

Institution: University of Wolverhampton

Unit of Assessment: 12 Engineering

1. Unit context and structure, research and impact strategy

1.1 Unit Research Structure

Engineering is a key subject area of the Faculty of Science and Engineering at University of Wolverhampton (UoW). The Faculty was established in 2013, providing a multidisciplinary research environment which would enable the introduction of Aeronautical, Medical and Chemical Engineering courses and provide a platform for the University to expand research in a coherent and strategic fashion around a broad central theme of applied engineering.

The Unit comprises 30 staff (29.1 FTE) who have significant responsibility for research. Research within this Unit can be broadly split between Engineering and Science, with activities aligned with the University's ambition to transform lives through research, extending from theoretical studies, to delivering research-led innovation and solutions aiming to benefit society and the economy.

Activities in the Unit are organised through two overarching Research Centres (Figure 1). These create an environment for interdisciplinary work by drawing together researchers from a range of disciplines under broad research themes:

- 1) Centre for Engineering Innovation and Research (CEIR): based at Telford, CEIR has benefitted from a multi-million pound investment in equipment, infrastructure and buildings to facilitate the development of a successful research centre. This brings together groups working on Advanced Materials and Composites, Advanced Manufacturing, Energy and Battery Storage and Structural Mechanics and Vibrational Acoustics. The research has a strong focus on industrial strategy, often co-developed with local companies and looking further afield into emerging technological applications.
- 2) Centre for Materials Science Research (CMSR): based at the City Campus and established in 2018, CMSR has benefitted from a total refurbishment of laboratory facilities providing a focus around which chemical, biological and physical materials sciences has been able to flourish. The Materials and Polymer Science groups along with the group on Light-Matter Interactions work in areas of research with a strong emphasis on sustainability, directed towards industrial application. CMSR provides fundamental expertise in both theoretical and developmental work, which complements the work of CEIR, providing a route from research idea, to bench, and then to industrial application.

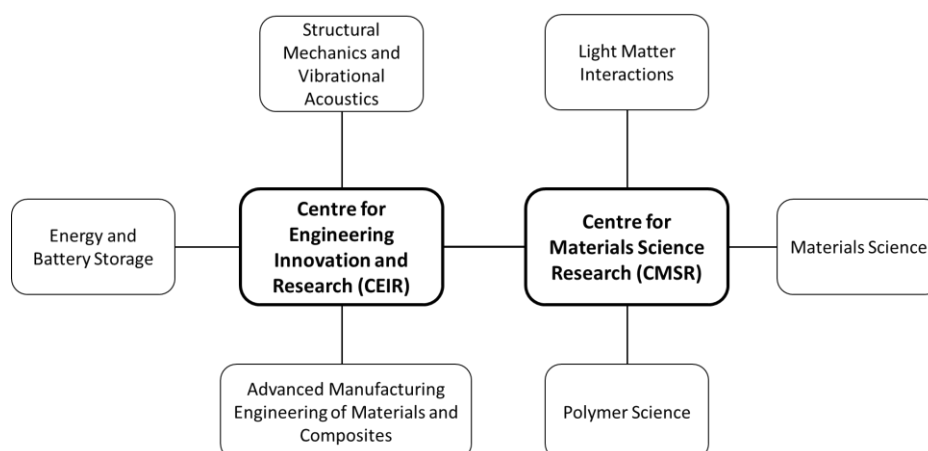


Figure 1. Structure of UoA12

Researchers are usually members of 1 or more research groups and/or Research Centres, and actively collaborate in projects with researchers in other subject areas. Each operates as a flexible hub-and-spoke model to create clusters of researchers with common interests. This model promotes collaboration between groups and wider University and external communities of research and practice, and creates a nurturing environment that facilitates new research collaborations and, via mentoring and support, fosters the research careers of early career researchers (ECRs).

1.2 Achievements against Past Research Objectives

The strategic direction identified in REF2014 was to increase the level of funded research activity, particularly in EU funded programmes such as ERDF, and Marie Skłodowska-Curie Partnerships and Fellowships. Since 2014, these have been extended with the addition of five new objectives:

- O1. To build engineering research through targeted replacement of staff who have retired/left and appoint ECRs to build a sustainable research environment.
- O2. To implement research support mechanisms through mentoring and to encourage applications for schemes designed to support ECRs.
- O3. To develop theme focussed research groups which provide opportunities to undertake interdisciplinary research, particularly encouraging research aligned to the sustainable use of resources.
- O4. To grow numbers of postgraduate research students and increase the number of doctoral completions.
- O5. To concentrate on applied research and end-user applications engagement with industry through Knowledge Exchange and Partnerships (KTP, KTN, and KEEN awards) and InnovateUK funding.

The portfolio of EU funded projects has increased to include ERDF projects Smart Concepts (Pollard), Science in Industry SIRC (Pollard, Burnham, Hix, Radecka, Keddie, Arjunan), and Composite & Additive Layer Materials CALMERIC (Pollard, Hasan, Arjunan, Bari). These are multidisciplinary projects which are specifically aimed at building research collaborations with regional industry to improve productivity, and to enable access to research facilities for companies.

Developments in the University Research Policy Unit (RPU) and the Project Support Office (PSO) have promoted internationalised research and assisted with the development of networks for Horizon 2020 and other European funders, as well as UK sourced funding. These developments saw overall research income increase from GBP 2.6M in REF2014 to GBP 3.68M. EU sourced funding saw a nearly 3-fold increase from GBP 358k to GBP 1.02M in the same period. The REF2014 goals to realise increased applied research and to increase EU derived funding have been met.

The UoA12 REF2014 submission was centred on researchers from the School of Engineering. The reintroduction of a wider range of engineering disciplines, along with physical and medical sciences to the University's portfolio, led to diversification of research activity, and provided a mechanism for UoA12 to create a vibrant multidisciplinary research environment which has fostered collaborative research to achieve O1. This was supported by significant infrastructure investments (see Section 3). The number of FTEs being returned in the Unit has increased from 12 to 29.1 since 2014, which includes 4 ECRs (O1/O2).

The creation of the two Centres (CEIR and CMSR) is how we have been able to bring researchers together with a view to successfully achieving Objective O3 regarding sustainability research. Primarily this is based around biopolymer developments and evolution of the research environment which will continue into the next period.

As the establishment has grown, doctoral completions have increased from 14 to 26, representing success against objective O4. Over the next period, the foundations we have laid by appointing a

significant number of ECRs will mature and realise an increase in funding capture and doctoral completions throughout the next REF period.

As outlined in Section 3 we have been particularly successful in meeting Objective O5 through obtaining KTP and InnovateUK awards to conduct collaborative research projects with regional companies.

Overall, we have achieved success against the strategic objectives set in 2014 and all objectives subsequently set. We will maintain the principles included in objectives O1-O5 as the basis on which we will continue to build, in order to realise our future goals as well as providing avenues to new research areas as the research landscape unfolds in coming years.

1.3 Research Centre Structures

CEIR and CMSR bring together researchers from across engineering and science under specific research themes. This creates a vibrant environment for the exchange of ideas and exploitation of expertise in developing new projects, and the basis on which we will build over the next period.

Centre for Engineering Innovation and Research (CEIR):

Underpinning CEIR are 3 themed research groups.

Advanced Manufacturing Engineering of Materials and Composites Group

(Burnham (Lead), Arjunan, Baroutaji, Bari, Ekere, Gulia, Hasan, Pollard, Oduoza)

Advanced Materials and Composites brings together a multi-disciplinary team of researchers. The group focusses on the development and design of innovative hybrid processes and materials for Additive Layer Manufacturing (ALM) applications. Research addresses current societal challenges included in the UK Government's Industrial Strategy focussing on new product innovation and development, process engineering, process optimisation, integrated transportation systems and control engineering (Burnham), biomedical healthcare systems (Arjunan), manufacturing systems, and supply chain logistics and optimisation. All activity is aimed at delivering practicable solutions to local and national manufacturing companies.

ALM has been a major central theme and specifically includes: 3D printing (Arjunan, Bari), study of material behaviour (Bari), and properties and structural integrity (Baroutaji, Hasan, Ekere, Oduoza). In particular, the researchers investigate the design and optimisation of ALM-produced structures and the scalability issues associated with the manufacture of parts for microscale and nanoscale machines manufactured by 3D printing (Arjunan). It forms the basis for the 'Additive Manufacturing' Impact Case Study submitted.

The work of Arjunan and Bari on new laser-melted biomaterials and scaffolds for tissue engineering applications has led to the production of engineered templates for tissue regeneration, which contributed to the UK parliamentary POSTnote to inform policy development regarding 3D bio-printing (<https://post.parliament.uk/research-briefings/post-pn-0620/>). Combined with simulations studies, 3D-printing methods have delivered new swabs which provide a greater degree of patient comfort undergoing nasal sampling (e.g. for COVID-19 testing).

In the next five years the focus of ALM/3D-printing will shift towards the production of biocompatible materials. Research related to biomaterials has already realised success and will be central to the development of bioengineering as a specific autonomous topic of interest which is an area CEIR will be developing in the next REF period.

Future research activity will be focussed on the aims stated in regional and UK Industrial Strategies and specifically focussed on fundamental innovation in key areas of interest in transportation, energy and device manufacture from the bench to commercialisation.

Energy and Battery Storage Group

(Ekere (Lead), Dhir, Baroutaji, Adebayo, Anani, Cerminara)

The group focuses on Energy and Battery Storage research directed towards energy generation and efficiency, addressing the Clean Growth Grand Challenge of the UK Industrial Strategy. Key areas of activity include renewable energy capture and storage (Anani, Ekere, Oduoza), fundamental knowledge of new materials (Baroutaji, Dhir) and technologies for energy storage applications (Dhir, Ekere, Oduoza).

The primary objective realised by the group was to engage in industry-led KTP projects as part of UKs Industrial Strategy Grand Challenge transformative programme, which aimed to bring together the materials, manufacturing, and energy sectors to develop and commercialise energy and battery storage technologies for mini and smart-grid applications. Closely related work on Solar PV interconnection technologies (Ekere, Oduoza) and Finite Element Modelling (FEM) of Solar PV module interconnections reliability (Anani) has addressed specific challenges in the West Midlands related to energy infrastructure, energy efficient buildings and energy storage for transportation and electric vehicles, as well as the issues of clean air, energy access and fuel poverty.

In the next period, activities will draw together research arising from the Light Matter Interaction and Materials Groups and provide solutions for the inclusion of new materials in reliable device manufacture. As the group becomes more established, the natural synergy with the other groups will provide a multidisciplinary bench-to-commercialisation vector to realise the development of commercial applications from fundamental research in materials chemistry and physics.

Structural Mechanics and Vibrational Acoustics Group

(Arjunan (Lead), Baroutaji, Cerminara, Bari, Adebayo)

This group encompasses aerodynamic and structural performance of composite structures (Cerminara), biomaterials and tissue engineering (Arjunan), structural crashworthiness (Baroutaji), multi-objective optimisation design, computational modelling (Baroutaji), vibroacoustics and destructive interference (Arjunan) and computational simulation of thermal and acoustic behaviour of surfaces at hypersonic speeds (Cerminara). Cerminara has been a key contributor to the NATO AVT (Applied Vehicle Technology)-240 working group. The activities of this group are closely aligned with the UKRI/HM Government's Industrial Strategy focussing activities on the Grand Challenges related to future of mobility. In particular, research on the properties of metals and materials and their applications in advanced aerospace and lean transportation technologies will be investigated.

Vibroacoustic research provided mechanisms to exploit acoustic interference to create frequency dependent noise cancelling devices using additive manufacturing, has contributed significantly to the Department for Transport (DfT) project, "Adoption of Destructive Interference to Minimise Noise Pollution Associated with the Proposed High Speed Rail Network" (Arjunan). Arjunan has also worked with Hadley Engineering Group PLC, Europe's largest producer of steel sections, to produce sound reduction solutions for roll formed sections.

The future direction of this group will see it continuing to develop the existing synergies with the Advanced Manufacturing group. Within the context of the overarching strategy of CEIR, the group will increase its collaboration with industry. Efforts will concentrate on aligning and embedding areas of growth, e.g. using ALM methodologies and new materials specifically to provide new industrial applications to aerospace and automotive industries, and in developing improved simulation methodologies.

Centre for Materials Science Research (CMSR)

Underpinning CMSR are 3 themed research groups.

Unit-level environment template (REF5b)Polymer Science Group

(Radecka (Lead), Keddie, Baldwin, Khan, Palframan)

The Polymer Science group focuses on the synthesis and study of polymers based on bio-available molecules decomposing back to biomolecular species rather than micro-plastic particles. This work is underpinned by fundamental chemistry (Keddie, Palframan), microbiology (Baldwin, Khan) and fermentation science (Radecka).

The development of truly biodegradable polymers has provided the mechanism to create a polymeric vector for the delivery of nutrients to plants through implantation into a polymeric sheet, which exhibits controlled release as the polymer biodegrades (Radecka, Baldwin, Khan). Biopolymers based on poly-glutamic acid have also provided a West Midlands cosmetic company with a biodegradable substitute for plastic glitter included in their products thereby significantly reducing their contribution to micro-plastic pollution (Radecka).

Radecka has been highly influential in the understanding of biodegradability of polymers making a significant contribution to the ERDF PLASTiCE project (3CE368P1 “Innovation value chain development for sustainable plastics in Central Europe”). Keddie’s work on RAFT polymerisation led to the award of a grant enabling him to spend time with Nobel laureate Prof Grubbs at Caltech in 2015.

The environmental significance of this research cannot be overstated. In the next 5 years, activity will concentrate on two aspects. Firstly, developing a wider range of biopolymers will complement the work of the Advanced Manufacturing Engineering of Materials and Composites group providing biodegradable alternatives to non-degradable plastics in the manufacture of consumer goods. Secondly, this group is studying how biological processes can be exploited to convert petrochemical-based plastic waste into feedstock for the formation of biopolymers, essentially returning them to a circular economy with full recyclability.

Materials Science Group

(Hix (Lead), Williams, Keddie, Henry, Jones, Karodia, Laussy, Del Valle, Nalitov, Dhir, Radecka)

The Materials Science Group brings together researchers from Chemistry, Biology and Physics under one umbrella. Group research explores synthesis and characterisation of materials ranging from purely inorganic systems, through hybrid inorganic-organic materials to biopolymers. Target areas for application of materials includes photonics, antimicrobial activity, magnetic materials, catalysis, and (non-bio) polymers. Study of photonic (Hix) and magnetic and catalytic materials (Jones) is underpinned by theoretical work carried out by the physics part of the group (Laussy, Del Valle, Nalitov). The polymer scientists (Keddie, Radecka) support antimicrobial materials research (Karodia, Hix), thereby creating a truly multidisciplinary research group.

The research is fundamentally aimed at the UK Government’s Clean Growth Grand Challenge as well as UN and EU actions on climate, environment, resource efficiency and raw materials. Future activity will concentrate on fundamental and applied research in developing materials and devices for efficient energy capture and production. This involves the development of new materials for energy capture and light generation, underpinned by theoretical study. These in turn will then be incorporated into working LED and photovoltaic devices. The activities of this group will link directly to those of the Advanced Materials and Composites, Advanced Manufacturing and Energy and Battery Storage groups providing a basis for IP exploitation and commercialisation.

Light Matter Interactions Group

(Laussy (Lead), Del Valle, Nalitov, Hix, Ekere)

Established in 2019, the Light Matter Interactions group is the newest in CMSR. Theoretical research (Laussy, Del Valle, Nalitov) forms the centre point of the work carried out by the physics team and this is complemented by a materials scientist (Hix) whose research interests lie in synthesis and characterisation of luminescent materials with applications in light generation and

solar energy harvesting, and the fabrication of solar cells (Ekere). Group members are collaborating with the Energy and Battery Storage Group in supporting the work of the Midlands Engine Energy Consortium and the Repowering the Black Country Project.

In the next 5 years the group aims to build on its early successes in Polariton research such as the European Research Council-funded Polaflo project (Laussy). Furthermore, through working in collaboration with other groups in Wolverhampton and internationally, the researchers aim to provide underpinning experimental research with theoretical modelling and bring their theoretical research in spectroscopy (Del Valle, Laussy) and quantum computing to life in real devices.

1.4 Future Strategy for the Unit

Having built a firm basis for engineering research, the aims for the next period initially concentrate on consolidation. We aim to fully realise potential of the groups in CEIR and CMSR through a focus on supporting career development of researchers and continued support of our ECRs. In line with the University's research strategy, we will continue to address environmental issues through interdisciplinary research on sustainability and materials.

Specific new research objectives for the next five years include:

1. Develop new research directions with respect to biological aspects of applied engineering recognising that biomaterials, biotechnology and bioengineering all figure significantly in the West Midlands and Black Country Region.
2. We will look to further increase industrial engagement and work more closely with local industry in relevant collaborative projects through existing ERDF projects (ENTRESS, SIRC and CALMERIC) highlighting initiatives to be enacted through the University's Science Park.
3. Increased focus on research activity towards key sustainability and environmental themes that contributes to mitigating climate change, centred on energy production and usage building on our existing expertise in photovoltaics and related areas.
4. Increasing funding from UK-based sources including UKRI, linking this to the key strategic goal of interaction with industry. Increased funding will support a concomitant increase in the numbers of doctoral completions within the Unit.
5. Establish a centre of excellence for manufacturing research and apply for funding to establish a Doctoral Training Centre.

1.5 Impact

Since 2014 the Unit has sought to achieve impact from research, initially focussing on industrial engagement through ALM and allowing this to evolve as new challenges and opportunities arise. Impact arising from the Unit is related to two main goals of the Research Centres, which are industrial collaboration to support competitiveness, and sustainability and environmental protection.

Moving into the next period our initial impact objective can be summarised as follows:

I1: Continue to develop industrial collaboration and impact through manufacturing and ALM research, with evolution of the subject into biomaterials research

I2: Extend the reach of biopolymerisation and polymer research

I3: Engage in research that delivers impact in energy usage and storage in response to the West Midlands Regional Energy Strategy.

Industrial collaboration has underpinned our activity in ALM and manufacturing research since before 2014. We work closely with regional and national companies in undertaking joint research projects, resulting in innovative manufacturing processes and developments. Our research has led to advances in Formula1 racing engineering, and medical devices using innovative 3D-printing methods.

Building on the successful impact in industrial engagement through ALM research, we will extend the areas in which we can demonstrate societal impact over the next five years, particularly within our regional 'place'. While continuing our existing activities aligned to national industrial goals, European and UN Grand Challenges which have influence on the national and international stages, we will place a greater emphasis on generating impact in our region. Working through SIRC, CALMERIC and similar projects, we will actively seek to engage in projects with industrial and other regional partners, which are made readily accessible through our existing infrastructure and resource base. Our current research in ALM is likely to evolve towards work in biomaterials and medical device/implants, supported by our strategic partnership with the Royal Wolverhampton NHS Trust.

The gap left by the retirement of Stanford (retired 2018), who was instrumental in developing the basis for ALM research, was filled by Arjunan who has taken the lead in continuing to manage collaborative links which have resulted in a continuing 'ALM' impact case in this submission.

Sustainability is a key societal issue in which the Unit has sought to generate impactful research. The natural channel has been through materials engineering and is based on our work in developing new materials and exploiting the properties of existing known materials. The use of plastics has been ubiquitous for generations and only recently have we begun to understand their environmental impact. Developing the reach of our biopolymerisation and polymer research has led to identifiable industrial impact aligned to our sustainability objective (O3) resulting in another impact case study ('Biopolymers'). Similarly, the 'Biogeotextiles' case study brings into focus the effects of changing climate on agricultural land, and how sustainable natural materials can be used to remediate affected land. The use of natural and synthetic materials in tackling and reversing the effects of climate change will remain an area of interest in future.

Energy production and usage is a new direction for the Unit in terms of impact, but it is an area where we have grown our research base. We will concentrate on developing Solar PV technologies, new materials and devices for low energy lighting and light harvesting, bringing together the collective expertise in a number of research groups and will engage with industry to realise impact from the work.

1.6 Open Research

The Unit aims to make published research available on the Wolverhampton open access repository (WIRE) wherever possible exceeding the requirements for REF and funding agency guidelines. From the submitted pool, 23/73 outputs are Gold open access articles distributed on the Creative Commons (CC) BY licence which goes beyond the requirements of the CC-BY-NC-ND licence, which is considered the baseline. Examples include: Anani's article in Energies, Ekere's articles in Metals, Radecka's publications in Materials and PLOS ONE, Hix's article in Inorganics and Nalitov's articles in Nature Communications on Exciton Polaritons and Bosonic Condensates and Radecka's paper on Bioactive polymers in PLOS ONE all have open access status.

Within UoA12 we will be actively advocating a policy of publishing a greater proportion of Gold route open access articles and aim to provide more support for publishing costs through QR funding, particularly to ECRs who will not have research income to cover these costs.

Training for secure and open data management is also planned, working towards compliance with the Concordat on Open Research Data at UOA level. We are currently upgrading our IT systems to enable the facility to upload (anonymised) datasets for analyses of data integrity in addition to existing current practice e.g. crystallographic data are routinely submitted to the Cambridge Crystallographic Centre database (CCDC) which provides other researchers access to experimental datasets.

Beyond journal outputs research and innovation successes are routinely reported in the local and national media (e.g. BBC Midland's Today: 'King Midas approach- turning plastic waste into high value materials' (September 2017 <http://www.bbc.co.uk/iplayer/episode/b093nt1g/midlands-today-lunchtime-news-06092017>). The university runs public engagement activities within the UoA to disseminate our activities to the lay public.

1.7 Research Integrity

The Unit supports and maintains the ethical and integrity requirements of the University and Faculty, inculcating the promotion of research excellence and inclusivity of the research culture. We ensure that research is conducted according to appropriate ethical, legal, and professional frameworks, obligations and standards, including the Concordat to Support Research Integrity. The research included within this submission is covered by a number of professional statutory regulatory bodies including the Royal Society of Chemistry (RSC), the Royal Society of Biology (RSB), the Institute of Physics (IoP), IChemE, IMechE, and IET.

2. People

As a Unit we are committed to supporting the University's action plans that underpins our commitment to the Researcher Development Concordat, and our Athena SWAN and Race Equality charters. We recognise that in a healthy research environment it is not just the academic staff who conduct research, but that it also includes the technical staff, research students, research assistants and administration staff that support those activities.

2.1 Staffing Strategy

The Unit has grown from 12 staff in 2014 to 30 staff members of whom 4 are classified as ECR appointments in the period. All staff in the Unit are permanent members of the staff establishment, with 2 on fractional FTE contracts through partial retirements. Alongside the academic staff we are supported by the 22 Faculty technical staff who work in Sciences (15) and Engineering (7).

Of the 12 FTEs returned in UoA12 in 2014 only Ekere and Oduoza remain, with the other 10 having left the University (6) or retired (4). Stanford, who was instrumental in establishing ALM as a major area of activity, retired in 2018, and leadership of this group was assumed by Arjunan.

The Unit has been reconstructed over the period applying a balanced approach to senior and ECR appointments to cover our core teaching needs, whilst at the same time providing a mechanism to realise sustainable growth into new research areas or supporting existing activity. New appointments have allowed the development of new research groups that will complement our existing research portfolio. This in turn has generated a multidisciplinary environment enabling student number growth. Within this Unit, newly appointed research staff are expected to have a PhD, or significant industrial R&D experience related to existing research.

The Unit establishment contains staff who were previously returned in other Units or had not been submitted previously. Specifically, these include:

- Appointment of early stage researchers, including ECRs
 - 8 in Engineering (Adebayo, Arjunan, Cerminara, Dhir, Eshiet, Gulia, Sayed and Tcheuenbou-Magaia), and
 - 6 in Sciences (Del Valle, Henry, Keddie, Nalitov, Nixon* and Palframan).
- Appointment of 9 established staff: 3 Professors (Burnham, Cox*, Karodia), 1 Reader (Anani), 2 Principal Lecturers (Bari, Laussy), 2 Heads of School (Hix, Hasan) and one Senior Lecturer (Jones)
- 3 staff were returned in UoA3 in 2014 (Baldwin, Radecka and Williams), and
- 3 staff returning to research who were not returned in 2014 (Besenyei, Khan, Pollard).

* Cox and Nixon left the University to take up more senior positions at other institutions before the census date.

Ongoing recruitment strategies will consider not only existing and emerging areas of research activity but will also actively consider Equality, Diversity and Inclusion aspects (*vide infra*) to provide balance with respect to under-represented groups (see Section 2.3). While recruitment has broadened the areas of activity, this growth must be sustainable, and we do not plan to increase the number of staff returned to REF through additional new appointments in the next period. The emphasis will be on staff retention and development in order to consolidate the research base we have constructed, enabling success and encouraging staff to seek promotion to reader and professor. In particular, we will actively encourage and support researchers from minority groups who are at present under-represented in higher level positions.

Recruitment strategies, policies, equality and diversity targets apply equally to technical staff who support research in the Unit. An ongoing review of technical services will provide specific support for research activity for this group of staff. For example, we will be offering the opportunity for technical staff to complete funded PhDs part-time. The technician's review will result in provision of services across the University on a thematic basis, which will allow researchers greater access to facilities and equipment thereby expanding the potential for multidisciplinary work.

2.2 Staff Development

Our staffing development strategy is based on the following pillars:

- Retention and development of talented researchers.
- Developing grant writing skills and funding capture, particularly among early stage researchers.
- Increased uptake of sabbaticals and visiting positions at other institutions.
- Development of strategy around outputs and dissemination, taking into consideration responsible use of research indicators.

Retention and progression are key aspects in recruiting and retaining ECRs. The appointment of ECR researchers presents opportunities for growth, however the appointment of staff who are not yet established researchers also means that there will be an impact on the Unit in terms of income generation and doctoral completions. These appointments represent an investment in the future, which will come to fruition over the next period through training and development. In line with our aim to increase grant capture, developing the skills of ECRs will result in an increase in funding capture over the next period as their experience and reputations grow. More importantly however we will actively support and work with these researchers to retain their expertise.

In accordance with University policy, UoA12 implements and adheres to the Research Development Concordat (RDC). ECR staff have access to an ECR Development programme including workshops and support sessions in line with the VITAE Researcher Development Framework. ECR staff in UoA12 are assigned a mentor who is a senior researcher in a relevant discipline who can give guidance on funding bodies, grant writing, local regulations and procedures at the University. They are also introduced to colleagues at the RPU and PSO and

provided with access to a variety of training courses to facilitate career progression. Staff new to research supervision undergo a programme of supervisor training provided by the Doctoral College; established supervisors are required to undergo periodic refresher sessions. New supervisors are supported by 1 or 2 experienced colleagues in a supervisory team.

Many of our newly appointed staff are in the early stages of their careers. To facilitate integration, all newly appointed staff are given remission from teaching in their first year, with additional hours for ECRs. ECRs are encouraged to apply for the internally funded Early Researcher Award Scheme (ERAS) and the Lord Paul Fellowship (LPF) programmes. ERAS provides GBP 5,000 and tailored mentoring to begin to manage a small-scale project and put in place a career development plan. The mentoring framework aims to support furthering individual career ambitions, by helping staff objectives for boosting the quality of publications, public engagement and impact projects, and developing individual and group bidding strategies for external funding. Two ERAS awards were won by staff: Arjunan (2015) and Baroutaji (2018).

Arjunan has subsequently been successful in realising GBP 93k in funding as PI for a KTP project with Wrekin Products, and a GBP 25k Transport Technology Research Innovation grant. His success in this regard and the development of his research profile resulted in him being promoted to Reader in 2020. Elsewhere, Keddie has also won GBP 138k in KTP funding and a GBP 4,000 grant to enable a sabbatical period at Caltech, USA.

Having invested in the recruitment and development of research active staff, a key strategic aim is retaining those staff and providing opportunities for advancement. More experienced staff have access to the Experienced Researchers Development Programme which further develops research skills and profile, e.g. internal and external examiner training, increasing research impact, IPR and leadership courses. The Unit also provides support and advice for staff seeking promotion to reader or professor through mentoring by senior colleagues. In this period, Radecka (2016) and Arjunan (2020) were conferred with Readerships. Additionally Radecka was further promoted to Professor along with Hix and Laussy in 2018. Staff are appraised annually and targets for training are set during an annual appraisal exercise. Staff are appraised by their line manager, with research targets informed by discussion with Faculty Associate Dean for Research and UoA co-ordinators; these are set in line with the criteria for promotion. Part-time staff are offered equal opportunities for staff development relative to other staff.

PSO also provides training opportunities such as the Grants Academy programme which is delivered in Brussels and provides a focus on European research funding for experienced researchers and ECRs. Adebayo, Cox, Ekere, Hix, Oduoza took part in this programme with Hix, Ekere and Oduoza subsequently submitting successful bids for EU (MSCA, Erasmus+ and H2020) funding. We aim to increase the uptake of opportunities such as these among experienced and newer staff.

To prioritise research excellence and impact we will use our Quality-Related (QR) funding to provide the Unit with a stream of income that will be strategically invested into research assistance and continuous professional development. Priority will be given to those projects that enhance the quality of research outputs and their impact, and to supporting early stage researchers including ECRs.

Sabbaticals provide an opportunity for staff to develop new ideas, learn new skills, write outputs and funding bids. The University provides the opportunity for up to one semester sabbatical for staff after three years' service. Applications for visiting roles are also supported in the form of match funding to cover the salary of members of staff taking up these opportunities. Examples include support for the award of a Professorial Fellowship for Hix at ITMO University in St Petersburg (Russia, 2018), the provision of travel and subsistence funding for Baldwin to spend 2 months at Yunan University (China) each year, and support for a 3-month research visit by Tchuenbou-Magaia to Turin (Italy, 2019). Over the next five years we will actively encourage increased sabbatical uptake, and support staff in spending time at other institutions.

2.3 Equality and Diversity

We continually strive to create and maintain an inclusive working environment for all researchers and have sought to remove barriers for staff from minority and under-represented groups, and researchers from developing nations. New appointments are made according to robust Equality and Diversity specifications and processes, including anonymised shortlisting and ethnic- and gender-diverse recruitment panels. We encourage applications for positions from a wide cross-section of diverse backgrounds by providing an inclusive environment to all staff and students, which includes provision of prayer rooms, access to parental leave and support for staff returning from extended parental or sickness leave. In recognition of the under-representation of women in engineering, we developed a Gender Equality Action Plan (GEAP), which addressed gender balance in supervisory teams and funding applications, amongst other initiatives.

Through these mechanisms we have promoted diversity and inclusion. 50% of submitted staff identify as Black, Asian and Minority Ethnic (BAME). Among senior research staff in the Unit, 2/3 Readers and 3/9 Professors are from BAME backgrounds. Of the 14 new early stage researchers appointed, 7 are from BAME backgrounds. Under the University's Race Equality Charter action plan there are institutional commitments to increase BAME representation among academic staff to bring it into line with student demographics, however this is an area where we wish to better the sector averages.

We also increased the number of women submitted – 6 in REF2021 compared to 2 in REF2014. Two female staff members are Professors (one of whom identifies as BAME), which is an improvement from 2014 where no female academic staff held senior positions. However, the UoW Athena SWAN action plan requires all parts of the University to reduce gender gaps, e.g. supporting the promotion of women to senior levels, enhancing support for research for those with childcare responsibilities. To that end, departmental Athena SWAN submissions are planned for Science (CMSR) and Engineering (CEIR).

Staff with caring responsibilities, those taking parental leave and those managing long-term illness have been supported through sympathetic workloads on their return to work, creative time-tabling, and additional cover when needed so as to free up research time and avoid disadvantaging these staff during periods of particular disruption.

PGR students are recruited openly and reflect the social and ethnic diversity of our region and the wider University community: our current cohort of 37 PGR students has a female/male ratio of 33:4 and includes 29 BAME, and 15 international students.

2.4 PGR recruitment

There are currently 37 PhD students enrolled within this Unit. As discussed in Section 2.1, we expect our current ECRs to become more established over the next five years which will enable us to recruit and support more PhD students. The aim defined in the 2015-20 UoW strategy was to see 30% growth in doctoral completions; this was realised with numbers increasing from 14 completions in REF2014 to 26 completions in REF2021. As well as PGRs attached to externally funded projects or on 50/50 industry collaborative matched programmes, we have recruited a significant number of self-funded students.

Over the next period we aim to double the number of PhD students and timely completions compared to this submission. To realise this, we will adopt a number of measures:

- Create a MSc by Research, to provide pre-doctoral training for candidates with non-standard backgrounds. This MSc will also provide a mechanism to enhance multidisciplinary research bringing together researchers from different disciplines to generate primary research in support of funding applications. UoW Alumni are offered a 20% discount for all research degree courses.

- Secure funding internally from the University's Research Investment Fund (RIF) to support PhD bursaries, to be prioritised for ECRs.
- Submit further applications UKRI-funded DTC awards as part of a consortium of universities.
- Build on successes in securing Newton-funded and self-funded PhD students (13 within this period) by strategic partnering with overseas universities with whom we already have links. For example, we have signed a Memorandum of Understanding with Yunnan Agricultural University, building on the long-established links of Baldwin and Fullen (submitted in built environment)
- Actively promote research through transnational partnerships and Erasmus+ funded exchange programmes to increase recruitment of international research students.
- Increase the number of industry-sponsored PhDs awarded via direct collaboration with local companies, facilitated through the Science Park and the Black Country Chamber of Commerce.
- Increase PGR student numbers on projects linked to regional industry through existing and future ERDF programmes (e.g. SIRC, CALMERIC, ENTRESS).

2.5 PGR Development: Monitoring and support mechanisms

The supervisory process for PGR students is quality assured on an annual basis and student progress is monitored through a university-wide Annual Progress Review (APR). PGR students present their work to two independent assessors, and also discuss progress with their personal development plan. Faculty Research Student Boards oversee the timely completion of APRs as well as sharing of good practice and lessons learned.

Feedback is sought PGR students through PRES surveys. This has highlighted in the past concerns over study space for PGR students, which we addressed through the development of the engineering research facilities at the Telford Campus. Further opportunities for feedback from postgraduates include regular meetings between postgraduate research students and the Associate Dean for Research and the Faculty Postgraduate tutors. The Associate Dean for Research is a member of the University's Researcher Development Concordat sub-committee, which proactively supports the career development of researchers. Key issues are escalated to the University's Research Committee.

PhD students are actively encouraged to publish work as they proceed through their studies and training in scientific writing is provided by their supervisory teams and through specific skills workshops offered by the Doctoral College. PhD students have access to all resources by the Doctoral College, including materials on the virtual learning platform CANVAS. The Postgraduate Researchers' Development Programme provides face-to-face and online workshops, and is mapped to the Vitae Researcher Development Framework. Engineering PGRs also participated in a workshop on IP facilitated by Vitae. These central development opportunities are supplemented by monthly seminars and workshops run by CEIR and CMSR. These provide access to renowned international researchers (e.g. Ramsay from the Hitachi Cambridge Laboratory or de Liberato from Southampton), and an opportunity for students to showcase their work and enhance their presentation skills.

Employment opportunities are provided for the PGR community through laboratory demonstrating work and conducting small group tutorials. Final year research students may also be actively involved in supervising final year UG projects.

3. Income, infrastructure and facilities

This REF period has been one of building for the engineering submission, where we reviewed our research portfolio and coalesced research teams. This was supported by investments that the University made in science and engineering facilities, supplemented with growing external grant capture.

3.1 Facilities investment

Researchers in UoA12 are based either at the City Campus (Sciences and Chemical Engineering) or the Telford Campus (Engineering). On the City Campus, research is supported by state-of-the-art laboratory and computing facilities within the Rosalind Franklin and Wulfruna Buildings.

During the period the University has invested GBP 250m in research and teaching facilities, and GBP 24m of this supported the development of engineering.

At Telford there has been investment in research facilities and infrastructure totalling GBP 2.95M. These included:

- Wind tunnel: GBP 600K to support aerospace and aerodynamics research
- Composite lab facility: GBP 270K, supporting Advanced Materials and Composites research
- CT scanner: GBP 800k for surface analysis and non-destructive characterisation for Advanced Materials and Composites
- GBP 500k 3D metal powder printer, and 3- and 5-axis machining facilities
- GBP 395K for Advanced Materials and Advanced Manufacturing Engineering laboratories
- GBP 230K investment in renewable and electronic, aerospace and mechanics laboratories
- GBP 100K for an upgraded materials testing facility

On the City Campus, GBP 21m was invested in new laboratory facilities in the Rosalind Franklin Building (RFB). This building now contains state-of-the-art research laboratory facilities which span the full gamut of sciences research activity at UoW. Specialist equipment was provided as part of that investment which is particularly relevant to the materials science and polymer groups. These include fermentation/biopolymerisation facilities, diffraction and analysis equipment (scanning electron microscopy, solid state NMR (GBP 500k), thermogravimetric differential scanning calorimetric analysis, and X-ray diffraction (GBP 200k)). These centralised laboratory facilities further promote the development of interdisciplinary research within engineering and between engineering and other subjects such as biomedical sciences, and construction and the built environment. The new facilities have enabled us to win funding for collaborative projects including the ERDF-funded CALMERIC and SIRC, and the PhosCycle InnovateUK projects. The investment in the RFB laboratories will lead to the further development of our sustainability research and its related impacts, and the materials aspects of our proposed energy strand of work.

3.2 Income

Research income for the period was GBP 3.7M which represents a 42% increase from GBP 2.6M in REF2014. Key successes include a H2020 RISE grant for a project on Reliable Electronics for Tomorrow's Active Systems (PI Ekere), a Marie Skłodowska-Curie fellowship (PI Hix) and Laussy's ERC grant (PolaFlow). These projects helped further our innovative research, e.g. on light matter interactions, whilst creating sustainable international partnerships (see Section 4).

We have also been successful in attracting ERDF funding which supports impact of our research. Pollard, in his role as Industrial Professor, along with Bari, Arjunan and Hasan were awarded GBP 1.8M funding for CALMERIC Project; an ERDF part-funded grant providing support to advanced engineering and manufacturing companies in developing high performance lightweight components. Pollard also secured funding for IPSS (Innovative Product Support Service), and SIRC which are respectively GBP 2.4m and GBP 2.2m ERDF-funded 3-year projects, providing support to local small-medium enterprises with intellectual property, prototyping and research expertise to enable them to develop take their products and take them to market. IPSS funding was used to set up the FabLab at the University's Science Park. The FabLab houses an extensive range of equipment to support prototyping activities, such as 3D printers, Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), PolyJet Polymer hi-resolution printing, Micro 3D printing, Photo-Grammetry Laser Scanner reverse engineering, Laser cutter- plastic, vinyl, wood,

aluminium, CNC table router – wood and polymer sheet, and a CNC mini mill. The SIRC and CALMERIC projects have also provided additional infrastructure investments. These include specialist equipment for 3D printing facilities (GBP 50k) and TGA/DSC equipment (GBP 50k).

Having established success in applying for European funding, we have sought to encourage applications to UK funding bodies and improve success rates. In so doing we have strengthened intra- and inter-faculty multidisciplinary collaborations within the University. This has allowed researchers within the Unit to develop a record of research funding successes acting in concert with staff in other schools and subject areas.

The international reputation of the Energy and Battery Storage group has led to 2 Royal Academy of Engineering Distinguished Visiting Fellowships being hosted at UoW, along with visiting scholars from Italy, South Korea and France. We have been particularly successful with respect to KTP and InnovateUK awards, amounting to GBP 1.94m of income generated. These have largely involved regional companies such as Rozone (Keddie, Hill; GBP 130k), Wrekin Products Ltd (Pollard, Arjunan; GBP 225k), and Whale Tankers (Stanford; GBP 160k).

Over the next 5 years a major goal is to focus on increasing UK funding, in particular UKRI funding, which has been an area of difficulty in the past. Building on our success in generating EU and KTP/InnovateUK income we will concentrate efforts on improving impact and developing a strong track record of successful bids.

3.3. Organisational Infrastructure Supporting Research and Impact

Research support is provided at University, Faculty, and School levels. At University level, the Project Support Office (PSO) focuses on pre- and post-award project support. The Grants Academy programme in which research staff receive training in research project development and management was successfully completed by Hix, Ekere and Oduoza, and resulted in the successful H2020 projects described in Section 3.2, and ERASMUS+ funding that supported the international mobility of our researchers. The PSO also provides regular updates, including the e-publication of a regularly updated research grants register specific to the subject areas within the Faculty; help with bid-writing including costings; and follow-on support for successful awards.

At the Unit level, an Impact Officer is available to support the development of impact in our research. Part of the role of the impact officer is to provide development opportunities for research staff through coaching on development of impact, how the pathways to impact can be presented and evidenced in grant bids, and how to write for non-academic audiences. PGR students are supported by a research administrator, who also assists with the organisation of research seminars, Academic staff are also supported by the highly experienced team of technicians (described in Section 2).

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

4.1 Research collaborations

The Unit has successfully increased research engagement with regional industry. The ERDF/LEP funded projects SIRC and CALMERIC have actively promoted interaction with regional SMEs and promoted multidisciplinary research with the Unit. These projects have raised awareness of University and Science Park facilities and how they can be drawn upon to support companies in the West Midlands to undertake research projects aimed at developing new science-based products, prototyping or exploiting IP.

SIRC brings together 7 academic researchers from chemistry, biomedical science, engineering and pharmacy with 4/7 researchers being returned in engineering. SIRC funding also supports 7

PhD students, a postdoctoral fellow and a research technician, who facilitate the interactions with industry but also contribute to the research environment within CEIR and CMSR.

An additional outcome from SIRC is that having brought together a multidisciplinary group, it has generated new interdisciplinary projects, e.g. Arjunan is working with Dr Heaselgrave from biomedical sciences on developing the manufacture of medical implants which address issues around microbial infections, which affect around 40% of joint replacement surgeries in the UK.

CALMERIC is more specifically related to interaction with Engineering manufacturing companies in the West Midlands and the Black Country. It uses the expertise of colleagues in CEIR to provide bespoke research collaboration and is aimed at developing new manufacturing practices within the region. We are already seeing joint InnovateUK funded projects arising from these interactions. An example is the Phoscycle project which investigates how recycling waste fire extinguisher powders can be used to produce a commercial product, and reduces waste going to land fill from this source by 95% (Hix, Williams, Cox).

Outside of these projects, there are other interdisciplinary collaborations. Examples include Hix and Laussy who collaborate with colleagues in Russia (ITMO, St Petersburg) looking at photonic materials; Spain (Malaga) and Greece (Crete) studying proton conducting materials and France (Brest) looking at antimicrobial applications of materials. Laussy was part of an €1.5M EU funded international project looking at Polariton Condensates (Polaflow; cordis.europa.eu/project/id/308136) involving partners in Italy, Greece and Spain. He also collaborates with colleagues at the quantum optics group at the Technical University Munich and the ultrafast spectroscopy group from the CNR-Nanotec facility in Lecce.

Tchuenbou-Magaia collaborates with biotechnology and food science colleagues from the University of Verona. She has made several research visits to Verona as part of this collaboration. Ekere has established collaborations in Hong Kong and Seoul, South Korea, spending 2 weeks in each location in 2017 as part of ongoing collaborative projects, funding for which was awarded by the Royal Academy of Engineering (Distinguished Fellowships).

The chemistry team is part of the MERCIA (Middle England Regional Chemistry Interactive Alliance) group of departments (merciachemistry.org); these include chemistry departments from UCLAN, University of Hull, Sheffield Hallam University, Liverpool John Moores University, Keele University, Manchester Metropolitan University, and Nottingham Trent. MERCIA actively promotes the sharing of research equipment between departments and engages in collaborative postgraduate training events, staff training and organises yearly regional research meetings. The most recent Christmas meeting took place at UoW and attracted approximately 50 attendees with Prof Sabine Flitsch (University of Manchester) giving the Keynote lecture. The conference was supported by local companies and the RSC.

4.2 Contributions to wider research base, economy and society

Several projects and researchers reach a wide range of national and international audiences. The work of Radecka with colleagues at the Polish Academy of Sciences in Warsaw on biodegradable polymers has led to engagement with commercial companies who use plastics in their manufacturing processes. The outcomes of this work were implemented in the ERDF PLASTiCE project (3CE368P1 "Innovation value chain development for sustainable plastics in Central Europe", <http://www.plastice.org/home/>), which has in turn informed governmental policy for some EU nations and has significantly influenced research in the area.

The Unit hosted the Flexible Automation and Intelligent Manufacturing (FAIM 2015) Conference in 2015, attracting 250+ academic and industry delegates from over 30 countries. Invited lectures and keynotes include Radecka's keynote at the 6th IC4N held in Corfu, Greece, 2019. Hix delivered keynote presentations on Luminescent materials at New Trends in Chemistry of Advanced Materials in Timisoara in 2019 and at the International Symposium on Nanophotonics

and Metamaterials in St Petersburg in 2018. He also delivered an invited lecture at the international METANANO meeting held in St Petersburg in 2019.

A number of staff have roles on external committees and panels. These include Burnham who is a member of the UK Automatic Control Council Executive, as the Institute of Measurement and Control representative, and former Council member of the Institute. Ekere is a committee member of the International Congress on 3D Printing Additive Manufacturing Technologies and Digital Industries executive board. Oduoza is a committee member for the Energy Group of the UK Society of Chemical Industry, and Williams serves on the committee of the British Zeolite Association and the RSC Applied Materials Chemistry Group. Keddie, who is an early stage researcher, has become a member of the IUPAC Subcommittee on Polymer Technology.

Most staff peer review for academic journals including; *Nature Photonics*, *Physical Review A and B*, *Advances in Polymeric Materials for Biomedical Applications*, *Journal of the American Chemical Society*, *Inorganic Chemistry*, *Journal of Materials Chemistry* and *Dalton Transactions*, *International Journal of Control*, *IET Proceedings Control Theory and Applications*. Radecka was guest editor of a special issue of Materials entitled "Advances in Polymeric Materials for Biomedical Applications". Unit staff also regularly review grants for a number of awarding organizations including: EU (MSCA, Erasmus+, KTN, and ERC awards), UKRI (EPSRC, BBSRC and MRC), Innovate and KTN/KTP awards, Leverhulme and many charity-based funding agencies.