales.
- **Lee** is a Fellow of the Royal Academy of Engineering; City and Guilds Institute; Institute of Materials, Minerals and Mining; American Ceramic Society and Foreign Fellow of the Indian National Academy of Engineering. He was also President of the American Ceramic Society (2016-17), the first from outside the USA in its 120-year history.
- **Tang** is a Fellow of The ERA Foundation.
- **Kettle** is member of International Electrotechnical Commission (IEC) 63288 Technical Discussion Group (2018-present).
- **Neill** is a member of the International Electrotechnical Commission (IEC) committee on Tidal Resource Characterization and Assessment (developing the international technical specification), plus the corresponding British Standards Institution committee (2016-present)
- **Rushton** and **Middleburgh** both sit on the Materials Chemistry Committee of the Institute of Materials, Minerals and Mining and are members of the Nuclear Institute. **Middleburgh** has been awarded Fellowship of the Institute of Materials, Minerals and Mining (2020).

4.6 Editorial boards/Conferences

Five members of staff have been full editors/sub-editors of journals since 2014 including **Lee** (*Journal of the American Ceramic Society*, *Ceramics International*, *Advances in Applied Ceramics*), **Kettle** (*RSC Advances*), **Vidal** (*Array*), **Roberts** (*Journal of Information Visualisation*), **Neill** (*Renewable Energy*), **Middleburgh** (*MRS Advances*).

4.7 Conferences

Bangor's Engineering researchers have made 67 invited research presentations and 18 keynotes/plenary presentations since 2014. We have acted as 16 conference chairs/convenors including at major conferences such as IEEE International Microwave Symposium (Honolulu, 2017). Our staff have been members of 32 programme committees, and we have hosted three

international conferences. **Middleburgh** was a symposium organiser for the Fall Materials Research Society 2019 meeting “Structure–Property Processing Performance Relationships in Materials for Nuclear Technologies.” **Lee, Rushton** and **Middleburgh** hosted the UK Nuclear Academics Meeting at Bangor with Imperial College, attended by around 100 academics, industry and civil servants, and **Kettle** the 13th PVSAT (Photovoltaics Science, Applications & Technology) with around 200 academics. **Vidal** was the Conference Chair for Eurographics: Computer Graphics & Visual Computing 2019.