

Institution: University of Central Lancashire
Unit of Assessment: UoA12 – Engineering
1. Unit context and structure, research and impact strategy

1.1 Structure

Research in UoA12 comprises engineering and functional materials conducted in the Schools of Engineering and Natural Sciences. It combines research submitted across three UoAs in REF2014: Electrical and Electronic Engineering Metallurgy and Materials (UoA13), General Engineering (UoA15), and Architecture, Built Environment and Planning (UoA16).

Since 2014 the University of Central Lancashire (UCLan) has committed sustained, strategic investment to expand research as well as innovation and enterprise (I+E) in Engineering. An (additional) new building, staff and equipment have contributed to significant increases in both scale and scope, including a **93% increase in external funding, an 84% increase in PhD completions and a 35% increase in journal publications** compared with REF2014. Table 1.1 compares key metrics for 2021 with aggregated data for UoAs 13, 15 and 16 in REF2014.

Table 1.1 Key performance indicators

	Staff FTE	Research income	PhD completions	Research income per FTE	Completions per FTE
2014	29.5	£5.6M	38.75	£189,830	1.31
2021	48.6 (+64%)	£10.8M (+93%)	71.5 (+84%)	£222,222 (+17%)	1.47 (+12%)

Publication strategy has included implementing an open access approach to deposit publications, data and other outputs on the Institutional Repository (Central Lancashire Online Knowledge, CLoK) and encouraging publication in peer reviewed journals, leading to an increase in journal output (Table 1.2).

Table 1.2 Publication details

	Journal papers	Conference papers	Book chapters
2014	377	423	67
2021	510 (+35%)	157 (-63%)	25 (-63%)

We have invested £50M in Engineering since 2015. Key to our expansion and impact development is the **£35M, 7,000 m² Engineering Innovation Centre (EIC)**, a 'signature project' within the Local Enterprise Partnership (LEP) Economic Plan. It has involved co-investment including: **£5M (HEFCE), £5.8M European Regional Development Fund (ERDF) and £10.5M Local Growth Deal.** These investments and active collaborative network of over 200 organisations, have made a critical contribution to the Government's Industrial Strategy, involving the development of the Northern Powerhouse and the private sector.

Activities since 2014 have been integrated by five subject themes, supported by research centres and groups as detailed below:

- (i) **Digital Engineering (Profs Shark/Matuszewski; 7.5 returned FTE, 7.33 Current PhD, 10.5 Completions, 9 PDRA, 4 Graduate Engineers, 6 Project Engineers, 2 Business Development Officers):** Applied Digital Signal and Image Progressing Research Centre

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(ADSIP), Advanced Digital Manufacturing Technology Research Centre (ADMT), Computer Vision and Machine Learning Group (CVML).

- (ii) **General Engineering (Profs Sherrington/Ansell/Dr Francis; 19 returned FTE, 16.67 Current PhD, 13 Completions, 6 PDRA, 1 Research Engineer):** Aerospace and Sensing Group (AASG), Innovation Clinic, Jost Institute for Tribotechnology (JifT), including: Intelligent Machines and Maintenance and Additive Manufacturing), John Tyndall Institute (JTI), (incorporating Energy and Engineering Simulation).
- (iii) **Functional Materials (Profs Reddy/Eccles; 10.6 returned FTE, 8 Current PhD, 22.25 Completions, 4 PDRA):** Centre for Smart materials.
- (iv) **Fire Science and Fire Engineering (Profs Hull/Stec; 6 returned FTE, 5.67 Current PhD, 8 Completions, 8 PDRA):** Centre for Fire and Hazards Science (CFHS) and Fire Engineering Research Group (FERG).
- (v) **Construction Management and Environmental Engineering (Profs Liyanage/Williams; 5.5 returned FTE, 11.5 Current PhD, 17.75 Completions, 3 PDRA , 5 Research Assistants, 1 Research Fellow, 1 Project Engineer, 7 Business Engagement Officers):** Centre for Sustainable Transitions (ST), Centre for Waste Management (CfWM), Earthworm Research Group (ERG).

Research groups operate both independently and in fruitful collaboration. For example:

- CFHS have projects with the AASG employing UAVs to assess environmental pollution from fires in waste storage facilities.
- CVML has worked with JTI to apply machine learning to predict energy demand.
- ST have worked with CfWM to address waste management issues in relation to community resilience.

1.2 Achievement of strategic aims

We have developed an integrated agenda **addressing local, regional, national and international priorities** whilst **aligning with UK Industrial Strategy**. For example, in transport (supporting growth and productivity in aerospace) and in applying AI for diagnosis of disease (supporting the healthy ageing agenda). We have **increased interdisciplinary collaboration** across the sciences, engineering and health/social sciences supporting clean growth (e.g. developing water pollution treatment) and supported longer independent living (e.g. through new approaches to drug delivery). We have **supported the UK “places agenda”**, working with partners, contributing to regional development of the Northern Powerhouse, and **national competitiveness** through collaboration with key companies such as BAE Systems, Johnson Matthey, and Sellafield Ltd.

Our reach and impact has been extensive and includes:

- **Environmental management**, e.g. research to turn automotive shredder residue from old vehicles into a saleable product and electrical energy, reducing environmental impact and diverting material from landfill. (Awarded **“Most Innovative Contribution to Business-University Collaboration”**, Times Higher Education Awards, 2018).
- **Business enhancement**, using our ERDF programmes to drive local growth and regeneration, over **500 business assists** have delivered new product generation and job retention/creation.
- **Positive societal influences**, encompassing contributions to review of the Grenfell disaster and a sustained outreach programme **reaching over 40,000 people** via platforms such as the Lancashire Science Festival and the IET Faraday Challenge.
- **Treatment and diagnosis of illness**, Interdisciplinary collaboration with partners in Europe

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and the UK, including DEFRA and NHS, has led to several innovations, including:

- Identifying ***Fire Officer's clothing as sources of potential carcinogenic materials.***
- ***Improving surgical practice*** by modelling haemodynamics and microvascular anastomoses.
- Development of ***molecular imprinted polymers to identify and destroy viruses.***
- Development of a ***well-being self-assessment device*** for early detection and monitoring of cardio-vascular conditions.
- ***International support***, for example, ***enhancing research and innovation in disaster resilience*** in association with Local Government Agencies in Asia.

1.3 Research integrity

Our research is bound by a commitment to research integrity set out in UCLan's Code of Conduct for Research and Ethical Principles. These documents are reviewed annually by the Committee for Ethics and Integrity. All research meets sector specific ethical standards. For example, work involving creation or testing of autonomous and intelligent systems is conducted in accordance with the ethical principles of the IEEE Ethically Aligned Design Guidance Document (IEEE, 2019). We are also committed to following the Global Code of Conduct for Research in Resource-Poor Settings (relevant to our work is Asia). ***All PGR and staff research projects must gain formal ethical approval*** prior to being conducted, with an ethics submission directed to the University Ethics Review Panel specific to the project. Where activities involve any external organisation for which separate and specific ethics clearance is required (e.g. NHS), all relevant approval processes are followed. To maintain our high standards, we provide dedicated training and seminars on "Research Integrity and Ethics" for all staff and research students, with the most recent seminar on "Artificial Intelligence and Ethics" delivered by leading experts in June 2020.

1.4 Achieving research and impact ambitions 2014–2021 and 2021 onwards

Progress towards discipline specific goals outlined by the principal themes in their 2014 REF returns is summarised below along with their strategic aims for the next REF.

(i) Digital Engineering

2014-2020 Performance

This group has grown from strength to strength with each research assessment. ADSIP (signal and image processing) emerged after RAE2001, ADMT (digital manufacturing) following RAE2008 and CVML (computer vision, machine learning and AI) following REF2014. Since 2014, the group's ***grant portfolio rose from £3.8M to over £7M.*** Through national and international collaboration with over 30 universities and companies, we have established a world leading position in:

- ADSIP on medical acoustic emission as a new clinical tool for joint diagnosis,
- CVML on well-being self-assessment and computational automation of decision support in endoscopy,
- ADMT on 3D ultrasonic tomography for industrial non-destructive evaluation.

By utilising the unique digital manufacturing platform developed in the last REF for ICT-enabled manufacturing execution, ADMT has undertaken research for major manufacturing primes and small and medium enterprises (SMEs) in the region, and transformed the local digital manufacturing landscape by supporting numerous Lancashire manufacturing companies to adopt smart digital technology solutions.

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2021-2028 Strategic Goals

- Focus on developing medical acoustic emission into a major new discipline to support early detection, monitoring and treatment of common musculoskeletal diseases, thereby maintaining its global lead.
- Grow development of AI technologies to unlock the diagnostic potential of biomedical data. CVML will push applications in multiple areas including scientific (e.g. earth observations), industrial (e.g. energy), and social (e.g. affective computing).
- Extend the ADMT research agenda to **deliver benefits of Industry 4.0 to ADMT's network of regional manufacturers through £1.7M secured funding**. ADMT will focus on development of lifecycle-based digital twins of processes, products and services, and integrate them towards an organic whole for data-driven monitoring and optimisation.

(ii) General Engineering

General Engineering comprises four research groups **supported by £2.8M income**. Since 2014 we have focused on driving expansion in the breadth of topics addressed. In particular, introducing activities in aerospace, sensing and additive manufacturing (AM).

2014-2020 Performance

Aerospace engineering was established as a new area in 2014. It aims to strengthen Lancashire's position as a National Centre of Excellence for Aerospace. Research and development in aerospace includes accelerating development of unmanned aerial vehicles (UAVs) and their mission systems in areas such as:

- swarm optimisation,
- aerial sensors for landmine detection,
- application of graphene enhanced (GE) technologies which led to several world firsts (GE wing coatings (2015)/GE carbon-fibre wing (2016), full GE blended fuselage UAV (2018)),
- applying aerospace technology in the medical sector, developing ultrasound wearable medical devices to treat children with Nocturnal Enuresis.

The Innovation Clinic, funded by the LEP and ERDF, has delivered business support and product development to enhance competitiveness of SMEs, increasing their innovation capacity and productivity. It has also provided a conduit for commercialising research, supported by eight staff and academics, developing new products/services from concept to launch. Since 2014 it has:

- Delivered workshops, tailored 1-2-1 advice, feasibility assessments and new product development.
- Assisted 220 SMEs, created 22.36 jobs, and developed 22 research collaborations.

From 2014 JIfT pioneered development of "tribotronics" (active tribological components/systems). Working with academic/industrial partners, a range of tribotronic devices, were built and evaluated. JIfT also founded, and leads, the "European Tribotronics Network", an informal consortium of academia and industry. Innovation in tribotronics has precipitated expansion in staffing (3.6 additional FTE) and resources in allied developments especially condition monitoring, AM resources and systems reliability.

From a base in nuclear engineering, JTI has developed a broader scope of activity. Research now includes:

- Energy, especially energy distribution, demand prediction and generation. Including:
 - modelling of energy consumption profiles, involving interdisciplinary work in machine

Unit-level environment template (REF5b)

- learning to enable large-scale renewable energy system design,
 - new methods for wind turbine blade design,
 - legacy waste management of aerodynamic components, including predictive computational modelling to determine progressive damage and ultimate service life.
- Medical applications involving interdisciplinary studies with clinical staff, mathematicians and engineers conducting computational haemodynamics, modelling of bone (especially damaged mandibles) and design of replacement prosthetics.

2021- 2028 Strategic Goals

- Establish UCLan as a lead institution for UAV technology, specialising in sensor applications and AI and creating a ‘Lancashire Innovation Drone Zone’ to support UAV related businesses and end users.
- Advance the delivery of KT to the region’s SME community through the Innovation Clinic. This includes adopting research developments to deliver solutions, over several sectors.
- Develop novel tribotronic components, sensors and actuators with integration of components/systems into practical uses employing the internet of things.
- Develop a range of novel AM processes, including, manufacture of large-scale components, use of recycled polymers and freeform printing with hollow tubes.
- Use AM to underpin the design and manufacture of a broader class of components and “intelligent machines”, especially within health technology.
- Develop and apply AI based predictive capabilities in energy research.
- Extend interdisciplinary activity, especially within clinical engineering/medical technology.

(iii) Functional Materials2014-2020 Performance

The Functional Materials Group (FMG) has delivered significant, interdisciplinary advances in surface science and catalysis, carbon nanoscience, nuclear separation science, biomaterials science and magnetic nanomaterials impacting healthcare technologies and the environment. Highlights include:

- approximately **£1M in competitive funding** from UKRI; UK-based Charities; UK and Non-EU Industry and EU to support 4 PDRA/Fs and contributing to 22.25 PhD completions (123% increase on REF2014),
- patents WO2016042337A1 (large-scale production of fluorescent materials based on C-dots;); WO2010139972 granted in 2014 (commercialising MIP technology as novel nucleant for protein crystallization) and WO2015059445 (reprocessing nuclear waste or spent nuclear fuel),
- magnetic nanoparticles-based nucleic acid separation technology leading to a commercial product with Q-bioanalytic GmbH, Germany,
- translation of spectroscopy into the clinical environment leading to the establishment of the International Society for Clinical Spectroscopy (CLIRSPEC) to improve cancer diagnosis and prognosis.

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2021- 2028 Strategic Goals

- Address Grand Challenges in clean growth (impacting climate change; next generation fuel cycles and nuclear waste legacies) and ageing society (impacting disease diagnostics and therapeutics for healthcare provision).
- Expand regional, national and international academic collaborations, initiate clinical links and target UKRI, UK-based Charities and industrial funds, part-supported by UCLan investment.
- Strengthen and grow our industrial collaborative links with diagnostic and waste management companies Sellafield Ltd and NNL; and explore opportunities to license/commercialise our functional materials research.

(iv) Fire Science and Fire Engineering

We provide multidisciplinary research supporting science, industry and government. **Income (£1.4M) and researcher numbers (14) have doubled from 2013.** Focus has progressively shifted from fire science and fire-retardant chemistry to short and long-term hazards of fire effluents and residues. The 2017 Grenfell Tower fire had a profound influence on the importance and direction of our work.

2014-2020 Performance

- 2014-17, new fire-retardant formulations were developed for timber (KTP/Lonza, £160K); using carbon nanotubes (EU DEROCA £351K); and in collaboration with leading Chinese experts. Work also included developing low smoke toxicity insulation products; and developing drone-based analysis of large waste fire smoke.
- 2017-20, Prof Stec's interaction with the highest-level UK institutions illustrates the shift in focus.
 - She found high levels of carcinogenic and toxic substances around the Grenfell site leading to her appointment as the leading expert to the Scientific Advisory Group on **Grenfell Environmental Contamination**, chaired by **Sir Patrick Vallance** and including **Professor Chris Witty**.
 - Appointed to **Dame Judith Hackitt's Review of Building Regulations**.
 - Appointed **expert witness to Grenfell Tower Inquiry** to investigate fire derived residues and quantify the extent of penetration and toxicity of smoke from individual products in the Tower.
 - She presented our research, in person, to the **House of Commons Environmental Audit Committee**.
 - Her analysis of firefighters' PPE for carcinogenic and other harmful substances led to a **£250K project with the Fire Brigades Union**.
- Alongside this high-profile work, interest in improved fire safety led to two additional funded PhD studentships in fire toxicity (£80K), and fire-safe intumescent coating development (£80K), KTP on fire toxicity (Silentnight £160K) and research on risk and reliability.

2021-2028 Strategic Goals

- Development of new fire-safe products (considering fire retardancy and fire toxicity).
- Providing regulators with tools to regulate smoke toxicity alongside flammability.
- Providing the evidence to minimise firefighter's exposure to toxic fire effluents and residues.
- Practical investigations into the toxicity of pyrogenic atmospheric particles.

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(v) Construction Management and Environmental Engineering:

2014-2020 Performance

- Since 2014 there has been a dramatic increase in research activity. **Over 15 PhD students have been recruited**, with 17.75 MPhil/PhD completions (compared to one completion REF2014) and the **Research grant portfolio has increased from £511K (REF2014) to over £7M** during the current REF period (~1300% increase).
- The group has engaged business and public sectors to support resource efficiency and carbon reduction. Three ERDF programmes have delivered innovation and environmental support to SMEs within North-West England helping the move to net-zero carbon targets through business engagement activities by 2050. The work has **assisted 110 SMEs, provided £191,276 worth of grants to install green/low carbon technologies, saved 1,175 tCO₂eq and engaged in 10 research collaborations.**

2021-2028 Strategic Goals

- Expansion of waste management support within China, Vietnam, Philippines, Indonesia and Sri Lanka (the worst locations for plastic waste pollution). Extending research outcomes from the joint thermal UCLan/Recycling Lives processing facility to support the development and exploitation of appropriate technologies, fitting in with local needs, and cultural and social paradigms.
- Build on newly developed techniques in earthworm ecology for application in agroecosystems (involving collaboration Finland and Austria). To examine ecosystem engineering interactions between earthworms and crops leading to pathogen suppression.
- Continue to build national and EU/international networks expanding activities on management and recovery relating the impacts of disasters to ensure continuity of critical services, infrastructure and build capacity of staff and communities.

1.5 Future Operational Structure

From August 2019 research staff were grouped into UCLan Research Institutes/Centres to:

- increase focus on national and international priorities,
- improve planning/resourcing,
- facilitate multi-disciplinary activity,
- focus attention toward local, national and international strategic priorities.

Four UCLan Research Centres, relevant to UoA12, accommodate existing research groups. These are for: Engineering, Fire and Hazards Science, Smart Materials and Sustainable Transitions.

The Research Centre for Engineering will focus on research and impact development responding directly to Industrial Strategy and other priorities as in Table 1.3.

The Centres for Sustainable Transitions, Fire and Hazards Science and Smart Materials (incorporating Functional Materials) will contribute to Clean Growth. Smart Materials will also contribute to Ageing Society.

The UoA has three general strategic targets for the next REF:

- **increasing capacity**, including expansion of the research student population. (Supported by a range of initiatives particularly international collaboration with organisations in the Middle East),

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- **increased research in healthcare**, including multi-disciplinary development of sensors, medical devices and therapeutics, involving collaboration between the Functional Materials group and Engineering researchers,
- **explicit growth of impact delivery**, Supported by commitment to the Knowledge Exchange Concordat, collaboration with other centres in UCLan, targeting of internal funding to projects with strong potential impact, training activities related to impact planning, and increased contact with public and commercial organisations through the EIC.

Table 1.3 UCLan Research Centre for Engineering

Strategy Area	Research groups
<i>Future of Mobility</i> <i>Ageing Society</i>	Aerospace and Sensing Group
<i>Intelligent Machines and Maintenance</i> <i>Ageing Society</i>	Jost Institute for Tribotechnology John Tyndall Institute
<i>Product Design</i>	Innovation Clinic
<i>Digital Manufacturing</i>	Advanced Digital Manufacturing Technology Research Centre
<i>Artificial Intelligence and Data Analysis</i>	Applied Signal and Image Processing Research Centre Computer Vision and Machine Learning Group
<i>Clean Growth</i>	Centre for Waste Management Earthworm Research Group

2. People

2.1 Staffing strategy and research development

UCLan has been awarded the European HR Excellence in Research award, acknowledging alignment to the European Charter for Researchers and the Code of Conduct for their recruitment. This incorporates the Concordat to Support the Career Development of Researchers and national evaluation/benchmarking of our implementation plans.

Since REF2014, we have targeted recruitment of research active staff, increasing the proportion of researchers by replacing departing “teaching-only” lecturers with active researchers (**18 new appointments since 2014**). This strategy has been complemented by supporting existing staff to study for a PhD, sponsored both financially and by time allocation, followed by progression to “Significant Responsibility for Research” (SRfR) status on completion. In recent years, four staff have developed their careers in this way. Four others are currently working towards a doctorate.

More explicit allocations of time for research/I+E activity have been introduced within workload modelling, with a minimum of 20% FTE for SRfRs, 10%-20% FTE for staff developing a research profile and up to 10% FTE for staff wishing to have limited involvement in research. This has resulted in greater transparency of workload management, more targeted appraisal objective setting/accountability, and a significantly higher level of research/I+E activity. The success of this strategy is **evidenced by growth in number of staff returned in 2021 (48.6) compared with REF2014 (29.5) and the increase in ECRs. Seven staff are included as ECRs in REF2021.**

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2.2 Staff - Equality, diversity and inclusion

We value and celebrate diversity. Research staff and students come from a wide range of backgrounds with individual needs, beliefs and values. We follow University policies for equality, diversity and inclusion and aim to develop good practice and positive attitudes across the UoA. We believe that all people should have an equal opportunity to learn and develop. The University is **a member of Athena Swan, the Stonewall Diversity Champions Programme, AccessAble, Disability Confident, holds a Mindful Employer Charter Mark and the UNICEF Baby Friendly Initiative Gold Award**. Our values are reflected in the approaches detailed below.

2.2.1 Staff - Application process

The UoA recruits internationally, following a policy of **equality and diversity to attract the strongest possible candidates**. The cultural and ethnic diversity of our submission reflects this approach. Vacancies are advertised internationally via the web and applications are made through an online system to facilitate wide reach. All applicants with declared disabilities, meeting the essential criteria, are offered an interview.

2.2.2 Gender balance

Table 2.1 compares the gender balance of REF2014, the University population, staff eligible for UoA12 and those returned for REF20121.

Table 2.1 Staff gender comparison

Gender	REF2014	REF2021			
		University		UoA12	
		Eligible staff	Submitted staff	Eligible staff	Submitted staff
Female	44%	53%	44%	23%	18%
Male	56%	47%	56%	77%	82%

Figures for UoA12 and the return are broadly consistent with HESA data for UK university engineering departments (~20% women) and we are encouraged that the **proportion of female staff returned exceeds that normally found in UK engineering industry**. (The Learning and Work Institute reports 9% of the UK engineering workforce is female).

The School of Engineering has several women in leadership and decision-making roles, ensuring a broad range of views and perspectives inform our strategic direction. **One of the professors leading REF preparations is female, a female represents the school in negotiations with employers, the Head of School and Deputy Head (Academic) are female and over the REF period we have employed a female Outreach Officer** who provided an important role model encouraging young female students towards engineering. The School of Engineering has an Athena Swan Steering Group and a “Women in Engineering Network” to support communication, encourage engagement in gender equality, organise events and support women's careers. It has recently submitted an application seeking a School level Bronze Athena Swan Award.

2.2.3 Ethnicity, culture and race

We embrace the 2010 Equality Act pro-actively discouraging discrimination and follow the Royal Academy of Engineering Equal Opportunity Guidelines. Anti-discrimination training and unconscious bias training is mandatory for all. The UoA encompasses a wide variety of staff backgrounds. Table 2.2 details the balance of race when compared to UoA 2014 and the current balance within the University, eligible staff and the UoA.

Table 2.2 Staff racial balance

Race	REF2014	REF2021			
		University		UoA12	
		Eligible staff	Submitted staff	Eligible staff	Submitted staff
Asian	6%	6%	5%	11%	11.76%
Black	3%	3%	3%	8%	5.88%
Mixed	3%	2%	3%	1%	0%
Other	0	4%	6%	15%	19.61%
BAME total	12%	14%	17%	35%	37.25%
White	80%	83%	80%	60%	60.78%
Not stated	9%	3%	3%	5%	1.96%

The UoA reflects ***the balance of race within the eligible staff group and exhibits a significantly larger proportion of the BAME population than the University as whole.*** The returned percentage also significantly exceeds that in the REF2014 population. We believe that the global span of our research collaboration and its racial diversity is one of the factors driving the development of our international research network. Understanding other ethnicities and their cultures leads to innovation, creativity, increases in scale and improved financial performance. There may also be other, less tangible, benefits including greater motivation for individuals and improved staff retention based on “job satisfaction”.

2.2.4 Age profile

Table 2.3 details the age profile of the return in comparison with that of UoA 2014, the current balance within the University and the eligible staff group. It is evident that there is a slightly smaller proportion of younger staff in the return than there is for the University as a whole. The data also illustrates that in this UoA younger staff are more likely to be included than those at later career stages ***pointing favourably to the development of an increasingly vibrant research culture in the future.***

Table 2.3 Staff age profile

Age	REF2014	REF2021			
		University		UoA12	
		Eligible staff	Submitted staff	Eligible staff	Submitted staff
≤ 30	6%	3%	1%	2%	1.96%
31-40	27%	23%	25%	18%	19.60%
41-50	35%	31%	33%	33%	41.17%
51-60	25%	34%	30%	31%	21.56%
61 and over	6%	10%	11%	17%	15.69%

2.3 Staff - Research development

A self-identified group of staff, defined as an ECR forum, work together to actively plan their own programme of activities to support their personal development following guiding principles from

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Vitae. These activities augment formal development planning within staff appraisal processes. We assist ECRs to develop into research active roles by **requiring that requests for University funded PhD Research Studentships must include at least one and preferably two ECRs** within the Supervisory Team. Mentorship and guidance of the Supervisory Team is then provided throughout the project by an experienced supervisor, often a Professor.

Research training includes: approaches to securing external funds; the Research Excellence Framework; planning impact pathways; research governance, integrity, policies and ethics; scholarly communications, open access (publications and data), public engagement, publishing models; career development planning (including the Concordat and the role of Vitae); intellectual property management and commercialisation.

Staff development in I+E has been supported by appointment of two high-profile industrialists, with one at Professorial level. Their role is to facilitate industry links and drive development of industrially based research, supporting academic staff, particularly in areas related to aerospace.

Explicit time allocations are made to support development of developmental research activities. For example, within the School of Natural Sciences:

- originally recruited as Guild Research Fellows, Kellarakis and Kulkarni were supported by a three-year period of reduced teaching workload to build their research capacity,
- Readman and Zlatogorsky were each given research focus sabbaticals for 6 months,
- Sen was allocated research time to apply for a Royal Society Industrial Fellowship to work in Feedwater Ltd. and develop a nanoparticle-based Legionella test-kit.

2.4 Staff - Mentorship in research

Research development has included the **appointment of two experienced individuals as “Research Mentors”**. One is a distinguished Professor from a Russell Group university the other an accomplished researcher from industry. Their role is to guide and support staff in the preparation of requests for grant funding and the preparation of output, providing appraisal and support for preparation of funding proposals. All staff may request support from these colleagues, but their activity is focussed on those with less experience.

2.5 Staff - Reward and recognition

All staff are encouraged to participate in research or I+E and there have been **nine promotions to the role of Reader and Professor (including three BAME (one female), and one additional female)**. Promotion is based on formally recognised achievements in either research or I+E pathways, to encourage and reward exceptional engagement in these areas. Examples are:

- Ansell: appointed as Principal Lecturer in 2012, promoted to Professor in 2018 in recognition of contributions to aerospace engineering research, innovation and enterprise (Innovation route),
- Liyanage: recruited as Lecturer in 2008, promoted to Senior Lecturer (2011), Reader (2015) and Professor (2019) in recognition of her research in construction, facilities management and disaster resilience research nationally and internationally,
- Reddy: recruited as Senior Lecturer in 2016, promoted to Reader (2016), then Professor of Biomaterials and Analytical Chemistry (2018) in recognition of his internationally leading research in synthetic receptors and their application to biosensors,
- Stec: recruited as Lecturer in 2007, promoted to Senior Lecturer (2010), Reader (2012) and Professor (2017). She is internationally leading in the toxicity of fire effluents and residues,

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- Williams: recruited as a Lecturer in 2006, promoted to Senior Lecturer (2008), Principal Lecturer (2012), then Professor (2018) in recognition of applied research and knowledge transfer activities within the environment and resource field (Innovation route).

2.6 Staff - Development for innovation and enterprise

Responding to regional and national strategies, the School of Engineering has embarked on an integrated strategic development plan to help academic staff expand I+E work. It has developed a programme of increased support for industry supported by the EIC with:

- **Three large ERDF supported schemes** with teams including administrators, engineers, designers, software engineers, etc., ensure a rapid response to urgent industrial enquiries, while facilitating academic staff engagement with I+E activities on a longer timescale.
- Staff specifically **supporting development of industrial applications in aerospace**.
- **An EIC Innovation Manager** to co-ordinate support for industry and community activity, conferences, events, training activity, summer schools, professional institution meetings, visits by local schools, and commercial activity.
- Strong links with AMRC (North West), **with their north-west base in university buildings** facilitating a range of opportunities for staff to develop collaborative I+E activity.

2.7 Recruitment, training and support of Post Graduate Research (PGR) students

UCLan Graduate School (GS) and Student Registry (SR) oversee recruitment, training, support and progression of PGRs, ensuring that policies, procedures, quality frameworks and regulations are applied uniformly. Working with Research Degree Tutors, Supervisory Teams and Examiners, GS/SR also manage progression, training and examination arrangements.

2.7.1 Student recruitment

Funded PhD opportunities are advertised internationally via the web and awarded following public advertisement and competitive interview. Candidates holding their own financial support may apply to become students at any time following an admission process similar to that for funded projects.

The UoA is working to increase the PGR establishment and research supervision capacity. One aspect of this involves agreements with partner university campuses in Egypt. Staff from partner campuses can study on PhD programmes at UCLan under favourable fee arrangements partly funded by Erasmus+ (2018-1-UK01-KA10, 2019-1-UK01-KA107, €1.7m) **supporting 30 PhD positions**. Up to **15 additional PhD positions** will be supported by Summer School income.

2.7.2 Student training and support

PhD programmes are designed in co-operation with students on a bespoke basis addressing individual needs. They incorporate: a research plan, technical training, research skills training and workshop/conference attendance. Training is selected from a portfolio and is available in either on-line or face-to-face format. Research skills training has been mapped to the Vitae Researcher Development Framework and has received the HR Excellence in Research award.

Within our research environment:

- Action plans and progress reviews are documented at mandatory, regular meetings between PGRs and Supervisory Teams.
- PGRs play an active role organising/participating in events at School, national and international levels.
- UCLan hosts the Three Minute Thesis (3MT) competition and an Annual PGR Conference.

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- The School of Engineering hosts an “Engineering Expo”, showcasing undergraduate and PGR projects (3MT and poster sessions).
- There are research seminars, reading groups, workshops, international conferences.
- There is competition participation. (Competition successes include: MICCAI (1st in two challenges, Quebec 2017), Mission of Tribology (1st London 2017), Best Paper Award at ICIAR 2014 (San Francisco).
- There is a “hands-on” equipment operating philosophy, PGRs can access training, including on-line video support, to develop operating skills for equipment including SEM, EDX, AFM.
- Contact with staff from other universities and companies is facilitated through a programme of visiting researchers and placements with collaborators.
- Some research students are involved in collaborative projects, some are multi-national.
- To aid teaching skills development, training in teaching is provided by the Centre for Collaborative Learning, providing access to professional recognition with Advance HE (commonly D1).
- PGRs are invited to paid employment within Summer School operation (delivered to undergraduates) by the School of Engineering.
- To facilitate undergraduate involvement in research we offer a range of final year projects allied to research activities.
- We operate an Undergraduate Research Internship Programme.
- PGRs volunteer to support weekly meetings of Engineering Societies, strengthening the network between undergraduate and postgraduate population and encouraging communication between the two groups.
- The UoA offer funding to support PGR led activities.
- PGRs are invited to identify their representatives at school and University level.
- We encourage PGRs to contribute to the PGR Society.
- Channels to listen and respond to the PGR student voice are provided.

2.8 PGR Student diversity, gender and cultural balance

Our approach to diversity in the PGR population embraces the University principles of inclusivity. Data presented below is drawn from HESA data for the cost centres of engineering and chemistry at UCLan, representing UoA12 at UCLan (with 34.4 FTE students) and these subjects nationally.

Table 2.4 details the gender balance for PGRs. It can be seen that UCLan demonstrates a ***slightly more representative balance of gender than the sector in general.***

Table 2.4 PGR gender balance (2019-20)

	Equivalent UK group	Representative UCLan UoA12
Male	69%	63%
Female	30%	37%

PGRs are admitted from a wide range of backgrounds, countries, faiths and gender. ***BAME admissions to UCLan are slightly above those for the sector as a whole,*** with 10% BAME

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admissions in the sector and 13% BAME admissions at UCLan. UCLan supports initiatives to encourage greater levels of BAME participation and develops general BAME focused support, for example “Race in Focus” studentships to understand inequalities within HE.

Applications from disabled students are welcomed at UCLan and there are support services to facilitate progress for a wide range of disabilities. The proportion of research students with a known disability at UCLan (7.8%) is about the same as that of the sector (7.5%).

2.9 PGR - Progression following award

The number of PhD completions in this REF period is **71.5, an increase of 85% over REF2014 (+12% per FTE)**, underlining our commitment to enhancing research activity.

Graduating PGRs have progressed to Post-Doctoral positions, senior positions in industry/academia and further training/education in the UK and overseas. Example destinations include: Universities of Edinburgh, Aberdeen, York (Canada), Shah Abdul Latif (Pakistan), and companies: National Nuclear Laboratory, Electricity North West and Ove Arup.

Five former UCLan PGRs have joined UCLan as lecturers delivering topics in fire science, nuclear technology, mechatronics and intelligent machines.

2.10 Research environment - Continuous improvement processes

The UoA regularly reviews and reports on the quality of the research environment to develop improvement plans through consultation with key stakeholders. For example:

- PGRs give feedback through formal and informal routes. Formal feedback through the PGR Experience Survey (PRES), Research Degree Tutor Annual Report and Annual Progress Review. Less formally via PhD Supervisors, student representatives, the Student President and Staff Student Liaison group. Formal Action Plans are formed, actioned and reviewed annually, informal comments are generally actioned as they arise.
- Research staff feedback is received at regular meetings, including discussions accompanying weekly seminar events, Professors Forum and a substantial annual summer meeting where longer-term plans are developed to improve research practices.
- Research Centre Heads compile Annual Reports reviewing outputs, impacts and achievements.
- The Researcher Concordat is addressed by ECR forum activities, appraisal discussions and extensive institutional activities to communicate and address the Concordat Principles,
- Sabbatical opportunities have supported research developments.

3. Income, infrastructure and facilities

3.1 Income: UoA overview

Since 2014 external research, innovation and knowledge transfer funding claimed from funders (i.e. not including match and other support) **has increased to £10.8M (£1.5M pa) from £5.6M (£1.1M pa) including a 350% increase in EU funding**. Recognising the potential impact of Brexit, we are working towards diversification of funding streams. With £6M in awarded grants over the last three years of REF2021 we anticipate research income will grow strongly in the next REF cycle.

Research, returned in UoA 20, is also conducted by School of Engineering staff on the interaction between engineering and social policy. It includes participation in a €3M Horizon 2020 Euratom research project, History of Nuclear Energy and Society (HoNESt) with 24 EU member states, the USA and Russia, focusing on the interaction between nuclear energy and society.

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3.2 Research group funding

Research groups in this submission adopted their own funding strategies, focusing on different sources. Key examples of funding income are provided below.

(i) Digital Engineering:

Through a strategy of growing from successful bids in the previous REF and leveraging regional advantages for impactful research, it has led to a larger **grant portfolio of over £7M** (total project value over £22M), which include:

- £331K from EU FP7 for the SEMEOTICONS project to develop sensing and data analytics technologies for well-being self-assessment.
- £393K from EPSRC for the project on reconfigurable assembly system with in-process quality improvement.
- £103K from MRC for the project on knee acoustic emission.
- £673K from BAE Maritime for a series of projects and an industrial PhD studentship on ultrasonic weld inspection.
- £95K from EPSRC and BAE Military Air and Information for a CASE studentship on energy driven manufacturing execution.
- £5M from ERDF for the project of Digital Integrated Manufacturing Execution (DigitME) and its extensions.
- £292K from RGF for the Growing Autonomous Mission Management Applications (GAMMA) programme.
- £40K from STFC CDN+ for Machine Learning System for Computational Automation of Early Cancer Detection in Colonoscopy.

(ii) General Engineering:

This **group's income was £2.8M**. Our priority was to establish capability in aerospace, aligning with LEP regional strategy and aiming to support ~13,200 aerospace jobs in the LEP area (~15.6% of the manufacturing workforce) with aerospace activities to support and grow this local industry. Collaborative SME projects include:

- Intelligent Diversion Assistant (£40K), pilot emergency decision support technology.
- Aerial Uptake £31.5K (EU Interreg) promoting drone use and influencing policy instruments.
- Flight Guardian (£27K), monitoring analogue aircraft instruments advising pilots of potential failures/unsafe situations.
- Impact Classification System (£15K), developing graphene-based impact measurement sensors and classification software.

Aerospace spin-off projects include:

- £83K (SBRI) and £238K (NIHR) wearable medical device development for children with nocturnal enuresis.
- £47K (InnovateUK) Nano-tooling, proof-of-concept automotive GE tooling.

Additionally, **£1.21M (LEP capital equipment funding) was awarded in 2020** (EIC Extension: Drone Command and Control Centre), supporting industry on drone innovations.

Unit-level environment template (REF5b)

(iii) Functional Materials

Enabled by **£930,000 in research funding**, FMG research has focused on disease diagnostics, drug delivery and infection control; nanomedicine and radioactive waste treatment. Examples include:

- A grant portfolio comprising EPSRC (£273K), CASE studentship from Johnson Matthey (£33K) and National Nuclear Laboratories (£43.6K) to develop zeolite catalysts; advanced nanostructured hybrid composite materials for radioactive wastewater treatment; chromatographic separation techniques for Actinides; and decontamination of C-14 from irradiated graphite.
- Wellcome Trust (collaborating with The Pirbright Institute), Royal Society, UKIERI and Daiwa Anglo-Japanese Foundation (totalling £129K) to investigate smart materials (molecularly imprinted polymers) for protein and virus biosensor development.
- DEFRA, FERA, MOD, Rosemere Cancer Foundation and Lancashire Teaching Hospital NHS Foundation Trust (£101K) to develop non-invasive vibrational spectroscopic methods for disease diagnosis; assessing drugs of abuse and application to clinical practice.
- UCLan Biomedical Technology (Shenzhen) Ltd., UK (£90K), UKIERI and the British Council (£83K) collaborating with Feedwater Ltd., UK; Hosokawa Micron Ltd; UK; Tata Chemical Ltd.; Delhi University (India); and ECUST (China) to deliver magnetic nanoparticles-based technologies to remove arsenic from groundwater.
- Daphne Jackson Fellowship (£70K) to investigate magnetic nanoparticles for drug delivery; and two EU DTA3/COFUND PhD fellowships (£200K) to investigate smart materials-based viral detection and therapeutics for healthy ageing.
- PhD funding (£68K) from BZA, Nuclear Decommissioning Authority and Magnesium Elektron to develop ion-exchange materials for heavy metal separation.

(iv) Fire Science and Fire Engineering

Our underlying strategy has been to work directly with research users (industry, government and other agencies). **Income of £1.4M was acquired:**

- [Text removed for publication].
- £351K from European FP7 to develop replacements for brominated flame retardants based on carbon nanotubes (DEROCA); £97K from Saint-Gobain to develop fire-safe insulation products.
- [Text removed for publication].
- [Text removed for publication].
- £67K (of £250K) from the Fire Brigades Union to investigate the exposure of firefighters to carcinogenic and toxic fire effluents and residues.
- £20K (of £160K) from Silentnight Beds/Innovate UK (KTP project) to develop fire-safe beds.

We also benefit from significant in-kind funding (estimated at £320K) from a consortium led by the Fire Protection Association, for large scale testing in their BS8414 facility (see impact case study); each test costs £80K.

(v) Construction Management and Environmental Engineering:

Group's total grant portfolio is over £7M. This includes:

- £14M multi-regional ECO-I NW (2020-2023), UCLan share £665K.

Unit-level environment template (REF5b)

- £13M INTERREG Circle (Concrete solution dRaining for the CLimate and Environment, 2020-2023), UCLan share £660K.
- £2.7M ERDF MaCaW (Making Carbon Work, 2017-2023), UCLan share 100%.
- £2M Eco-innovation Cumbria (2016-2020), UCLan share £233K.
- £1.4M ERASMUS+ “EwasteR” (Electrical Reuse training programme with third sector organizations across Europe) 2014-2016), UCLan share £89K.
- €1.5M H2020 BENEFIT (Business models for enhancing funding and enabling Finance of infrastructure in transport 2014-2016), UCLan share €130K.
- €1M Euro-China ESRC ODESSA (Optimising care delivery models to support ageing-in-place, 2016-2019) UCLan share £217,941.
- €1M ERASMUS+ BRITAE (Building Resilience in Tropical Agro-Ecosystems, 2020-2023) UCLan share €131K.
- €1M ERASMUS+ CABARET (Capacity Building in Asia for Resilience EducaTion, 2017-2020) UCLan share €66K.
- €1M ERASMUS+ ASCENT (Advancing Skill Creation to ENhance Transformation, 2016-2019) UCLan share €83K.
- €1M ERASMUS+ SECRA (Strengthening University-Enterprise Collaboration for Resilient Communities in Asia, 2021-2024) UCLan share €131K.
- €0.5M ERASMUS+ REGARD (Rebuilding AfteR Displacement, 2019-2022) UCLan share €92K.
- £120K two jointly funded studentships with Myerscough College on sustainable food production (2019-2022).
- £100K for a DTA3/COFUND Marie Skłodowska-Curie PhD fellowship on Energy Trading Models (2020-2023).
- Three Innovate UK-KTP awards: £123K Equestrian Surfaces (2014-2016), £135K Frank Whittle Partnership on Building Information Modelling (2015-2018), £213K Recycling Lives (2016-2018), additional £173K Recycling Lives (2020-2023).

With Brexit and removal of EU structural funding, we will seek funding through the proposed UK Shared Prosperity Fund, which will focus on innovation and research, the digital agenda, support for SMEs and low-carbon economy.

3.3 Infrastructure and Facilities

Major developments of infrastructure have supported expansion. Key amongst these is a **£35M investment** in a 7,000 m² **Engineering Innovation Centre** and equipment to support growth in innovative engineering activities. This development is part of **an overall £50M investment in UCLan Engineering since 2015** and was identified as a signature project within the LEP’s economic plans. The EIC was supported through significant co-investment including £5M HEFCE, £5.8M ERDF and £10.5M Local Growth Deal. It opened in November 2019, providing several state-of-the-art laboratories, including equipment for Additive Manufacture (AM), Intelligent Machines and Maintenance (IMM), Fire and combustion, and Aerospace **It aims to promote multidisciplinary activity in research and innovation/enterprise between academics and industry to provide a focus for regional partnerships.**

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(i) Digital Engineering:

Facilities have been continuously extended and updated to support research/industrial activities. Equipped with 3 Fanuc and Kuka robots, a prototyping CNC, RFID and IOT/IIOT systems, ***the ADMT digital manufacturing platform now offers a unique laboratory-based production line with 6 reconfigurable stations for simulation of data-driven automated manufacturing execution.*** It has been recognised as a valuable asset for the region's manufacturing sector and has been extensively used to support over 100 SMEs for technology trial run and take-up. Furthermore, the group now has a state-of-the-art full-matrix-capture phased-array ultrasonic system for industrial non-destructive evaluation, and a unique angle-and-force based acoustic emission system for medical non-invasive diagnosis of joints. The group also have access to multiple camera systems, 3D scanners, high-speed and thermal imaging systems to support research on visual information processing, including biomedical imaging (e.g. neonatal imaging), objects real-time characterisation and manipulation, 3D mapping and navigation.

(ii) General Engineering:

Significant investment has supported developments in aerospace. This includes a Flight Simulation Suite supporting collaborative research to enhance flight safety with AI based technologies, and access to a site to flight test UAV technology. UCLan has invested in facilities to design and manufacture UAVs, with particular focus upon improving the flight safety and utility of drones for civic applications. ***We have received £1.21M from the LEP*** to invest in drone technology to support growth of the UAV sector in Lancashire. ***Over £430K of equipment procurement*** from that grant was placed during this REF period, and full investment will be complete by March 2021. Two wind tunnels have been procured enabling subsonic and supersonic testing.

Research in human factors is a significant part of the Innovation Clinic programme. The EIC has made a £76K investment in data capture technology. Human Centred design and engineering capability has been enhanced through resource efficiency solutions supported by VR and rapid prototyping/manufacturing solutions enhancing KT and research development capability.

JlFT have focused on developing a suite of test equipment for research on condition monitoring and development of tribotronic components/intelligent machines. It is located in a new EIC laboratory and partly funded by income from summer schools. The equipment facilitates investigations on bearings, transmissions, lip seals, piston-ring packs, etc. using novel sensors/actuators allowing development of demonstration systems for future components and machines in collaboration with companies, e.g. James Walker Ltd., Michell Bearings, Micromass plc. and the Royal Mail. There is also an excellent tribology laboratory including: SEM (with EDX), nano-indentation facilities, scratch tester, vacuum/high temperature friction/wear test apparatus, and other tribometers to support essential fundamental measurements in tribology.

JTI simulation studies use UCLan's High Performance Computer and high specification PC systems with packages such as ANSYS and COMSOL. These facilities support multi-disciplinary collaboration with partners such as the NHS in projects on predictive modelling for healthcare (e.g. modelling of haemodynamics / microvascular anastomoses), Sellafield Ltd. and North Composites Engineering (addressing structural integrity of composite materials and components).

(iii) Functional Materials

The impressive ***£12M purpose-built JB Firth Building*** houses research laboratories comprising a wide range of state-of-the-art analytical and research facilities, constantly evolving to ensure alignment with modern industry practice. Facilities are funded by UCLan, Research England QR allocated funds, The Royal Society, nanoScale Biomagnetics, EU Framework VI and Q-bioanalytic GmbH.

Analytical Suite facilities include:

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- spectroscopies (FTIR, NMR with solid state probe, UV, GCMS, LCMS, ICPMS, fluorescence, Raman),
- chromatography (HPLC, GCMS, LCMS, ICP-MS),
- microscopies (optical, fluorescence, infra-red, SEM with EDX),
- XRD.

They are used in characterisations of zeolites, lipid nanostructures, carbon dots and magnetic nanoparticles with impact in additive manufacturing of tablets, water purification and nuclear waste treatment technologies.

State-of-the-art equipment, located within 5 dedicated FMG research laboratories include:

- Autolab potentiostats and quartz crystal microbalance (QCM-D) for electrochemical characterization of carbon nanomaterials, biomimetic materials and for biosensor development with impact in novel disease diagnostics and infection control.
- Anton Parr Microwave for rapid nanoparticle synthesis, DLS for nanoparticle sizing, fluorescence lifetime spectroscopy, thermal analysis (TGA, DSC), BET surface area analyser.
- Micromeritics Autopore IV Mercury porosimeter for nanocomposites analysis.
- DM 100 Magnetic hyperthermia instrument (unique within the UK) for magnetic nanoparticles heating in targeted therapy applications.
- Simulated Moving Bed (SMB) technology uniquely configured at UCLan for separation of inorganic cations (radionuclides).

(iv) Fire Science and Fire Engineering

We are very fortunate to have ***one the best fire research facilities in the world***. The large fire laboratory in the new EIC houses all the standard fire test equipment, and bespoke fire dynamics experimental facilities (trench effect, flashover boxes, model houses and shopping mall for smoke movement etc.). In addition, the existing fire laboratories (purpose-built in 2011) occupy 264m² with 3 specialist facilities:

- ***Pyrolysis laboratory*** (thermal analysis equipment including 2 x TGA FTIR, one also interfaced to GC-MS analysis, 2 x DSC, 2 x TGA, a UPLC-MS, a parallel plate rheometer with environmental chamber up to 550°C, a micro-scale combustion calorimeter, a benchtop mass spectrometer and cryogenic grinder etc.
- ***Fire toxicity laboratory*** for quantifying the yield of toxic products from flaming combustion, equipped with the world's widest range of standard techniques including ISO 19700, ISO 5659, EN 45545-2, ASTM E662, NF X 70-100, with complementary analytical facilities.
- ***Clinical laboratory*** for analysis of human (firefighter) samples including GC-MS, GC-MS-MS, 2 x UHPLC-MS, and automated Soxhlet extractor.

(v) Construction Management and Environmental Engineering

Work with Recycling Lives has enabled UCLan to enter a joint venture leading to the partnership building and owning ***a £740,000 research facility***. This thermal process facility will transform residue into a saleable product and electrical energy; creating a closed-loop recycling solution and reducing waste sent to UK landfill. The plant will be capable of processing 100 kg hr⁻¹ offering significant benefits for the waste management industry and supporting applied research.

4. Collaboration and contribution to the research base, economy and society**4.1 Introduction**

Our vision is to use the EIC to establish UCLan as a leading university for engineering innovation, exploiting its location within one of the most important engineering and manufacturing areas in the UK. Extensive investment has built a sustainable platform for collaboration with partners regionally, nationally and internationally enhancing links to major employers. An EIC Industry Steering Group, includes representatives from global companies such as Rolls Royce, BAE Systems and specialist architecture practice Frank Whittle Partnership alongside the North West Aerospace Alliance and The Manufacturing Institute, representing large numbers of supply chain companies and providing a powerful insight into the research, skills and knowledge required to help them innovate.

4.2 Group collaboration, beneficiaries and audiences

The benefits of collaborations and partnerships in the context of contributions to the research base, economy or society are detailed below.

(i) Digital Engineering:

Collaborative and interdisciplinary research, linked to user needs, is reflected in all projects with examples below.

- **Internationally**, ADSIP collaborated with North China University of Technology on hand vein-based biometric recognition funded by China National Natural Science Foundation, and Ukraine National Aerospace University on multi-channel signal processing funded by British Council, leading to exchange visits, joint publications, and a consumer-level high-security biometric system.
- **In Europe**, CVML collaborated with 9 partners from 6 countries (including Italian National Research Council and Linköping University) on the SEMEOTICONS project and developed a well-being self-assessment device for early detection and monitoring of cardio-vascular conditions. There were also research collaborations with Cergy-Pontoise University on biomedical image analysis and with University of Côte d'Azur on tackling international machine learning challenges, which led to winning Medical Image Computing and Computer Assisted Intervention international challenge on Surgical Workflow Analysis.
- **Nationally**, ADSIP collaborated with universities of Lancaster and Manchester, Imorphics, Mistras and local hospitals on clinical trial of acoustic emission for knee diagnosis and has discovered a significant cartilage thickness biomarker. ADMT collaborated with Warwick Manufacturing Group on reconfigurable manufacturing systems; and with AMEC, BAE Maritime and Bristol University on ultrasonic inspection of welds. The collaboration generated several novel algorithms, such as statistical modelling of material scattering for rapid defect identification, and computational ultrasonic tomography for replacement of hazardous radiographic inspection. CVML is developing machine learning systems for computational automation of early cancer detection in colonoscopy, supported by the DiRAC supercomputer facility.
- **Regionally**, ADSIP collaborated with NWAA, BAE, National Nuclear Laboratory, universities of Lancaster, Liverpool, Manchester, and Salford on innovative civil applications of UAV, which supported 18 SMEs to complete 24 technology projects with ADSIP leading the work on surveillance security and intelligence. CVML collaborates with oncologists at Lancashire Teaching Hospital and radiologists at East Lancashire Hospitals NHS Trust (ELHT) on estimation of CT density heterogeneity to predict response to immunotherapy in renal cancer and works with the UCLAN THRIVE Centre and ELHT on development of novel thermal imaging monitoring system for neonatal care. ADMT collaborated with BAE on digital

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manufacturing capabilities for aerospace platforms. This led to a best paper award for work on genetic optimisation of production schedules for variable renewable energy supply. Furthermore, through the DigitME project, ADMT has assisted 126 manufacturing SMEs, created 16 jobs, safeguarded 41 jobs, helped create 35 improved processes, and 14 new to firm products.

(ii) General Engineering

Collaboration covers a range of geographical scales.

- **Internationally**, collaboration with NASA has produced mission *critical software for solar science sounding rockets and UCLan are developing instrument pointing software for a grazing incidence X-ray spectrometer mission launching 2021*. Collaboration on UAVs with the Cambodian Government's Mine Action Authority has enabled sharing of UCLan's landmine detection sensor technology. Collaboration with almost 30 members from industrial/academic backgrounds across Europe has allowed us to form the European Tribotronics Network, to accelerate development and application of "tribotronics". Research with the European Space Tribology Laboratory (ESTL) has enhanced understanding of lubricant degradation in space mechanisms, resulting in a *system installation on the ESA Bepi-Colombo mission to Mercury*. Ongoing work, supported by the Emirates Nuclear Energy Corporation, seeks to *improve understanding of acceptance criteria for new nuclear builds*.
- **Nationally**, UCLan became a foundation partner of the Manchester Graphene Engineering Innovation Centre following work involving aerospace applications for graphene materials. UCLan successfully lead Preston's bid in NESTA's Flying High Challenge influencing national drone investment policy. SME collaborations include The Great Circle (flight safety systems), and Aspira (spraying UAVs). UCLan also built a wildfire photogrammetry Fire Service research drone and signed an MoU with BAE Systems to support UAV research. Collaborations with James Walker Ltd, to develop intelligent seals, has resulted in a novel design for a seal with controllable contact pressure. Other commercially relevant research has led to **patent applications/awards**:
 - For nanoindentation/indentation testing of viscoelastic materials (application number 1701591.8).
 - To reduce corrosion in large two stroke marine engines (PCT/GB2016/052345).
 - To estimate bladder status (granted WO2017017426A1).

Research in the aerospace, energy and medical sectors is supported by collaboration with organisations such as BAE Systems, ANSYS-UK, Businesswise solutions, Bombardier Inc., North Composites Engineering Ltd, Numeca-UK, Sellafield Ltd, NHS Health Care Trusts, etc. Simulation studies have impacted clinical practice, reducing the likelihood of failure of surgical procedures. Research in nuclear engineering has contributed to the development of novel methods to manage nuclear waste (using ion diffusion and cementitious products).

- **Regionally** the Innovation Clinic project has supported **183 businesses, created 18 jobs and helped to launch 63 "new to the market" products since 2014. 223 businesses have received KT support delivering £1,217,980 Gross Value Added (GVA), lifting the average GVA of beneficiaries by £36,908. 18 research projects have been supported to date**, mainly in association with transdisciplinary projects in the area of health.

(iii) Functional Materials

Academic collaborations include: University of Graz (Austria) for C-dot research; University of Sao Paulo (Brazil) and University of Tokyo for biomimetic materials research; Delhi University; Tata

Unit-level environment template (REF5b)

Institute of Fundamental Research (India); University of Manchester; Ilmenau Technical University (Germany); ECUST and Shihezi University (China) for magnetic nanoparticle research leading to water purification technologies; a UCLan-led consortium, including Reading University, and Kyungpook National University and Chosun University (S Korea) to develop nanostructured hybrid composites for Advanced Radioactive Waste treatment.

Industrial/Academic Partnerships leading to benefit of society and the economy include:

- Feedwater Ltd and Hosokawa Micron Ltd ***in water treatment and materials processing*** respectively,
- Partnering with organisations in China and India and Nanoscale Biomagnetics SL (Spain) leading to a nanoparticles-based technology ***for arsenic clean-up from ground water*** and producing a simple arsenic extraction kit used by local communities in groundwater-polluted states of West Bengal,
- IQ-bioanalytic GmbH, Germany to produce ***a simple one step magnetic nanoparticles-based separation technique to replace the classical and laborious methods of separating biomolecules from cellular systems,***
- University of Manchester to develop radical new reprocessing technology, ***significantly reducing both CAPEX costs with consequential impacts in waste treatment*** and disposal.

Networks include the Society for Functional Nanomaterials offering a forum for academic collaborations with industry and clinicians. UCLan's Research Centre for Smart Materials has attracted support from four Faculties and 50 academics. The Centre enables multidisciplinary teams of research-active academics to collaborate and achieve an effective and sustainable critical mass to address translational academic research.

(iv) Fire Science and Fire Engineering

Before the Grenfell Tower fire in June 2017, the group had a world-leading position in fire toxicity and internationally competitive position in materials' fire behaviour. Since the Grenfell disaster, fire safety and regulatory compliance have moved up the national and international agenda, with our expertise constantly in demand. Prof Hull's work with mainstream media (over 20 national broadcast media appearances, including BBC's Breakfast, Newsnight and Panorama, ITV News, C4 Dispatches, World at One, Sky News etc.) has brought fire science to a much wider audience.

CHFS regularly collaborates outside UCLan. Within the UK, we are working with colleagues at Imperial College and University College London, and Universities of Edinburgh (façade fires in the aftermath of Grenfell), Birmingham (environmental contamination by flame-retardants), and key UK institutions. Internationally, Stec works with Universities of Arizona, Waterloo, Stockholm, and Nordic institutions (firefighter cancers), and Warsaw Medical University (toxic smoke injury). Hull has extensive fire-retardancy networks in China (USTC, BIT, Sichuan, Zhejiang Universities) and Europe with University of Lille-1, Danish Technical University, Abo Akademie etc. Outside academia extensive cooperation with leading government institutes NIST, NRC (Canada), CSIRO (Australia), BRANZ (New Zealand), NILIM, (Japan) RISE (Sweden) BAM and Fraunhofer Institute (Germany).

Impact Case studies describe this work in more detail:

- ***Making Tall Buildings Safe from Fire:*** has led to the combustibles ban and a £3.5bn government budget for remediating flammable cladding.
- ***Regulating Smoke Toxicity:*** has led to the launch of an £605K research project, led by MHCLG, with Hull in Steering Group, to assess the smoke toxicity of building products, and has also led to dramatic action in continental Europe and within the European Commission.
- ***Protecting People from Toxic Fire Residue:*** describes the change in firefighters' daily operations and has driven the environmental remediation around Grenfell Tower.

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(v) Construction Management and Environmental Engineering:

Collaborative and interdisciplinary research is reflected in all projects across different sectors/countries. Some examples are:

Academic: Collaborating with Universities across Europe, e.g. Belgium, Germany, Finland, Greece, Italy, Netherlands, Poland, Portugal, Spain, Serbia, in a Horizon 2020 BENEFIT project (2014-2016) on Public Private Partnerships (PPPs) in Transport led to **working with the UN Economic Commission for Europe (UNECE) in developing policies on 1) PPP Rail Infrastructure, 2) PPP Road Standards**; as a result of recommendations from the 6th session on PPPs held in Geneva (2014).

Industrial and third sector: We collaborated with local governments, industrial organisations, European national training providers including ERIFO Vocational Training (Italy), IIBE Educational Research Institute (Poland), Intercollege, CPC Cyprus Productivity Centre and third sector to build innovative solutions to manage different waste streams, as part of EwasteR project: 2014-2016. This led to the **development of waste training courses and creation of an electrical reuse EU competence license for workers** to demonstrate their transferable skills.

Nationally, we worked with NGOs, Waste and Resource action Programme (WRAP), London Waste and Recycling Board, Merseyside Waste Authority, Preston Council, Lancashire County Council, and Southend Council. This resulted in the **development and delivery of a National Recycling Manager Training Scheme to all authorities in the UK**.

Internationally, we collaborated with EU and Asian universities on five ERASMUS+ projects, leading to many successful outputs, for example, through the ASCENT project (2016-2019), University/Industry partnerships were identified as an essential medium for improving research and innovation in building community resilience which led to:

- **Successful implementation of business incubators (about 10) in Sri Lankan Universities** with the collaboration of the private sector and the Ministry of Social Empowerment and Primary Industries (2019).
- **Organising first University-Industry Engagement in Sri Lanka (October 2019) with an audience of 250 academic staff and researchers** from Sri Lankan Universities, and private and public-sector stakeholders to showcase and brainstorm ideas for collaborations.
- **Conducting a livelihood programme for Displaced communities in landslide areas** in Sri Lanka with University-Industry Collaboration (July 2019).
- **Securing another €1M ERASMUS+ grant (SECRA: 2021-2024)**, which UCLan is co-leading.

4.3 Covid response

UoA12 have supported the response to the pandemic by:

- Collaborating with The Pirbright Institute, developing low-cost antibody-like smart materials, molecularly imprinted polymers (MIPs) with potential **for the rapid detection and potential to capture and neutralise SARS-CoV-2**.
- Design and manufacture of **3D printed connectors to convert Continuous Positive Airway pressure (CPAP) masks to valve-less versions**, allowing easier cleaning and assembly reducing likelihood of infection and accident, for Salford Hospital (~120 manufactured).
- **Developing emergency visors**, initially 3D printed, but then manufactured using water jet technology, ~200 were manufactured for local hospitals, dentists, charities, care homes and UCLan security staff.

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- Supporting development of **commercial bio-degradable PPE face visors**. This involved the Innovation Clinic and other University partners and is now marketed by PPECO. The visors also have a **substantially lower carbon footprint than conventional visors**.

4.4 Public engagement

Public engagement has been supported by a full-time (PhD qualified) Engagement Officer. Activities have been delivered collaboratively with the IET (Faraday Challenge), Royal Institution, Lancashire Science Festival (attracting thousands of school children and members of the public), Big Bang Fair. They also include contributions to “Comic Book Science” (an Impact Case Study for UCLan UoA 10) as well as the National Festival of Making. There have been activities for Primary Schools, Year 12 students, events to encourage girls to science/engineering, *FIRST*[®] LEGO[®] tournaments and involvement with robotics/engineering and “Primary Engineer”. The Engagement Officer has provided informal training and mentoring for academic staff and PGRs involved in outreach. Outreach has been supported by a portfolio of funding for public engagement from a range of sources including the Royal Academy and HEFCE.

4.5 Esteem factors

UoA12 members have global influence and recognition within their profession through **almost 100 professional appointments and awards**. Some examples are:

Government or industrial panels (10 appointments):

- Ansell: Chair Lancashire UAV Regional Steering Group
- Shark: Panel Chair of Advanced Manufacturing & Engineering Programmatic Fund for Singapore, Agency for Science, Technology and Research (A*STAR); USA Department of Defense Congressionally Directed Medical Research Programs: Panel Member
- Stec: GTI, Hackitt Review, SAGE Env Cont, IARC
- Hull: BEIS Furniture flammability; MHCLG Smoke Toxicity

Professional Bodies (Institutional) (10 appointments):

- Hull: RSC expert to BSI Furniture flammability (FW/06) and smoke toxicity (FSH/16) technical committees; UK Principal Expert on Physical Fire Models to ISO TC92 (Fire Safety)
- Stec: UK Principal Expert on Fire Chemistry to ISO TC92 (Fire Safety)
- Shark: Member of IET Vision and Imaging Network Executive Committee, BINDT Aerospace Executive Committee
- Sherrington: Executive Director ITC, Chair elect IMechE Tribology Group
- Williams: Committee member NWCIWM, Scientific and Technical Group CIWM

Major Awards and Leadership (16 awards):

- Feng / Sherrington / Rahnejat: Donald Julius Groen Prize (2015, 2017, 2020)
- Kulkarni; Hind Rattan Award (2014) / Bharat Gaurav Award (2014)
- Sen: Hind Rattan (Jewel of India) Award (2018)
- Simo: IAAM Scientist Award (2019)
- Taylor: Tribology Silver Medal (2020)

Editor in Chief / Associate Editor (7 appointments):

Unit-level environment template (REF5b)

- Liyanage: Journal of Built Environment Project and Asset Management
- Rahnejat: Lubricants, Journal of Multi-body Dynamics
- Shark: IET Image Processing; Journal of Machine Intelligence and Data Science (JMIDS)

Editorial Board (24 appointments):

- Brooks: Intl Journal of Rapid Manufacturing
- Kelarakis: Nanomaterials; Sensors; Journal of Nanomaterials; Frontiers in Nanotechnology
- Kulkarni: Scientific Reports; Journal of Science Research International; Advances in Biomembranes and Lipid Self-Assembly; Advances in Planar Lipid Bilayers and Liposomes.
- Liyanage: International Journal of Disaster Resilience in the Built Environment

Guest editorships for special issues of journals (12 appointments):

- Kelarakis: Carbon-based nanomaterials as novel nanosensors, in: Journal of Nanomaterials.
- Sen: Nanomedicine in: Future Medicine. London; Nano Bio Interface, in: Biomedicine, MDPI, Switzerland; Functional Nanomaterials in Industrial Applications: Academic-Industry Meet (29 – 31st March 2016), in: Materials Today: Proceedings
- Hull: Stec Polymer Degradation and Stability 2015

Leadership (Chair of conference) of International Conferences (14 appointments):

- Liyanage: Chair, 'University Industry Partnerships' Policy Dialogue at the Final ASCENT (Advancing Skills Creation for Enhancing Transformation) Project Festival (Jan 2019)
- Sen: Chair, International conference on "Functional Nanomaterials in Industrial Applications: Academy-Industry meeting", 2016
- Simo: IAAM Co-organiser, 9th ICSFFMT; 26th AAS/AIAA Space flight mechanics (Chair)
- Matuszewski: Co-organiser of the International Workshop on Visual Computing and Machine Learning for Biomedical Applications (ViMabi'2019)