

Institution: Queen Mary University of London
Unit of Assessment: 12 – Engineering
<p>1. Unit context and structure, research and impact strategy</p> <p>Queen Mary University of London (QM) staff submitted to UoA12 are from the Schools of Engineering & Materials Science (SEMS) and Electronic Engineering & Computer Science (EECS). Both schools provide a vibrant research environment to support the performance and dissemination of research of the highest quality across a range of engineering disciplines. A strong track record of impact generation from our research has been strengthened in the current REF period, through technology transfer and public engagement, to deliver the widest economic, health and societal impact. Our research environment is underpinned by a distinctive ethos that is collegiate and inclusive to ensure that researchers are supported to achieve the highest quality in their research through organisational structures that promote collaboration, interdisciplinary research and engagement with key external partner organisations.</p> <p>The UoA12 Engineering Research & Impact Strategy (2014-2020) aligns with the overarching QM Research & Innovation Strategy and is focussed on the following strategic aims:</p> <ul style="list-style-type: none"> SA1.To increase the size and quality of our research base by recruiting and investing in staff with a record of exceptional achievement in research or extraordinary potential. SA2.To align research in selected areas with distinctive strength and develop multidisciplinary research themes to enhance the quality and breadth of our research activity. SA3.To conduct research of the highest standard that results in world-leading outputs, as assessed by our peers. SA4.To increase and seek diversity of our grant income, PDRAs and research fellowships as a means of enhancing research quality and volume. SA5.To increase the number and quality of PhD students and their 4-year submission rate. SA6.Provide a world-class physical and virtual research infrastructure, available to all researchers, supported by strategic use of internal funds and leveraged external funding. SA7.Deliver the widest possible economic, health and societal impact from our research. SA8.Regularly assess how we support, review and undertake research to foster diversity and inclusion and ensure that our research practice is of the highest quality in terms of research ethics and integrity. <p>Throughout the Environment Statement narrative achievements and developments are cross-referenced to the overarching eight Strategic Aims as set out above.</p> <p>Building on the success of the UoA13 and 15 submissions in REF2014 a major strategic aim during the current REF period has been to build research capacity while enhancing research quality (SA1), through growth in activities including major investment in new academic staff. During the REF2021 period implementation of the strategy has focussed on the development of distinct clusters of research excellence, organised within defined research Centres that provide both a critical mass for research activity and also mechanisms for managing and supporting research excellence, including infrastructure (SA2, SA6).</p> <p>The major growth in eligible staff FTE, from 48.0 in REF2014 (relevant research activities from UoA 13 and 15 submissions) to 71.5 in REF2021 has permitted refreshment of research clusters aligned with distinctive research strengths and multidisciplinary opportunities to enhance the quality and breadth of our research activity (SA1, SA2). Through assessment of research strength, capacity and alignment with drivers such as the Industrial Strategy we have retained and developed three of the research clusters from REF2014 (<i>Antennas & Electromagnetics; Bioengineering & Biomaterials; Materials Engineering</i>). Following a strategic review of research strengths and opportunities, we have reorganised elements of the generic REF2014 <i>Centre for Simulation and Modelling in Engineering Systems</i> to align experimental, theoretical and simulation</p>

activities into three new research Centres that are grand-challenge aligned and application focussed: *Aerospace & Fluid Mechanics*; *Chemical Engineering & Renewable Energy*; *Mechanical Engineering, Robotics & Design* (SA1, SA2). The new research Centres are staffed by a combination of key academics from the REF2014 clusters augmented by significant strategic investment in new academic staff (SA1). In addition to the investment in new academic staff our research activity has benefitted from major capital investment in infrastructure and facilities, including the £32M investment into the Engineering Building Transformation programme over the REF2021 period (SA6).

Interdisciplinary and cross-faculty research is supported by three University-wide Research Institutes in *Bioengineering*, *Materials Research* and *Applied Data Sciences* while health-oriented activities are aligned with *QM/Barts Life Sciences* (see section 4).

RESEARCH THEMES AND CENTRES

1. Centre for Aerospace Engineering and Fluid Mechanics

Academic staff Headcount (FTE)	12 (12FTE)
Professor	Stark; Toropov
Reader	Avital; Karabasov; Mueller; Sui; Wen
Senior Lecturer	Castrejon-Pita; J-Chen
Lecturer/Academic Fellow	Cagney; Ismail; Nanjangud
PDRA	4.0FTE
PGR	24

The Centre for Aerospace Engineering and Fluid Mechanics was established as part of our strategic review of research strength and clustering and involves a strategic partnership with Airbus Defence and Space, together with links with many academic and other industrial partners. Research is focused on problems relevant to aerospace as well as to a wider fluid engineering. The Centre's research is aligned with three sub-groups focussing on *Optimisation methods*, *High-resolution modelling and fluid-structure interaction* and *Electrohydrodynamics and drop science*.

Major achievements during the REF period:

Optimisation methods

- Development of design optimisation techniques for large-scale problems with computationally expensive and noisy function values obtained by a CFD or nonlinear structural dynamics analysis (Toropov). Collaboration with Rolls-Royce, Airbus, DLR, Altair Engineering, Jaguar Land Rover, Parker Hannifin, TU Delft, and Hiroshima University. Support by large EU consortia (PoLaRBEAR and AMEDEO (Marie Curie ITN) both finished in 2016) and Technology Strategy Board (SILOET II Programme, finished in 2016).
- Numerical optimisation with CFD using the adjoint approach (Mueller). Support by large EU project consortia (About Flow, finished in 2016 and IODA, finished in 2018). Support by industrially co-funded projects (Rolls-Royce 2016-2019, Airbus 2018-2022) and fully funded industrial projects (Mitsubishi Heavy Industries 2016-2018, 2019-2020).
- New lecturer appointment (Dr Chen in 2017) brought expertise in multi-objective optimisation, interpretable fuzzy systems, data-driven modelling and intelligent transportation systems. Winning major EPSRC projects (EP/N029496/1, EP/N029356/1 and EP/N029577/1, in total in excess of £1M) and contributing to the successful QM Data-Centric Engineering CDT. Collaboration with BAEs, Air France-KLM, Rolls Royce, Manchester and Zurich Airports, and Simio plc.

High-resolution modelling and fluid-structure interaction

- High-resolution modelling in computational aero/hydro-dynamics (Karabasov). Supported by major EPSRC grant with the University of Bristol (EP/S002065/1, total in excess of £1M), EPSRC INGENIOUS project (EP/J004170/1, finished in 2015), EC DJINN project (2020-2023), and two 2-year Marie Curie Fellowship projects. Outcomes are published in

major journals (J.Fluid Mechanics, J.Comp.Physics, Phil.Trans.A, R Soc Open Sci, Nature Comm., Langmuir. Collaboration with Rolls-Royce, Honeywell, UTRC, BAE Systems, Airbus, and Embraer. Commercialisation via a spin-off company GPU-Prime.Ltd.

- High-intensity acoustics and fluid/structure interaction (Avital). Collaborative project funded by General Fusion (GF) Canada. Application to blood fluid machinery supported by NIHR (£1M, II-LB-111-20007, finished in 2017). Commercialisation via a spin-off company PICS Therapeutics. Research on kinetic wind and marine turbines with international collaborations (Beihang, Tijanin - China) and (IITM, VIT-India) supported by the British Council and the Royal Society.
- High-resolution modelling of complex multiphase flows, e.g. suspending particles/cells, moving contact lines (Sui). Outcomes published in leading journals (J. Fluid Mech., Phys. Fluids, J. Comput. Phys., Annual Review of Fluid Mechanics). Support by two 2-year Marie Curie Fellowship projects (finished in 2017) and by the Royal Society (Newton Mobility Fellowship in 2015 and Newton International Fellowship in 2019).

Electrohydrodynamics and drop science

- Spacecraft electric propulsion and high-resolution electrostatic printing (Stark). Supported by 3 projects (Horizon 2020 HiperLoc-EP – High, European Space Agency ESA and Airbus Defence and Space, total projects value £1.7M). Collaborators with Airbus Defence & Space Ltd, NanoSpace AB (Sweden) and Systemat!C Designs (Netherlands). Applications to high resolution printing of functional materials are funded in 2 projects (Horizon 2020: Hi-Response and Innovate UK/EPSCRC: Hi Prospects, total projects value £9M). Resulted in European patents (EP1963024B1 and EP2162228B1).
- Fundamental research on drop science, inkjet printing and their applications to bioengineering and 3D printing (Castrejon-Pita). Outcomes are published in high-impact journals (Physical Review Letters, Proceedings of the National Academy of Sciences, Advance Functional Materials, and Scientific Reports). Supported by BBSRC (BB/P026788/1) and InnovateUK (TS/P001793/1) grants

Future strategy: The Centre will continue to promote high-quality research in the areas of expertise which span from high-resolution modelling in computational mechanics (aero and hydrodynamics as well as solid mechanics) and fluid/structure interaction to electrohydrodynamics and drop science. Advances in these core areas will be underpinned by the research into multi-objective design optimisation with the goal to further increase collaboration with industry. The Centre will further strive to extend the developed methods to important areas outside conventional aerospace engineering areas such as ink-jet printing and fluid-structure interaction in bioengineering and materials science.

2. Centre for Antennas & Electromagnetics Research

Academic staff Headcount (FTE)	12 (10.9FTE)
Professor	Brown; X-Chen; Hao; Parini
Reader	Alomainy; Donnan
Senior Lecturer	Mehran
Lecturer/Academic Fellow	Castles; Dubrovka; Ioppolo; Kelly; Qin
PDRA	13.6FTE
PGR	48

The Centre for Antennas & Electromagnetics Research (CAER) was established in 1968 with a mission of 'High Quality Research backed by High Quality Measurements'. In the past 50 years, the centre has been at the heart of technology and innovation in antennas and electromagnetics, collaborating with academic and industrial partners working nationally and globally. Its notable work includes corrugated and reflector antennas, optical waveguides, metamaterials and transformation optics, which have made significant impact to the UK through developing new technologies, supply chains and job creation through spinout activities.

Over its history CAER has built an extensive Antenna Measurement Laboratory (AML) including antenna test ranges and electromagnetic characterisation facilities, which now covers the whole RF to THz frequency bands, from 400 MHz to 3 THz. Supported by full-time professional staff, the facility is arguably one of the most comprehensive among European universities.

Interdisciplinary research interfacing with materials, physics and chemistry, life sciences and medicine has led to new transformative research ideas and clearly shapes its grant portfolio. The group has strong links with industry (Cobham Antennas, Plextek, AGC Japan, Qinetiq, Thales) and its work has raised the international status of UK antenna research attracting many citations and a number of patents (several with BAE Systems). CAER has now doubled its size by attracting talented ECRs, who, in turn, extend our portfolio of research to: THz spectroscopy for space exploration (Ioppolo); power electronics and battery control technology for Green Energy (Mehran); digital manufacturing of antennas via 3D printing (Castles); and 5G wireless communications (Kelly and Qin). CAER has hosted research fellows from the Royal Society and EPSRC. CAER has a current active grant portfolio of over £7M.

Major achievements during the REF period:

- The transformative nature of the EPSRC Programme Grant on Transformation Electromagnetics (QUEST, £4.6m, completed 2017), prompted QinetiQ to establish a strategic investment of £1M with CAER and Materials Research Institute colleagues through the additional financial support from EPSRC ANIMATE (Software Defined Materials for Dynamic Control of Electromagnetic Waves, £1.3M, 2018).
- EPSRC grant Adaptive Tools for Electromagnetics and Materials Modelling to Bridge the Gap between Design and Manufacturing (AOTOMAT, £936k, 2016) concerns low profile antennas that are conformal, multi-band and electronically steerable and suitable for low drag aircraft applications. The resulting lens antenna designs for satellite communications led to commercialisation through \$45M startup Isotropic System Limited (2016, now employing 30 engineers in Reading and 10 in USA), and forms an Impact case study for UOA10.
- The AML capability has been recognised by EPSRC through a £1.2M grant to build a national facility for THz Antenna Fabrication and Measurement Facilities (TERRA, 2018). TERRA will facilitate an integrated "digital" manufacturing and characterisation capability in the UK for a wide range of THz antennas and passive components, which, in turn, will accelerate the impact of our THz research especially for metamaterials.

Future strategy: will maintain focus on the development of its strength in wireless technologies for 5G and beyond, contributing to the UK Strategy for resilient and connected nation. Discovering novel advanced materials for antennas is a key strategy and this will be enhanced via new emerging technologies including AI, machine learning and research lab automation enabled by the EPSRC TERRA facility. New cross-disciplinary research will be fertilised by developing new tools for THz spectroscopy, diagnostics, and plasmonic nanoantennas for nanoscale communications in collaboration with clinicians, biologists, chemists and astronomers. CAER is committed to nurturing future generations of engineers from diverse background, who will carry forward skills and expertise for the benefits of society.

3. Centre for Bioengineering and Biomedical Materials

Academic staff Headcount (FTE)	14 (11.7FTE)
Professor	Alonso-Rasgado; De Bruijn; Gautrot; Knight; Krams; Lee; Screen; Shelton; W-Wang
Reader	Azevedo; Gupta; Hing
Senior Lecturer	Chowdhury; Iskratsch
PDRA	16.8FTE
PGR	45

The Bioengineering and Biomedical Materials Research Centre, originating from the IRC in Biomedical Materials, was inaugurated in 1991 as one of the first centres in the UK focussing on biomedical materials. Since then, the Centre has developed a strong focus around three main

research themes: *Biomaterials and Biointerfaces*; *Biomechanics and Mechanobiology*; *Predictive Bioengineering*. Over the last five years, the Centre has attracted over £10M external funding and published >300 articles and filed more than ten patents.

Major achievements during the REF period:

- The Centre established an internationally recognised program on self-assembled biomaterials: high impact papers (Nat Chem, Nat Comm, Nano Lett, ACS Nano, Biomaterials, Chem Rev), £4M funding (including ERC consolidator grant ProLiCell – Gautrot – and ERC starting grant STROFUNSCAFF – Mata – as well as RCUK and Leverhulme Trust), six PCTs filed by Gautrot and Mata, involvement in the organisation of conferences and chairing of sessions (>20 at international conferences, including the chairing of the 11th World Biomaterials Congress 2020 – Tanner), invitations to give seminar as keynote or plenary speaker (>150).
- Developed a centre for Predictive Bioengineering and Organ-On-Chip Technologies, supported by the Organ-on-a-Chip Technologies Network funded by the RCUK, led by Screen and Knight, as well as grants from the NC3Rs and industry (GSK, Emulate) and in collaboration with the Medicine Discovery Catapult. £1.6M overall.
- Consolidation of our internationally leading programme on mechanobiology and biomechanics: research is supported by grants from BBSRC, MRC & EPSRC (>£3M total), BHF (>£1.2M); Research articles published in top tier journals in the field (Nat. Materials, eLife, PNAS, Nano Lett., Circulation, JACC, Dev Cell, Biomaterials); seven PCT filed by de Bruijn and Gupta. Members were involvement in the organisation of conferences and chairing of sessions (>20 at international conferences), along with invitations to give seminars as keynote or plenary speaker (>150).
- The Centre has developed and is consolidating its impact on industry: Development of bone graft substitutes with Baxter (\$25M turnover in 2017), technology currently used to treat hundreds of patients in over 30 different countries. The impact was recognised through a stamp, issued by The Royal Mail to celebrate seven engineering innovations of the last 50 years (May 2019); Bioceramics for healthcare technologies by the spin-out Biomin Technologies Ltd developed by Hill; Development of bone graft substitutes with Kuros Biosciences AG (de Bruijn, CEO); several IP developed and commercial sales since June 2018; Bioreactor systems for stem cell culture with Scinus Cell Expansion BV (de Bruijn founder).
- The Centre has led a large number of public engagement activities in the UK: the award-winning Centre of the Cell science centre, which hosts bioengineering interactives related to tissue engineering; the bioengineering interactive game at Explore Health, an interactive game raising awareness of biomedical engineering for school children; contribution to a bioengineering film (YES Programme) for primary schools in which to explain the importance of maths and science in a wide variety of professions (Knight).

Future Strategy: A rapidly developing field the Centre is proposing to develop is Predictive Bioengineering and organ-on-chip technologies. QM's ambition is to lead a major effort to bring the UK to the forefront of developing innovative technologies in this area. The Centre is supported by the leading OOC company Emulate, which will bring academic collaborations and further industrial partnerships. These activities will support programmes to develop emerging technologies in microfabrication, biomaterials and stem cell technologies.

Extensive collaboration in cardiac engineering has been initiated with the WHRI and the Bart's Heart Centre, which has accumulated in a £6m funded Cardiovascular- Hub (co-led by Krams). This Centre has initiated 15-30 mutual projects between Cardiologists and Engineers, interactions with ~40 companies and the refurbishment of a new building (official opening in Oct 2020). About £9M of funding is related to this initiative and plans are on their way to integrate molecular methods (Biodivision/Chemical Engineering) and it is expected to expand with larger Industry involvement in Cardiology-Engineering projects.

In parallel, the Centre will consolidate and expand on its long-term programmes in mechanobiology and biomechanics and biomaterials/biointerfaces, underpinning research in tissue engineering, medical device/implant design and biosensor development, which now represent an important footprint in the UK biomedical industry. The Centre will develop collaborative programme grants and aim to develop a CDT and an MRes in mechanobiology. In addition, we will continue to expand our ties with the UK industry (Baxter, GSK, Lucideon, RB).

4. Centre for Chemical Engineering and Renewable Energy

Academic staff Headcount (FTE)	11 (10.8FTE)
Professor	Jiang; Livingston
Reader	Smoukov
Senior Lecturer	Boek; Jorge-Sobrido
Lecturer/Academic Fellow	Balcombe; Briscoe; Cullen; Slavchov; Szilágyi; Volpe
PDRA	3.0FTE
PGR	24

The Centre for Chemical Engineering and Renewable Energy was established as part of our strategic review of research strength and clustering, seeking to harness existing expertise at Queen Mary augmented by major investment in outstanding new research talent. The Centre is applied and challenge-focussed in its research to align with major external drivers including the UK Industrial Strategy and GCRF. In the past three years, we have recruited additional world-leading researchers from a number of fields that would interact with synergy. We have established excellent collaborations with a number of international institutions and many industrial partners. Problems under investigation include artificial morphogenesis, molecular manufacturing, turning waste into sustainable energy materials, batteries and thermoelectric generators that could improve our carbon footprint, methods for harvesting solar and thermal energy, and (electro)catalysts to store the energy into high value chemicals. Current Research funding portfolio is £4.7M. The Centre has been supported by major investment in infrastructure, including multi-million investment in new laboratory facilities for chemical engineering and renewable energy materials.

Major achievements during the REF period:

- We are combining the strong achievements in interdisciplinary fields, such as functional materials, phase transitions, programmed synthesis, as well as their applications in robotics, bioengineering, and multi-phase fluid flows. Research articles are featured in top science journals, from Science, Nature publications (Mater., Chem., Commun.), to PNAS, ACS Energy Lett., PRL, J. Mater. Chem. A, Angew. Chem. Int. Ed. and others.
- Research spans the scales from single molecules to consumer devices and has created group synergies, specifically with four UKRI/EPSRC grants - £1.3M for Molecular Manufacturing of Macroscopic Objects, £1.0M in Designing Electrodes for Na Ion Batteries, £0.8M in 2D materials for novel battery electrodes, and £0.8M for the Sustainable Processing of Energy Materials from Waste.
- Significant awards have been achieved by members of the Centre, including the Royal Academy Chair in Emerging Sustainable Technologies (Titirici) and 2020 Top 50 Women in Engineering: Sustainability Award (Szilágyi) are noteworthy.
- We are combining materials, energy storage, fluid flows, and electrical stimuli to create artificial muscles that would transform the robots of tomorrow from hard objects with many motors and controls, to soft, smart materials that often replace whole devices by themselves. They have on-board energy storage, are lightweight with higher energy density, and are safe to work with humans. Fundamentally, we are also discovering the basis of phase transformations that may have been the cause of shape changes in the first proto-organisms, making use of them for manufacturing in space.
- The Chemical Engineering division serve on professional bodies (Editorial Board of Multifunctional Materials, Frontiers in Smart Materials, Frontiers in Energy, Journal of

Materials Chemistry A, Board of Delegates of the European Materials Research Society), and have led a large number of public engagement activities, including hands-on interactive sessions at the Science Museum, London and Trash-to-Treasure Workshop on building low-cost instruments by recycling electronic trash. It featured international presenters and demonstrated isolation of DNA using recycled hard-drives, 3D printed microscopes for research, and spectral analysers from CD-rom disks.

Future strategy: We will maintain our focus on the strength of our discovery of artificial morphogenesis and phase transitions, through both experimental and modelling to create iterative discovery loops. The Centre will expand its activities in polymeric and inorganic nano- and micro-scale templating of new functional materials. We will accelerate our current research efforts in the field of energy conversion and storage, energy harvesting, as well as creating higher value materials from waste streams (e.g. upcycling of plastic waste into energy materials and value-added products such as metal-organic frameworks). A high impact direction is the creation of low-cost instruments capitalising on recent advances in inexpensive electronics and additive manufacturing. These will be platforms for changing lives in resource-poor regions of the world, supported by Global Challenges Research Fund (GCRF) and international foundations focused on world development. A critical direction is the addition of bio-inspired and bio-based engineering technologies, a key domain bridging academia and industry, predicted to grow significantly in the coming decades.

5. Centre for Materials Engineering

Academic staff Headcount (FTE)	18 (15.1FTE)
Professor	Bastiaansen; Busfield; Bushby; Humphreys; Krause; Pugno; Reece; Sukhorukov; Tanner; Vadgama
Reader	Bilotti;
Senior Lecturer	Crick; Fenwick; Z-Li; Su; Yan
Lecturer/Academic Fellow	Papageorgiou, H-Zhang
PDRA	10.75FTE
PGR	43

The Materials Department at QM was the first non-metallurgy department when established in 1967, developing materials that underpin a broad range of engineering applications. In recent years, the Materials Engineering Research Centre has organised its activities to reflect the current engineering landscape, developing advanced rubbers for automotive and oil-and-gas industries; implantable bioceramics; polymer composites for structural, electronic and thermal applications; sensors; thermal and vibrational energy harvesting materials; advanced ferroelectrics for energy storage; electrodes for fuel cells, batteries and supercapacitors; and much more.

The Materials Engineering laboratories were refurbished in 2016 at a cost of £2.5M, incorporating 15 new fumehood bays and £300k of equipment for the Organic Thermoelectrics Laboratory. Other notable equipment investment includes an X-ray and UV photoelectron spectroscopy system, and a UK facility for high magnetic field synthesis (EP/M507246/1). The Centre has a current active grant portfolio of £9.7M. One member is a Fellow of the Royal Society (Humphreys) and three are Fellows of the Royal Academy of Engineering (Busfield, Humphreys & Tanner). Our research has been reported in major international journals (PNAS, Science, Nat. Mater., Nat. Commun. etc.), and our staff have editorial roles on >30 journals.

Major achievements during the REF period:

- **Electronic materials** research includes piezoelectric energy harvesting technology to charge mobile phones using sound (with Nokia) or rollercoaster vibrations (Thorpe Park). Sustainable energy storage technology created from palm tree residue in Columbia was nominated for the 2018 Newton Prize, whilst Dr Fenwick was awarded a Royal Society University Research Fellowship for the study of organic thermoelectric materials. Thermoelectric research was awarded >15 grants in this period (Reece, Fenwick, Bilotti, Yan), collaborating with companies such as Johnson Matthey and European Thermodynamics Ltd. Humphreys' spin-out company, Paragraf Ltd., now has over 50

employees (two in 2018). QM has developed graphene as an electrode in light-emitting diodes with Paragraf resulting in a patent and KTP funding (InnovateUK 104714). The **Centre for Doctoral Training in Plastic Electronic Materials** (EP/L016702/1) was renewed for 2014-2022 and has supported PhD training and collaborative research with Imperial College London (lead), University of Oxford and industry.

- **Polymer and Composite** research was recognised by the IOM³ with the Swinburne Medal (Bastiaansen, 2018) and the Griffith Medal (Pugno, 2017) for innovations in polymer composites and nanomechanics. Self-regulating heaters were developed with LMK Thermosafe Ltd (WO2016012762A1) and the Knowledge Transfer Partnership (KTP) with LMK Thermosafe Ltd won the UK Engineering Excellence Award in 2019. A new KTP with The Unseen, will develop a woven electrochromic device to be incorporated into wearable fabrics. Constitutive models have been developed for the behaviour of **elastomers**, allowing safer products for oil and gas sealing, improved tyres, and dielectric elastomer actuator devices. This has attracted funding from 12 companies.
- Ultima Forma Ltd. was spun-out in 2017 from Bushby's **electro-deposition** technology (EP/C518004/1) for creating metallic microstructures with bespoke mechanical and thermal properties (QM 2018 Innovation of the Year Award, WO2019016543A1).
- **Bioactive glasses** were developed to remineralise teeth. Spun-out as Biomin Technologies in 2014 from a QM interdisciplinary team (inc. Bushby and Hing), 'Biomin' toothpaste has had 800,000 world-wide sales to date. Schottlander Ltd signed an IP transfer agreement on "Sustained Release Chlorhexidine Particles Technology" for **dental** applications (WO2017158379/A1, Sukhorukov with Cattell and Shahid (Institute of Dentistry)). **Biomarker sensing** technology developed for point-of-care testing has been spun out as Camstech Technology (CSO Vadgama), and a novel photoelectrochemical system for imaging the underside of live cells is being developed (EP/R035571/1).
- A UK Facility for Materials Engineering in Magnetic Fields (MagMat, EP/M507246/1) has been established at QM for synthesis in strong magnetic fields to create materials that cannot be accessed by conventional routes.

Future Strategy: To increase our global presence, a Joint Research Institute in 'Advanced Materials and Structures' was formed with Northwestern Polytechnical University, China, in 2017. The JRI creates the conditions for high-level academic research and international cooperation, including the bilateral exchange of staff. Following an award of £28M for an Institute of Technology (IoT), the Centre launched an Urban Transport Technology Centre (www.utt.QM.ac.uk) to link our activities to broader transport research topics at QM and in the IoT's anchor employers.

To support our strategy, appointments in this REF period will enable the Centre to continue working at the cutting edge of functional polymer composites (Papageorgiou, Zhang), (opto)electronic materials (Fenwick, Humphreys, Li, Su, Jorge-Sobrido), biomaterials (Tanner), and functional surfaces (Crick). We will be strengthening our facilities with a £3M refurbishment to create a new space for Functional Materials Manufacturing.

6. Centre for Mechanical Engineering, Robotics and Design

Academic staff Headcount (FTE)	13 (11.4FTE)
Professor	Althoefer; Bailey; HS-Wang
Reader	Duddeck; Karimi; Shaheed
Senior Lecturer	Jamone; G-Li
Lecturer/Academic Fellow	Birn-Jeffery; Buchan; Farkhatdinov; Tan; K-Zhang
PDRA	5.0FTE
PGR	35

The Centre was established to support delivery of world-class research, focusing on the themes of thermal fluids, sustainable energy, control systems, structural mechanics and robotics. The Centre hosts the prestigious heat transfer laboratory established in the 1950s; much of the research work, both theoretical and experimental, is now widely quoted in textbooks, reference

books and design handbooks. A recent investment of £20M led to the establishment of a state-of-the-art robotics laboratory. The Centre has secured £6.5M research council funding since 2014 and has internationally recognised expertise in experimental and computational engineering and robotics, specialising in low-carbon energy and clean water generation, control of autonomous vehicles, and robotics for surgery, manufacturing and use in hazardous environments.

Major achievements during the REF period:

- Developed novel inverse methods to measure local heat transfer and pressure distributions during condensation and flow boiling of fluids in microchannels (EPSRC, EP/L001233/1, £360k; DENSO Marston £55k), condensation of ordinary and self-wetting fluids in microchannels (EPSRC, EP/N001236/1, £399k). Developed advanced models for condensers with novel liquid-vapour separation technology (EPSRC, EP/N020472/1, £211k).
- Co-lead of National Centre for Nuclear Robotics (NCNR) revolutionising the treatment and decommission of nuclear waste and impacting on the nuclear industry (£1M of the total ~£11M, EPSRC EP/R02572X/1). Developed advanced reactor physics models, being incorporated within the software codes (ANSWERS-Jacobs) for UK nuclear industry (EPSRC Fellowship, EP/M022684/1, £662k).
- Pioneering research on predicting the transmission risk of COVID19 through an integration of machine learning and computational methods, EPSRC (RELIANT, £193k of total £1.3M) and Oil & Gas Technology Centre (£33k).
- Developed renewable energy driven, hybrid desalination system for remote areas (British Council Newton Institutional Links with Egypt, 216423297 and 26214-STDF, £300k) and rainwater purification system (Royal Society NAF-R2-192189, £74k). Development of sustainable clean energy in Malawi (Scottish Climate Justice Innovation Fund, £122k). Four patents issued on liquid flow control for sustainable energy systems (e.g. ZL201610792318.7).
- Developed novel advanced control strategies to resolve practical engineering problems, achieving: Launch and recovery control system (EPSRC, EP/P022952/1, £303K), optimal power management of electrical vehicles (EU Marie Curie Fellowship, €225K), control system design for sea wave energy converters (including: winner of Control Programme by Wave Energy Scotland, £644k; Advanced Newton Fellowship, Royal Society, NA160436, £111k).
- EPSRC New Investigator Awards for machine learning human-inspired robotic manipulation (Jamone, EP/S00453X/1, £325k) and for novel wearable robots for physical assistance in industry (Farkhatdinov, EP/T027746/1, £466k).
- Developments of miniature and morphable perching robots for inspection in extreme environments (EPSRC NCNR Flexible Partnership Funding 20461, £100k), perception for robot manipulation (Innovate-UK 103676, with Shadow Robot Company, £100K), soft robots for infrastructure inspection and thermal insulation (Innovate-UK 104056, with q-bot, £150K), and intelligent human-robot tool handover assisting industry workers (Alan Turing Institute, £150K). Developed new soft robot structures for human-robot interaction for use in robotic surgery and other assistive technologies for the elderly, and novel locomotion strategy for robotic active capsule endoscope.

Future Strategy: The Centre will continue to promote high-quality research in the areas of strength including thermofluids, sustainable energies, solid mechanics and computational engineering, control systems and robotics. Underpinned by the highly complementary expertise, the activities within the Centre will be focussed on the UK Grand Industrial Challenges of clean growth, future of mobility and ageing society. As an example, the strengths in nuclear engineering and robotics will be combined to tackle the pressing problem of nuclear waste management. The Centre will also liaise with the Alan Turing Institute and major industries working on Net-Zero greenhouse gas emissions (e.g. Equinor) to further enrich the research and substantiate its impact.

IMPACT STRATEGY AND SUPPORT FOR IMPACT REALISATION

During this REF period we have embedded a culture where impact, innovation and engagement are an innate part of all research activity, and publicise our impact internally, nationally and internationally to enhance our global reputation (SA7). Delivering research impact is supported at Institutional, Faculty and School levels. An **institutional impact team**, within the Business Development unit is responsible for overall strategy with academic leadership provided by the **Deputy Vice Principals for Research (Impact) and Research (Enterprise)**. Operational support is additionally provided at Faculty and School levels by Impact Manager posts and Academic Impact Champions whose role is to identify research with the potential for impact and manage the process of realisation of impact via a range of institutional support routes.

Commercialisation of research to deliver impact is supported by **Queen Mary Innovations Ltd** (QMI), QM's wholly owned technology transfer company, who support IP protection, start-up activities and licensing. Funding is available to accelerate impact via internally-managed EPSRC and STFC Impact Acceleration Accounts (IAA) and through Proof of Concept funding from HEIF to support both commercial and non-commercial impact realisation (SA4, SA7). **QM's award winning Centre for Public Engagement** (QM achieved the first Gold Watermark from the National Co-ordinating Centre for Public Engagement, NCCPE) provides expertise and funding for relevant impact generation activities, and major impact activities are recognised annually at our Engagement and Enterprise Awards, frequently won by SEMS and EECS researchers. QM has recently been awarded University Enterprise Zone (UEZ) status, one of only twelve in the UK, with £1.5M funding from Research England to enhance engagement and impact generation with innovative businesses within East London, with a focus on Medical Technologies and Digital Health innovation (SA4, SA6, SA7).

As a support service, the Impact Team has a cyclical set of objectives: visibility, engagement, support and satisfaction. The flexible nature of the support required allows for the team to proactively engage with both academics and senior management to maximise the potential for impact across the university. QM is one of the few universities in the UK to have a permanent impact team that is not just focused on the REF.

Key to its activities are:

- Raising the profile of research impact with the aim of embedding its planning, collection and evidencing in the research process.
- Creating new relationships and improving existing ones across the university. This involves working with experts across QM in areas such as patenting and commercialisation, business development, public engagement, media relations and professional development to deliver joined up, high quality impact support and training across QM.
- Establishing and maintaining relationships with commercial, government and other external academic and non-academic organisations to collect and evidence research impact.

Working with and advising academics on the generation, collection and evidencing of impact in line with individual researcher impact needs along with larger institutional and strategic impact needs.

2. People**STAFFING STRATEGY AND STAFF DEVELOPMENT**

Staffing strategy: The REF2021 period has been one of major growth compared to the equivalent research areas that at the REF2014 census date, as outlined in Table 1 (SA1, SA3, SA4, SA5). Total eligible staff FTE now stands at 71.5 compared to 48.0 in REF2014 (relevant research activities from UoA 13 and 15 submissions). In order to maintain the highest quality during a period of growth QM has an active strategy to recruit only staff with an internationally recognised research profile and the potential to be world leading (SA1). Appointments are used strategically to grow, strengthen and deepen existing areas of research excellence (e.g. Antennas & Electromagnetics; Bioengineering & Biomaterials; Materials Engineering) or to support the development of new

research clusters with the potential to be world leading and aligned to external drivers such as the *Industrial Strategy* or *Global Research Challenges*, for example Chemical Engineering & Renewable Energy; Advanced Robotics@QM (SA2).

In total 44 (41.2FTE) new UoA12 eligible academic staff (10 Professors; 2 Reader; 3 Senior Lecturers; 29 Lecturers; 4 Academic Fellows) have been recruited during the current REF period. During this REF period 15 academic staff submitted to the REF2014 have left, of which 12 have taken more senior posts in major UK or International Universities (including Barber, Botto, Becer, Gavara, Novak, Mata, Peijs, Titirici), one has taken a senior post in industry (Dunn) and one has retired (Munjiza).

Table 1. Eligible staff FTE 2013-2020 at 31st July each year

	2013*	2014	2015	2016	2017	2018	2019	2020
Eligible staff FTE	48.0	49.2	47.9	52.7	57.7	64.9	67.4	71.5

*REF2014 census date

The current REF period has shown a strong growth in postdoctoral research staff (PDRAs), which aligns with enhancement in research income throughout the REF period (see section 3). Importantly there is a marked increase in the PDRA per REF eligible staff FTE compared to REF2014 (Table 2), indicating that growth in absolute numbers is not driven by increase in academic staff FTE alone (SA1, SA4).

The University has supported specific targeted initiatives aimed at attracting the best research talent (SA1, SA4), for example: Early Career Fellowship schemes linked to our cross-Faculty Institute of Bioengineering and Materials Research Institute and Institute of Applied Data Sciences (e.g. Sobrido; Briscoe; Fenwick); and the Science & Engineering Talent scheme aimed at attracting internationally leading senior academic researchers to join QM (e.g. Krams, Tanner, Humphreys).

Table 2. PDRA staff FTE 2013-2020 at 31st July each year

	2013*	2014	2015	2016	2017	2018	2019	2020
PDRA FTE	29.6	41.2	53.1	49.3	54.9	50.0	62.4	53.2
Per eligible staff FTE	0.62	0.84	1.11	0.94	0.95	0.77	0.93	0.74
Average annual PDRA FTE per eligible staff FTE during REF period								0.90

*REF2014 census date

New academic staff benefit from a generous start-up package scheme to ensure that research momentum is maintained, typically involving institutional-funded PhD studentship(s) and funding for key equipment/research costs (SA1, SA6, SA8). The University has invested significantly in new research facilities to support the growth in academic staff numbers as part of the £30M Engineering building refurbishment programme (SA6, see section 3). A pro-active three-year probation system ensures that new staff are supported in developing independent programmes of research, with a focus on attracting external research funding and high-quality outputs. The probation system allows and encourages new members of academic staff to complete the process in less than three years through the use of goal-based targets and objectives rather than a simple time-based approach (SA8).

Career Development for Established Academic Staff: A work-load model is used to equalise loads and achieve a balance between colleagues' responsibilities, typically ring-fencing 50% of time for research activities. During annual appraisals staff are appraised and mentored by a senior colleague who discusses research plans, publication placement, research funding, public engagement and professional development through the Learning Institute. The appraisal and mentoring approach builds on the probation process to ensure that clear and consistent expectations are set for academic staff that align with personal career ambitions and the requirements for academic promotion.

During the REF period to University has revised its academic promotions processes to ensure that promotion aspirations are encouraged through alignment with mentoring support and

appropriately recognise excellence across the whole range of academic activities (SA1, SA8). In the context of research we have broadened the evidence used to support promotion beyond traditional publication and funding activities to include successful impact generation (including technology transfer and spin-out development) and public engagement activities that support wider understanding of our research. The Research Centres and academic mentors are pro-active in encouraging suitable members of academic staff to consider applying for promotion. In order to ensure transparency of the process and to support our equality and diversity commitments statements of support from the Head of School are informed by Research Centre leads and other senior members of staff and an EDI representative is present at each formal stage of the promotion process.

During the current REF period the following promotions have been confirmed: 14 Lecturer/Academic Fellow to Senior Lecturer (Bilotti, Botto, Castrejon-Pita, Chen, Gautrot, Gavara, Iskratsch, Jorge-Sobrido, Li, Su, Sui, Yan), 14 Senior Lecturer to Reader (Alomainy, Azevedo, Bilotti, Botto, Donnan, Duddeck, Gautrot, Gupta, Hing, Karabasov, Mueller, Shaheed, Smoukov, Sui, Wang HS) and 8 Reader to Professorship (Bushby, Dunn, Gautrot, Krause, Mata, Screen, Titirici, Wang HS). Of the 35 promotions 7 are for female staff (20% of promotions with female staff representing approx. 15% of eligible staff across the REF period). Notably 3 of the 8 promotions to Professor are for female staff.

Support for Early Career Research Staff: In 2012 QM were awarded the HR Excellence in Research Award by the European Commission. The award functions in biennial cycles, alternating between internal review by the HR Excellence in Research working group, and external review by a Vitae panel. In 2016, our progress and 2016-2018 action plan were reviewed with award confirmed in 2016. Now in its 8th year, the QM award was confirmed again in 2018 (SA4, SA8).

The *Vitae* Concordat is fully supported at QM through the Researcher Development (RD) team, part of QM's *Academic Development Group*. The RD team promotes research excellence by supporting researchers to excel in their careers, whatever their career goals. It provides personal, professional and career development opportunities to support the UoA12 researcher communities in SEMS and EECS. The RD team work in collaboration with the academic community, other research support services at QM and with external bodies to provide innovative experiential learning opportunities, knowledge sharing and one-to-one support for researchers. Training, delivered as workshops or online, covers topics such as applying for fellowship and research funding, research governance, writing and dissemination, career planning and management, developing a research profile and networking, media and public engagement, leadership, equality and diversity, and researcher wellbeing. Further support includes:

- One-to-one support including a range of mentoring schemes and one-to-one coaching opportunities
- Careers support
- Online training and resources, including Nature Masterclasses

Support for Equality and Diversity (SA8): QM and its academic schools are committed to the highest standards for equality and diversity, exemplified by the following mission statement:

“QM will ensure that all staff and students work and study in an environment free of unfair discrimination, harassment and victimisation, and have access to equal opportunities. QM will actively promote equality and diversity”

QM is arguably the most inclusive research-intensive University, with inclusivity at the heart of everything we do (SA8). We are working towards gender equality and 30% BAME representation at all levels of employment. A revised equality, diversity and inclusion (EDI) governance structure implemented in 2019 spreads best practice across the University, a two-way communication from the School EDI self-assessment teams through Faculty EDI groups to the EDI Steering group that reports directly to the University Senior Executive Team chaired by the Principal. In addition, the **Gender Equality Steering Group** works specifically on gender equality across the institution, and the EDI forum provides opportunity for engagement on equality and diversity from anyone in the University community. We have fair representation and insist on at least one woman on every

recruitment panel and at every formal meeting and EDI is a standing item on all meeting agendas. **We promote the Dignity at Work and EDI policy to new staff**, supported by workshops. We have wheelchair access to all laboratories, teaching rooms & offices. Our nursery has recently expanded to 65 places, with priority given to academics.

QM currently holds 11 externally reviewed inclusion and diversity awards, including **Athena Swan Silver award** in 2017, while **SEMS and EECS hold Departmental Athena Swan Bronze awards**. QM holds a Race Equality Charter Mark, is a Stonewall Diversity Champion and has worked with DisabledGo in order to produce Access Guides for our campuses.

SEMS and EECS are engaged in the faculty-wide WISE (Women in Science and Engineering) initiative which started in 2008 as a networking platform for female undergraduates, postgraduates and academic staff in science and engineering, seeking encouragement and advice on managing their careers and tackling life important questions such as work-home balance. The schools actively **promote flexible and part-time working** to support parents of young children and those with other caring roles. Flexible working requests are decided by the line manager advised by the EDI SAT; all requests have been supported in the REF period. We guarantee that staff who have requested to reduce commitment to part time can return to full time working at their discretion. We currently have 4 UoA12 staff (3 women, 1 man) benefiting from these arrangements.

We have introduced a **beacon scheme to allow T&R staff to maintain research vibrancy** during periods of single or shared parental leave, with support tailored to individual needs. This can involve, for example, fully-funding the salary cost for a Postdoctoral researcher for a 12-month period and/or reduction in teaching following return from maternity leave. We ensure that key meetings are held in core hours (10-4) and are recorded.

Table 3. Eligible staff by gender, ethnicity and disability status 2013-2020 at 31st July each year

	2013*	2014	2015	2016	2017	2018	2019	2020
Female FTE	7.4	7.4	7.4	9.2	10.2	12.2	13.0	10.1
BAME FTE	14.6	15.6	16.6	17.6	18.8	18.8	22.3	26.1
Disability FTE	0.0	1.0	1.0	1.0	2.0	5.0	5.0	5.0

*REF2014 census date

Table 4. Eligible staff gender and ethnicity by academic level

		Lecturer		Senior Lecturer		Reader		Professor	
		FTE	%*	FTE	%*	FTE	%*	FTE	%*
REF2014 Census Date	Female	1.0	5.9	2.6	39.4	2.8	28.0	1.0	6.9
	BAME	8.0	47.1	1.0	28.6	1.0	10.0	4.0	27.8
REF2021 Census Date	Female	2.6	10.5	2.0	20.0	1.6	11.6	3.9	17.0
	BAME	6.2	25.0	7.0	70.0	6.6	47.8	6.3	27.5

*Represents the % of staff at that academic level who are female/BAME

We have recruitment processes that ensure that women and BAME candidates are encouraged to apply and that the selection process itself is both fair and welcoming. There is a requirement of a gender balance on all recruitment panels, with external panel members approached if the correct gender balance is not available. **It is compulsory that all panel members should be appropriately trained** ('Recruitment and Fair Selection Training' & 'Unconscious Bias Training') and this culture is incorporated into the entire recruitment process. The REF2021 period has seen a 60% increase in female staff FTE (average 11.8FTE, 2018-2020 compared to 7.4FTE in REF2014, Table 3). The proportion of female staff at professorial level has increased at the greatest rate, 3.9FTE compared to 1.0FTE, and now represent 17.0% of Professorial staff compared to 6.9% in REF2014) and there is now a broadly equivalent proportion of female staff at all academic levels, compared to 2014 (Table 4). BAME FTE has risen nearly 80%, again with a more balanced representation across academic levels compared to REF2014. The proportion of eligible staff with a disability has risen from zero to 7% during the REF period. These data

demonstrate the success of both recruitment and promotional policy and practice in supporting the careers of female, BAME and disabled academic staff.

On average 25% of our PDRA population are female, a value which has remained relatively constant over the REF period. The proportion of PDRA staff from BAME backgrounds increased throughout the REF period from 24.7% in 2013-2014 to 53.4% (average 2017-2020).

In order to ensure a diversity of role models for our research community we monitor the gender and BAME of high-profile research leaders invited to contribute to our research seminar programmes as external speakers, with a target of 50% female speakers.

POSTGRADUATE RESEARCH STUDENTS (SA5)

UoA12 PhD students are aligned with the six research centres described above. Cross-faculty support is provided through the Institute of Applied Data Sciences, Institute of Bioengineering and Materials Research Institute to encourage interdisciplinary collaborations. The research Centres and Institutes enhance the distinct cohort identity for PhD students, supported by seminar series (typically weekly) as well as cohort training activities. QM allocates internal PhD scholarships to promote broader collaboration across the engineering disciplines, with typically 10 per year allocated to UoA12 activities.

Table 5. PhD student completions 2013-2020

	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
PhD completions	26.5	33	39.2	50.4	47.9	56.2	47.1
Per eligible staff*	0.55	0.67	0.82	0.96	0.83	0.87	0.70
Average annual PhD completion per eligible staff FTE during REF period							0.77

*Staff FTE at start of relevant period

A key strategic aim for the UoA during the current REF period is to increase the number and quality of PhD students and their 4-year submission rate (SA5). This has been achieved. A total of 300.3 doctoral degrees were awarded in the REF period, which equates to 0.77 awards per eligible FTE/Year, in excess of the combined total for REF2014 UoAs 13 and 15 from QM of 0.67 awards per eligible FTE/Year (where QM ranked 4th overall). Comparisons with the combined REF2014 UoAs 12-15 (representing the REF2021 UoA12 Engineering portfolio) are highly favourable, with the top decile level of 0.56 awards per FTE/Year and the top ranked institution in 2014 attaining 0.73 awards per FTE/Year. Through the REF period 4-year submission rates improved from less than 60% to over 90% (SA5).

Table 6. 4-year submission rates for PhD student cohorts completing within the REF period

Cohort start date	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
4-year submission	57.9%	57.6%	73.7%	85.5%	92.0%	79.3%	91.7%

PhD Recruitment and progression: During the REF period we recruited 380 PhD students, with an average enrolment of 0.99 students per eligible FTE/Year. Our vibrant PhD student population is supported through EPSRC, EU, Industry and part University-funded positions but also through strategic engagement with international schemes such as CSC (China), CONACyT (Mexico), HES (Pakistan) and Science without Borders (Brazil). UoA activity aligns with three Centres of Doctoral Training.

Table 7. New PhD student enrolment 2013-2020

	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
PhD enrolments	53	57	49	52	59	64	46
Per eligible staff*	1.10	1.16	1.02	0.99	1.02	0.99	0.68
Average annual PhD completion per eligible staff FTE during REF period							0.99

*Staff FTE at start of relevant period

The UoA adopts a robust approach for the recruitment of PhD students. All studentships are advertised both within QM and externally. Shortlisted applicants are interviewed by two members

of academic staff to ensure recruitment of the highest quality students. Where recruitment is to a multidisciplinary project interviewing academics represent the disciplinary breadth. Wherever possible we ensure that the interview panel has gender balance. 39% of our PhD population are female, compared to the national benchmark of 25%, and 69% are from BAME groups (both 15/16-18/19 data).

Students are allocated two supervisors, at least one of whom will have a proven track record of supervisory success to ensure that early career academics and their students are supported. All PhD supervisors must complete mandatory training in current best practice prior to being appointed as a supervisor, with refresher training required every two years. Progress is formally assessed three times at the 8th, 18th and 30th months of registration. Workshops are available to help students prepare for each stage of their progression throughout their degree. For PhD students starting their studies within the REF period, close to 100% of the students submitted within 4 years, highlighting the supportive environment and robust approaches adopted for recruitment, progression, supervision and training.

PhD Training: QM have established a **Doctoral College** to support both PGR students and postdoctoral researchers. Led by a Doctoral College Management Group its activities are delivered by two dedicated Researcher Development Officers (Centre for Academic Development) and a Careers Adviser for Researchers (QM Careers). QM operates a **Points-Based Training system** to support delivery of our College-wide training strategy for PGR students, based on the RCUK endorsed Vitae Researcher Development Framework. This allows disciplinary flexibility, ensuring that all students receive appropriate transferable skills and research training. The Doctoral College runs a compulsory interdisciplinary PhD induction and annual Interdisciplinary Cohort Training courses (*Maximising the Impact of Conferences & Networking; Understanding the Impact of your Research; Developing academic and non-academic careers*). The Doctoral College supports an annual student-led Graduate Festival, where students can apply for funds of up to £500 to run a training event, conference or workshop of their own design. The Graduate Festival includes: *PhD Show Off* - PhD students present their research as a comedy set and *Decent Exposure* - PhD students supported to build online research profiles and websites. On average the Graduate Festival hosts 30 events attracting 550 PhD attendants annually. In 2018 the Doctoral College was awarded **£40,460 HEFCE Catalyst Funding to support PGR Mental Health and Wellbeing**, with matched funding by QM's Student Services Team.

Subject-specific training for UoA12 PhD students is delivered primarily through SEMS and EECS and their three affiliated research institutes. Students participate in an annual PhD research symposium, presenting their research to their peers and the wider academic community. Students judged to have delivered the best presentation within their research field are awarded prizes. The Schools recognise and encourage exceptional achievement from the PhD cohort through the annual presentation of postgraduate research excellence awards. On average four awards are made and these have stimulated high quality publications in top journals such as Nat. Chem., Phys. Rev. Lett.

Engineering UoA students have access to research funds up to £800 per person to support their attendance at external training and conferences and are encouraged to apply for the QM Postgraduate Research Fund (up to £2000 per person) to support their research travel, networking, attending international conferences and accessing facilities or equipment. The school has organised a seminar series for PGR career development, where successful QM PhD alumni currently working in academia or industry are invited to return to talk to the Engineering students about their careers. The school has a PhD-academic forum at which nominated PhD student representatives meet the research leads of each academic division and the PGR support team twice per year. PGR training is a key topic at the forum; specific training needs of PhD students are identified and discussed alongside suggested improvement/tailoring to existing training.

3. Income, infrastructure and facilities**RESEARCH INCOME (SA4)**

The total value of research income over the REF period is £53.5M, equating to an average value of £138k per eligible FTE/Year (Table 8). This represents a substantial increase over the combined total for REF2014 UoAs 13 and 15 from QM of £112k per eligible FTE/Year (where QM ranked 12th overall). There is a strong upwards trend in annual income through the current REF period which outstrips increase in eligible staff FTE. This is particularly impressive as an increase in research income tends to lag growth in staff numbers as new staff typically require a considerable lead period prior to establishing a significant funding portfolio.

The strong growth in research funding through the REF period is closely aligned to the strategy to significantly increase external research funding (SA4). Specific initiatives have been established during the REF period to support enhancement in research funding including:

- Research support fund – a structured approach to provide institutional support for large and strategic funding bids where researchers can request institutional support equivalent to 40% of residual overhead on a grant to be invested in equipment, PhD studentships etc from institutional sources.
- Research enabling fund – QM provides Principal Investigators with flexible funding from institutional sources equivalent to 10% of residual overhead to support pump-priming/preliminary studies that enhance the likelihood of a successful grant application.
- One to one coaching and mentoring, often delivered by an external expert, to support major personal fellowship and other applications, for example ERC grants.
- Internal peer review of grant proposals and grant writing workshops/retreats.

Table 8. Research income 2013-2020

	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20 ²
Income (£) ¹	6,144,865	6,508,703	7,176,573	7,823,401	8,219,586	9,427,309	8,157,427
Per eligible staff ³	128,018	132,290	149,824	148,452	142,454	145,371	121,030
Average income per eligible staff FTE/year during REF period							138,206

¹Combination of REF4b and REF4c income

²COVID impact – delay to start of new grants and grant-funded capital expenditure

³Eligible staff FTE at start of relevant period

Some examples of large grants (>£700k) awarded and/or active during the REF period include:

- EPSRC Programme grant 'QUEST- Quest for Ultimate Electromagnetics using Spatial Transformations', ended March 2017, £5.4m (Hao)
- EPSRC Capital Equipment grant 'TERRA: Thz antEnna fabRication and measuRement fAcilities', value £1.2m, (Hao)
- EPSRC Grant: Software Defined Materials for Dynamic Control of Electromagnetic Waves (ANIMATE), £1.33m, (Hao)
- European Commission (Botto), ERC Start Grant, £1.1 million
- European Commission (Mueller), AboutFlow Marie Curie (ITN), £899k
- European Commission (Mueller), IODA H2020 Marie Curie (ITN), £734k
- European Commission (Mata), STROFUNSCAFF - ERC Grant, £1.1 million
- European Commission (Gautrot), ERC Start Grant, £1.1 million
- EPSRC (Reece), Material Systems for Extreme Environments £980k
- EPSRC (Reece), MASSIVE Materials, £703k

Infrastructure and Facilities:

The REF2021 period has seen very significant investment in research infrastructure and facilities. Over £32M has been invested in a phased programme of refurbishment of the Engineering building to provide the highest quality research environment as well as supporting teaching. New/enhanced research laboratories and workshops include:

- Development of a new 328m² research lab for Advanced Materials research with a focus on electrochemistry and aligned with our major collaborative Northwestern Polytechnical University/QM Joint Research Institute.
- The provision of a new laboratory (120m²) to support the development of the Centre for Advanced Robotics. Enabled the establishment of new Advanced Robotics@QM research group and appointment of new staff (Althoefer, Birn-Jeffery, Farkatdinov, Jamone).
- New joint EECS/SEMS research mechanical workshop combining previous separate workshops into one new space plus investment of £150k in new machine tools (188m²).
- Major refurbishment of 359m² Aeronautical Engineering laboratory enhancing experimental facilities to support fluid mechanics and aerospace engineering research including suite of wind-tunnels.
- A new 230m² computer lab/research student space with greater access to specialist software needed by engineering PGR students specifically.
- New 128m² electrical characterisation laboratory for electronic engineering research activities.
- New 74m² Human Performance laboratory to support whole body biomechanics research.

There has been significant investment in new equipment/facilities during the REF period, involving external funding and/or institutional investment. This includes investment via the QM Strategic Facilities Investment Fund which aims to support major new strategic facilities development with a focus on providing matched funding to leverage significant external funding. Significant investment includes:

- £250k investment in a new spherical near-field antenna test facility and upgrade to existing compact antenna test range, completed March 2017.
- The installation of a 15T wide bore magnet is currently ongoing as part of a successful capital equipment grant from the EPSRC (£318k) and has been supported by £125k from QM for the refurbishment of a laboratory space and associated running costs.
- £150k investment in new robotics engineering research equipment to support the establishment of the Centre for Advanced Robotics.
- Over £300k in new equipment to support Mechanobiology research, including BOSE, MechanoCulture FX and Flexcell systems.
- £500k investment in state-of-the-art Super-resolution microscopy system (Zeiss Elyra).
- The £1.2m EPSRC TERRA facility is unique to the UK and combines a state-of-the-art millimetrewave spherical near-field antenna measurement system with a sub-micron resolution 3D printer to provide rapid prototype fabrication and test of antennas and devices up to 500GHz. TERRA is housed in our world class Antenna Measurement Laboratory and is registered as an EPSRC Small Research Facility (SRF).
- In 2016 QM was the first European university in Europe to install one of two Nvidia DGX-1 deep learning supercomputers (170 teraflops of processing power) for deep learning and big data analysis. The supercomputers are part of a three year (2016-2019) joint industry-sponsored research project (DeepInsight - 'the Deep Learning Research Project on Big Video Analysis') with industrial partners SeeQuestor Ltd (part of the Anglo-Scientific Group) and Vision Semantics Ltd (a QM spin-out company).

- Over £1.5M investment in Materials research equipment including; Cross Faculty Electron Microscope Camera Upgrade: 4K Camera for Jeol 1230 (£164k); Differential Scanning Calorimeter (£44k); High resolution Raman system (£199k); QM Cross Faculty NMR Facility (£296k); Deposition facility (£430k); XPS – Thermofisher K-Alpha (£535k).

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

COLLABORATION AND CONTRIBUTION TO THE RESEARCH BASE

Collaboration: The research environment in SEMS and EECS actively promotes collaboration, both within QM and as part of external national and international collaborations and consortia.

Internal collaboration across disciplines is supported via a range of initiatives, including seminar programmes, networking events, and research sandpits as well as funding for collaborative PhD scholarships, strategic infrastructure projects and equipment. UoA12 researchers are facilitated to engage in interdisciplinary collaborative research by the presence of outstanding infrastructure within QM including the following cross-faculty Research Institutes:

- **Materials Research Institute (MRI):** (www.materials.QM.ac.uk) Created in 2013 as a virtual Centre of Excellence with over 60 staff from several schools, including 28 UoA12 staff. The MRI supports dynamic inter-disciplinary materials research, in collaboration with academia, research councils and industry professionals. The MRI offers a dedicated seminar and workshop series and has funded approximately 10 PhD studentships involving UoA12 staff (collaborative between at least two schools). In 2016 the MRI funded 5 academic research fellowships, two of which were subsequently awarded lectureships within UoA12 (Fenwick and Sobrido). The MRI has also supported key strategic c£750k of equipment for materials research including X-ray Photoelectron Spectroscopy (XPS)
- **Institute of Bioengineering (IoB):** (www.bioengineering.QM.ac.uk) A cross-faculty initiative bringing together more than 50 academics, including 20 UoA12 staff, that facilitates the highest quality discovery science and drives translation to clinical use and commercialisation. The IoB runs a dedicated seminar programme, has supported approximately 15 PhD studentships and QM has funded two super-resolution microscopes, an atomic force microscope and a suite of mechanobiology and organ-on-a-chip facilities totalling over £1M. The IoB links to a new Centre for Predictive *in vitro* Models (CPM), encompassing the QM+Emulate Organs-on-Chips Centre (www.cpm.QM.ac.uk/emulate) which is co-funded by industry partner Emulate Inc and QM as a cost of c£1.25M. UoA12 staff lead the UK Organ-on-a-chip Technologies Network (www.organonachip@org.uk), one of five prestigious networks funded via the Technologies Touching Life scheme.
- **Institute of Applied Data Science (IADS):** (www.applieddatascience.QM.ac.uk) Established in 2018 to a University-wide research institute that encompasses all three faculties at QM, with more than 40 academic members, many of which are UoA12 staff. IADS draws on a broad base of expertise ranging from ethical considerations through to applications of data science and medical challenges. The Institute is a multidisciplinary entity and dynamic network that allows researchers from different areas to work together to find innovative solutions to a variety of challenges. IADS provides the key link between QM academics and the Alan Turing Institute for Data Science and Artificial Intelligence.
- **Barts Life Sciences:** (<https://www.QM.ac.uk/lifesciences>) QM/Barts Life Sciences is a multidisciplinary endeavour that includes the three QM Faculties and Barts NHS Trust. It aims to create a unique life sciences cluster across the campuses to act as a beacon, attracting partners from higher education, the NHS, industry, patients and the local community. Collaborative research activity is focussed around four research clusters: Bioengineering; Computational Biology; Genomic Health; and Mind in Society, with major involvement from UoA12 academics supported by investment in collaborative PhD scholarships, equipment and networking.

The UoA submission has substantial external collaborative research activities including a major strategic international collaboration with Northwestern Polytechnical University, China which is supported by a Joint Research Institute (www.sems.QM.ac.uk/china/research/). This has a particular focus on collaborative materials engineering research which supports student and staff exchanges leading to joint publications, grant applications and PhD studentships.

In addition, over 90% of staff within the submission have significant individual external collaborations spanning six continents (see map below). These collaborative partners include leading academic institutions such as Massachusetts Institute of Technology, The Johns Hopkins University, Cornell University, Monash University, University of Auckland, NYU Singapore, Lund



University as well as many of the UK Russell Group institutions including Cambridge, Oxford, Imperial and Manchester. Our collaborations are strengthened by over 25 long-term visiting or joint professorships (see table 9) and at least 100 visiting researchers from collaborating institutions embedded within QM. These collaborations have led to numerous staff and student research visits, journal publications, patents and spin-out companies. Key funding arising from these collaborations include major EU project funding such as STIFF-FLOP (soft robotics for minimally invasive surgery) and other robotics projects SQUIRREL and FourByThree; RAPIDOS (bone graft materials) as well as Innovative Training Networks (ITN) such as the Industrial Optimal Design using Adjoint CFD Analysis (IODA) project.

Table 9. Example of collaborating institutions with whom our staff hold long term professorial appointments

University of Cambridge, UK University of Oxford, UK University College London, UK Twente University, The Netherlands Technical University of Munich, Germany Ecole des Ponts ParisTech, France University of Grenoble Alps, Switzerland Ecole Polytechnique Federale de Lausanne, Switzerland Lund University, Sweden	Central Aerohydrodynamic Institute, Russia Saratov State University, Saratov, Russia IPN (Instituto Politécnico Nacional), Mexico Universidad Autónoma de Chihuahua, Mexico Suncheon University, South Korea Northwestern Polytechnical University, China South China University of Technology, China Southern Medical University, China Changsha University of Technology and Science, China
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Table 10. The % of Journal Papers from Eligible staff involving national and international collaborations (data from SciVal)

	2014	2015	2016	2017	2018	2019	2020
All collaborations	79.0%	86.5%	84.4%	89.0%	90.3%	92.7%	93.6%
Average during REF period							88.3%
International collaborations	61.9%	65.8%	68.1%	72.7%	76.2%	77.7%	78.7%
Average during REF period							72.1%

Over the REF period 72.1% of research papers published by UoA12 staff involved international collaboration (data from SciVal – Table 10), markedly above the Engineering discipline benchmark for all UK Universities (UUK) of 65.0% and the Russell group (64.2%). 88.3% of research papers involve national or international collaboration, above the benchmark for UUK (77.5%) and the Russell group (78.5%) for Engineering. The UoA has an excellent track record for collaborative research with industry partners, with 11.3% of all research papers involving co-authors in industry, above the benchmarks for UUK (7.7%) and the Russell group (8.4%) in Engineering.

CONTRIBUTION TO THE ECONOMY AND SOCIETY

Our impact strategy has yielded a healthy portfolio of 12 Impact Case Studies shortlisted for REF2021 submissions in UoAs 11 and 12 across SEMS and EECS. Most reflect mature impact case studies, many involving underpinning research that occurred prior to 2014. However, our vibrant research environment supports a robust pipeline of impact-generating research with active investment to deliver the widest possible economic, health and societal impacts (SA7). During the REF period SEMS and EECS have generated **88 patents**, signed **66 commercial agreements** for technology transfer and created **5 spin-out companies**. Impact from our research is typically multi-faceted with a range of economic, health and social impacts generated.

Impact generation is supported through internal funding schemes run by Queen Mary Innovation Ltd (QMi) and our Business Development team. EPSRC/STFC IAAs support **Flexible Innovation Starter Funds** (<£5k) allows exploration of ideas with major Impact potential, while larger **Proof of Concept awards** of up to £50k are available via QMi/IAA to support projects through TRL levels 4-6 (so called Valley of Death) to prime for investment and full commercialisation. QMi have also launched the QM Enterprise Investment Fund, providing early-stage seed capital for our spin-out enterprise. The success of our technology transfer activities was recognised in the Entrepreneurial Impact Ranking (<https://octopusventures.com/entrepreneurial-impact-ranking/>) where QM ranked 4th in the UK in both 2019 and 2020 for production of spinout companies, and successful exits, relative to the total funding received. Most of that success relates to spin-out activities arising from research in SEMS and EECS.

QM offers free legal and business advice to tech start-ups and new entrepreneurs through *qLegal*, from the Centre for Commercial Law Studies, and for financial issues *qNomics*, from the School of Economics and Finance. The Centre for Public Engagement (CfPE) provides funding for small grants (up to £1k) and large grants (up to £10k) with an emphasis on innovative projects that demonstrate two-way engagement with community/public/patient involvement. The CfPE actively supports leverage of external funding for public engagement from organisations including the Royal Society of Chemistry, EPSRC and the Royal Society.

Contribution to the Economy: Economic impacts typically involve commercialisation of research through the establishment of spin-out companies and/or licensing to established industry. Examples include successful high growth spin-out companies such as Apatech – a \$330M acquisition by Baxter Inc; AIM-listed Actual Experience (<https://www.actual-experience.com> – analytics tools to assess systems performance). Technology transfer via licensing to existing industry includes PURE/TEGRIS light-weight materials developed at QM and now in a wide range of products from body armour used by the USA army to high-end lightweight luggage (supporting the acquisition of TUMI by Samsonite in a \$1.8billion deal in 2016). Sugru–moldable adhesives, developed through QM research, is used in 178 countries with over 20 million sales.

Our Impact Case Studies represent the tip of the iceberg with more recent research activities having led to spin-outs including Ultima Forma (<http://www.ultima-forma.com>), a joint venture with

Morganic Metal Solutions Ltd producing lighter, stronger and more heat resistant materials for Aerospace and other applications) and FXive (<https://fxive.com/#home>) – providing synthesised sound effects for video and gaming applications.

Contribution to Society: UoA12 research has contributed to a wide range of societal impact, that include policy impact, enhancement of health-care through delivery of innovative therapies and community-based/public engagement.

UoA12 research has delivered significant impact on policy (Actual Experience) and health (Biomin, Apatech, Progentix). Major impacts in society include the work our Centre for Advanced Robotics on nuclear waste removal and Bailey's role as one of the four members of the Government's Building safety: independent expert advisory panel established to provide advice to the Secretary of State for Communities and Local Government, on immediate building safety measures following the Grenfell Tower fire. Humphreys in the only engineering member of the Royal Society committee, Science in Emergencies Tasking – advising Government on COVID.

UoA12 staff have an established track record for the highest quality public engagement activity. This includes extensive interaction with the multi-million pound award-winning Centre of the Cell (centreforthecell.org) - the first science education centre in the world to be located within working biomedical research laboratories. Bioengineering research is featured both in the centre and online, with several interactives based on our tissue engineering, biomaterials and medical devices activity. The Centre had over 30,000 visitors within the REF period, whilst online interactives on the Xplore Health website have attracted over 300,000 visitors (xplorehealth.eu/en/media/engineer-skin). Our research has featured at major science festivals including the Royal Society Summer Exhibition and Big Bang, as well as local science festivals such as QMs 'Festival of Communities'. Many of our research outputs have generated media coverage including articles in national press, radio and magazines such as New Scientist. We have even had our research featured on a special Royal Mail stamp celebrating British Engineering (www.royalmail.com/britishengineering).

Contribution to the discipline / Selected esteem indicators:

Honours and Awards (examples)

- Officer of the Order of the British Empire (OBE) in New Year's Honours List 2016 (Tanner).
- Henry Clifton Sorby Award, the highest honour of the International Metallographic Society (international award), 2017 (Humphreys) <https://www.springerprofessional.de/en/2017-henry-clifton-sorby-award/12284848>
- [Women's Engineering Society: Top 50 Women in Engineering winner 2020 \(Szilágyi\)](#)
- Rosenhain Medal, Institute of Materials Mining and Minerals 2016 (Titirici - most distinguished materials scientist under the age of 40 in the UK).
- Griffith Medal and Prize, Institute of Materials Mining and Minerals 2017 (Pugno).
- [Frontiers Innovator Award, Wellcome Trust 2015 \(Mata\)](#).
- IET AF Harvey Research Prize 2015 (Hao)
- Royal Society Wolfson Research Merit Award (Hao)
- BAE System Chairman's Silver Award 2014 (Hao)
- "Cell Scientist to Watch 2020", Journal of Cell Science (Iskratsch).
- Major prestigious Research Fellowships: Royal Society University Research Fellowship (Fenwick); EPSRC Fellowship (Buchan and Smoukov); ERC Fellowships (Mata, Botto, and Gautrot); British Heart Foundation (Iskratsch).
- Fellows of learned societies and institutes include: Royal Academy of Engineering (Bailey, Busfield, Hao, Humphreys, Parini, Tanner, Wang); Institute of Mechanical Engineers (Jiang, Tanner, Wang); Institute of Materials, Mining and Minerals (Busfield, Bilotti, Briscoe, Smoukov, Tanner, Vadgama); Institute of Electrical and Electronics Engineers (Hao, X-Chen); Institution of Engineering and Technology (Brown, Donnan, Hao, Parini, X-Chen) Institute of Physics (Donnan, Vadgama); Institute of Physics and Engineering in Medicine (Tanner); Royal Aeronautical Society (Avital, Stark, Toropov); Royal Society of

Edinburgh (Tanner); Royal Society of Biology (Vadgama); Royal Microscopical Society (Humphreys, Bushby, Hing); Royal Society of Medicine (Vadgama); Royal Society of Chemistry (Azevedo, Krause, Vadgama); American institute of Medical and Biological Engineering (Vadgama); European Ceramics Society (Reece).

- Twenty submitted staff in [World Top 2% of Scientists by Stanford University](#) (Althoefer, Bailey, Bastiaansen, Boek, DeBruijn, Gupta, Hao, Hing, Humphreys, Jiang, Livingston, Lee, Parini, Pugno, Reece, Screen, Sukhorukov, Toropov, Vadgama, Wen).

National/International Research Leadership Roles (examples)

- **Funding Panel Membership:** EPSRC (20+ staff); BBSRC (Krams); Versus Arthritis (Screen, Knight); Chair of Royal Society Committee 4 (Engineering) to select new Fellows of the Royal Society (Humphreys 2020-22); Chair of Royal Society Research Appointment Panel (2013-2016, 2020- Humphreys); Royal Society Funding Panel (Karabasov); Chair of European Synchrotron Radiation Facility Panel C08 (Gupta); International Review Panel for Japan World Premier Research Centre Initiative (2013-2016, Humphreys), EPSRC ICT Advisory Team (2013-2017, Hao).
- **External Advisory Boards:** Sandia National Laboratory, USA (2013-2016, Humphreys); Monash Centre for Electron Microscopy, Australia (2013- Humphreys); Materials Science Committee and Venture Prize Committee, Armourers and Brasiers Company, London, (2014- Humphreys); Royal Society Judicial Primer on Ballistics (to advise senior judges) (2019, Humphreys); Scientific and Technical Committee of the Italian Space Agency (Pugno); RAeS Professional Standards Board (Stark); Royal Academy of Engineering - Board of Trustees (Tanner); European (CEN TC184 / WG5) and International (ISO TC164 / SC3, ISO TC107/ SC2) Standards committee for instrumented indentation testing (Bushby); External Advisor to the Science & Technology Commission of the Mexican Congress (Alfonso); Chairman of the American Institute of Aeronautics and Astronautics (AIAA) Multidisciplinary Design Optimisation Technical Committee (2015-2017, Toropov); Chairman of the Association for Structural and Multidisciplinary Optimisation in the UK (ASMO UK, Toropov); European Synchrotron Radiation Facility Panel (Gupta), International Advisory Committee (IAC) of Cominlab, France (Hao), The Alan Turing Institute ASG management Board (Hao).
- **Society Leadership:** Chair of the Rubber in Engineering Group (RIEG) of the IOM3 (Busfield); Co-Director of Barts Heart Centre Device Institute (Krams); Member IOM3 committees on Nanomaterials, Smart Materials and Biomedical Applications (Vadgama); BSI committees on Nanotechnology, Cell therapies (Vadgama); UK representative ISO Nanotechnology nomenclature (ISOTC 229, Vadgama), Publication Committee Chair of IEEE Antennas and Propagation Society (Hao).
- **Conference and Network Organisation:** World Biomaterials Congress 2020 (Tanner); International Rubber Conference (Busfield); Osteoarthritis Research Society International - World Congress 2014 (Lee); UK Biomedical Engineering 2016-19 (Screen, Knight, Wang); Organ-on-a-chip Technologies Touching Life Network (Screen, Knight); Imaging Technologies Touching Life Network (Gupta); Cell & Tissue Engineering Society Meetings (Screen, Wang, Tanner), Chair of European Antennas and Propagation Conference (EuCAP 2018, Hao).

Journal Editorships on 30+ peer reviewed journals: This includes: Specialty Chief Editor of Biomedical Robotics, Frontiers in Robotics and AI (Althoefer); Editor, Journal of Medical Robotics Research (Althoefer); Editor in Chief Bioelectrochemistry (Vadgama); Co-editor of Journal of the International Society for Structural and Multidisciplinary Optimisation (Toropov); Editor in chief Frontiers in Materials (Pugno); Associate Editor Proceedings of the Institution of Mechanical Engineers, Part H: Engineering in Medicine 1996 – (Tanner); Associate Editor Frontiers in Energy Research 2015 (Szilagyi); Associate Editor Multi-Functional Materials (Smoukov); Associate Editor PlosOne (Screen), Associate Editor Nature Scientific Reports (Knight, Screen, Gautrot, Gavara, Pugno). Editor in Chief, IEEE Antennas and Wireless Propagation Letters (AWPL, Hao), Founding Editor-in Chief, EPJ-Applied Metamaterials (EDP Sciences, Hao).