

Institution: University of Hull

Unit of Assessment: Engineering

1. Unit context and structure, research and impact strategy

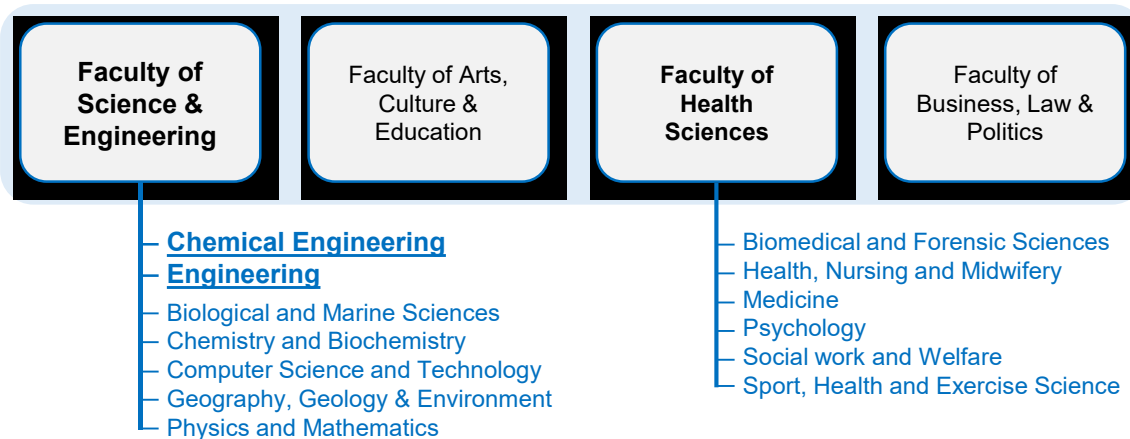
A. Context and structure

The research and impact activities submitted under the Engineering UoA are focussed on two themes: **Energy, Environment and Sustainable Engineering (EES)** and **Biomedical Engineering (BE)**. The activities directly support two of the University's strategic priorities – namely Energy and the Environment, and Health and Wellbeing – and bring together colleagues from the **Department of Engineering, Department of Chemical Engineering** and **Energy and Environment Institute (EEI)**.

There have been a number of organisational changes since our last REF submission with the introduction of a new University structure. As a result engineering activities are now organised into a Department of Engineering, including Electronic & Electrical Engineering, Mechanical Engineering and Medical Engineering, and a separate Department of Chemical Engineering. In addition, some of Engineering's energy-focussed research activities have been relocated to the Energy and Environment Institute (EEI) to strengthen Engineering's links with the EEI, while colleagues in Chemical Engineering now also contribute to the EEI's activities.

The engineering activities are central to other major developments at the University level (e.g. Aura) as discussed below. Overall this has been an exciting time for Engineering and these changes have resulted in a significant expansion of its activities within the University. The two Departments now sit within the Faculty of Science and Engineering (FoSE) as illustrated in Figure 1. As a result of these changes, the appointment of new academic staff and the appointment of a number of independent researchers to support these developments, the number of staff returned in this UoA is more than double the size of the return made in REF2014 (which was to General Engineering).

Faculties



Research Institutes



FIGURE 1: Schematic showing the position of the **Departments of Chemical Engineering and Engineering**, and the **Energy and Environment Institute** within the University, and highlighting the departments of the Faculty of Health Sciences.

B. Overview of research groups and activities

Research in the EESE and BE priority themes is supported by five research groupings, including one centre (the Centre for Sustainable Energy Technologies). Members of staff are attached primarily to one of these groups, although inevitably some contribute to more than one activity. The following paragraphs give a brief outline of the groups' primary research interests. In broad terms, the research is aimed at addressing the most important challenges facing the world today: (1) maintaining energy security and maximising use of scarce resources while minimising waste and reducing environmental impact; and (2) improving the healthcare of an increasing and often ageing population while satisfying growing patient expectations.

Advanced Materials and Acoustics

(led by Professor Mi with Fancey, Heyes, Itskevich, Rubini, Qin)

Discovery of new materials and more efficient methods of producing the desired structures and functionalities is the foundation of modern industry and society. The Advanced Materials and Acoustics group focuses on designing, developing and exploring new structural and functional materials with a step change in performance and functionalities as well as sustainable materials manufacturing technologies for modern industry. We use the most advanced synchrotron X-ray and neutron sources around the world to study the fundamentals of materials synthesis *in situ* and research the optimal manufacturing strategies *in operando*. These include the design and development of new metallic glassy alloys for improved neutron absorption, and pulse magnetic field and ultrasound-based materials processing technologies for metallic alloys and 2D functional materials; viscoelastic morphing polymer composites; scalable on-chip single-photon sources for integrated quantum photonic circuits and networks; design, analysis and implementation of new sound attenuation devices in industrial gas turbine combustors; and novel simultaneous gas temperature and velocity measurement techniques based on thermo-graphic phosphor particles in heated flows.

Biomedical Engineering

(led by Professor Fagan with Fancey, Gilbert, Jaganathan, Langley, Wadhawan, Watson)

The impact of the ageing population and pressure on healthcare budgets makes the continued wellbeing of the population difficult to ensure, while in parallel, there is a continuous drive to develop better medical devices to improve patients' quality of life as well as improve the way in which healthcare is provided. The Biomedical Engineering group works across a number of areas to address these issues in a combination of applied and fundamental research projects, including: wound management and novel biomaterials especially scaffold-based materials; craniofacial biomechanics and musculoskeletal form and function in general; advanced data processing and diagnostic techniques to monitor cardiac health; development of novel medical devices and telehealth and care technologies to improve patient care while improving healthcare efficiency.

Centre for Sustainable Energy Technologies

(led by Professor Zhao with Li G, Li J, Ma, Monyei, Wang, Xiao, Zhu)

The Centre for Sustainable Energy Technologies (CSET) develops new technologies for renewable energy, improved energy efficiency, and sustainable, integrated heating, cooling and power systems. Members of the group undertake a broad range of research, but have particular expertise in heating systems, including solar heat and power, heat pumps and heat pipes, cooling systems, novel energy materials, information systems and processing and energy management.

Chemical Engineering

(led by Dr Skoulou with Hasan, Ibadon, Ke, Kuvshinov, Lawrence, Oko, Patel, Stevenson, Taylor, Wadhawan, Zein)

The Department of Chemical Engineering pursues research aimed at solving industrial problems for the benefit of society in the broad areas of novel materials and chemicals, fuels and energy, and feedstock. This includes: electrochemistry for clean energy and specialised sensor development; process modelling and simulation of carbon capture and storage; multiphase flows, process control and simulation, microfluidics for pollution control, carbon nanofibers and H₂;

pyrolysis and gasification of waste for syngas H₂ and optimized fuels, 'green' catalysis for the production carbon nanotubes and fatty acids, bio-oils, carbonaceous and other eco-friendly materials and sustainable chemistry; photocatalysis, carbon nanoparticles and chemicals and other new materials, metal frameworks and water splitting. This wide diversity in Chemical Engineering expertise allows us to deliver research ranging from new materials, low carbon energy, green fuels, and feedstock plant scale simulations, through innovative unit operations and bench-scale testing, down to molecular-level understanding of new generation, low carbon chemical engineering processes.

Renewable Energy Technologies and Energy Storage

(led by Professor Gilbert with Fagan, Fancey, Gilbert, Patton)

The drive to reduce carbon emissions worldwide and the UK's commitment to net zero requires a rapid adoption of renewable energy technologies for power generation while the intermittent nature of some renewable energy technologies means that large-scale energy storage, integrated with dispatchable generation technologies are needed to maintain supply. The Renewable Energy Technologies and Energy Storage Group aims to improve the performance and reduce the cost of marine renewable energy, through improved design, manufacture and control of offshore wind, wave and tidal energy devices. Through recent investment (after July 2020, see Section 2 below) the group's activities are now poised to include bioenergy, biofuel and bioproduction technologies for integration into future energy systems, establish new technologies for efficient large-scale energy storage and introduce innovative techniques to manage heat and air flow in the built environment to reduce energy use.

C. Research strategy and developments since REF2014

We aim to deliver high quality and impactful research across a broad range of engineering activities, in particular (but not exclusively) in the areas outlined above. As demonstrated below, we facilitate this by supporting and nurturing our academic and research staff, while working to enhance our research infrastructure to support our staff's ambitions and continuing to develop strategic external links and other partnerships to maximise new research priorities and opportunities.

Open Science. We are enthusiastic supporters of open science, and the UoA's publications meet the University's Open Access Policy requirements. Supporting data from our research are also made publicly available when possible, for example either on a journal's website and/or on recognised database repositories to ensure maximum accessibility. For example, for **BE** REF2 paper Dutel *et al.* (Nature, 2019) 3D data have been made available on <http://paleo.esrf.eu> and <http://phenome10k.org>; and for **EESE** REF2 paper Wang *et al.* (Acta Materialia, 2018) data and synchrotron videos are available at data repository journal [Data in Brief](#). In addition, we make our research tools available, such as our bespoke bone modelling software, VOX-FE, which is freely available on SourceForge (<https://sourceforge.net/projects/vox-fe/>).

Research Integrity. Members of this UoA follow the principles of the UKRIO Concordat for Supporting Research Integrity and this is supported through the University's framework of regulations, principles and standards of good practice. Before research grant applications can be submitted, a statement on ethics must be submitted with the application on our (Worktribe) research management system, while a full ethics application must be approved before a research project can start. The University's ethics review system is managed through Faculty Ethics Committees to ensure that all research is subject to appropriate scrutiny and is undertaken with the highest levels of integrity. Ethics and integrity training are mandatory for all staff and postgraduate students undertaking research.

Developments since REF2014. In REF2014 we said that we would continue to focus on and prioritise the EESE and BE themes but broaden our activities, which we have done. For example: BE staff have established a University-wide collaboration with Smith and Nephew on wound management, and we have expanded our biomaterials and electrophysiology research; while EESE areas of strategic growth include research into new heating and cooling systems, research on renewables, the development of energy from waste and biofuels, and the development of new

materials, processes and devices.

2016 saw the formation of the EEI to focus on the environmental and energy challenges that are facing the world today. The **Centre for Sustainable Energy Technologies** (CSET) is a key part of that activity and works to develop new technologies for renewable energy, improved energy efficiency, and sustainable, integrated heating, cooling and power systems. Two exemplars of the value and practical outcomes arising from CSET's research are described in an Impact Case Study.

Opening of Siemens-Gamesa's £310M wind turbine blade manufacturing facility in Hull prompted the formation of [Aura](#) in 2015, a research facility aimed specifically at bringing together industry, universities and other expert organisations to develop the low carbon energy sector, with a particular focus on offshore wind. Engineering has taken advantage of that development with a very significant expansion in wind and renewables research (led by Gilbert) who also leads the underpinning research, development and innovation activities of Aura and provides a link with the £9M EPSRC Supergen Offshore Renewable Energy Hub. With its strong links to industry and local government, Aura exemplifies our research ethos, and provides the ideal conduit through which the impact arising from the EESE groups' research can and is being exploited and maximised. To facilitate and further expand that interaction, the £12M **Aura Innovation Centre** (AIC) has recently been built at the Bridgehead Business Park on the outskirts of Hull. The AIC not only provides a common space for large businesses, SMEs and the University to collaborate and innovate, but also houses the Engineering research labs and equipment that support those activities.

Hull's **Institute for Clinical and Applied Health Research** (ICAHR) is focused in particular on our ageing population and the multiple medical conditions that increasingly more people have to cope with. The **BE** groups in Engineering work on both applied and fundamental research projects with clinical colleagues in ICAHR, Hull-York Medical School (HYMS) and Faculty of Health Sciences, and further afield, which provide direct routes for application and adoption of the outcomes of that research. As an example of this, over this REF period ME's activities with Smith and Nephew (S&N) Wound Management has been formalised through a Framework Agreement with the University to facilitate joint research (and services rendered). This agreement now not only includes Biomedical Engineering but also Biomedical Sciences, Chemistry and HYMS and saw the establishment of a PhD cluster in Advanced Wound Care, funded by the University and S&N, to work on topics that support S&N's long-term research goals. That cluster has now drawn in other areas of Engineering, for example additive manufacturing and bioelectronics, and has recently led to the registration of two S&N employees on part-time Engineering PhD programmes.

D. Impact strategy

Through our innovative research we work to develop new products, processes and devices that generate: (1) a reduction in overall environmental impact from our collective activities; (2) improved delivery and cost-effectiveness for both industry and the NHS; (3) improved patient care and quality of life; (4) opportunities for commercialisation, with concomitant job and wealth creation. There are many potential beneficiaries of this work. For the **EESE theme** these include: industry, local government, policy makers and the general public; and for the **BE theme**: patients, the NHS (as an organisation, as well as nursing and medical communities), medical device companies and the general public.

For both the EESE and BE themes we have strong, established relationships with industry and the NHS through which we can actively promote translation of our research. For example, recent past and on-going research and development partnerships with industry, include Airbus, Airco, ANB Sensors, Ansell Microgard, Aolan, Baosteel (the largest steel company in China), BASF, Bemrose Booth Paragon (BBP), BP, Centrica, Chevron, DSM Nutritional Products, Energy Works, Evonik Industries, Five Star, Gateway Chassis, Ideal Boilers, INEOS, Jaguar Landrover, Johnson Matthey, McPhy Energy, NPS Group, Ørsted, PCM (Phase Change Material) Products, Practical Control, Schlumberger, Siemens Gas Turbines, Siemens-Gamesa, Singleton Birch, Sinogreen, Smith & Nephew, Spencer Group, Stoli catalysts, TWI, Unilever, Zimmer and many others. Funded directly by the company, as partners on research grants or through Knowledge Transfer Partnerships (see below), these links demonstrate that staff are actively involved in, and enthusiastic about, exploiting

their research and expertise.

Support for existing collaborations, the identification of new partnerships, and the development of research and commercialisation opportunities, are supported by the University's Knowledge Exchange team, Faculty Directors of Business Engagement and Enterprise, and most recently the Aura Innovation team. These teams provide two-way engagement with industry and other bodies, either finding potential partners to join with or exploit on-going research activities, or identifying the best academic or research group to respond to an external enquiry for information or assistance.

Where appropriate, we arrange meetings aimed at particular industries, clinical and/or academic colleagues where we outline and directly promote our current research and direction of travel of that research. For example, in order to promulgate our research in computational biomechanics, we ran a workshop in 2019 on the advanced computational techniques that we have developed to model the biomechanics of the cranio-cervical system. The attendees had a wide range of engineering and non-engineering backgrounds and came from the UK, Europe, USA and Australia.

The University's Research and Innovation team provides day-to-day support to assist with sources of research funding and research applications, to maximise research and innovation opportunities, and provide advice on governance and impact. This team provides support and advice on the protection and exploitation of intellectual property, and additional commercialisation and impact support; for example, through a University-funded Impact Acceleration Fund, KTPs and HEIF funding, as well as acting as a conduit for industry to secure funding to work with University experts, for example, through the ERDF-funded Sparkfund (Innovation Vouchers and R&D Grants).

KTPs (Knowledge Transfer Partnerships) are considered as an effective and direct means of fostering impact, and over the REF period six KTPs have been active with two further due to start shortly. Innovate UK has ranked the three partnerships that finished during the period as either "Outstanding" or "Very Good". The success and value of these KTP activities is further evidenced by the fact that two of our Impact Case Studies are based on very successful KTP programmes. **Wadhawan** has been particularly successful in securing KTPs over this period, and is now a University KTP-champion.

Over the REF period, 34 patents were applied for to protect the research undertaken by members of the EESE and BE themes, covering areas such as speech synthesis, bone fracture repair, novel suture materials, and novel heat exchanger and heat pump designs. Some of these patents have been assigned to a joint spin out company (Stoli Catalysts, based at the University of Warwick) which has attracted over £2.3M start-up funding, while the worldwide patents associated with the Kingston Speech Valve (an impact case study from REF2014) have recently been assigned to a medical device company for exploitation in India where an increased valve life would have significant benefits to laryngectomy patients.

E. Vision and future strategic aims

With the expanded position of the Departments of Engineering and Chemical Engineering in the University, the University's stated ambition to be a key driver of regional innovation, and the recent (after July 2020) and further planned increases in Engineering staff numbers, the next five years promise to be a time of significant opportunities for Engineering. Our current priority themes and research groupings have served us well and we expect to continue to focus on these priorities, but with development of our ECRs coming to fruition, new staff appointments and other organizational changes we are planning for a significant expansion of our activities.

In particular, as outlined in REF5a the Humber region (currently the most carbon intensive region of the UK) is embarking on a transition to low carbon energy, to support the UK's ambition to achieve Net Zero emissions by 2050, and indeed is already leading on the development and deployment of Offshore Wind (OSW) energy. Staff within the **EESE theme** are already heavily involved with that effort on OSW and other renewables. That work is accelerating with the recent award of the £5.5M EPSRC/NERC funded Aura Centre for Doctoral Training in Offshore Wind Energy and the Environment. Additional opportunities are developing for UK and international

collaboration through Hull's involvement with the EPSRC Supergen ORE Hub. Similarly, CSET will continue to develop new heating/cooling energy systems and novel technologies to improve energy efficiency. In addition to securing more project and programme-level type of support, it is also in a strong position to look for opportunities for involvement in larger programme and infrastructure type of projects, for example addressing the Clean Growth Grand Challenge and its missions. CSET already has very strong links with China but will also look for other international development opportunities that have 'carbon neutral' priorities. Direct contact with government departments, for example, local councils (we already have links with Hull City Council, Nottingham City Council and Portsmouth City Council) and hospitals will also be pursued, to provide them with advice on policy, strategic planning and technologies where appropriate.

Research in the Advanced Materials and Acoustics Group continues to develop and explore new materials and sustainable manufacturing technologies. Examples of current priorities include: new metallic glassy alloys and coatings with exceptional mechanical strength and corrosion resistance for offshore and marine infrastructure applications; responsive programmable materials and photonic devices for increased efficiency in energy harvesting; and, pulse magnetic field and ultrasound-based environmentally-friendly materials processing technologies.

In addition, we anticipate that these EESE activities will be significantly bolstered by the recent employment (since July 2020) of four new staff in the areas of energy efficiency in buildings and energy storage technologies to better manage renewable energy supplies.

Furthermore, within the **EESE theme** we also see significant opportunities through the recent expansion of Chemical Engineering activities in the University and their co-location with Chemistry, and the many chemical and allied industries in the Humber region. For example: (1) the Research England THYME project which is a joint venture with the Universities of Hull, York and Teesside in collaboration with regional industry and LEPs (Local Enterprise Partnerships) which focuses on transforming bio-based waste into new products, re-purposing industrial sites for bio-based manufacturing and growing the productivity of the region's bioeconomy; and (2) the EPSRC-funded Evolving Circular Plastics Economy (ECPE) project involving both Chemistry and Chemical Engineering. "Adjacent innovation" between the different energy and environment themes of EESE and EEI is also now occurring.

Under the **BE theme**, the recent renaming of the local NHS trusts to Hull University Teaching Hospital Trust is expected to further raise the profile of and opportunities for multi-disciplinary medical and biomedical engineering research with NHS colleagues and other academic colleagues in ICAHR. Within our current portfolio of projects, we aim to expand our activities in wound management and novel scaffold-based materials, as well as new developments in smart medical devices. For example, new research in real-time and remote wound-monitoring (with Smith & Nephew), and installation of bespoke electrospinning equipment is expected to lead to the development of a number of novel biomaterials for a wide range of different applications, including wound management. Meanwhile our transformatory UKRI (RCUK)-funded work on skull biomechanics is now transitioning from (largely) academic outputs to impact, including application of our methods to novel solutions for cleft lip and palate, craniofacial malformations (e.g. craniosynostosis), and 3Rs replacement of testing of novel biomaterials in cranial defects. An additional approved senior appointment in Medical Engineering will see further expansion of the BE research activities.

In addition to these specific examples of expected developments over the next REF cycle, we will continue to proactively develop links with industry and promote effective technology transfer across the UK and worldwide. Aura is expected to act as a nucleus for that and we anticipate a significant boost in opportunities as Aura's activities expand and its reach increases. Of course we will continue to focus on opportunities that support the UK's priorities, for example, by addressing the relevant Grand Challenges identified in the UK's Industrial Strategy, and by directing our efforts towards the specific priorities of the Research Councils and other international funding bodies and major charitable funders. We will also continue with our efforts to look further forward to new and emerging societal and industrial challenges, both locally and internationally, and prepare for those

opportunities where we can.

We will continue to develop links with other universities and research organisations to promote our work and take advantage of joint research, academic exchange and knowledge sharing opportunities. Similarly, we will continue to develop links with research councils and contribute to theme development and research grant review.

In terms of more immediate, shorter-term actions, we will continue with our strategy to focus our activities and any investment opportunities in our research strengths and priorities. With increasing staff numbers and a recent review and rationalization of degree programmes, we anticipate a substantial reduction in academic staff loading, freeing up more time for research and, in the longer term, allowing us to further build our research activities and community of postgraduate and independent researchers. This REF submission is a step change compared to REF2014, most significantly in terms of the number of staff submitted. We anticipate another step change in our next REF submission, with a significant increase in volume and quality of research submitted.

2. People

A. Academic staffing

Changes and strategy. Two professors and six other members of staff have left since REF2014, and this, together with a strategic investment in Engineering has led to the recruitment of sixteen new members of staff, across all grades, plus eight independent researchers. As a consequence this submission is more than double the size of REF2014. Since the July 2020 census date, four further staff appointments have been made in the Department of Engineering, targeted towards renewable energy and energy storage, including an RAE Fellow in CCS and board member of the new £21M national test facility at Sheffield's translational energy research centre, a Hobart Fellow in nanomaterials from Adelaide, and a new Head of Department. A senior-level appointment has also been approved to further expand the Biomedical Engineering research. These were additional posts to support the University's ambition to expand and develop its Engineering activities, normally, general succession planning, recruitment and retention issues are dealt with through the annual budget round to which departments and research institutes submit plans.

Research fellowships. Five staff benefited from *personal* research fellowships, won in open competition, during the REF period, namely:

- **Blanke:** Deutsche Forschungsgemeinschaft (DFG) fellowship, 2015-2017; now Professor at the University of Bonn.
- **Haywood:** Royal Society Industry Fellowship.
- **Mi:** Royal Society Industry Fellowship, 2012–2016.
- **Moazen:** Royal Academy of Engineering/EP SRC Fellowship 2013-2018; now Professor at UCL.
- **Yong Jiang Huang:** Royal Society KC Wong Fellowship, 2012-2014; now Departmental Director at the School of Materials Science and Engineering, Harbin Institute of Technology, China.

In addition, our research activities have benefited from six Marie Curie Fellowships, all working in CSET.

International staff visits. The following have made extended visits to Hull to collaborate with staff in the UoA:

- Dr Copley (University of Michigan),
- Professor Dendorfer (University of OTH Regensburg),
- Professor Yulong Ding (University of Birmingham),
- Dr Fazara (University Malaysia Perlis),
- Professor Gangadhavan (Sahrdya College of Engineering & Technology),
- Professor Jun Ji (China Natural Science Foundation Council),
- Professor Mehta (Panjab University, India),
- Dr Michopoulos (University of Cyprus),

- Professor Riffat (University of Nottingham),
- Dr Sato (Geological Survey of Japan),
- Dr Volpe (Enna University),
- Professor Witzel (Honorary Professor of Biomechanics & University of Bochum, an annual visitor),
- Professor Zabaniotou (Aristotle University of Thessaloniki),
- Professor Zhiguo Zhang (Ji Nan University, China).

Staff development and support. The University introduced the Academic Careers Framework (ACF) scheme in 2018 which was designed to allow academic staff to be recognised and rewarded for their contributions in the primary domains of research, education or knowledge exchange, with equality in promotion opportunities and personal and professional development regardless of domain. The ACF also provides the opportunity for staff to transfer between domains.

Workload allocation is used to ensure that a balance is achieved between the demands of teaching, administration and research, with early career staff receiving a lower teaching and administration load for typically two years. For more established staff, research time is allocated dependent on the numbers of postgraduates supervised, research grants awarded, research output and the potential for strategic development of new activities. Research targets are established and subsequently monitored during annual staff appraisals.

The University provides a comprehensive staff development programme including research seminars on key funding providers and special funding initiatives, managing research, and postgraduate supervision (compulsory for new academic staff). Within the Faculty of Science and Engineering a series of other initiatives has also been introduced which are open to all, but in particular aim to support new staff in developing their research careers. These include research training opportunities, for example: grant writing and paper writing workshops (run by Thinkwrite), mentoring and leading research teams (run by AdvanceHE), and media training (run by the Conversation), plus writing retreats and improved peer review processes.

As outlined above, maximising research impact is encouraged and supported by the University's Knowledge Exchange team and Faculty Directors of Business Engagement and Enterprise. These not only help with training and practical help in exploitation, but earlier stage identification of potential new areas of impact, and training and advice on mitigating conflicts that can arise within a research impact context, and collecting corroboration for maximising the evidence of impact.

Early career academic and independent research staff. In addition to normal staff development opportunities, early career researchers (ECR) and independent research staff (IRS) are assigned a personal research mentor whose role is to help them establish themselves as a successful, fully-independent academic/researcher within the Academic Career Framework (ACF) established by the University. For example, the mentor is expected to give advice and support on the development of their research profiles, to partner with (and/or suggest other potential internal/external contact(s) who might partner with) the new member of staff to increase their chance of success in attracting research funding, to help polish and optimise funding applications, to provide specific advice on procedures relating to grant applications, to support the process of postgraduate supervision and examination, and encourage participation in University research activities. Probation is dealt with through the standard University staff appraisal system.

Research staff. The University is a member of Vitae and actively supports the Concordat to Support the Career Development of Researchers. It has held the HR Excellence in Research Award since 2012 and its practices align with the principles of the European Charter for Researchers and Code of Conduct for Recruitment. (PhD students are discussed further below). We take regular feedback from the research community through staff surveys, including Careers in Research Online Survey (CROS) and Postgraduate Research Experience Survey (PRES).

Flexible staff and research support. To further support and encourage the research culture and environment within the Faculty, it has introduced Faculty Research Support Funds for academics

(in particular ECRs), post-doctoral researchers *and* PhD students. These funds are used to develop researchers and can cover the costs of conferences, fieldwork, consumables, and pump-priming of research impact projects, for example. The funding supports colleagues returning from parental leave, illness or career breaks especially (and can cover childcare costs). It also offers post-doctoral researchers the chance to develop their personal research profile (rather than solely the grant they work on). In addition, Faculty funds are available to support Visiting Research Fellows, and Faculty Research Awards have been introduced to celebrate all aspects of research success.

Research management. A new research information system (Worktribe) has been purchased since REF2014, streamlining operations and providing research staff with a single source of data on their research. In addition it provides automatic updates to staff website profiles and easy management of Open Access compliance. The University also provides access to Grantfinder, enabling researchers to search for relevant funding sources, identify new funders and identify new funding opportunities.

B. Research students

Research students are at the heart of our research activities. With the primary allocation of UKRI studentships now through CDTs, unfortunately some areas can find it difficult to attract as many PhD students as they would like. However, those that do come to Hull are nurtured and well looked after. The University supports PhD research directly with an annual investment of typically £3M for 50-60 studentships which are now focused to create thematic clusters, encouraging researchers (especially ECRs) to collaborate on projects aligned with University priorities.

Recruitment. PGR student applications in Engineering, Chemical Engineering and EEI are directed towards our priority themes wherever possible. All PGR vacancies, whether funded externally or by the University or Departments, are also advertised externally to ensure we attract the best applicants, who are always interviewed before being accepted for any postgraduate position. These advertisements are placed on academic recruitment websites, such as www.jobs.ac.uk, but in addition on subject specific distribution lists and websites, e.g. Biomech-L for the BE positions. Unsolicited applications to study for a self-funded PhD are also scrutinized carefully with an interview, in person or by video calling services.

One success story is the Aura CDT in Offshore Wind and the Environment funded by EPSRC and NERC which has recently been established in collaboration with the Universities of Durham, Newcastle and Sheffield, and 20 industry and government partners (including Siemens-Gamesa, Ørsted, the Offshore Renewable Energy Catapult and National Oceanography Centre). In addition to approximately 60 core studentships, we have attracted direct industry funding of a further 8 studentship to date. Students enter with a variety of backgrounds, and after studying for a University of Hull PG Diploma in Wind Energy, undertake their PhDs at one of the four partner institutions. These and other industry relationships create and maintain networks that obviously assist our students to transition into industry if they wish to do so.

The PhD cluster in Advanced Wound Care was established in 2017 with Smith & Nephew and involves Biomedical Engineering, Biomedical Sciences, Chemistry and HYMS, and is aimed particularly at multi-disciplinary projects. After an initial allocation of 7 studentships (3 of which came to Biomedical Engineering) the number of PhD students working in this area has now expanded to 13, over half of which are now in the BE group.

In addition to two studentships funded directly by Smith & Nephew in the Wound Care cluster, a number of other positions have been funded directly by industry and other bodies. For example, by Keresa Plantations (Malaysia), Shanxi Jingxu Solar Energy Ltd (China), Suzhou Building Energy Research Institute (China), Diamond Light Source (UK) and a significant number by overseas governments, including 15 supported by the prestigious China Scholarship Council (CSC).

PGR training and support mechanisms. The Doctoral College at Hull is an on-campus purpose-built facility with 24-hour access for research students and their supervisors. Both an administrative centre and a resource, with its own IT and common rooms, it liaises with all University faculties and

departments on matters concerning research students. It also delivers continuing professional development for supervisors, and coordinates an established and fully-comprehensive Postgraduate Training Scheme which enables students to graduate with certificated evidence of their research and employability skills at master's level. Interdisciplinary modules offered by the Doctoral College cover (for example) project management, career development, and enterprise and entrepreneurship skills. An annual 'PhD Experience' conference, organised by students, is hosted by the Doctoral College. The College also offers more informal activities supporting PGR students, for example, PGR Drop-in sessions, a PGR Writing Support Group and PhD Thesis Boot Camp.

The University also promotes the use of the Researcher Development Framework (RDF), developed by Vitae, for both research students and staff – to plan, promote and support their personal, professional and career development – with the Staff Development Unit available to run focussed briefing sessions and more extensive workshops on using the framework.

Within the Engineering areas, PhD students sit with post-doctoral researchers in dedicated Group research offices within the Engineering buildings and normally adjacent to the Group's research labs. With typically 6-10 researchers in each office, this provides an ideal environment in which the PhD students can undertake their research and take advantage of the combined wisdom of their more experienced colleagues. Regular research seminars are held across the University, and within the Engineering subjects, which any researcher can attend, providing the PhD students with the opportunity to understand more what research is being undertaken, and, later on, for them to present their own research.

The University's response to the Covid-19 pandemic included funded extensions for PhD students (and PDRAs if needed), support with IT and workstation equipment for researchers working off-campus, and additional Research Culture and Community Seminars to sustain the research environment while normal university conditions were suspended.

PGR progress monitoring. Each research student is supported by at least two supervisors. Where the project is multidisciplinary (multi-departmental) for example Biomedical Engineering projects, a supervisor from each department will be selected. Progress (in research, training and thesis preparation) is formally reviewed every six months, involving both supervisors and an independent, research-experienced chair – a process which is coordinated and managed by the Faculty. The review meeting finishes with a private discussion between the chair and student to allow the student to raise any issues or concerns they might with the project or supervisor(s). The chair will then follow this up with the supervisor(s), and Doctoral College if necessary. Typically we would expect the submission of one draft chapter or part-chapter every meeting. In parallel with formalised academic monitoring and support, the University has a pro-active student welfare system, which provides an additional support mechanism if the research challenges or any personal well-being issues become too much.

C. Diversity and equality

The University and members of the Engineering groups are committed to equality of opportunity and respecting and promoting diversity for both staff and students. This is championed across the campus by the University's Inclusion and Campus Community Team which manages activities, communications and monitoring to advance this agenda.

The University has an Athena SWAN bronze award, but the Engineering departments are still working on their individual applications. All eligible research staff are returned under UoA12, but because the number of female Engineering staff is low, they are inevitably under-represented in our submission (just 6.6%). There is clearly a long way to go with this, but it is hoped that University staff participation in initiatives such as the Minerva Network for Academic Women, the Women in Higher Education Network (WHEN) and Aurora Leadership programme (AdvanceHE), will eventually improve this. We are embedding policy and support for transgender colleagues with assistance from Gendered Intelligence for training and Stonewall as a member of their Diversity Champion Programme. We have also made significant commitments over the past year in direct

response to both the Equality & Human Rights Commission report on Tackling Racial Harassment and the #blacklivesmatter movement to more thoroughly advance our agenda for racial inclusion. We also remain committed to supporting our staff and students with disabilities and the University is a member of the UK Government's Disability Confident (Employer) scheme.

To support all these activities and raise awareness about equality, diversity and inclusivity (EDI), different training opportunities ranging from online modules to bespoke training packages are offered by the University's Staff Development team. Training participation is compulsory, recorded and reported regularly to all Deans and Heads of Department. For example, relevant modules include Equality and Diversity, Unconscious Bias, Safeguarding in HE, and Research Integrity. Within Engineering, Gilbert has a particular interest in EDI and recently co-authored a [report on EDI](#) in offshore renewables for the EPSRC Supergen ORE Hub, which have led to improved processes in CDT recruitment (and have been recognised by EPSRC) and are being implemented in Engineering.

3. Income, infrastructure and facilities

A. Infrastructure and facilities

The Engineering departments are currently well equipped with bespoke Energy Technology Labs, Biomedical Engineering Labs, Materials and Nanotechnology Labs, Acoustics Lab, Fluid Dynamics Facility, Chemical Plant Simulation Lab and Waste to Energy Lab, for example. The Chemical Engineering labs have recently been relocated adjacent to the Chemistry labs, significantly improving their facilities and providing easier access to a wider range of characterisation equipment. Significant investment in underpinning engineering support services has also been made over the period with the purchase of new CNC machines and a suite of rapid prototyping machines. As discussed in Section 1C above, some of these facilities are now based at the new Aura Innovation Centre including SEM, materials characterisation, PCB, virtual reality and composite manufacturing facilities.

To support health related research, a £28M health campus was completed in 2017. This brings together clinically-focussed research across the University, and is conveniently located adjacent to the main Engineering building. At a similar time, a £3M collaboration with global medical technology company Smith & Nephew (S&N) was formally established (as previously described in Section 1C) to facilitate joint research. Building on the long-standing collaboration between the BE Group and S&N, this also brought in Biomedical Sciences, Chemistry and HYMS and saw the establishment of the PhD cluster in Advanced Wound Care, funded by the University and S&N. To support that activity a dedicated Biomedical Research Lab was also established in the Engineering building to support a number of PhD projects concerned with the development of novel *in vitro* wound models for improved device testing.

In 2019, a new Energy and Environment Building was completed to house the EEI and, provide a dedicated collaboration space for research on environmental resilience and sustainability. In addition, CSET's laboratories were rehoused with bespoke testing facilities for heating, cooling and power systems driven by solar and natural energy, and technology demonstration facilities also housed at the Aura Innovation Centre.

One of the most important investments for Engineering during the REF period, was the purchase of a High-Performance Computer (VIPER) with 5500 processing cores – an investment of £2.9M for the machine and host facilities. VIPER ran its first job in 2016, and to date, over 3.2 million jobs have run on VIPER, consuming 120 million core hours. VIPER is used across Engineering, for example for computational fluid dynamics, high resolution finite element analysis and synchrotron data processing.

In addition to specialist facilities, the University has invested significantly in research equipment across the University to improve and replace redundant equipment and provide support to new research areas. This included redeveloping PGR workspaces, including in some Engineering

areas. Another relatively small but important investment in Engineering in 2019 was the purchase of a replacement nanoindenter and bioindenter (£0.13M), allowing the measurement of mechanical properties of both hard and very soft materials, in particular of biological materials. A specialist 3D printing facility (FabLab) was also established in Engineering (£0.35M), which includes a high-resolution multi-material + digital-materials printer, a printer that can print biocompatible materials, other 3D printers that can be modified for specific research projects and a high specification laser cutter.

The University's Brynmor Jones Library was also fully refurbished in 2015 at a cost of £28M. The library has separate research study areas, a PGR only facility and collaborative working zones, and is open 24/7. The Library also supports internal systems and contracts with external suppliers to meet research data storage and preservation needs through the Research Data Management and Sharing Policy. This includes the provision of research data storage facilities and expert advice on data management plans.

B. Research funding portfolio

During the REF period, the BE and EESE groups have secured grants from a wide variety of sources, reflecting the diversity and broad impact of the research. The different mix of that funding for the groups is summarised in Table 1, followed by a brief comment about that support for each of the five research groups.

Funding sources / total income	Advanced Materials ...	Biomedical Engineering	Chemical Engineering	CSET	Renewable Energy ...
UKRI, Royal Society etc	67%	35%	45%	28%	53%
UK Charities (incl Leverhulme etc)	1%	20%	2%	0%	0%
UK government	0%	20%	26%	42%	10%
EU government	0%	13%	19%	29%	26%
Industry	27%	7%	8%	2%	4%
Other	5%	4%	0%	0%	7%
Total income	£0.95M	£1.98M	£1.95M	£2.80M	£0.74M

Table 1 Table showing the percentage income from different funding sources and total funding over the REF period for the different research groups

Advanced Materials and Acoustics. The group's activities are funded from a variety of sources including: EPSRC(x4), STFC, Royal Society(x2), Royal Academy of Engineering and industry including Jaguar-Landover(x2), Siemens(x4), Baosteel(x1) with total funding over the period of £0.95M, as well as beam time awards from the major synchrotron X-ray and neutron facilities around the world, i.e. Diamond Light Source, ISIS Neutron and Muon Facility (STFC), Advanced Photon Source (USA), European Radiation Facility (ESRF), the Swiss Light Source (value £0.87M). In particular, three notable EPSRC projects were awarded since 2014 (with total EPSRC funding of £2.2M) to support our new initiative on developing ultrasound-based materials processing technologies for metal alloys, 2D functional materials and catalytic esterification of pyrolysis bio-oil.

Biomedical Engineering. This group's research has been supported by BBSRC(x4), EPSRC(x2) and NERC(x2) grants, reflecting the multidisciplinary nature of the work, plus funding provided by the Royal Academy of Engineering, EU(x2), NIHR i4i/NHS(x3), Leverhulme Trust, Wellcome Trust, Action Medical Research and other small charities, plus industrial sponsors and collaborators including Smith & Nephew and Zimmer. The total spend over the period has been £1.98M. In addition, in-kind facility-specific support has been received from ARCHER (UK National

Supercomputing Service), Deutsches Elektronen Synchrotron (DESY DORIS III and PETRA III) – although this is not included in the data return. Research related to musculoskeletal biomechanics has again been particularly successful over this REF period, as it was during the previous REF review. It has again been supported by all three main research councils (BBSRC, EPSRC and NERC) and in total this research (led by Hull) has now received over £8M (awarded to Hull and the projects' co-investigators). Further information on these partnerships and the success and reach of this research is provided in Section 4. The breadth and standing of the journals in which this research has been published also reflects the interdisciplinary nature of the group's work, and the reach of the findings, and include: Nature journals (x3), Royal Society journals (x6), Journal of Experimental Biology (x2), Computer Methods & Programs in Biomedicine (x2), PLoS ONE (x3) and many others.

Centre for Sustainable Energy Technologies (CSET). The Centre's funding over this REF period has been provided by a variety of sources, including EPSRC(x2), EU(x8), Innovate UK(x2), DBEIS(x3), British Council(x2), Newton Fund, Royal Society, and industry partners including China Singyes Solar Technologies and Shanxi Jingxu Renewable Energy Co Ltd, with total funding of £2.80M. During this REF period, CSET has been particularly successful in demonstrating the impact of its research through installation of its patented, novel cooling and heating systems in different environments in the UK and China, as described in more detail in Section 4 below and in an Impact case Study.

Chemical Engineering. Our funding over this REF period comes from a variety of public sources, such as BBSRC(x2), EPSRC(x10), NERC, Research England(x3), EU(x3), British Council(x4), Royal Society(x2), Royal Academy of Engineering, Innovate UK(x4), and industry partners including Alstom, Johnson Matthey and Schlumberger, with total funding of £1.95M. Much of the work of the Chemical Engineering group is industry facing, which is evidenced by the award of 6 KTPs over the period and 2 new KTP projects due to start in 2021, and related contributions to sustainable chemical engineering solutions for efficient energy, fuels/chemicals, materials and feedstock for the benefit of the global society. For this REF submission we have selected two Impact Case Studies from Chemical Engineering's research to demonstrate the impact of our research.

Renewable Energy Technologies and Energy Storage. Funding over the current REF period has come from EPSRC(x2), BEIS and EU(x4), Hull City Council, THYME Teesside, Hull and York Mobilising Bioeconomy Knowledge Exchange, Green Port Hull, Mocean Energy and UK/international government agencies, with total funding of £0.74M. With the recent recruitment of four additional staff (since July 2020) significant additional funding has been secured by this group from sources including EPSRC, BEIS, Innovate UK, EU and UK/International industry.

Our research funding is further complemented by approximately £30M innovation funding awarded directly to the University which enables us to collaborate further with external partners and provides opportunities to drive impact from our research. These investments include £12M for the Aura Innovation Centre and the £17M [Sparkfund](#), an innovation support and grants programme funded by ERDF. These more impact-focused activities have been described earlier in Section 1.

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

A. Overview

Members of Engineering, Chemical Engineering and the EEI recognise the many obvious benefits of collaborative research and the great majority of on-going projects involve collaboration with one or more academic, industry and/or healthcare partners. There is insufficient space to list all those interactions. Instead, *three exemplars* are included to illustrate that commitment and highlight a selection of the contributions to our discipline (and others) over this REF period:

Energy Technologies: A major focus of the EESE Theme is the development of new technologies for renewable energy, improved energy efficiency, and sustainable, integrated heating, cooling and power systems. For example, we have been working with a number of Chinese companies (e.g.

Five Star, Sinogreen, Jinxu), UK companies (e.g. NPS group, PCM) and Hull City Council, and Universities (e.g. Shanghai Jiao Tong, Tsinghua, University of Science and Technology of China) and the China Academy of Building Research (CABR). This research has led to a number of impacts that are addressing some of the greatest challenges facing the world today. Two examples of the output of this research are described in an Impact Case Study. The first of these, a novel super-performance dew point cooling technology, has won a number of awards (see Section 4B below) and has been licensed to Keda Ltd (China) and is now being transferred to PCM (UK) and Aolan (China). A number of buildings in the UK, including the Aura Computer Centre, the Hull Maritime Data Centre, and the Sinogreen Industry workshop, have also installed this technology. The second example is a novel near-zero carbon heating system. Again this technology has won a number of awards (see below) and has been applied in three villages in China and a number of office buildings and data-centres in China and the UK, including Hull University's Library and Applied Science Building. The University is currently working with Group-Atlantic to set up a joint venture to commercialise this technology.

Bone and skull modelling: One of the core activities of the BE Theme is modelling and simulation applied to musculoskeletal biomechanics. For example, we have a particular interest in the modelling of skulls, and they now lead the world in the complexity and biofidelity of their skull models. It is true interdisciplinary research, for example co-authors in this REF period are from dentistry and orthodontics (Dundee), paediatric orthopaedics (Liverpool, London, Oxford, Paris), human and animal anatomy (Aberdeen, Bonn, Chicago, Cologne, Leeds, Liverpool, Paris, York), evolutionary anatomy (Paris, UCL), Palaeobiology (Birmingham, Bristol) and computational biology and bioengineering (Bochum, Shandong). Originally focussed on the modelling of animal skulls, this research is now being applied to clinical applications, including novel research into dental biomechanics, cleft lip and palate, and craniosynostosis. Meanwhile, other 3Rs research (replacement, reduction and refinement of animal experiments) is now working to replace animal experiments which are still widely used to test new biomaterials and dental and orthopaedic devices.

Other bone modelling work is (for example) researching the growth and development of the human femur, including an investigation into the biomechanical causes and potential prevention of Legg-Calvé-Perthes' disease in young children, while fundamental computational biology models are being used to understand the interaction of cells in diseases such as multiple myeloma.

In a tangential development we are using our VOX-FE bone modelling software, developed at Hull, to examine the possibilities of biomimetic design of the internal structures of wind turbine blades, as part of an EPSRC Prosperity Partnership Project "A New Partnership in Offshore Wind".

Fault detection, diagnosis and fault-tolerant control: Another core activity within the EESE Theme is Control and Intelligent Systems Engineering (C&ISE), which has extensive expertise in the development of new theories and application studies using mathematical techniques for the diagnosis of faults in uncertain and non-linear systems. C&ISE members continue to develop new tools to ensure that fault effects can be estimated robustly in the presence of modelling uncertainty and bounded disturbance, and compensated within active fault tolerant control (FTC). Since 2014 work has focussed on application of FTC methods to enhance reliability, whilst optimising energy capture of offshore wind turbines. Several important contributions have been made, again most recently through the EPSRC Prosperity Partnership Project in Offshore Wind (2017-2022). In 2015 a new project on wave energy conversion (WEC), developed with our own scaled device, was modelled and tested in the University's wave tank. This work, using Gaussian process machine learning control for wave force estimation and energy enhancement, was one of three final entries in the WEC control competition ([WECCOMP](#)).

B. Evidence of contribution to the discipline and leadership

The following non-exhaustive list provides further examples of the wider activities and contributions to the research base, economy and society provided by members of this UoA.

Editorial board membership and book editorships: For example, **Ibhadon** is on the editorial

boards of *Catalysis and Synthesis*, and *Chemical Technology and Biotechnology*. **Jaganathan** is a Biomaterials editor for *Open Chemistry* and on the editorial board of *International Journal of Polymer Analysis and Characterization*. **Langley** is on the editorial board of *Biomedical Physics and Engineering Express*. **Ma** was a member of the editorial board of the *Journal of Energy* of the American Association for Science and Technology (2014 to 2016). **Mi** is on the editorial board of review of *Metallurgical and Materials Transactions*, and was the lead editor on the first technical book on *Solidification Processing of Metallic Alloys under External Fields* (Springer Nature, 2018) which has so far attracted over 5000 paid downloads. **Patton** serves as a subject editor for *International Journal of Applied Mathematics & Computer Science*, and subject editor of *International Journal of Adaptive Control & Signal Processing*. **Skoulou** is the Guest Editor for a number of special editions, for example, *Sustainability* on: the use of bioenergy-biofuels originated waste for value added feedstock; biochar and bioenergy; and sustainability and resilience to climate change hazards and gender equality. **Stevenson** is on the editorial board of *International Journal of Chemical Engineering*. **Zein** is on the editorial board of eight journals including *Natural Science*, *Journal of Applied Sciences*, *Trends in Applied Sciences Research*, *Research Journal of Nanoscience and Nanotechnology* and *Current Research in Chemistry*. **Zhao** has served on the editorial boards of a number of journals during the REF period, and is currently a board member of *Energy*, *Renewable Energy*, *Energies*, and *Journal of Architectural Research and Development*. **Zhu** was the editor for a special issue of *Energy* on: Scientific and Technological Advances in EU and China; and Guest Editor for a special issue of *Energy* on: 2018 EU-China Symposiums on Renewable Energy/Sustainable Energy and Energy Storage Technologies.

Keynote and invited lectures: Staff have given many keynote and invited lectures around the world, and organized a wide variety of sessions and symposia. For example, **Ibhadon** was invited to give a plenary lecture at the *Green Chemistry and Engineering Conference* (2016 Washington). **Li** delivered a plenary lecture at the conference of *Alternative Energy Sources, Materials and Technologies* (2019 Sofia). **Ma** gave a keynote lecture at the *EU-China Symposium on Renewable Energy/Sustainable Energy and Energy Storage Technologies* (2018 Hull). **Mi** gave a plenary lecture at the *8th International Conference on Electromagnetic Processing of Materials* (2015 Cannes). **Patton** gave plenary lectures in Auckland at the IEEE/ASME Conference on *Advanced Intelligent Mechatronics* (2018), and in Xiamen on Fault Tolerant Control at the 2019 CCA *Safeprocess Conference*. **Zhao** has also delivered a number of keynote lectures during the period, including those at the *2nd International Conference on Materials Technology and Manufacturing Innovations* (2018 Moscow), the *18th International Conference on Sustainable Energy Technologies* (2019 Kuala Lumpur) and the *International Energy and Environment Summit* (2017 Dubai). **Zhu** was invited to give a keynote lecture at *Data Centre World* (2018 Hong Kong).

National/international advisory panel and academic group membership: Over the REF period, staff have undertaken a number of key advisory roles. For example, Haywood (recently retired) was the President of the Engineering Professors Council (2015-2017), gave evidence to the UK Government's Education Select Committee on [Brexit and Higher Education](#) (Jan 2017), and organised the 2016 EPC Congress at Hull. **Ibhadon** is a member of DEFRA's *Expert Panel on Chemicals*, and recently provided expert advice to the Department of Business Energy, Innovation and Skills (BEIS) on plastics. **Langley** is a member of the international *Consortium for ECG Imaging* in particular working on atrial arrhythmias. **Paulson** is a member of the *International Telecommunications Union UK Study Group 3*, and is a co-author of the influential 2017 *UK Climate Change Risk Assessment Evidence report* (for telecommunications), and is currently working on the 2022 version. **Skoulou** is a member of the Management Committee for the *COST action for the Establishment of a Pan-European Network on the Sustainable Valorisation of Lignin*. **Zhao** is an executive board member of the *World Society of Sustainable Energy Technologies*, a steering committee member of the *European DHC (District Heating and Cooling) Technology Platform*, European Heat and Power Association, and an expert panel member of the *International Academic Exchange Information Centre*. **Zein** is an Academic Adviser to the *Commonwealth Scholarship Commission*. **Zhu** is a member of the *World Society of Sustainable Energy Technologies*.

Participation on grant reviewing: All academic staff review for a large range of national and international grant awarding bodies regularly, including the main UK research councils and

charities. Many are members of the *EPSRC Peer Review College*. In addition, the following sample illustrates other contributions: **Langley** served on the *2019 EPSRC Healthcare Impact Partnership panel*, and **Mi** served on the *EPSRC 2018 Centre for Doctoral Training Outlines panel*, the *EPSRC Engineering Prioritisation Panel (2018)* and the *EPSRC Future MAPP Hub mid-term review (2020)*. **Fagan** was an invited member of the *ERC LS7 Advanced Research Grants panel (2007 to 2015)* and continues to regularly review for other ERC bio/medical funding panels. **Ke** reviews applications for the *British Council Newton Fund*. **Patton** served on the *EPSRC Review and Prioritisation Panel for the Joint UK-China Offshore Renewable Energy (ORE) call*. **Zhao** is a Member of *EPSRC Engineering Prioritisation Panel* and an external advisor on the *Newton Fund China Collaboration programme*, and advises a number of other international funding bodies.

Prizes and awards: Members of the UoA have received a number of prizes and awards during this assessment period, the most significant of which are: **Ma** and **Zhao** were awarded the *Rushlight Energy Reduction Award (2019)*. **Oko** won the prestigious *Ludwig Mond prize* in 2015 for their Humber CO₂ pipeline design. **Zhao** also won the *WSSET Innovation Awards* in 2016, 2017 and 2018, the *EU Dragon Star Innovation Award in 2015*, and the *UK Newton Prize Finalist Award in 2019*.

Institutional fellowships and senior memberships and other external recognition: Most staff returned under this UoA are members of professional bodies and hold chartered engineering status. In addition, during this REF period: Haywood (recently retired) became an Honorary Fellow of the IET. **Patton** holds a prestigious lifetime Fellowship of the Institute of Electronic & Electrical Engineers (IEEE) for research contributions to fault diagnosis and fault tolerant control, is a Senior Member of the American Institute of Aeronautics and Astronautics, and is a Fellow of the Institute of Measurement and Control. **Ibhadon** holds two visiting professorships at Panjab University (2016 to present) and Sholini University (2016 to present) in India. **Stevenson** is an Adjunct Associate Professor at the Centre for Energy, University of Western Australia (2013 to present), and Visiting Professor at the School of Petroleum Engineering, China University of Petroleum (2013 to present). **Zhao** is a Fellow of the European Academy of Sciences, a Fellow of the Energy Institute, a Fellow of Chartered Institution of Building Services Engineering, a Fellow of World Society of Sustainable Energy Technologies and held a number of Honorary Professorships during the period. He also appeared in the 2017 most highly cited researchers in Web of Science, one of only five in an Engineering subject in the UK.