

<b>Institution:</b> University of Greenwich																								
<b>Unit of Assessment:</b> 12 - Engineering																								
<p><b>1. Unit context and structure, research and impact strategy</b></p> <p>The unit contains a multi-disciplinary team of staff covering a range of engineering and applied science disciplines, which transcends the traditional disciplines of mechanical, civil, electrical, and chemical engineering. Together, we address key challenges facing society such as safety and security, sustainable energy, sustainable and resilient infrastructure, materials engineering, and advanced manufacturing. This submission consists of staff drawn from the <b>Centre for Engineering Excellence (CEE)</b>, based in the School of Engineering, Faculty of Engineering and Science at our Medway campus, and the <b>Centre for Numerical Modelling and Process Analysis (CNMPA)</b>, based in the School of Computing and Mathematical Sciences, Faculty of Liberal Arts and Sciences at our Greenwich campus. Our submission involves 57 research staff and 84 PhD students. During the REF period, the unit received income of £11.14M from external sources and produced 684 outputs that were cited 5,521 times (Scopus, 6th Jan 2021). Achievements during the assessment period include:</p> <ul style="list-style-type: none"> <li>• Recruiting 21 research-active staff to support sustainability of our research in strategic target areas of manufacturing, materials, modelling, electronics, and chemical and environmental engineering resulting in a 58% increase in staff submitted to REF compared to 2014.</li> <li>• Growing the volume of our PhD research, evidenced by a 52% increase in completions (50 completions in REF2014) during the REF period.</li> <li>• Investing over £5.4M to support our research staff, their activities, and new infrastructure/facilities.</li> <li>• Growing our research income from external sources by 30% (£8.4M in REF2014)</li> </ul> <p><b>Table 1: Research Outputs by Centre</b></p> <table border="1"> <thead> <tr> <th>Centre</th> <th>Returned Staff</th> <th>PhDs completed</th> <th>Research Income</th> <th>Outputs</th> <th>Impact Case Studies</th> </tr> </thead> <tbody> <tr> <td>Centre for Engineering Excellence</td> <td>28</td> <td>50</td> <td>£3.63M</td> <td>369</td> <td>1,2,3</td> </tr> <tr> <td>Centre for Numerical Modelling and Process Analysis</td> <td>29</td> <td>34</td> <td>£7.51M</td> <td>315</td> <td>4,5</td> </tr> <tr> <td>Totals</td> <td>57</td> <td>84</td> <td>£11.14M</td> <td>684</td> <td></td> </tr> </tbody> </table> <p>Research projects within the unit are organised through seven research groups across the two centres: four research groups situated in CEE and three located in CNMPA, each providing a coherent structure for staff management and financial planning. Each member of staff has a primary research group that they are aligned to, but they may be engaged in others across the two centres.</p> <p><b>i) Centre for Engineering Excellence (CEE)</b></p> <p>This Centre brings together a wide spectrum of research themes including civil and environmental engineering, electrical and electronics, chemical engineering and materials, information and communication technologies, mechanical and manufacturing engineering, sustainability and multi-disciplinary topics. The Centre's location at the Medway Campus facilitates close collaboration with colleagues from our School of Science, the Natural Resource Institute, and the University of Kent and Canterbury Christchurch University, with whom Greenwich shares the campus to provide a world-leading learning and research environment and facilities collectively.</p> <p>Since 2014, the Engineering School has expanded its staff base with significant responsibility for research. This has been mainly through recruitment (16 staff) and has established a new</p>	Centre	Returned Staff	PhDs completed	Research Income	Outputs	Impact Case Studies	Centre for Engineering Excellence	28	50	£3.63M	369	1,2,3	Centre for Numerical Modelling and Process Analysis	29	34	£7.51M	315	4,5	Totals	57	84	£11.14M	684	
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strategic research area: Materials and Chemical Engineering. Research within the Centre is undertaken through the following 4 research groups:

- **Mechanical, Manufacturing and Management Group (MMMG)** covering topics such as digital manufacturing, supply chain management, product lifecycle management, AI, automation, mobile communication, industrial robotics and Internet of Things.
- **The Wolfson Centre for Bulk Solids Handling Technology (Wolfson)** specialising in the physical behaviour of powders, granular and particulate materials in all aspects of handling, processing and use.
- **Civil and Environmental Engineering Group (CEEG)** covering topics such as sustainable development, resilient infrastructure against natural hazards, non-destructive methods and health monitoring of structures, environmental engineering and geotechnical engineering.
- **Materials and Chemical Engineering Group (MCEG)** who undertake research on several length scales, all the way from the nanoscale and the molecular level (carbon nanomaterials including fullerenes, carbon nanotubes, graphene and related structures) to industrial processing, food engineering and manufacturing.

The centre is managed through its co-directors – Bradley, Gao, Hills, Ercolino and Porfyrakis – who also lead the above research groups: Gao (MMMG), Bradley (Wolfson), Hills/Ercolino (CEEG), and Porfyrakis (MCEG).

#### **ii) Centre for Numerical Modelling and Process Analysis (CNMPA)**

Based at our Greenwich Campus, CNMPA contains a multi-disciplinary team of engineers, mathematicians, physicists, computer scientists, and psychologists who collaborate within an environment of shared infrastructure and resources. In this way, tools, techniques, and expertise developed to solve one problem can be adopted to best effect in solving related problems across themes. Research within the Centre is undertaken through the following 3 research groups:

- **Fire Safety Engineering Group (FSEG)** whose research interests are in the development and application of computer models for evacuation, combustion, fire/smoke spread, and fire suppression. It's core activities relate to the development and application of the EXODUS evacuation and SMARTFIRE CFD fire modelling tools.
- **Computational Mechanics and Reliability Group (CMRG)** has research interests in the development of computer models for multi-physics/multi-scale predictions, numerical optimisation, failure analysis, reliability and maintenance of engineering structures. A particular focus of its modelling research is applied to electronics manufacturing and electronic systems.
- **Computational Science and Engineering Group (CSEG)** whose research covers multi-physics models for metals/minerals processing (smelting, casting, welding, solidification microstructure, particulate handling) expressed in unique algorithms and software, including the multi-physics code PHYSICA and the spectral MHD code SPHINX (induction melting, levitation).

The centre is managed through its co-directors – Galea, Pericleous, and Bailey – who also lead the above research groups: Galea (FSEG), Pericleous (CSEG), and Bailey (CMRG).

#### **iii) Support Structures**

In addition to central university support from Greenwich Research and Enterprise (GRE) and the Research and Enterprise Training Institute (RETI), each faculty/school has R&E support teams, including a Research Development Officer (RDO) and Enterprise Development Manager (EDM). Each faculty has a Director for Research & Enterprise (Prof Westby, Faculty of Engineering & Science; and Prof Bailey, Faculty of Liberal Arts and Science), who chair the Faculty Research and Enterprise Committee (FREC). Each research group is represented on FREC through their school research leads. FREC also has representation from each faculties Research Degrees Committee, Research Ethics Committee, Early Career Researchers (ECR), and Post Graduate Researchers (PGR) communities. FREC is responsible for implementing the university's R&E

strategic plan and allocating internal funding to support research groups and the ECR and PGR networks within each faculty.

### **B) Research & impact strategy: progress since 2014 & plans for next five years**

Each of the unit's research groups have been supported to deliver their own research and impact plans and objectives (as detailed in REF2014), which align with the evolving university strategy for R&E from 2012-16, and 2017-21. Therefore, whilst each individual research group has its own strategic plans and objectives, each is consistent with the overall values and strategy of the university. A summary of the achievements for each centre during the assessment period are listed below, as are each group's future research plans for the next five years.

#### ***i) Centre for Engineering Excellence (CEE)***

In 2018, the centre underwent a strategic review with an emphasis for growth in strategic areas. This resulted in the recruitment of 16 staff over the following three years and establishing MCEG in 2019. In REF2014, the centre submitted staff to UoA12 (Wolfson), UoA13 (MMMG), and UoA15 (CEEG & MMMG), and UoA8 (CEEG).

***Mechanical, Manufacturing and Management Group:*** MMMG research objectives were to further develop its digital/mobile technologies and knowledge management tools for product lifecycle applications. This has been achieved through university investment and external grants from EPSRC, the EU, and Industry. During the REF period, a new paradigm for virtual knowledge sharing in product development based on emergent social software platforms was further developed and validated with BAE Systems in the EU Interreg project BENEFITS (ID: 4177, €2,400,000), in which employees can share and interact with knowledge more effectively and easily in the global supply chain across geographical and functional boundaries. A knowledge capturing and sharing framework for improving the testing processes in global product development was developed in a project with industrial partner Cummins. MMMG also further investigated manufacturing capability of high value safety critical aerospace products across global supply chain, and developed a manufacturing defect driven knowledge framework as a design support tool in a project funded by EPSRC and BAE Systems (EP/L505444/1). MMMG has also been developing autonomous robot management systems in real-time dynamic manufacturing systems in an EU Interreg project CoRoT (Id: 99, €3,902,330). Collaborating with industry partner Edwards, MMMG has been continuously developing integrated ICT systems to support designers to select optimised tolerances using real manufacturing capability (inspection data). New innovative solutions for digital-twin models and collaborative robots, as well as biomodels, personalised implants, and surgical guides for bone reconstruction were developed in projects funded by Newton Fund (Ref. 528085858), Vingroup Foundation Innovation (VINIF) and the British Council. Significant results have also been achieved in the following emerging areas: living green walls (acoustic absorption, measurement and environment impact), cyber security in Internet of Medical Things, mobile networks and devices. **Research plans for the next five years:** MMMG will focus on AI, automation and data-driven technologies in manufacturing related applications. In particular, it will further develop (i) its dynamic data and knowledge management framework for product lifecycle activities; (ii) industry 4.0 technologies including simulation, digital twins and autonomous industrial robots, Internet of Things and cyber security technologies in mobile networks and devices, (iii) smart, sustainable and resilient technologies including eco-design, design for automation and Living Green Walls by strengthening collaboration with industry and governing bodies.

***The Wolfson Centre for Bulk Solids Handling Technology (Wolfson):*** Research objectives have focused on the enhancement of science and practice in measurement and control of powder processing technologies. This includes power properties and modelling/design techniques to improve process efficiency and quality. This includes the EPSRC project "Virtual Formulation Laboratory" (EP/N025261/1, £1,742,000), which is delivering insights into powder behaviour (the relationship between particle size, surface energy and flow), new characterisation techniques (e.g. drop test to determine the adhesion forces across a population of particles) and new models to trap and eliminate potential manufacturing problems early in formulation.

Additive Manufacturing research includes developing novel means to measure spreadability of powders for fusing or sintering, to produce a new characterisation instrument to enhance AM parts quality. Biomass research has yielded a novel, validated, low-computational-expense numerical model to help predict and reduce particle size de-mixing, now used also in pharmaceuticals. A new area of research is in particle transport and modelling mitigations to transmission of viral infection (with Cambridge University). Outputs were reported in newspapers globally, read by 1.4 billion people. discussed in parliament, and swayed the government from “against” to “for” use of face masks in the general population. **Research plans for the next five years:** Wolfson will build on its extensive networks with leading academics and industry nationally and internationally; to continue delivering major improvements in products, knowledge and methods that will be key to overcoming existing and future problems in powders and bulk solids. Its strong relationship with industry (income £600k+pa) will continue to identify technology opportunities to stimulate medium to long term research leading to mutually exploitable IP in products and services. Incorporation of research outputs in advanced professional practice and open courses are at the heart of sustaining the group’s world leading position in achieving impact of our research in industry and developing the future generation of leading researchers.

**Civil and Environmental Engineering Group (CEEG):** CEEG’s objectives concern the expansion of CCUS technologies involving solid and gaseous waste, numerical modelling and non-destructive testing methods in civil engineering. The group met its key deliverables incl., new research grants and international collaborations. The University’s spin-out company **Carbon8 Systems won the 2017 Queens Award for Enterprise:** Innovation for commercialising innovative technology developed by CEEG. Further, the most recent innovation is the world’s first mobile carbonation plant that directly extracts CO<sub>2</sub> from flue gas (recently achieved commercial deployment at Vicat in Sept. 2020). In 2016, the Indo:UK Centre for Environment Research and Innovation (IU:CERI) was launched in partnership with the Indian gov. Council for Scientific and Industrial Research, resulting in new government, industry and academic institution partnerships. Further, innovative research on the mineralisation of CO<sub>2</sub> gas in biomass residues is part of the GCRF-related research interests in developing countries (e.g., GCRF-FoD2021\4\12; Newton Institutional Links Grant - 172596355). Innovation in Structural Engineering, re: resilient infrastructure systems (EP/P028233/1, £1,381,845), and extra-terrestrial structures (EP/S036393/1, £170,439), have resulted in new international collaborations (e.g., Cassino, Italy). Other international collaborations include Dalhousie, Canada and LPU, IITK, BHU and NITIE in India. Two Group members (Hills and Tripathi) were invited by the UNEP to contribute to the GEO6 in 2016, and in reviewing the UNEPs forthcoming report on Sustainable Cities report (Hills). The involvement of the Group within the Chartered Institute of Highway and Transportation (CIHT) extends to current vice-presidential level. **Research plans for the next five years** extends research on biomass residue valorisation and engineering in extra-terrestrial environments. Further, CEERG will enhance its science and engineering support of Carbon8 on new ‘low carbon’ construction products from point-source of CO<sub>2</sub>. CEEG will further enhance its academic collaborations via new consortia-led grant applications to funding bodies such as UKRI, GCRF, the Royal Society and DFID/UNDP programs.

**Materials and Chemical Engineering Group (MCEG):** MCEG is a new group established in 2019, consisting of researchers in the new chemical engineering discipline that is strategically important to the School of Engineering. Led by Prof. Porfyraakis, he held an EPSRC Fellowship with a budget of £1.5M under the theme “Manufacturing the future” in the development of materials for use in the electronics industry, the energy harvesting sector (photovoltaics) and medicine (free radical probes). MCEG is in a unique position in the U.K. and one of only a handful of research centres in Europe that is capable of controlling the synthesis, purification, characterisation and functionalization of endohedral fullerenes that contain both metallic (metallofullerenes) and non-metallic N@C<sub>60</sub> and N@C<sub>70</sub> elements. At Oxford his research group was part of a major European Collaborative Research Programme called Smartonics (www.smartonics.eu) on the development of flexible organic solar cell devices for the automotive industry. It was a consortium of 18 Institutions across Europe with a budget of over £7,000,000 as part of the EU Horizon 2020 programme. The group has significant expertise in formulation

science and food technology. Prof. Phil Cox (also the Head of School of Engineering) has developed a variety of new analytical and processing tools in food processing and food microstructure research. He has led research council funded projects in the areas of whipping of dairy cream alternatives, hydrophobins for stabilisation of air-filled emulsions and self-structuring in the Human GI tract to combat obesity. Cox has also led industrially sponsored projects including: gelation structuring in food, hydrophobins for technological applications, and searching for novel food appropriate proteins and the production of healthy and indulgent high fat foods.

**Research plan for the next five years:** MCEG will continue to focus on performing world-leading research in nanomaterials, powder agglomeration, formulation and food technologies underpinned by multi-scale modelling. We are part of a consortium developing sustainable and industrially scalable technologies for manufacturing 2D functional materials (EPSRC funded project EcoUltra2D, EP/R031975/1, £600,000). We will continue to build interdepartmental collaborations with colleagues in the Natural Resource Institute and School of Science in food engineering under the Partnership for a Sustainable Food Future – Centre for Doctoral Training (PSFF-CDT), led by the University of Greenwich.

**ii) Centre for Numerical Modelling and Process Analysis (CNMPA)**

In REF2014, the centre submitted staff to UoA12 (FSEG, CSEG, CMRG), UoA13 (CSEG, CMRG), UoA15 (FSEG), and UoA11 (FSEG, CMRG). This demonstrates the interdisciplinary nature of the research underway in the centre. During the REF period, 5 new staff were employed.

**Fire Safety Engineering (FSEG):** FSEG's research objectives were to further development is modelling expertise in human evacuation and its CFD fire modelling capabilities and to imbed these into its software tools, as well as extend its capabilities from safety into security. An enhanced understanding of human behaviour and evacuation modelling for urban scale disaster situations has been developed through EU funded projects such as IN-PREP (EU-H2020, €9,5583,827, ID: 740627), and GEO-SAFE (EU-H2020, €1.386,000, ID: 691161). These led to the development of a new version of the EXODUS software called urbanEXODUS. Enhanced lift models and wayfinding models were introduced into buildingEXODUS software through new commercial releases (V6.1, 09/14; V6.2, 12/15) and a lift model was introduced into the maritimeEXODUS software for passenger ship applications (V6.0 12/20). Another objective was the development of a unique modelling capability to simulate movement assist devices for the mobility impaired and so better represent mobility impaired in evacuation scenarios. This was achieved through a doctoral research project (Michael Joyce) and the development of the HEPTAD software. The continued development of the CFD fire modelling capabilities have continued through projects such as the EU project AIRCRAFT FIRE (EU-FP7, €4,200,000, ID: 265612) and AUGGMED (EU-H2020, €5,535,637, ID: 653590) and the project funded by the Australian Government DSTO (201418). These projects developed various toxicity and smoke modelling capabilities within SMARTFIRE and explored faster simulation through the use of GPUs and hybrid modelling capabilities. Further CFD fire modelling capabilities were developed to address the requirements of the Grenfell Public Inquiry (2017-20). Through the REF period, FSEG have collaborated with UK the government departments such as the DSTL (security related projects), Innovate UK (GATEway project), Home Office (Grenfell Public Inquiry and CPNI bollards project), and foreign government departments such as the Australian DSTO (Royal Australian Navy project) and the USA government through the DoT (railEXODUS developments), Italian government through the Italian Fire service (CNVVF, through the EU In-Prep and GEO-SAFE projects). **Research plans for the next five years:** FSEG will further develop its Exodus software through new developments in evacuation modelling for mobility impaired individuals, as well as enhance the modelling of urban-scale evacuation associated with natural disasters such as wildfires, and to enhance its agent-based modelling to include the impact of marauding armed terrorists. It will also further develop its CFD fire modelling capability (Smartfire) to better represent the dispersion of respiratory aerosols within enclosures taking into account wake effects produced by moving people. Research will also explore the incorporation of high fidelity fire (SMARTFIRE) and evacuation (EXODUS) simulation tools within immersive virtual and augmented training environments.

**Computational Mechanics and Reliability (CMRG):** CMRG's objectives were to further development its modelling capabilities for predicting the behaviour of materials in the packaging and subsequent reliability of electronic components and systems. Its objectives have been achieved through numerous UK, EU, DoD (USA), and industry funded projects throughout the REF period. As a partner in the EPSRC Centre for Innovative Electronics Manufacturing (EP/H03014X/1, £9,088,809), CMRG developed multi-physics modelling for advanced electronic packaging assembly processes that exploit microwave curing technology, as well as extended its multi-physics physics-of-failure reliability prediction capability on projects related to advanced electronics packaging. The US Government/General Dynamics projects (HQ727-16-D-0003, £594,573 to CMRG) extended the groups modelling capabilities to electronic components for use in harsh aerospace environments (such as the radar systems developed by project partner Leonardo). Being a partner in the EPSRC Centre for Power Electronics (EP/K034804/1 & EP/K035304/1, £6,805,158), in collaboration with the Universities of Nottingham, Cambridge, Bristol, Newcastle, and Imperial College, extended the modelling capabilities to power electronics components, packages, and systems a key technology for electrification of transport and renewable energy. The EU project NextFactory (EU-FP7, ID: 608985, €4,788,207), investigated the feasibility of using 3D printing technologies for the fabrication of novel 3D designs for electronic systems. CMRG led on the modelling and simulation activities in this project extending its modelling capabilities to a number of 3D printing processes including ink-jet. Our research into the modelling of packaged wide-band gap semiconductors and systems is being supported through the an EPSRC project in collaboration with Nottingham and Bristol (EP/R004390/1, £1,079,258) where our modelling techniques have been extended to address thermal management and reliability issues materials such as Silicon Carbide. **Research plans for the next five years:** CMRG will continue to enhance its modelling capabilities to address complex challenges in the electronics industry as 56-years of Moore's Law semiconductor scaling comes to an end. For interconnects, we will be build on our current EPSRC project with Imperial College (EP/R019207/1, EP/R018863/1, £1,405,624). This will include new developments in multi-physics/scale modelling techniques to address key reliability challenges for advanced manufacture and packaging of compound semiconductor components. Coupling data science methods to physics-based modelling techniques will be a strong focus of future work. We will also continue to lead and contribute to the IEEE Heterogeneous Integration Roadmap (HIR) for the chapter on modelling and simulation.

**Computational Science and Engineering (CSEG):** CSEG's research objectives were to develop further its multi-physics modelling capability for advanced materials processes and manufacturing systems. Since 2014, CSEG involvement in a number of high-profile collaborative EU funded projects including EXOMET (EU-FP7, ID: 280421, €17,660,881) and SIKELOR (EU-FP7, ID: 603718, €1,954,286) and as consortium leaders in EPSRC funded projects such as Ultramelt#2 (EP/R011001/1, EP/R011044/1, EP/R011095/1, £988,664), Top-Coil (EP/P034411/1, EP/R000239/1, EP/R002037/1, £1,098,439), Ultramelt (EP/K00588X/1, EP/K005804/1, £603,705) and TECalloy (EP/K011413/1, EP/K006649/1, EP/K007734/1, £563,332). These activities led to the development of new modelling capabilities and software geared towards the advancement of lighter, stronger materials and environment-conscious process methods in their manufacture. Continuing the development of multi-physics software such as PHYSICA, TESA and SPHINX, CSEG explored the effects of power ultrasound (acoustics plus cavitation) and external magnetic fields on alloy microstructure (EM stirring, induction melting, impurities expulsion, thermoelectric effects), while the group's aluminium smelter code MHD-Valdis maintains its leading position worldwide as the de-facto MHD solver in the primary aluminium industry. To meet the groups increasing computational needs, it assembled with help from RCIF funds its own HPC platform (168 cores), which allowed the team to perform calculations reaching a record-breaking 32 billion cells in crystalline microstructure calculations. As modellers, CSEG teamed with experimental academic partners to carry out our research (e.g. with Birmingham, Brunel, Imperial, Manchester, Oxford, UCL in the UK, the Helmholtz centres in Dresden and Geesthacht in Germany, Padua and Torino in Italy, Nancy France, NTU Norway, NW University China, Ural University Russia, etc.). On the industrial side, the group has collaborated with organisations like Rolls-Royce, the European Space Agency (ESA), Arcelor Mittal (F) and established new partnerships with Airbus, Constellium (F), Hydro

(D), KBM (NL), Kobe (J), Volvo (S). **Research plans for the next five years:** CSEG will further develop its modelling capability for multi-physics analysis to improve material properties of solidifying alloys. Particularly to remove component defects in the rapidly expanding additive manufacturing sector, and to investigate new technologies such as that of giant liquid metal batteries for renewable energy storage. CSEG's plans for impact include further exploitation of its patented contactless electromagnetic sonotrode for the treatment of high temperature/reactive alloys and metal/metal emulsions for the aerospace, transport, and nuclear industries.

### iii) Support for open access, research integrity, and interdisciplinary research

All research outputs throughout the assessment period were made available on the University depository (GALA) to and for UKRI funded project funds are available from GRE to **support open access**. During the REF period, a total of 684 publications have been deposited by the unit and 59.7% of these were open access. This compares to 480 publications during the previous REF period, for which 15% outputs were open access. The university is also compliant with the **Concordat on Open Research Data** and this has been implemented across the unit. Many of our outputs are published by IEEE. Staff are also encouraged to publish their research data sets on the IEEE Dataport, as well as other similar depositories to support reproducibility of research findings. The primary responsibility for **research integrity** is devolved to the research groups and is managed through the oversight of each faculty's research ethics committee, which reports to the university research ethics committee. The UoA is committed to implement the principles of the **UUK Concordat to support research integrity**. Over the assessment period several staff members submitted to this UoA have attended a new **RETI** training offering related to research integrity (and good practise).

The unit supports **interdisciplinary research** within each centre, across the university, and externally. For example, the work in Wolfson has been supported by the Computational Fluid Dynamics work undertaken by CSEG to design and optimise the performance of particulate flow systems. Similarly, FSEG research into human behaviour during emergencies, agent-based modelling and fire modelling, are inherently **multidisciplinary** and so the research team consists of staff from a range of disciplines including behavioural psychology, engineering, mathematics and computer science.

### C) Achieving Impact

As can be seen above, our research is applied in a wide variety of sectors such as Safety & Security, Electronics, Energy, Materials Handling, Materials, Aerospace, Chemical and Manufacturing, and Infrastructure. The five impact case studies submitted demonstrate our impacts in a number of areas and industry sectors:

- ICS 1: **Carbon 8**, Hills and CEEG, details the impacts achieved from underpinning research related to solid waste from landfills into light-weight carbonated construction materials using mineralised CO<sub>2</sub>
- ICS 2: **FSEG evacuation research**, Galea and FSEG, details the impacts achieved from underpinning research related to evacuation modelling
- ICS 3: **Product Lifecycle Knowledge Management for Digital Manufacturing**, Gao and MMMG, details the impacts achieved from underpinning research related to product lifecycle information, knowledge and communication management for digital manufacturing
- ICS 4: **Quality and Efficiency in Handling of Particulate Materials in Industry: 'QPM' and related projects including 'Powder Flowability Tester'**, Bradley and Wolfson, details the impacts achieved related to underpinning research in bulk solids handling.
- ICS 5: **Design-for-reliability for High-Value / High-Reliability Electronics Systems**, Bailey and CMRG, details the impacts related to the underpinning research on modelling and reliability of electronic systems.

Over the assessment period, the unit has worked with more than 200 companies in over 30 countries delivering knowledge transfer and impact to industry. Our approach to facilitating the achievement of impact as well as its relationship to the five impact case studies submitted is described below:

- **Collaborative Research, Consultancy, and Services:** Through Government & Industry funding, these projects provide a direct route to knowledge transfer. The university has a standard collaboration and consultancy agreement that details the terms and conditions for any research and enterprise work to be undertaken and the protection of foreground and background IP. **ICS 2:** demonstrates how FSEG and its beneficiaries have used the EXODUS software to deliver economic impact across a range of sectors from the design of the Airbus A380 to the development of a new dynamic emergency signage concept. **ICS 5** demonstrates how knowledge from the results of CMRG's modelling work has informed the reliability of next generation radar systems and other electronic systems generating both economic and environmental impact. **ICS 3:** details the economic impact from the knowledge management work undertaken by MMMG for its beneficiaries in terms of productivity, efficiency, global competitiveness, employment and employee satisfaction. **ICS 4** details the economic impact from the use of its infrastructure used as a service to industry.
- **Spin out companies and licensing/sales of IP:** Commercialisation of IP is encouraged by the university. For example, **ICS 2** details the economic impact resulting from licensing of the unit's software: EXODUS. **ICS 1** details the economic and environmental impacts results from licencing agreements for the units IP related to Accelerated Carbonation Technology, through the university's spin-out company Carbon 8. **ICS 4** details the economic benefits from sales of the unit's novel shear-tester.
- **Knowledge Transfer partnerships:** GRE has a dedicated KTP Manager who promotes our expertise to industry through the university KTP webpage. Relevant industry enquiries are passed to us by the KTP manager who, together with our EDM, helps staff and the company complete the application process. If the KTP application is successful, the KTP manager supports the project throughout its duration, facilitating good communications between the research groups and the company. Example KTP projects through the REF period include the FSEG partnership with the Kent Fire and Rescue Service (KFRS). This led to major reforms in the way KFRS deals with dwelling fires. The CSEG partnership with FloPlast used its CFD expertise to optimise designs of piping systems, and the MMMG partnership with NIC Instruments Ltd led to a smart control for lightweight robotic explosive ordnance disposal vehicles which can compete in a new segment of the global marketplace.
- **Education programmes for beneficiaries:** Outreach of our research expertise is also facilitated through short courses and CPD, which are supported at the faculty level through our research and enterprise support teams in collaboration with GRE and through dedicated facilities to run short courses. Both **ICS 2** and **ICS 4** provide details on training programs that have been used as a route to deliver impact. For example, FSEG delivers two five-day short courses concerning human behaviour and evacuation modelling and fire dynamics and fire modelling, accredited by the IFE. Since 1997 these courses have attracted over 650 engineers, scientists and regulators from 44 countries and since 2014 some 130 have attended the courses generating £134,000. Research outputs described in **ICS 3** include outputs and impacts of two EU Interreg projects (BENEFITS & CoRoT) both having tasks of training over 200 employees of as part of the project deliverables.
- **Influencing policy and standards:** Staff are encouraged to be members of standards/policy bodies to provide the opportunity for our research outputs to impact policy and industry standards. For example, staff are members of government committees, international regulatory organisations such as IMO, and international professional bodies such as the IEEE, SFPE (Society of Fire Protection Engineers), and IAFSS (International Association of Fire Safety Science) where they participate in shaping professional guidelines. **ICS 2** details the work undertaken by FSEG that has contributed to regulatory authorities in Australia and UK as well an IMO standard for ship evacuation. The work in **ICS 5** details CMRG's contributions to both an IEEE Standard and an IEEE industrial roadmap.

#### D) Unit Investment plans and support for the next 5 years

In addition to the future five-year research and impact plans detailed above, the unit will support the objectives detailed by each research centre and its groups through activities related to the following:



## Unit-level environment template (REF5b)

- **Organisation:** Multidisciplinarity will be strengthened through coalescence of the current Centres/Research Groups within an overarching research Institute to bring focus to challenge-led programmes and facilitate internal investment.
- **People:** strategic recruitment of staff will be undertaken to ensure leadership succession as well as strengthen our broad range of expertise across the unit. We will use our international networks to grow our portfolio of PhD students through joint doctoral programmes and transnational education (TNE) research initiatives.
- **Partnerships:** The unit will strengthen its engagement with research-intensive universities, organisations such as the Catapults, and industry. We will also grow its KTP portfolio and investigate and grow its number industrial/professional doctorates to support knowledge transfer and impact.
- **Income** – the unit’s research offers the opportunity to continue to address priorities in the UK Industrial Strategy (2018) and in the UK Research & Development Roadmap (2020). For example, the creation of an ARPA-style body and funding to support defence and security related research provides significant opportunities for our unit. We will prioritise our RDO and BDM support for such opportunities both nationally and internationally.
- **Investments:** The unit will continue to invest REF, HEIF and RCIF funds to support its research excellence, impact activities and outreach. The unit will also establish an Institute for Engineering Excellence (in-line with the university structure for institutes, centres, groups, etc). As the unit grows we will invest in new labs and infrastructure. For example, subject to approval, we plan to refurbish 3-floors of the Hawke building at Medway to support our planned **institute for engineering excellence** with state-of-the-art facilities.
- **Performance:** The unit will monitor the excellence of its research through tools such as SciVal, Clarivate, etc, as well as implement the university’s new proposal management system RADAR, the online PhD support system SkillsForge, and Impact Tracker.
- **Visibility:** The unit will continue to provide routes to support open science/scholarship, including open access to generated research data through depositories such as IEEE Dataport and others. The unit will continue to provide support for staff to engage with public engagement initiatives such as Pint-of-Science and the TED-like talks.

## 2. People

### A) Staff Profile

The university recognises the roles that academic staff make to the university’s endeavours through three career pathways: teaching and scholarship, research, and enterprise. Research active staff are assigned to a research group and are line managed by their research group lead and head of school and senior staff are managed by the PVC for each faculty. The vitality of the unit is demonstrated by its ability to maintain a strong, rich, diverse, and multidisciplinary research team and environment, including a network of links with laboratories, companies, and research organisations worldwide. The unit has submitted 56.3 FTE that have significant responsibility for research (based on the university code of practice). The staff profile for the unit is given below:

**Table 3:** staff profile by grade

	FTE (AC2/Fellow)	FTE (AC3/Snr Fellow)	FTE AC4 (Associate Professor)	FTE AC5 (Professor)	Total FTE
2021	12.5%	47.5%	15.8%	19.2%	56.3

Our investment in people and staff requirement has resulted in a significant increase in early career and mid-career staff (60%) with SRR.

### B) Staffing strategy & staff development

Recruitment is guided by the university recruitment policy. At the unit level our policy is to employ staff on the research or enterprise career pathways that can contribute to the aims of our R&E strategy and its goals. This includes ECRs and mid-career to late-career researchers when

these positions become open. In this UoA submission, 54% are new staff with significant responsibility for research. 33% of staff were recruited (16 staff in CEE and 5 in CNMPA) and 21% of staff (6 in CEE and 4 in CNMPA) gained significant research responsibility during the assessment period. New staff recruited includes 4 Professors/Associate Professors and 15 Senior Lecturers/Lecturers/Research Fellows.

The 54% increase in staff with significant research responsibility has been driven by our **recruitment strategy**, which has been to strengthen and broaden our research portfolio and to secure the vitality and sustainability of our research groups through the appointment of recognised research leaders and high-calibre new academics who have the vision and enthusiasm to shape national and international research agendas. Staff recruited at professor grade include Bonet (Swansea, 2015) – strengthening our computational mechanics research, Porfyraakis (Oxford, 2019) and Cox (Wolverhampton, 2020) – who are leading researchers in our new areas of chemical engineering and nanomaterials detailed in the MCEG described above. Prof. Bonet is also Deputy Vice-Chancellor for Research and Enterprise and Prof Cox is Head of the School of Engineering. In summary, sixteen new academic staff were appointed in **CEE**: Cox (2020), Porfyraakis (2019), Elamin (2019), Ercolino (2016), Garcia-Trinanes (2016), Kampas (2017), Kaur (2017), Kloukinas (2018), Kordolemis (2020), Mantas (2018), Pedram (2019), Salehi-Kahrizsangi (2018), Taheri-Najafabadi (2019), Tipathi (2014), Walsh (2018) and Akpoyomare (2018). Six staff recruited in CEE before the assessment period changed career pathway or became independent researchers: Adekunle, Gorman, Romanova, Farnish, Le, and Okereke. Five new academic staff were appointed in **CNMPA**: Bonet (2015), Palacios (2016), Reis (2016), Gao (2019) and Tonry (2016). Four staff recruited in CNMPA before the assessment period changed career pathway or became independent researchers: Blackshields, Grandison, Hulse, and Veeraswamy.

The unit's **strategy for staff development** fully aligns with the **Concordat to Support Career Development of Researchers**. Staff within each research group are collectively managed by the research group lead and the relevant line manager in each school (who may also be the research group lead). All staff have the opportunity at the annual appraisal and throughout the year to raise development issues with line managers and identify research objectives aligned with the strategy of their research group, school and university. Staff on the research career pathway share the teaching and supervision load and contribute to under/post-graduate teaching, supervision of PhD students. Staff also have a specific workload allowance (of at least 20%) to undertake their research. For example, during the 2019/20 academic session, an average of **63%** of academic time was devoted to research across staff submitted.

Continuous professional development is provided both centrally (through RETI) and within each faculty through variety of internal courses, including induction, workshops in managing research supervision, and through funded attendance on external courses. RETI/GRE provides regular training and support sessions for staff planning external research bids. The faculty RDO, EDM and research group leaders also provide monthly updates on any funding opportunities and particular planned actions/events to research staff.

We reward excellence by nominating staff for discretionary rewards and through **promotion** (CEE: 5 promotions to Associate Professor/Reader [Garcia-Trinanes, Romanova, Melis, Okereke and Tee]; CNMPA: 1 promotion to Professor [Bojarevics] and 2 to Associate Professor [Kao and Ramesh]). Each year, the University allocates a proportion of REF & HEIF income to Faculties to distribute to research groups to support their research and impact plans as well as other research activities within each centre, such as conference travel and support for ECR's. These funds are allocated through the faculty research and enterprise committees. Since 2014, the unit has received investments of £3,729,043 from REF, £685,170 from HEIF, and £66,844 from Proof-of-Concept (POC) funds to support its activities. In addition to this, the unit was awarded with 48 university Vice-Chancellor PhD scholarships, worth £2,880,000.

**Early Career Researchers** and new academics are allocated substantially lighter teaching loads and minor administrative posts for the first 6 months of their appointment to establish

themselves as independent researchers. New academics and ECRs are provided mentorship to develop contacts with potential beneficiaries, and build experience in collaborations, drawing upon support from the EDM. All new lecturing staff complete the GOLD certificate in teaching and learning for fellowship of the Higher Education Academy. ECRs are provided opportunities to develop small-scale exploratory projects, internally funded by faculty research development grants of up to £5,000 annually. This is organised through the ECR network, which reports to the Faculty Research and Enterprise Committee. Post-Doctoral Researchers have the opportunity to gain teaching experience through supporting undergraduate and post-graduate lectures where this is feasible.

Senior staff routinely publish with ECRs and provide guidance on career plans, knowledge transfer, and pathways to impact. The Engineering Research Staff Forum (ERSF) was established in 2019 and is co-ordinated by an ECR. The aim of ERSF is to enhance the research environment by providing a nurturing research culture that supports ECRs and gives opportunities for more experienced researchers to embrace new and multidisciplinary ideas (particularly initiated by ERCs). ERSF workshops are held 4/5 times a year for communications and discussions about any research-related queries or issues, with a focus on PhD student supervision (including dealing with difficult management and personal matters). Bridging funds (REF supported) are provided to ensure a smooth transition between research projects for our research fellows/post-doctoral research assistants. It should be noted that of the staff submitted, three Professors/Associate Professors and twelve academic staff started their careers as PDRA's at the university.

Staff are encouraged to take **sabbatical leave** to strengthen their research profile and outputs. The length of a staff sabbatical is 12 weeks. Staff **secondments** are also encouraged to develop closer engagement with our research users. Examples of recent projects that support staff secondments include the Horizon2020 Marie Curie project GEO-SAFE, which supported staff secondments of 1-3 months between project partners in the UK, Italy and Australia through the period 2017-2020: Hulse (1 month to the Service Departmental d'Incendie et de Secours de la Haute-Corse [Corsica] and 1 month to CNVVF [Italy]), Galea and Veeraswamy (3 and 2 months at RMIT [Australia]). In addition 7 staff from Italy and Australia were seconded to FSEG.

Staff are supported to undertake **knowledge exchange to achieve impact**. Dedicated funding from sources such as HEIF (including seedling fund, proof-of-concept funding, and impact development funds) are provided to drive engagement with research-users. HEIF funding can be used flexibly and locally to create and respond to opportunities for knowledge exchange. Staff are **rewarded** for successful commercialisation of intellectual property, where staff receive a share of income. Staff are also rewarded through the university awards programme for their contributions to research excellence and significant impact. For example, in 2018, Prof Galea received the university Career Research Excellence Award. Georgios Kampas is now leading the Engineering Research Staff Forum after being awarded the university Early Career Researcher (ECR) award in 2019.

### **C) Research Students**

**Recruitment** of excellent post-graduate students, and their training to a high-quality standard, is a core function for the unit. The number of PhD's awarded during the assessment period was 84 (52% increase from 2014). Students are recruited from across the engineering community and financially supported through several routes, including the university vice-chancellor scholarship scheme, from which, since 2014, our research groups have been awarded 48 VC scholarships (worth £2,880,000). Examples of other funded PhD studentships include 2 Alliance DTA studentships related to research in energy supported by the Alliance DTA fund, one securing additional funding from industry (Mentor Graphics). Examples of externally funded PhD's include industry support from Cummins, BAE Systems, Ford and Edwards who have sponsored 4 full-time PhD students and 4 part-time research students during the assessment period working on research and innovation projects directly beneficial to their business.

## Unit-level environment template (REF5b)

All PhD students must complete a period of induction at the start of their studies, and a research skills programme/portfolio prior to completion. Each student is assigned two or three supervisors. The University has a well-developed procedure for **monitoring** PhD research programmes, administered by each Faculty Research Degrees Committees (FRDC) and RETI, and supported within each faculty by their research and enterprise support teams. There is also a program of training provided by RETI with the task of integrating a PGR culture across the university and to provide a university-wide programme in research methods, research skills training, and guidance for supervisors in research training. Local bespoke training for PhD students is supported locally at faculty level. The University also provides an academic writing skills centre, which is open to students including PGR students.

A regular programme of invited **external speakers** enhances awareness of relevant research beyond the university. All PhD students have access to state-of-the-art computational and laboratory facilities supported by RCIF and project funds. PhD students from all research groups are invited to speak about their research in an informal way. In addition, students can bid to the Faculty for up to £500 to cover conference attendance and fieldwork expenses, as well as engaging with the university's 3-minute thesis competition. There is also the PGR network supported by a senior academic and support staff within each faculty to monitor PhD student progression and provide pastoral care.

The quality of support in **skills development** provided to the unit's PhD students is evidence by the positions they obtain after graduation. Examples include, Dr Aoife Hunt (2016) now associate Director at Movement Strategies; Dr Markus Sauter (2015) is involved in Systematic Portfolio management and research for USA based Principal Global Investors, Dr Madeline Togher (2015) is now an Assistant Professor in Computer Information Science at the Higher Colleges of Technologies in Dubai; Dr Xiaoqin Hu (2015) is now a research fellow at Western Norway University of Applied Sciences; Dr Owain Thompson (2020) is currently an Inspection and Governance Officer in the Business Intelligence Team of Kent Fire and Rescue Services; Dr Mohammad Shahjala (2018) is now a research fellow at the Warwick Manufacturing Group. Dr Richard Evans (2013) is now senior lecturer at Brunel University.

In the future, Engineering staff will also have the potential to collaborate in the new interdisciplinary Greenwich-led UK Food Systems **Centre for Doctoral Training** (<https://foodsystems-cdt.ac.uk/>) that was awarded in 2020. This centre provides a unique opportunity for transformative and interdisciplinary food systems research. Led by the Natural Resources Institute of the University of Greenwich, the UKFS-CDT aims to develop the next generation of food system change makers for a healthy and sustainable food future.

#### D) Equality & Diversity

The university makes every opportunity to promote quality and diversity through its support strategies in place for staff and research students returning from periods of leave or ill-health, managing long-term illness, or with caring responsibilities, and for staff with protected characteristics (e.g. disabilities). The unit also supports female staff to join networks such as the IEEE Women in Engineering Network and the university Aurora Programme which supports leadership development for women up to senior lecturer grade.

**Table 3:** Staff profile by gender, ethnicity, and contract type

	Contract Type (% permanent)	Gender (% Female)	Ethnicity (% BME)	% Full-Time Equivalent
UoA12 (Staff)	90.5	17.9	53.3	90.5
UoA12 (Not SRR)	87.2	25.6	46.2	87.2
UoA12 (SRR)	92.9	12.5	58.5	92.9

The characteristics of REF2021 (SRR) cohort compares favourably with the wider discipline, at least in terms of contract type, BME and FTE. Whilst the unit lags somewhat in gender balance, there has been a doubling in the number of female staff submitted compared to the 6 returned in REF2014. Investment in early career and mid-career staff is also evident in the age profile.

**Table 4: Staff Age Profile**

Age Group	16-24	25-34	35-44	45-54	55+
UoA 12 (Staff)	0%	12.6%	25.3%	28.4%	33.7%
UoA12 (Not SRR)	0%	12.8%	10.3%	28.2%	48.7%
UoA12 (SRR)	0%	12.5%	35.7%	28.6%	23.2%

During the assessment period several female members of staff participated in Aurora. During the REF period, 27 staff have successfully applied for promotion, and of these, 22% were female and 67% were BME. Arrangements to support flexible and/or remote working are governed by the university policy. Career pathways for part-time and fixed-term staff are available. Conference travel and other travel is supported for staff/students with caring responsibilities/ill health. Under-represented staff are considered equally in terms of support for funding applications, access to internal funds, and promotion. During the preparations for this REF submission the unit followed the university code of practice. An EDI representative was on the panel and outputs submitted by staff were both internally and externally reviewed.

### 3. Income, infrastructure and facilities

#### A) Income

The sustainability of the UoAs research endeavors is evidenced by its ability, within a highly competitive research environment and during uncertainties related to BREXIT and COVID, to attract UK government, EU, overseas, and industry funding to support its research. Over the assessment period, the unit was supported by £11,142,900 of external income received from both UK and Non-UK sources as detailed below:

**Table 5 Income**

Funding Source	REF 2014 (£k)	REF 2021 (£k)	% Change
UKRI/Govnt/Charities	3,523	4,144	18
UK Industry	1,464	1,724	17
EU-Govt, Charities, etc	2,530	3,904	36
EU-Industry (exc. UK)	253	332	31
Non UK/EU (Industry, Other)	499	1,039	108
Total	8,578	11,142	30

The groups within each center exploit their established networks with academia and industry to generate income. For example, CMRG's long-term collaboration with the universities of Nottingham and Loughborough and industry in the electronics sector generated income through prestigious large consortia awards such as the £9,088,809 EPSRC Innovative Electronics Manufacturing Centre (EP/H03014X/1), 2010-15, and the £6,085,158 EPSRC Centre for Power Electronics (EP/K035304/1, EP/K035304/1), 2013-19, (<https://www.powerelectronics.ac.uk/>). These large consortia projects in collaboration with both academia and industry provide opportunities to generate high quality outputs which include papers, software, and equipment. For example, the 17,660,881 € EU-FP7 project EXOMET (2012-16), with 28 partners enabled CSEG to patent its research findings for the Contactless Sonotrode, and this led onto to a new EPSRC project - Contactless Ultrasonic Processing for Liquid Metals (EP/P034411/1) – in collaboration with the Universities of Birmingham and Oxford and Rolls Royce. The €2,400,00 project BENEFITS (2011–2015) under EU Interreg FCE Programme with academic and industrial partners in UK and France led to a follow up project CoRoT (2016-2021) of €3,900,00 in collaboration with 10 partners and associate partners in UK and France.

#### B) Infrastructure & Facilities

We believe that world-class facilities are vital to the delivery of our research and impact activities. Throughout the REF period, we have invested £542,464 into the lab/equipment in CEE and computational and modelling facilities in CNMPA through RCIF and other sources. Investment has been made in a new food innovation laboratory (£379,000 in 2020 with an

additional £1.050,000 in 2021) at the Medway Campus to support interdisciplinary research to support the food industry.

**Infrastructure and facilities in CEE:** The **Wolfson Centre** has extensive analytical labs containing all the cutting-edge techniques for measuring and characterising the behaviours of powders, including a pilot plant occupying 1000m<sup>2</sup> of floor space, containing the largest selection of industrial-scale equipment for conveying and processing of powders and bulk solids under one roof anywhere in the Northern hemisphere. All scales are catered for, from atomic force microscopy of single particles, through micro-dosing down to 10mg for pharmaceuticals, up to 150 tonnes/hr for minerals processing and pipelines up to 400m long. **MCEG** laboratory is equipped with a unique ion implantation reactor for the synthesis of endohedral nitrogen fullerenes (such as non-metallic N@C<sub>60</sub> and N@C<sub>70</sub>). It also has 2 pilot plant arc-discharge reactors for the synthesis of fullerenes, metallofullerenes (M@C<sub>n</sub>) and carbon nanotubes. We have advanced separation instrumentation consisting of 3 high performance liquid chromatography (HPLC) units including the largest commercially available HPLC column for fullerene separation. We have a suite of spectroscopic characterisation tools including (UV-Vis-NIR spectrophotometry, Photoluminescence (PL) spectroscopy, Electron Paramagnetic Resonance (EPR) spectroscopy and Matrix-Assisted Laser Desorption Ionization (MALDI) spectrometry. We have a series of synthetic chemistry tools including a cyclic voltammetry apparatus, a number of Schlenk lines and analytical tools such as optical microscopes, microbalances etc. **MMM** has access to Advanced automation, AI and digital manufacturing technologies including CAD, CAM, CAE, industrial mobile and collaborative robots, humanoid robot, ERP, Product Lifecycle Management (PLM), and Supply Chain Management software tools to supports its research and impact activities. This includes advanced computer numerical control (CNC) machines, simulation systems, advanced rapid prototyping and 3D printing facilities. It also possesses a state-of-art Living Green Wall Lab dedicated to acoustic testing that also benefits from an XYZ gantry system adoptable to various activities. **CEEG** has bespoke facilities to carbonate materials at ambient and raised temperature and pressure conditions (to 70 bar), isothermal calorimetry, pelletising and aggregation equipment, leach testing (BE 12457), up-flow testing (BS 14405) and a range of performance (e.g. efflorescence) microstructural (EDAX/electron/polarised light imaging) and mechanical tests (crushing/bending/thermal). CEEG also has access to testing equipment in geotechnical and structural engineering, and a new 3D printer (Delta WASP 40100 Clay printer) that can be used to investigate innovative material e.g. for the optimal seismic design of submarine structures.

**Infrastructure and facilities in CNMPA:** The computational engineering activities benefits from organisational infrastructure such as the high-performance computing cluster which has received c£400K of investment. Bespoke computing clusters are also available within each research group to support their research activities. **FSE** has 20 node windows CPU/GPU cluster to undertake compute intensive, large-scale applications of its CFD fire simulation (SMARTFIRE) and agent based evacuation simulation software (EXODUS). This includes running detailed simulations for a wide range of safety and security applications and its VR/AR/MR training simulation environment allows trainees, for the first time, to interact with, high fidelity engineering quality simulation environments. **CMRG** research into physics-of-failure reliability predictions is supported by an 8 node / 160 core Xeon E5 cluster with a total of 1024 GB memory. This is linked to 2 NAS storage systems with a capacity in excess of 45 TB. This central compute facility is augmented by High-End GPU workstations with 20 Xeon cores, 128 GB memory and Nvidia P5000 GPUs. The group have a range of state-of-the-art structural mechanics, computational fluid dynamics and multiphysics software packages, including ANSYS multiphysics and COMSOL and CAD packages such as Autodesk Inventor. **CSE** has a mini cluster comprising 8 Intel Xeon nodes with a total of 168 cores. One of the nodes has 768GB of RAM used for high memory applications and data processing of large scale data sets. The cluster nodes are linked by 40Gbit Mellanox fibre interconnects for fast communication and connected directly via 10Gbit ethernet to a 300TB storage array for fast data writing and processing.

The units infrastructure, facilities and expertise is continually utilised to **support impact activities**. Throughout the REF period we have undertaken a number of projects with industry

that exploit our expertise and infrastructure to deliver impact. In total the units infrastructure has supported over £2,000,000 of impact-related work directly funded by industry. Using our extensive network of academic and industry collaborators worldwide we also **access major research facilities** both nationally and internationally. An example being the work undertaken by CSEG in collaboration with the Univ of Manchester, which used the Diamond Light Source facility (Harwell) and the European Synchrotron Research Facility (ESRF), Grenoble, to observe in situ the effect of magnetic fields on solidifying alloys. Another example is that BAE Systems and Cummins provided dedicated desks and access to the equipment and data for PhD researchers of MMMG on collaborative projects. CSEG also maintains its involvement in the ESA ELIPS material projects THERMOLAB-ISS and PARSEC assisting the development of electromagnetic levitation experiments on the International Space Station.

Our large portfolio of projects with industry also provides benefits from **in-kind support for the unit's research and impact plans**. This can run into £M's. For example, CMRG's work with Leonard provides access the state-of-the-art failure analysis equipment for assessing failures in semiconductor packages, as well as access to data from reliability tests which have a value of £100,000's per semiconductor package. Access to this data and facilities is used by the group as data for its modelling research and its validation. CSEG's collaboration with the European Space Agency on the EXOMET project resulted in significant in-kind support through access to micro-gravity experiments worth £8,000,000+.

In terms of **equality and diversity**, accessing the unit's infrastructure is addressed through the university policies. For example, RCIF funded equipment is available to all staff. At faculty level internal investments of REF and HEIF funds are made based on the needs of each research group and the quality of proposals submitted for funding. Assessment panels are used to rank externally reviewed proposals and membership of each panel represents the diversity and backgrounds of staff across the faculty.

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

##### i) Research Collaborations, Networks, and Partnerships

The units strategy aligns well with the **UK's Industrial Strategy** – particularly the Grand Challenges in AI and Data (Industry 4.0 and data-driven Advanced Manufacturing), Clean Growth (Clean manufacturing, low carbon technologies) and Future of Mobility (electrification of transport, safety and security). Exemplar projects include:

- **AI and Data:** MMMG's participation in the EU Interreg CoRoT project, developing autonomous data driven mobile and collaborative robot systems for real-time dynamic manufacturing systems, and the EU Interreg BENEFITS project, developing product lifecycle management systems for data and information sharing and integration across manufacturing global supply chain. CMRG's participation in the EU-funded Next Factory project developing advanced data driven 3D-printing manufacturing processes for next generation of electronic systems.
- **Clean Growth:** CMRG's participation in the multi-institution UK EPSRC Centre for Power Electronics has addressed the national priority detailed in the UK Government paper – UK Power Electronics Industry: a strategy for success (Department for Business Innovation and Skills, 2011) and led to growth in UK expertise and resources for power electronics research to address challenges in Green Transport and Renewable Energy. CEEG's participation in EU Interreg project 'sustainable aggregate production with imbibed carbon dioxide', which processed one hundred waste 'types' including thermal residues into carbonated light-weight products.
- **Future of Mobility:** FSEG's participation in numerous EU and UK-Government funded projects developing its EXODUS and SAMRTFIRE software tools to aid the design of future transport infrastructure that is safe and secure in terms of mitigating fire hazards and supporting safe evacuation.

The unit actively collaborates with Universities, Government bodies, and Industry both nationally and internationally to address national and international priorities and initiatives. Exemplar

**National projects** that are the result of long-term collaborations include Contactless Ultrasonic Processing for Liquid Metals (EP/P034411/1) – in collaboration Birmingham and Oxford Universities, and Rolls Royce plc; 2017-21; **Virtual Formulation Laboratory for prediction and optimisation of manufacturability of advanced solids based formulations** (EP/N025261/1) - in collaboration with Universities of Leicester, Leeds, Imperial College, and Surrey; 2017-21, and **Multi-Domain Virtual Prototyping Techniques for Wide-Bandgap Power Electronics** (EP/R004390/1) – in collaboration with Univs of Nottingham and Bristol; 2017-21. **International collaboration** is at the forefront of our strategy and a key support component for this activity is funding from the EU. Exemplars of international projects and collaborators **AUGGMED**, (EU, ID: 653590), 2013-2016, in collaboration with Piraeus Port Authority (Greece), Ferrocarrils de la Generalitat de Catalunya (Spain), Geomobile, (Germany), ISRA-TEAM 98 Ltd (Israel), Kardaras Konstantinos (Greece), Police and Crime Commissioner for West Yorkshire (UK), Serco Belium (Belgium), Serco Ltd (UK), Sheffield Hallam Univ (UK), Sistema D’Emergencies Mediques (Spain), University of Birmingham (UK), Universidad Politecnica de Madrid (Spain), and YDEAP (Greece).; **NextFactory** (EU ID: 603716), 2013-2017, in collaboration ARRTIC (France), Cellasys (Germany), Heliotis (Switzerland), Microchip (UK), Profactor (Austria), Acreo (Sweden), Sunplugged (Austria), Tiger Coatings (Austria), and Unitechologies (Switzerland). **CoRoT** (Proj id: 99) 2016-2021 in collaboration with CESI (France), Exeter University (UK), BA Systems (France), Autofina (UK), Univ of Du Havre (France), CERI (France), and IRSEEM (France). Global-Challenge-related research interests in developing countries have also been strengthened by new collaborations with international institutions in Africa, Malaysia, Mexico, Indonesia, Turkey and India. These collaborations have led to grant winning in (1) risk management engineering solutions for natural hazard mitigation, in Malawi and Mozambique (GCRF - FoD2021\4\12); (2) improved socio-economic conditions via integration of wave energy and oceanic macro algae farming platform (Newton Institutional Links Grant - 172596355); and (3) Waste management/valorisation via sustainable, circular economic, CCUS technology (industrial grants from Chandan Steel and HZL, India).

During the REF assessment period the strength of our international collaborations is evidenced through the percentage of our publications that are co-authored by international academic partners as detailed below:

**Table 6** Collaboration (source SciVal)

<b>Publications</b>	<b>International Collaboration</b>	<b>National Collaboration</b>	<b>Institutional Collaboration</b>	<b>Corporate Collaboration</b>
2021 (%)	48	20	30	9.5
2014 (%)	31	24	42	7.1

**Research-user engagement:** In addition to engaging with researcher-users on funded projects (as detailed above), the unit is also involved in other pathways for engagement. For example, within **CNMPA**, FSEG has licensed its EXODUS software to over 100 licensed users in 31 countries, and over 130 research users have attended its two five-day short courses from 44 countries. During the COVID pandemic FSEG was invited to be part of the Royal Society RAMP intuitive where it is using its software tools with research users to a range of disciplines and infrastructure operators associated with rail, hospital, and retail facilities to discuss appropriate mitigation strategies. CMRG has increased its engagement with the IEEE (Bailey, UK & Ireland Chapter Chair for EPS and Reliability societies) disseminating its research through IEEE organised events. It is also engaged in the IEEE Heterogeneous Integration Roadmap providing a route to disseminate its research to electronics companies worldwide. Within **CEE**, Wolfson runs post-experience courses 1 to 3 days duration, which have recruited over 1700 paying attendees from industry. Long-standing courses have been regularly updated with latest research outputs but various latest outputs have led to new courses including advanced-level courses in two phase flow (pneumatic conveying) and powder flow (hoppers and silos), and a course especially for additive manufacturing. MMMG co-ordinates a Manufacturing Industry Focus Group in Southeast England and organise regular industrial workshops (normally twice a year). Researchers of MMMG and participating companies in this region present their industrial challenges, requirements, R&D projects and discuss/share knowledge, experiences and view of



future technology development. CEEG hosts the Kent and Medway Contaminated Land Forum (a partnership with the Environment Agency), which hold twice-yearly workshops at Medway (Hills is Vice-Chair). Advances in e.g., waste handling, contaminated soil and waste remediation, policy and risk-related issues are delivered to typically >100 industry practitioners. This Forum and Workshop are in their 20<sup>th</sup> year of 'delivery'. In summary, over **200** companies worldwide have partnered/engaged with the unit throughout the REF period. This has led onto many **impacts not detailed in the ICS's**. For example, the work by CSEG under the SIKELOR project, developed a process for recycling silicon kerf silicon kerf produced during the sawing of photovoltaic solar panels using HF electromagnetic induction. This process has been put into practice by Garbo SRL in Italy. In summary staff within the unit have engaged with large multi-national companies such as BASF, Rolls Royce, BAESystems, Airbus, MBDA, Roche Pharma, Kaiser Aluminium, Microjoint, Micross Semiconductors, General Dynamics, HSBC to small and medium sized companies such as Clevertronics.

**Public and community engagement:** Working with the media, many of the unit's research findings have been disseminated to the wider public. This includes the FSEG project AUGGMED findings disseminated on BBC Click (2017) and the New York Times interview with Prof Galea on Why Grenfell Tower Burned: Regulations put before safety (2017), the Radio 4 programme "All in the mind" featuring FSEG research concerning how pedestrians interact with autonomous vehicles, and the Radio 5 Live Breakfast Programme, where Prof Galea was interviewed for a item titled "Use of escalators on London Underground". MMRG's research has been disseminated through Romano's interviews with BBC One London News (2019) on 'Research finds green walls cut up to 30% of noise' and BBC radio Kent on 'Hanging Gardens of Babylon at Chatham Maritime'. Bailey (CMRG) also has webinars recorded on the IEEE Resource Centre detailing CMRG's research work into electronic systems reliability. The faculties also organise regular seminars/webinars open to the public where the units work is disseminated to the public.

**Supporting the discipline:** The unit supports staff engagement with engineering professional societies to disseminate engineering knowledge across the discipline globally.

- Examples of journal editorships include IEEE CPMT Transactions (Bailey), Journal of Molecules (Porfyraakis), International Journal of Forensic Engineering (Tee), Frontiers in Built Environment (Ercolino), Proceedings of IMechE, Part B: Journal of Engineering Manufacture (Gao), Safety Science (Galea), International Journal of Computer Aided Engineering and Technology (Le), Applied mathematical Modelling (Pericleous), Journal of Algorithms & Computational Technology (Lai), International Journal of Forensic Engineering (Tee)
- Examples of invited Keynote Presentations includes International Conference on Powder, Granule and Bulk Solids, India 2020 (Tong), IEEE ICSJ 2018, Japan, (Bailey), IEEE/ITU International Conference on Artificial Intelligence for Good, on-line 2020 (Gao), House of Commons, All Party Parliamentary Climate Change Group, London, Nov 2014 (Hills), International Conference on Construction and Project Management, Hong Kong, 2019 (Tee), International Conference on Building Materials and Civil Engineering, China, 2016 (Tee), International Academic Symposium on Quality, Safety and Credit, China, 2014 (Gao).
- Examples of chairing international conferences includes IEEE Thermnic (2014, Bailey), International Conference on Manufacturing Research, UK, 2017 (Gao), International Conference on Digital Enterprise Technology, China, 2016 (Gao), international conference on Computer Aided Design and Applications, UK, 2015 (Gao), EAI International Conference on Broadband Communications, Networks, and Systems, Portugal, 2018 (Mantas), International Conference on Test, Measurement and Computational Method (TMCM), China, 2017 (Tee)
- Examples of winning research prizes/awards includes Queens Award for Enterprise (Hills, CEEG, 2017), Society of Fire Safety Engineers 'Best Research Project for 2019' (Galea, Deere, Xie, Lawrence, and Hulse), Royal Aeronautical Society's Gold Award for 2017 (Galea, Wang, and Jia), The British Foundry Medal (Pericleous, Wang, Djambazov), Best Paper Prize at Fraunhofer Direct Digital Manufacturing Conference, Berlin, 2016 (Bailey, Stoyanov, Tilford), Engineering Leadership Award Winner (BUILD) 2017 (Hills), Most Outstanding Low Carbon Innovation Research Institution (AI Excellence Awards), 2017 (Hills), Recognised

## Unit-level environment template (REF5b)

Leader in Stabilisation & Solidification Systems (WF International), 2017 (Hills), CATRENE Innovation Award – NEWPASS, 2015 (Mantas).

- Examples of participating on award committees includes European Science Foundation (Hill), EPSRC Peer Review College (Bailey, Bonet), Latvian Academy of Sciences (Bojarevics), the Science Fund of the Republic of Serbia (Gao), Academy of Finland (Gao), the Science and Technology Board of Vingroup Innovation Foundation Fund, Vietnam (Le), French National Research Agency – ICT Department (Mantas)

Indicators of wider influence, contributions, and recognition of the unit's contributions to the discipline are detailed below:

**Table 7:** Summary of contributions to the community

Examples of leadership in the academic community	Count
Fellowships on learned societies (IET, IMechE, IEEE...)	29
Editorship of journals (Chief or joint)	10
Member of journal advisory boards	18
Conferences organised or chaired	18
Plenary of Invited Keynote lectures	37
Workshops, mini-symposium, special sessions organised	27
Research prizes or similar honours	30
Membership of national or international advisory boards (inc UKRI)	9
Other	66

Individual examples of senior leadership throughout the REF period include:

- **Bailey** FIMA, President of the IEEE Electronics Packaging Society. Chapter Chair for UK & Ireland IEEE EPS and Reliability Societies. Organised 2 conferences and four workshops, delivered 12 plenary or keynote presentations. Associate Editor for 2 journals, visiting Professor at IIT Kharagpur (India), and a member of the EPSRC peer review college.
- **Bonet**, Fellow of Learned Society of Wales, Visiting Professor at Tecnologico de Monterey (Mexico). Member of the Future Leaders Fellowship Panel (UKRI), member of ICREA (Catalan national research council), member of 3 journal advisory boards, and a member of the Life Science Advisory Board of the Welsh Government.
- **Bradley**, Chairman of Technical Committee of Solids Handling and Processing Association (SHAPA), Member of 4 advisory boards, Founder member of ISO standardization committee TC 238 / WG4 / TG1, Safety Standards for Pelletised Biofuels, Received the Bulk Solids Handling Award of the Institution of Mechanical Engineers, for personal contribution to the field of bulk materials handling.
- **Cox**, Member of Heads of Chemical Engineering UK (HCEUK), Honorary Senior Research Fellow of University of Birmingham, Visiting Professor of University of Wolverhampton. Adjunct Professor of McGill University (2014-16). Member of editorial board of 3 journals, including being a guest Editor for a special issue of MDPI Foods Journal. Regular referee for J. Food Eng.
- **Galea**, CMath, FIMA, CEng, FIFireE, Visiting Professor at University of Ghent (Belgium), Western Norway University of Applied Sciences (Norway), Institut Supérieur des Matériaux et Mécaniques Avancés (ISMANS, France). Vice-Chair of the International Association of Fire Safety Science. Associate editor for two journals. Winner of the Guardian University Award for Research Impact (2014), the Royal Aeronautical Society's Gold Award (2017), and SFPE (UK Chapter) Award for the Best Research Project of the Year (2019).
- **Gao**, FIMechE, Associate Editor for Journal of Engineering Manufacture. Member on 4 journal editorial boards. Grant reviewer for EPSRC, the Academy of Finland, and Science fund of the Republic of Serbia. 3 invited Keynote Presentations. Chair or co-chaired 4 national/international conferences/workshops.
- **Hills**, Fellow of the Royal Society of Chemistry and Geological Society of London. Founder and long-serving member of the scientific and organising committee of ACEME. Board Member of CO2Chem and ISCOWA. Received 5 awards including the Queens Award for

## Unit-level environment template (REF5b)

Enterprise (2017), and IChemE Green Chemical Technology Award. Visiting Professor at Dalhousie University (Canada) and Lovely Professional University (India). 14 invited Keynote presentations, and chair/co-organiser of 6 conferences. Founder of the spin-out company Carbon8 Systems Ltd.

- **Pericleous**, Member of 3 journal editorial boards, Scientific Advisory Board (SAB) Helmholtz Alliance of German Universities. EU ERC proposal evaluator, Grant reviewer for EPSRC, Leverhulme and Royal Society. Invited National Grant Reviewer for Cyprus, Israel, Germany, Latvia, Poland, Switzerland.
- **Porfyrakis**, FRSC, EPSRC Fellowship (2013-18), Academic visitor - University of Oxford. Visiting Professor at Aristotle University of Thessaloniki, Greece. Member of the Inner Board for the Irish Research Council panel. Grant reviewer for EPSRC and the German Research Foundation. Editor of Journal "Molecules". Director of the spin-out company Design Carbon Materials Limited.