

Institution: Manchester Metropolitan University
Unit of Assessment: B12 Engineering
1. Unit context and structure, research and impact strategy Overview: Research and knowledge exchange (RKE) across Manchester Metropolitan University has been significantly restructured and reorganised in the current assessment period, and this has been transformational to the quantity and quality of our RKE activities. We have established new research centres (University Centres of Research and Knowledge Exchange – UCRKE; embryonic centres are referred to as ‘groups’), highly focused on our core strengths and offering the benefits of critical mass and shared resources. UCRKEs are the primary location through which the University executes its strategy to increase the quality, scope and volume of RKE activities. To illustrate the growth that has been achieved as a result of this strategy, we have: • increased the staff that are being submitted by 127% (from 21.3 FTE to 48.5 FTE); • increased research income by 112% from £4.5M to £9.7M; • secured >£20M in research and knowledge exchange awards during the assessment period, including 32 Knowledge Transfer Partnerships. Structure of the Engineering Unit: Staff returned in this unit are full research members of: • The Advanced Materials and Surface Engineering (AMSE) UCRKE, led by Prof. Peter Kelly, are returning 27.5FTE; • The Smart Infrastructure and Industry Research (SIIRG) UGRKE, led by Prof. Bamidele Adebisi, are returning 16.4FTE; • The Centre for Mathematical Modelling and Flow Analysis (CMMFA), led by Dr. Ling Qian, are returning 4.6FTE. Advanced Materials and Surface Engineering (AMSE): Our aims are to generate new understanding of materials and processes, and to use that knowledge to develop new applications, components and devices with novel or enhanced properties, which support economic and social development at regional, national and international levels. AMSE functions at the interface between engineering, chemistry, physics, biology and surface science, with materials science acting as the common link binding these subjects together. AMSE staff are members of either the Surface Engineering Group or the Advanced Materials Group. The Surface Engineering Group can trace an unbroken history of research excellence back to the early 1970s, continuously supported by research council awards and industrial funding. The group specialises in the magnetron sputter deposition process for the production of a wide range of functional films and provides a unique interface between laboratory-scale development and industrial-scale production. The Advanced Materials Group, led by Prof. Craig Banks, is active in many areas, including: Low Carbon Fuels - exploring the production and application of sustainable fuels to reduce operating costs and carbon footprint in the transport sector; Electrochemistry – studying the fundamentals of how 2D materials function for exploitation in real world scenarios; and Additive Manufacturing technologies for the production of screen-printed sensors for medical diagnostics and environmental monitoring, and recently demonstrating the world’s first 3D printed battery (see output ref: 1817). The Smart Infrastructure and Industry Research Group (SIIRG) is actively implementing the Government’s Industry 4.0 strategy through the research-informed digitalisation of the physical aspects of infrastructure and industry. By taking advantage of the growing abilities of the Internet of Things (IoT), 5G, AI, digital twins and related technologies, we specialise in embedding sensing, communication, control and data analytic technologies in critical infrastructure, i.e. water, energy, transport (V2X/CAV), factories and buildings, which are then connected to the cloud, allowing real-time data acquisition and analytics, essentially creating a Smart device. We have been able to investigate this on larger scales by using the Oxford Road corridor in Manchester to create Smart energy grids. We were awarded funding from Triangulum (a €29 million award-winning H2020-

funded Smart cities project) to establish one of the EU's largest ICT-enabled test-beds of connected buildings, vehicles and energy assets on our own campus.

The Centre for Mathematical Modelling and Flow Analysis (CMMFA) is one of the UK's leading research groups in Computational Fluid Dynamics (CFD)'s modelling of wave structure interaction (WSI) with applications in offshore, ocean and coastal engineering. In the last 20 years, it has secured continuous support from the EPSRC, EU and NERC through the award of over 20 research grants, most of which are large multi-partner projects involving external academic and industrial partners. CMMFA puts environmental sustainability at the core of its research and, through the support of the national SUPERGEN Wind, Marine and ORE HUB programmes, it has developed advanced CFD tools and applied them to evaluate a number of novel and emerging wave energy converters and offshore wind turbine support structures. The CMMFA is a lead partner of the EPSRC Collaborative Computational Project in Wave Structure Interaction (CCP-WSI) aimed at building a UK community in WSI research, and developing a national numerical wave tank (NWT) facility and promoting its wider adoption by industrial end users. CMMFA is a group within the University Centre for Advanced Computational Science (CfACS), which leads our submission to B11 Computer Science and Informatics.

Staff from these centres are also members of three major cross-institutional, Engineering-led RKE initiatives, which are engaging with industry and extending our research into new fields:

- **Manchester Fuel Cell Innovation Centre (MFCIC):** Working with regional SMEs and industry in order to address the material challenges facing the development and deployment of hydrogen fuel cell technology. The MFCIC is a regional hub for research, innovation, economic growth and policy development in the fuel cell sector in the North West and beyond.
- **PrintCity®:** a digital manufacturing facility, underpinning our Industry 4.0 digitalisation agenda through teaching digital skills to students, researchers and supporting businesses, to utilise our range of additive manufacturing capabilities and expertise.
- **Circular Economy Network (CEN):** brings together academic expertise and practical waste management experience across the University. Working closely with industry, we offer a range of services that support the transition from a linear to a circular economy.

These centres/groups are based in the Faculty of Science and Engineering and include staff from the Departments of Engineering, Life Sciences, Natural Sciences, and Computing and Mathematics. RKE activities within Engineering are coordinated through these centres. The centres are based around members of academic staff with significant responsibility for research, but importantly, also serve as the intellectual home for our postgraduate research (PGR) students and KTP Associates. Furthermore, the boundaries between centres are porous, in that they allow members of one centre to have affiliations with other centres and provide a conduit for interdisciplinary research. Overall, our research structure is designed to:

- provide an inclusive, supportive environment for engineering and materials-related research staff, postgraduates, KTP associates and students;
- promote inter-group/theme collaborations to build on our strengths;
- provide an agile configuration to respond to staff changes and new calls for proposals;
- provide an open forum for discussions on all research-related issues;
- support Heads of Department when recruiting new staff.

Research and Impact Objectives: Our objectives are to produce high-quality research within the engineering field that has a beneficial impact on society, culture, the environment and the economy. We see knowledge exchange and innovation as important parts of a continuum with discovery research that can drive impact and industrial engagement, and address the Industry 4.0 agenda. We also seek to address global challenges, such as the UN's Sustainability Goals, and make a strong contribution to the government's Industrial Strategy and local strategies that align with our strengths, such as GM's 5-year Environment Plan and the Carbon Neutral by 2038 plan (more details in Section 4). To achieve our objectives, staff are supported in many ways, including through mentoring, annual professional development reviews, the development of individual five-

year research plans, internal funding award schemes and peer review (full details are described in Section 2).

The highly-applied nature of our research activities and their close (technological and physical) alignment naturally lends itself to significant levels of interaction and engagement with SMEs and larger companies. Consequently, we are able to promote our expertise to industry and secure direct or in-kind industrial support for the majority of our research awards. Indeed, this engagement underpins the rationale of our research and has acted as an engine of growth for RKE activities over the assessment period, and it is through this engagement that the impact arising from our research is largely generated.

To measure the success of our RKE strategy, we have a set of key performance indicators. These include: increasing the proportion of research active staff; increasing the number of high quality academic outputs; increasing research grant income and the number of principal investigators; and increasing national and international collaborators. Evidence for the success of this strategy and the attainment of our objectives can be seen in several metrics, such as the 121% increase in the number of staff returned in this unit; an increase in grant income of 112% (with 49 individual PIs); a very significant increase in KTP awards (from a low of 2 in 2013 to a current average of 15 p.a. and a total of 32 in the REF period); and 1,051 scholarly outputs in the assessment period, 57% of which (600) have international co-authors. All of these performance indicators have combined to increase the impact of our research.

Review of REF2014 plans: Whilst several elements of the strategy described above were in place in the plans described in the REF2014 submission, it is the transition to our research centres with their focus on our core strengths and delivering high quality sustainable research and the corresponding internal investment in staff, infrastructure and facilities, that has led to the significant increase in our research activities and outputs. Industry engagement was also an important feature in the REF2014 plans but the strategy put in place in this assessment period has expanded this interaction well beyond our expectations, to the point where it is the foremost mechanism through which external funding, outputs and impact have been achieved.

Support for Impact: All of our support processes require the potential impact of a proposal to be clearly articulated. In this way, we ensure that consideration of impact is embedded in our research culture at all stages, from initial meetings with new potential collaborators and the preparation of substantive grant proposals, through to the establishment of long-term partnerships.

The key strategy that has supported our sustainable growth in KTP projects was the establishment of an award-winning KTP office in 2013, which includes a dedicated KTP post-award support team that actively markets our capabilities. This brought greater consistency to our approach and means that enhanced levels of engagement and support are provided to projects, including the pursuit and delivery of impact. The sustainability and vitality of this strategy has meant that our KTP portfolio has grown very significantly (>30 projects in the REF period) and we are now consistently placed within the top five institutes for KTPs, and are the best performing modern University (post-92).

The strong relationship between our high quality underpinning research and the impact generated through it, is evidenced by the matched funded support of over £300k that we have received for six (to date) KTP awards from the EPSRC in this unit. This funding is linked to previous research grants that have demonstrated our track record in the field and how knowledge generated from our research has been utilised and transferred to the collaborating partner.

Additional support for impact is provided through a matched funded studentship scheme, in which we match the bursary and fee costs of a PhD studentship with an external partner. The scheme is highly competitive and prestigious, with approximately ten being awarded per year and has become a major source of industry engagement and impact generation for the unit (recent partners include: Cyraatek, CRESS, G-Volution, Manufacturing Technology Centre, OSL Rail, DST Innovations Ltd, VOLT Loudspeakers, Bobst Manchester Ltd. and United Utilities). Our Business Development Managers (BDMs) ensure that fair and equitable IP agreements are agreed with the partners.

Working with our BDMs, we have a very close and productive working relationship with the Business Growth Hub through our ERDF programmes supporting local SMEs to access university expertise and supporting our alignment to national and local Industrial Strategy. This route has successfully supported over 75 Greater Manchester SMEs to engage the services offered by the Manchester Fuel Cell Innovation Centre (MFCIC) in the fuel cell and energy sectors. Indeed, the MFCIC was awarded the Runners-up prize for 2020 in the Guardian 'Business Collaboration Competition'. Similarly, PrintCity has supported SMEs to develop their products through design consultancy and additive manufacturing. We also support MIDAS (Manchester's inward investment agency) to showcase the University's strength to potential new companies looking to locate to Manchester. Furthermore, the internally-funded MetroPolis think tank provides networks and fellowship opportunities designed to enable high-level research input into policy development, and facilitate knowledge exchange between the academic and the host organisation. For example, MetroPolis sponsored one of our PDRAs (Kulczyk-Malecka) to undertake a Policy Fellowship with the Northern Powerhouse Partnership to provide content for the hydrogen section of their energy strategy document.

Other measures to support and enable impact include: holding regular Industry Open Days to highlight the impact of our research; the appointment of a dedicated Impact and Engagement manager to oversee and guide activities; acknowledgement of the importance of knowledge exchange through industry engagement in the internal promotions process; and the establishment of postgraduate courses, such as the MSc in Industrial Digitisation, which is the first such course in the UK to offer bespoke units to industry partners (more details of our Industry 4.0 agenda are in Section 4).

Impact Case Studies: The case studies selected here reflect our impact strategy through which our high quality applied research generates strong industrial engagement:

- Development and productionisation of a coating solution for a component from the Trident nuclear deterrent system. The Surface Engineering Group was approached by the Atomic Weapons Establishment (AWE plc) in 2015 to develop a coatings solution to protect a critical component in the Trident missile system. AWE approached us because of our acknowledged expertise in the magnetron sputtering coating deposition technique and our experience of collaborating with industry to progress products through the TRLs. The rationale for the project and the full impact are considered ATOMIC SECRET PRINCIPAL. This work began as a contract research project, which identified a potential solution to their problem. Beginning at TRL 2, by taking an agile approach to problem solving, we were successfully able to develop a full-scale trial of the component (TRL 4) and demonstrate an optimised coating solution (TRL 5). We have now gone on to develop the pathway to productionisation for the coated component (TRL 6/7).
- Novel surface coating and modification techniques: driving production volume and market adoption of AlOx barrier films. The impact described in this case study is derived through our strategy of developing long-term engagements with companies, in this case Bobst Manchester Ltd., through the use of matched funded studentships and KTPs. In the initial PhD project, an AlOx (aluminium oxide) barrier layer for food packaging film was developed and characterised. The success of this research and the strong relationship developed between Bobst and Manchester Metropolitan led to a three-year KTP project (KTP009328: 'Conversion Processes for AlOx Coated Polymer Packaging', rated 'outstanding' by Innovate UK). The KTP project developed and optimised the multiple conversion stages required to take the AlOx coated polymeric film through to a finished product for food packaging. This, in turn, allowed Bobst to achieve market-leading worldwide sales of 'turn-key' solutions to packaging manufacturers (see output 1771).
- Innovation and culture change - transforming SMEs through Smart systems innovation: Impact has been generated through our strategy of pro-actively marketing our KE capabilities to SMEs seeking innovative product and process development to deliver first-to-market and disruptive technologies through Smart systems. Utilising the vehicle of KTPs, an example of this is the 'Non-Intrusive Mobile Advanced Metering Infrastructure (AMI) for Water Management' project with Aquacheck Engineering Ltd, a Greater

Manchester SME that provides innovative water solutions to large water utility companies. The project, which was rated 'outstanding' by Innovate UK, successfully transferred the research on sensor clustering and product energy efficiency to develop the world's first Smart, non-mechanical standpipe for initial launch in the UK. This project received the Best Knowledge Transfer Partnership Award at The KTP Best of the Best Awards in September, 2020. The judges said: "This KTP has revolutionised the traditional standpipe by turning it into a Smart, connected device, which delivers invaluable insight into water usage." The judges also felt this KTP had been "utterly transformative" for the business.

- CFD modelling of complex wave-structure interactions informs design and operations of major maritime infrastructure projects: Two decades of developing CFD codes and methodologies at CMMFA has led to the creation of a de facto national 'numerical wave tank' (NWT) capability, providing a high standard national R&D facility to support both academic research and industrial application in the area of wave structure interaction. The code has been used, most notably by Dutch engineering firm Royal Haskoning DHV, to model wave effects on a large-scale coastal defence project around Bacton, Norfolk, which will protect two villages and a major gas terminal from flooding and coastal erosion for 20 years. The code also informed the design of the new Littlehaven promenade and sea wall to prevent over-topping and flooding during storms.

Interdisciplinary Research: A major strength of the research carried out in the Engineering unit is the emphasis placed on multi-disciplinary and interdisciplinary activities. Our research structures and strategies are designed to encourage and support staff naturally from different disciplines to form collaborations to undertake research that would otherwise not be possible and we support this through internal funding competitions. Some examples include collaboration between sports materials engineers and apparel experts in the Manchester Fashion Institute to develop auxetic materials (output 1814) for protective equipment (e.g. wrist protectors) and healthcare scientists to prevent sports injuries (e.g. mouthguards). Water treatment, which is increasingly becoming a topic of international concern, is another strong example of interdisciplinary research in this unit, combining knowledge in materials science, surface engineering, chemistry and microbiology at interfaces to develop and optimise appropriate treatment technologies (outputs 1840, 1851). The Applied Imaging Engineering (AIE) Group includes staff from Engineering, Computing and Maths, and Ecology and Environment, and was formed to offer software solutions in computer vision and deep learning for researchers across the whole University, and externally, particularly those without the capacity to develop their own code. The AIE group provides an interdisciplinary service, with three-month projects supported by a software developer, to help researchers build a readable, reliable and efficient code.

SIIRG worked with the Manchester School of Architecture (MSoA) and the Department of Computing and Mathematics (DoCM) to deliver CityVerve (2016-2018), a £10m Innovate UK funded Smart city project that aimed to test better services, using the Internet of Things (IoT) technology. SIIRG was involved in development, integration and installation of energy efficient sensors for urban equipment, like street lamps, vehicles or home heating equipment. DoCM worked with SIIR on data analytics using AI and visualisation platforms, while MSoA developed the 'Green Travel Planner', a custom made digital tool, which encouraged more sustainable day-to-day transport choices for citizens.

Open Research: Staff returned in this unit are compliant with the Concordat for Open Research Data, and outputs comply with the REF open access policy. Outputs are submitted to the institutional repository 'e-space' through Symplectic, our research information management system, which is monitored and maintained by RKE Systems and the Open Access team in the Library. Institutional and UKRI funds are provided to cover APCs for gold access for high-quality outputs underpinned by external funding and outputs that have wider economic and societal benefits. Staff in this unit also take advantage of voucher schemes, such as that offered by the Royal Society of Chemistry to cover APCs – over 40 vouchers have been awarded in the REF period providing £60k for APCs. The University's research repository ('e-space') contains over 15k items, which have been downloaded over 1.5M times in the REF period. Four members of this unit (Banks, Rabie, Adebisi and Kelly) are amongst the top 25 most accessed authors out of over 1,000 entries, with papers

linked to our impact case study on surface coatings (output 1771) receiving over 1,500 downloads since publication.

We also recognise the importance of research data management as a part of good research practice in ensuring high standards of research integrity and excellence. All those engaged with research in this unit have a responsibility to ensure that the data they gather and generate is properly managed, adhering to research funder data policies where appropriate, and made accessible, intelligible, assessable and usable by others unless there are legitimate reasons to the contrary. All staff prepare data management plans, which include data storage requirements that they can access using the Research Data Storage (RDS) platform established with £500k of internal funding during the assessment period. Support for Research Data Management is provided by RKE Systems and the University Library. The EPSRC CCP-WSI project (a Collaborative Computational Project in Wave Structure Interaction), of which Manchester Metropolitan is one of the lead partners, gives an example of this in practice. Computer codes developed from the project and test cases used for validating the numerical models are being shared with the wider research community in wave structure interaction through dedicated open code and data repositories.

Research Integrity and Ethics: The Faculty Research Ethics and Governance Committee implements the University's research ethics and governance-related policies within this unit and oversees staff and student compliance with The Concordat for Research Integrity. We have three ethics leads within the unit including the deputy chair of the Faculty's Research Ethics and Governance Committee (REGC). It is a requirement that all staff, PGR students and visiting researchers obtain ethical approval for all projects and this is explicitly covered in training and induction processes. The REGC is the body of review for applications for ethical approval and has the remit to create unit level policies regarding research ethics and governance. Ethical approval is obtained through the online EthOS system and all research activities are required to secure approval before data collection can commence. Each application is reviewed on areas related to ethical conduct of research as well as GDPR, legal requirements, insurance and research communication before being signed off by the Committee Chair. Every year, our ethics leads participate in a monitoring and review process that feeds into our University's annual report for compliance with The Concordat for Research Integrity. Our ethics leads work closely with a professional Research Ethics and Governance Manager, who ensures that information and training is kept up-to-date and that everybody understands their responsibilities, including processes for investigating allegations of research misconduct.

2. People

Staffing and Recruitment Strategy: Our predominant staff recruitment strategy is to search out talented early career researchers with nascent potential to undertake high quality research in one of our core areas of strength, and to develop that potential through a structured support programme. Consequently, research track record and appropriateness of fit to a given UCRKE are key criteria in the recruitment process. 30 staff returned in this unit took up their posts since REF2014, including ten ECRs (20% of submission). Of these new staff, eight first joined us as either PhD students or PDRAs (Abd-Allah, Brownson, Duncan, Ma, Randviir, Redfern, Rowley-Neale and Sawtell) and were subsequently recruited to lectureships on the basis of their performance. Of course, staff are recruited at all career levels; four new Professors (Decent from Lancaster, Gibson from Manchester, Liskiewicz from Leeds and Holderbaum from Reading) were brought in to provide leadership and two experts in hydrogen fuel cell technology (King from Stanford and Regmi from Berkeley) were appointed from an international field to strengthen this area. Other staff were recruited in this period from Russell Group universities, including Manchester, Birmingham, York, UCL, Edinburgh and Liverpool, and internationally from DCU, Monash, Nanyang and Singapore Universities.

We support staff at every stage of their academic career, as reflected in our staffing contract profile (Table 1)

Professor	Principal Lecturer and Reader	Senior Lecturer	Lecturer, Research Fellow
15%	13%	46%	26%

Staff contract level profile (Table 1)

3 staff (1.4FTE) are on fixed-term contracts and, as such, receive exactly the same access to staff development opportunities and resources (see below) as other colleagues.

Development Strategy: Staff are appointed to one of the UCRKEs and integrated into a research group or team, where they will be assigned a research mentor appropriate to their level of experience. Mentors receive training to enable them to work with their staff to develop a research activity log or plan, which will set out a series of objectives for the short to medium term (up to five years ahead). These logs are considered to be live documents that are regularly updated. The research activity logs for all staff are reviewed annually with the Centre Director and are used as the basis for establishing a research time allowance within the departmental workload model that provides a fair and equitable balance between teaching, research and administration. Importantly, staff considered to be full members of the UCRKE are allocated a minimum of 20% (up to a maximum of 50%) of their workload to research.

Full membership provides access to UCRKE award schemes, specific investment for RKE activities (including internal strategic funds), the use of RKE systems, support from dedicated Research Development Managers (RDMs) and BDMs and through the central RKE Directorate. In return, full members are expected to produce high-quality outputs, achieve research income targets, supervise PhDs, engage with activities relating to impact, and produce individual research plans. Performance around these expectations is measured by Heads of Department through the annual Professional Development Review process. ECR staff not achieving full membership are categorised as associate members and given additional training, as required, to attain full status. The PDR process and activity logs feed into a robust promotions and succession planning process, which recognises staff achieving impact in their field and has provided a career progression route for several staff in this unit in the assessment period, including three internally promoted Professors (Banks, Alhussein, Adebisi and Qian).

Staff at the top of Lecturer, Senior Lecturer and Reader scales can apply for additional pay increments designed to reward excellent research or impact. Professors have their pay reviewed in an annual 'banding' exercise, an opportunity for the Faculty to reward outstanding contributions from top performers. Promotion from Lecturer to Professor is signposted via two Academic Career Pathways – *Education, Pedagogy and Citizenship* and *Research, Knowledge Exchange, Education and Citizenship*. Information workshops are delivered by the Faculty Head of RKE and Pro-Vice-Chancellor for RKE ensuring the process is open and inclusive. Additional workshops are held for BAME and female colleagues.

Additional support for staff to achieve their research and career objectives is provided through a number of routes, including:

- Within the Engineering unit, staff can apply for seed corn funding to develop RKE activities. Awards of up to £10k are available to support any activity that can leverage new funding opportunities or generate high quality outputs or impact.
- There is a sabbatical scheme available to staff, who are seeking to develop larger research themes or groups: for example, Doyle was awarded a 3-month sabbatical in 2018 to allow him to establish a Low Carbon Fuels (LCF) Group within AMSE. The LCF group has subsequently flourished, leading to a PhD completion, part-funded by G-Volution and contract research funding from Cryofuel.
- The Good to Great Researcher Career Development Programme (G2G) provides bespoke support for researchers, who are typically on a pathway to professorship, building on individuals' existing strengths and helping to remove barriers to progression. The programme focuses on academic professional development and research leadership skills development, and is a key element in our succession planning. Four staff are currently

participating in the scheme from this unit, receiving a combined total of £64k in funding to support their development.

- The RKE Future Leaders scheme, which is available to staff at an earlier stage of their careers, provides a cohort-based leadership programme structured around RKE-related agendas, such as funding, open access, research integrity and impact, etc. Five staff are currently participating in the scheme from Engineering.
- Grant development workshops: funding proposals are scrutinised and 'sense-checked' by experienced colleagues to ensure they are valid ideas that meet the criteria of the funding body, thus improving our success rate through improving the quality of the proposals.

Integrating new staff and Post Docs: All new staff undertake an induction programme, which gives guidance on the research procedures in the UCRKE. Other important elements of the staff induction programme include training in PhD supervision, chairing examination panels, health and safety, data protection, prevent duty, and implementing our equality and diversity policies.

An Engineering ECR Support Programme was launched in 2017, led by Doyle, to encourage and advise new staff members on how to secure grant income, particularly those calls unique to ECRs; and to project manage effectively in order to generate knowledge and deliver tangible outputs. ECRs on this programme are supported by a combination of informal one-to-one meetings and an annual grant writing workshop, which includes a Q&A session with a panel of experienced grant holders. The initial cohort of ten members of staff from this unit have gone through this programme and collectively secured over £1.1m from various external funding bodies. The scheme has since been extended to 17 members.

Staff, postgraduates and students are further integrated into the research culture through involvement in our seminar and development programmes: for example, we have organised one-day events aimed at showcasing our research excellence in priority areas, including water detection and treatment, low carbon energy, bioengineering and sustainable materials. In addition to contributed presentations from full members and selected external invited speakers, we encourage ECRs, postgraduates and PhD students to present their work with a view to forging collaborative research and joint grant applications. We hold bi-annual away days to bring members together to discuss strategy and evaluate group performance. We also hold regular research workshops where members of the unit, including academics, post-docs and PhD students, meet to discuss project progress, publication strategy and plans for external funding applications.

All support processes and structures for research comply with the principles of the 'Concordat for the Career Development of Researchers'. Manchester Metropolitan demonstrates its compliance with the Concordat via the EU HR Excellence in Research Award, which we first received in 2013 and have held for the past eight years.

Research Students: There have been 59 PhD completions to date in the REF period (compared to 50 in REF2014).

Recruitment: In this unit, recruitment of doctoral students, including those with protected characteristics, requires an interview, which are always conducted with a mixed gender panel to comply with E&D guidelines, usually containing the prospective DoS, an additional subject-related member of staff, an independent panel member and/or the appropriate Research Degree Co-ordinator (RDCo) as Chair. Our students are recruited from multiple sources, including through the matched funded scheme referred to earlier, other internal funding mechanisms, such as QR returned to the UCRKEs, Leverhulme, and the University Alliance DTA scheme. Our PGR community during the assessment period of 129 students, consisted of 86 home / EU (67%) and 43 overseas (33%), with recruitment from 29 countries. The gender balance was 75% male/25% female; 7% have a declared disability, 48% were from BAME backgrounds and the age profile ranged from 23 to 59.

Support for Students: Research students join the Faculty Graduate School, which provides an induction process and a comprehensive programme of workshops throughout the year aimed at promoting best practice, continuous professional development and helping postgraduate researchers to get the most out of their research experience (e.g. research methods, health and safety, experimental design, ethics, business skills and plagiarism). All PGRs also have access to

the same University Support Facilities as staff, e.g. Wellbeing Services. As part of their induction programme, all research students are integrated into a host research centre, usually the same one as their Director of Studies, and are invited to participate in centre activities, such as seminars.

All postgraduate students are encouraged to publish their work in journal papers and present at external research conferences, and financial support is available for this through their research centre. In addition to this, regular faculty- and university-wide events enable students to present their findings in poster and oral format at an early stage and in a broad supportive atmosphere. Such academic forums are supplemented with regular research student social events. We also offer public engagement and outreach opportunities to widen their research dissemination and communication skills. Working with the supervisory teams, we have a number of Departmental RDCos in the unit, who focus on improving and maintaining a positive PGR environment in their remit. They also sit on a University-wide PGR Training and Development working group to develop this provision and environment further, ensuring that all PGRs come out of their degrees with transferable employability skills. Supporting this is the Jobs4students service, which provides short-term posts for PhD students and PGRs in our research labs, giving them direct experience of working with our leading research staff. All our PGRs have access to lockers, staff common rooms and desk facilities, with the majority using university laptops to allow flexible working. The effectiveness of our systems is evidenced by over 90% of students in this unit reporting satisfaction with their supervision and in the development of their research skills in the latest 2019 Postgraduate Research Experience Survey (PRES). Engineering also features in the top quartile in this survey for Research Culture, Progression, Understanding of Responsibilities and Professional Development.

Monitoring and Support: Progress is monitored via a personal development portfolio and annual assessment meetings with an independent mentor, which is logged by the Science and Engineering Research Degrees team through the SkillsForge system. Furthermore, the Graduate School is fully engaged with, and supports access to, the Vitae Research and Development Framework. A mock viva programme is undertaken where all PhD students in this unit can get feedback on their work ahead of their PhD Viva.

Progression: Student career progression is also an important consideration in this unit. Several PhD students have progressed to lectureships in the assessment period; others, e.g. Struller, followed her PhD with a KTP Associate post at Manchester Metropolitan, sponsored by Bobst Manchester, was subsequently employed by them and is now the Industrial Supervisor of a further KTP project between Bobst and the University. At least six other KTP Associates have also been retained by their sponsoring companies. Regular teaching opportunities are offered, with the process usually de-coupled from the DoS in order to provide a range of academic viewpoints.

Equality and Diversity: We have aimed to be fair, transparent and inclusive in our REF preparation, complying with the University's *Code of Practice* to ensure that E&D is reflected in the submission. All colleagues with significant responsibility for research and independent researcher status are included in the submission. Staff involved in preparing the submission completed training on 'Managing Diversity', 'Equality and Diversity Essentials' and 'Unconscious Bias and REF2021'. We have taken positive steps to maximise E&D in the selection of outputs. All staff are aware of the REF2021 process for declaring individual circumstances (which is in addition to our annual UCRKE process for declaring equality-related circumstances) and five colleagues used the confidential process to declare a mixture of complex and 'simple' cases. We have not sought a reduction in the overall volume of outputs in our submission because we took the view that there is enough scope for us to manage the impact of individual circumstances within the REF2021 rules.

In April 2018, Advance HE confirmed that the University had been successfully awarded an Institutional Athena SWAN Bronze award. In the Engineering unit, we have our own Self-Assessment Team (SAT) for Athena Swan, led by a member of the University's working group. Any E&D matters arising within the unit are attended to by the Athena Swan unit lead (Sawtell) with support from the SAT, in consultation with Heads of Departments (HoDs), the Research Centre Directors (RCDs) and HR. Staff can be granted workload allowance or leave of absence to work remotely in order to minimise distractions to research and other continuous professional development (CPD). Working from home to fit around family and caring commitments can be

agreed on an occasional or temporary basis. For long-term arrangements, we have a 'Flexible Working Policy', which is a formal route for staff to request contractual changes to cater to their individual work and home circumstances.

The career pathways and progression opportunities, as stipulated by the University, apply to all academic staff who are Grade 8 (lectureship) and above, irrespective of their type of contract; indeed, reference was made earlier to the number of staff in this unit who have successfully progressed from fixed-term PDRA roles to permanent contracts. Inclusivity is at the heart of our support mechanisms for progression. Our internal funding application processes for staff take into account the E&D considerations that are applicable to the individuals seeking funding and workload allowance to pursue their research. For example, all research-related travel, including conference attendance by staff, is sanctioned by their department upon consideration of a business case developed by the staff member with their RCD. Decision to fund is taken on a case-by-case basis, and any applicable exceptional factors and E&D aspects will be considered in order to support the staff best in a fair and equitable manner.

In terms of support to staff returning from shorter to longer periods of leave, line managers conduct a formal return to work meeting with the staff member in order to understand the required transitional arrangements to help them settle back into work. This includes discussions around any changes in the individual's circumstances at and outside of work as well as a workload review of their teaching and research duties. Appropriate support mechanisms are put in place and documented with HR. To manage ill-health or long-term illness, HR guidance on staff health and well-being is followed and a referral to Occupational Health is prioritised by the line manager at the earliest opportunity. Any parental and caring responsibilities discussed with the line manager are dealt with confidentially and with HR guidance to provide optimum support to the staff.

Inclusivity also plays a major role in recruitment to research leadership roles. Gender equality, BAME and other E&D aspects, such as protected characteristics, are taken into serious consideration within this unit when recruiting staff for research leadership roles. We are a Disability Confident employer, which ensures that any disabled candidate, who meets the essential criteria for a vacancy, will be guaranteed an interview. All staff are encouraged to approach their line managers or any other members of the senior management team freely if they have any concerns related to their protected characteristics. Staff and students are also encouraged to join our Wellbeing Community, which promotes positive personal wellbeing and champions workplace wellness in a non-judgemental and confidential environment.

In this unit, 75% of the submission are male / 25% female (accounting for 20% of all outputs); 0% of staff have a declared disability and 57% of the submission identify as white / 43% as BAME (accounting for 42% of outputs) – figures, which are all close to the sector averages.

3. Income, infrastructure and facilities

External Income: As described earlier, one of the key performance targets in this Unit during the REF period was to increase research grant income. Our strategy for achieving this was based, in part, around promoting our expertise and engaging with industry, for example, through KTPs. In addition, our strategy to put in place staff development processes, including working with RDMs to target specific funders, funder visits and workshops, ECR development, supporting external collaborations, and internal investment in new clusters (e.g. the MCFIC), has successfully increased the proportion of research active staff and the number of principal investigators, and through that, has achieved the aim of increased income.

In 2013/14 research income stood at £870,220. For 2015/16, this had increased to £1,422,802 and by 2019/20 income had increased to £2,169,004, giving a total of £9,747,036 in the REF period. The total value of research awards stands at £12,806,757 with a further £8M in KE awards. KE income contributes another £2,249M to the unit's resources, collectively demonstrating the sustainability and vitality of the unit going forward. This compares very favourably to the REF2014 research income total of £4,578,960. Thus, it is clear that the strategies put in place through this REF period have resulted in a very significant (112%) uplift in research income. Furthermore, 49

of the staff submitted in this unit can be identified as Principal Investigators of individual external research income awards made in the assessment period.

Diversity of Income Sources

Source of Income	BEIS Research Councils	UK Charities, Open Competition & Other	UK Govt, Industry & other UK Sources	European Union	Non-EU
Percentage of Income	36%	2%	54%	5%	3%

Table 2: Diversity of Income Sources

Expanding on the income table, our biggest source of income is Innovate UK, with KTPs accounting for almost £3M in income (for example, Aquacheck Engineering: KTP010599; £311,836; PI: Adebisi). This justifies our strategy of engaging with industry, as does direct industrial funding from many companies, including the Atomic Weapons Establishment of £855k (PI: Kelly).

EPSRC funding accounts for approximately 1/3rd of our income, for example 'Additive Manufacturing Next Generation Supergen Energy Storage Devices' (EP/N001877/1; £509,084; PI: Banks); and 'Extreme Loading on FOWT under Complex Environmental Conditions' (EP/T004150/1; £353,155; PI: Qian). EU funding has been less significant; however, some substantial grants have been awarded, for example 'Developing and Implementing Sustainability-Based Solutions for Bio-Based Plastic Production and Use to Preserve Land and Sea Environmental Quality in Europe' (£371,668 European Commission; PI: Banks). This award develops important international collaborations and supports both our sustainability agenda and our Circular Economy Network.

Other sources include the British Council, the Royal Academy of Engineering, the Newton Fund, and the Royal Society, which indicates the international reach of our research.

Internal Funding: We have access to all the relevant QR funding that was earned in REF2014 (approx. £380k p.a. in this unit), plus an additional £30k p.a. to support our operational priorities. We use this funding to develop capacity for external funding applications including competitive internal awards, seed corn funding, and travel and subsistence costs to attend conferences or visit external partners. In each case, the funding provided support to help 'kick start' new research initiatives in these areas. A further £200k has been awarded to the unit from other internal sources, such as the Global Challenges Research Fund and our Research Accelerator Grants scheme. Along with the provision of staff time and workload allowances, the above represent a considerable internal investment into high-quality research.

Infrastructure: There has been significant investment in the REF period in all levels of organisational infrastructure for research and delivery of impact. Key outcomes from this investment can be seen in our Industry 4.0 activities and in the establishment of the Manchester Fuel Cell Innovation Centre, PrintCity and the Circular Economy Network. The Strategic Opportunities Fund is a centrally-managed fund, which staff can bid for to develop new substantial initiatives of this nature. In the REF period, this unit has received £233k through this fund to support the MFCIC, PrintCity and SIIRG.

At unit level, the research leadership teams meet monthly to plan activities, update strategy and agree internal funding awards. The centre directors then report activity to the Faculty RKE committee, which in turn reports at university level. In this unit, we have access to dedicated technical and support staff, estates and facilities teams and IT support, including professional marketing and web development support for our website and social media presence. Through the RKE office, we also have the support of the aforementioned dedicated RDMs and BDMs; an International Research Development Manager; the KTP office; Ethics and Governance teams to ensure compliance with the relevant legal standards (e.g. GDPR, etc.); a Research Delivery Team including post-award specialists; and a RKE Contracts and Legal team, which provides advice on contracting requirements for research projects, and negotiates agreements, such as non-disclosure agreements and collaboration agreements with external organisations of all types.

RKE Systems manage Symplectic, which staff use to maintain records of outputs, OA compliance, and web profiles; Worktribe is used for the online management of external funding applications and reporting; EthOS, for research ethics and governance; and SkillsForge, to manage the PGR student journey. RKE Systems also provide management reports and data for annual review processes.

Library: The University Library is open 24/7 and offers access to extensive online resources for staff and PGRs. A subject-specific librarian advocates for extra resources and updates journal provision, as well as contributing to workshops and training in InfoSkills and Open Research. Journal titles and online resources are reviewed annually. The Library also manages Green OA through the University's e-Space repository and funding for Gold OA APC charges.

Impact infrastructure: Measures taken to support the generation of impact from our research and to ensure the long-term sustainability of our activities include the appointment of a unit Impact & Engagement Manager, whose role is to optimise impact generation across the research life cycle. The role involves activities to raise impact literacy and embed best practice in impact development, delivery and monitoring at all staffing levels, and to ensure research proposals support strategic and ambitious impact goals. The Manager is an active member of the unit's management group and also champions delivery of public engagement activities.

Facilities: The majority of our materials and engineering research takes place in well-equipped laboratories in John Dalton Tower and the Engineering Workshop (a total lab space of approximately 2000m²) and is supported by a team of 40 dedicated technical staff. For example, the Surface Engineering Laboratory is fully equipped with state-of-the-art magnetron sputter coating deposition systems, ranging in size from lab-scale research units to pilot-scale production systems. Our materials scientists make use of analysis facilities including SEM, EDX, XPS, AFM, XRD, HPLCs, GCMC, ICP, NMR and various spectroscopic instruments. Sports Engineering utilises high speed cameras and digital image correlation software, plus bespoke instrumented impact rigs and bending rigs, e.g. for tennis rackets, cricket bats and snow board wrist protectors.

In the research areas of sensing, measurement and advanced communications, we have equipment, such as Power Network Analysers; Vector Network Analysers; Fibre-integrated reception satellite system testbeds; TV Signal analysers; Nordic Sampo (for RFID Tag characterisation); PCB Fabrication Facility and RF test accessories. There are high-speed/resolution line cameras and specialist line lights, a hyperspectral camera, high spec desktop for deep learning applications, and a software-defined radio test bed. We have a photogrammetric system called 'Digital Image Correlation' that allows us to carry out full-field displacement, strain and vibration measurement.

In the Smart Energy team, we have an E6 Ricardo engine, emission measurement kit, a 5.5kW Gearbox and 1kW Motor/Generator test rigs, and dSpace Control Systems and lab with connected facilities to various energy sources (PV, CHP, wind turbine, batteries, etc.)

We have lab facilities to conduct research in rehabilitation engineering. The lab has Functional Electrical Stimulation to restore motor function in paraplegia. The lab is also equipped with an instrumented frame to measure forces produced by paraplegic subjects while standing up. A motion capture system, Qualysis, with eight cameras is being used to measure the motion of the body in a 3D space.

At CMMFA, our main facilities are high-spec desktop PCs and a CPU/GPU cluster with 12 compute nodes (192 cores). Collectively, we invest in state-of-the-art software, such as Ansys Workbench, Abaqus 2019, OpenFOAM, Ansys Fluent, COMSOL Multiphysics, Matlab, NI LabVIEW FPGA, GOM correlate professional (commercial) and DICengine (open-sourced), CONVERGE CFD, CHEMKIN-PRO Advanced Design System (ADS), SystemVue, Python, Visual Studio C#, C++, and Cypress PSoC IDE PCB Design platforms, etc.

In the five-year period of delivering the Triangulum project we worked with the Estates and Facilities team at the Manchester Met Birley Fields campus (Living Lab) to install combined heat and power (CHP): 375 kwh, solar PV: 158 KW, Battery Storage: 400kWh, 18 Electric Vehicle chargers, and in the purchase of two electric vehicles. We also worked with the IT team to ensure seamless secure communication between our facilities and the Siemens Central Controller to

reduce demand on the energy network at peak times. These unique facilities acquired and installed during Triangulum (and also the Citiverve project) are available to SIIRG researchers as a 'living lab', allowing us to study people's reactions to the Smart technologies and their approach to sustainability.

Two major recent infrastructure initiatives to support high quality research and impact at the University contribute to the Engineering submission, namely, The Manchester Fuel Cell Innovation Centre (MFCIC) and PrintCity®. Both represent significant investment in this unit and expert academic and technical staff have been recruited specifically to support these initiatives.

MFCIC is a new (launched in 2018) £4.1M research centre, part funded by the European Regional Development Fund (ERDF). The funding was divided between refurbishment costs to a suite of existing labs in the John Dalton Tower; providing state-of-the-art hydrogen safety and alarm systems; providing meeting and seminar rooms; and installing a suite of materials analysis equipment (e.g. an X-ray photoelectron spectroscopy (XPS) system, and a 'first in the UK' combined atomic force microscope and Raman spectroscopy system; AFR/Raman) and fuel cell testing equipment including proton exchange membrane (PEM) test rigs, solid oxide fuel cell (SOFC) test rigs and an electrolyser.

PrintCity® has invested over £300,000 in capital equipment in the last two years. It boasts over 50 3D printers from eight different print technologies and high quality scanners. PrintCity has nine members of staff to support teaching, research, knowledge exchange and outreach activities.

Accessing External Facilities and Infrastructure: Banks utilised battery-testing facilities at Central South University in China to test 3D printed energy storage devices, which was an output of EPSRC project EP/N001877/1 and published in Nature Science Reports (article 42233 – ranked in the Top 100 in Chemistry series, see output 1817). Kelly is developing surface engineering solutions for accident tolerant nuclear fuels, which have been tested at the Dalton Cumbrian Facility (DCF), the UK's largest academic provider of nuclear research and development test facilities. At CMMFA, much of our EPSRC SUPERGEN funded work has been a collaboration between our specialists in computational fluid dynamics and experimentalists at the project partner institutes (Plymouth, Imperial and Queens University of Belfast). Our numerical modelling work is validated by the data from the dedicated wave tank tests, such as the COAST (Coastal, Ocean And Sediment Transport) laboratory at Plymouth, which provides physical model testing with combined waves, currents and wind, offered at scales appropriate for device testing, array testing, environmental modelling and coastal engineering.

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

Academic Collaborators: Staff returned in this unit collaborate with a multitude of national and international academics in many fields; the world-wide reach of our work is evidenced by the 600 published outputs from this unit in the assessment period that have international co-authors (57% of total outputs). Examples of our successful academic collaborations include CMMFA's successful long-term contribution to the SUPERGEN Wind, Marine and ORE HUB programmes, SIIRG's Triangulum and Citiverve projects, and the large multi-partner circular economy projects undertaken through the CEN. Internationally, we have established the Manchester Metropolitan Joint Institute, Hubei University (Vice Dean, Hong Li is returned in this unit) and have developed a joint Research Centre in Functional Materials with Wuhan Institute of Technology. We are also in the process of developing a joint Research Centre in Smart Energy Systems (including Hydrogen) with Sichuan Energy Internet Research Institute, Tsinghua University.

There are many other examples of successful academic collaborations, which have led to journal publications, funding proposals, student exchange, co-supervision, etc. and a selection are given below:

Prof. Bradley, Liverpool University (EPSRC projects; plasma physics); Dr. Assender, Oxford (EPSRC project; materials characterisation); Prof. Barber, Cambridge (Pilkingtons funded project on atomic diffusion); Profs. Preuss and Xiao, Manchester (BEIS funded project on Accident Tolerant Fuels); Prof. Wuttig, RWTH, Aachen, Germany (joint PhD project in high entropy materials); Prof. Tavares, Minho, Portugal (photocatalysis, co-conference series organiser); Prof.

Yun Gao, Hubei, China (Royal Society International Exchange Award IE140963), Prof. Selli, Milan, Italy (Erasmus student exchange programme); Prof. de Amorim, UFMG, Brazil (co-investigator on Newton Fund award, also visiting researcher at MMU); Prof. Prasertdam, Chulalongkorn, Bangkok (photocatalysis; co-investigator on Newton Mobility Grant NI170178); Prof. Ndlovu, Witwatersrand, South Africa (water treatment); Prof. Lundstrom, Aalto, Finland (gold recovery); Prof. Dutra, UFSC, Brazil (catalysis); Prof. Velarde, Buffalo, USA (spectroscopy); Prof. Feng, Hunan, China (physics); Prof. Marcolino-Junior, Universidade Federal do Paraná (UFPR) Brazil; Prof. Mahanthappa REVA University, Bengaluru, India; Dr. Khairy, Sohag University, Egypt; Prof. Richter, Federal University of Uberlandia, Brazil (electrochemistry); Prof. Plets, Ghent University, Dr. Rajbhandari, Coventry, Prof. O'Brien, Oxford, Dr. Dowhuszko, CTTC, Barcelona (optoelectronics), Dr. Schauer, Technische Universität Berlin, Dr. Remsing, Rhodes University, South Africa (smart energy); Prof. Cotton, Manchester, Prof. Malcom, Oxford, Prof. Li, Bath, Prof. Nasuto, Reading, Prof. Becerra, Portsmouth, Prof. Freemann, Southampton (Smart infrastructure).

In several cases, these collaborations have led to external chair appointments:

- Beijing University of Chemical Technology, Xingfa School of Mining, Wuhan Institute of Technology (Potgieter);
- Hubei University, Wuhan (Kelly);
- Central South University, Changsha; Xiangtan University, Hunan; Henan University of Technology, Henan; Xinyang Normal University, Henan; Jiangnan University, Wuhan, China; Thapar University, Patiala, India (Banks);
- Federal University of Juiz Fora, Brazil (Adebisi);
- Hohai University, China (Qian);
- Sichuan University (Zhou).

Collaborations, Networks, Partnerships: In addition to the aforementioned Triangulum Project, we are also a partner of CitiVerve, a £10M Smart city project in partnership with Cisco, BT, Manchester University and 18 others, which demonstrated the benefits of the 'internet of things' (IoT) in Smart cities. The facilities installed at our Birley campus were used as a testbed to prove that low-carbon, cost-efficient solutions are possible and could be rolled out to other urban centres across the continent. This has led to additional grant income, such as Energy-IQ project (UK-Canada; BEIS funded Project; £2.2M); and Nigeria Intelligent Community Energy (NICE) Energy (UK- Nigeria DFID funded project; £600k) funded by DFID. Other major networks include the H2020 funded 'Sustainable solutions for bio-based plastics on land and sea' circular economy project, which includes 22 partners from 13 countries and has a value of €8.4m over four years and the TRANSFORM-CE project to divert single use plastic to a feedstock for additive manufacturing, which is funded through Interreg North West Europe, has 20 industry partners and a total value of £9.4M.

Our engagement with G-Volution Ltd shows how we can grow a collaboration with a company through delivery of high quality outcomes, beneficial to the economy and society. We achieved this by offering a flexible portfolio of engagement tools and having an appreciation of the business environment in terms of budgetary and timescale constraints. Our collaboration progressed through matched funded PhD studentships, contract research and a three-year KTP to develop and embed into the company new catalyst solutions for dual fuel heavy goods vehicle exhaust streams, capable of meeting EURO 6 environmental standards. The total investment in the project to date is £680k. As a direct output, G-Volution has established an agreement with Johnson Matthey and US company Tenneco to scale up and install end product units in HGVs (output 1824).

Wider Economy and Societal Contributions: We contribute to society through our Circular Economy Network, which was established to address the challenge of decoupling economic growth from resources use. We aim to provide innovative research and consultancy support to the Greater Manchester Combined Authority (GMCA) and businesses, and position the network as the leader for CE within the NW. Our activities support the GM Industrial Strategy and 5yr Environmental Plan, and the GM zero carbon target for 2038, and, internationally, the UN Strategic Development Goals (SDGs). Examples of problem-solving within the waste industry include;

preventing in-vessel composting corrosion in anaerobic digesters; the identification of odour control system failures; the recycling of new wastes arising from advanced processing; and the optimisation of sludge management processes.

Our **Industry 4.0** agenda contributes to the economy and society through focusing on bridging the skills gap between industry and academia. We are doing this through our collaboration with Siemens and Festo on the connected curriculum programme, which includes I4.0-related research projects. I4.0, digitalisation and the use of Big Data provide enormous opportunities as a paradigm shift from centralized to decentralized Smart manufacturing and production. We see it as a key enabler for increased sustainability (and contributing to the Circular Economy), providing more interoperability and flexible industrial processes, and autonomous and intelligent manufacturing.

We were the lead authors of the 'Greater Manchester Hydrogen and Fuel Cell Strategy 2021–2025: How clean energy can help deliver Greater Manchester's 2038 decarbonisation ambition', which contributes to the highly ambitious Greater Manchester 'Carbon neutral living by 2038' mission. This strategy will support the North West to become the UK's first Low Carbon Industrial Cluster and is also aligned to the Northern Powerhouse ambition around hydrogen and fuel cells.

Beyond GM, our MFCIC staff were also selected as technical experts to present to the all-party parliamentary climate change group (APPCCG) during their "Achieving Net Zero: Low Carbon Mobility" APPCCG Roundtable. As a follow-up to the above meeting, we co-authored an essay with Alexander Stafford, MP, entitled 'Achieving Net Zero Emissions from the UK Transport Sector by 2050: The Role of Fuel Cell Electric Vehicles'. This has been published as part of a collection with the APPCCG on the theme of low carbon mobility. We have also contributed to an APPG report entitled, 'How the UK's hydrogen sector can help support the UK's economic recovery'. In addition, we were invited to contribute as expert reviewers for the Royce Institute 'Materials for the Energy Transition Roadmap' workshop.

Engaging the Public with Research: We launched the Hydrogen In Schools (HySchools) project, which is an Erasmus+ project that aims to deliver hydrogen education in schools at ages 13-18. Educational and online resources have been created for use in secondary schools across the European partner countries, aimed at providing teachers with increased confidence to teach students about Hydrogen Fuel Cell Technology (HFCT). HySchools aims to help schools enhance the quality of HFCT teaching to equip students with the future skills required by this growing sector.

We have also launched a two-week course entitled, 'The Challenge of Clean Growth and Cleaner Cities', which aims to help those who are considering working in the clean energy sector by giving them new skills and helping them to gain a better understanding of clean growth.

Another example of public engagement is the 'photocatalytic wall', in which we treated segments of the John Dalton Building with commercially-supplied photocatalytic and conventional paints and asked passers-by to identify the treated and untreated panels, and make a subjective assessment of the perceived cleanliness of the panels. Initially, members of the public attending a Manchester Science Festival event (2014) were asked to rank the painted panels and the experiment, which was also conducted via a social media platform (Facebook), continued for 44 months.

Contribution to Sustainability of Discipline: We contribute to the sustainability of our disciplines through taking active roles in numerous organising committees, editorial boards, professional bodies and strategy panels.

Invited/plenary lectures: The impact and reach of our research is further evidenced by the many invited presentations, plenary lectures and seminars given by staff in this unit at key international conferences. A selection is given below:

- 72nd IUVESTA Workshop on Plasma-assisted vapour deposition of oxide-based thin films and coatings, 2014, Austria (Kelly)
- Nanomaterials in Biotechnology Workshop, Qingdao, 2018 (Tosheva)
- 2nd International Workshop on Dissociative Electron Attachment, Mumbai, 2015 (Koehler)
- International Meeting on Atomic and Molecular Physics and Chemistry, Birmingham, 2015 (Koehler)
- INTERCORR 2014, Brazil (Liskiewicz)

- 9th International Symposium on Fretting Fatigue, ISFF9, Sevilla, 2019 (Liskiewicz)
- International Workshop on VR/AR over 5G for Smart City Moscow, 2018, Russia (Adebisi)
- 7th International Conference on Wireless and Satellite Services (WiSATS), Bradford, 2015 (Adebisi)
- International Conference of Industrial and Manufacturing Engineering, 2019, Prague (Albarbar)
- Invited Guest 2019 Huawei Connect Summit in Shanghai, China (Adebisi)
- 11th international Conference on Materials Processing and Characterisation, India, 2020 (Haider)
- Smart Cities Workshop, Tlalnepantla, Mexico, 2016 (Ekpo)

Conference Session Chairs/Organising Committee: Our staff are active members of the organising committees of several major conference series, including:

- Green Communications & Networks of the IET CSNDSP Conference Series (Adebisi)
- IEEE ISPLC Conference Series (Adebisi)
- International Hydrometallurgy Conference (2016, SA) and International Conference on Mechanical, Metallurgy and Materials Science, 2019, Italy (Potgieter)
- International Conference on Metallic Coatings and Thin Films (ICMCTF), Plasma Surface Engineering (PSE) and Reactive Sputter Deposition (RSD) (Kelly)
- 2nd Euro – Asia Zeolite Conference, 2015 (Tosheva)
- Stanford Hydrogen Focus Group Workshop, 2019 (King)
- 9th International Conference on Auxetics, 2018 (Duncan)
- Federation of European Zeolite Associations, FEZA, Series (Tosheva, Doyle)
- International Conference Series on Ocean, Offshore & Arctic Engineering (Wei)
- Virtual International Conference on Coastal Engineering, 2020 (Zhou)
- Advances in Materials and Processing Technologies (AMPT) Conference Series (Haider)
- 4th Global Summit on Nanotechnology, Czech Republic, 2020 (Velusamy)
- American Chemical Society National Meeting, San Diego, 2019 (Regmi)

Editorships:

Staff in this unit are members of the editorial boards or guest editors of many journals (>30), amongst the highest ranking in their fields are: Catalysis Today (Kelly); Corrosion Engineering, Science and Technology (Potgieter); Materials (Potgieter, Tosheva); Ocean Engineering (Wei); Journal of Water (Qian, Wei, Velusamy); Applied Chemistry (Banks); IEEE Access, Electronics (Adebisi, Chow); IEEE Wireless Communications (Rabie); Energies, (Holderbaum); Sports Engineering (Allen); Applied Sciences (West, Allen); and Nature Scientific Reports (Chow).

We have also contributed to the discipline by founding several new journals, including Journal of Carbon Research (Banks) and Frontiers in Communications and Networks (Rabie).

Selected Fellowships/Committees/Review Panels, etc.:

- Chair of the review panel of the Isaac Newton Institute for Mathematical Sciences (Decent)
- Chair of the Jisc-UUK Content Negotiation Strategy Group (Decent)
- Chair of the European Microwave Association (Gibson)
- Chair of the Institute of Physics Ion and Plasma Surface Interactions Group (West)
- Fellow, Institute of Advanced Science (Potgieter)
- Fellow of IMechE and IoP (Liskiewicz)
- Fellow of the Institution of Civil Engineers (Zhou)
- Treasurer of the British Zeolite Association (Doyle)
- UKRI and EPSRC Early Careers Forum member (Andrews)
- IET Tribology Group Committee (Liskiewicz)
- Member of IEEE Woman in Engineering (Velusamy)
- Co-leader, UK Special Interest Group in Wave Structure Interaction (Qian)
- Founding member of the UK Fluid Network (UKFN) (Qian)

- Co-Director and member of the Steering Group of the Collaborative Computational Project in Wave Structure Interactions (CCP-WSI) (Qian)
- Kelly, West, Banks, Macia Ruiz, Tosheva, Qian, Adebisi, Holderbaum, Collins and Liskiewicz are Members of the EPSRC College.
- UK National Commission for UNESCO (Chow)
- Banks named in the Top 1% of the World for citations, 2018
- European Science Foundation review panel member (Banks)
- REF2021 panellist in Engineering (Banks)