

<b>Institution: Imperial College London</b>
<b>Unit of Assessment: 12 Engineering</b>
<b>1. Unit context and structure, research and impact strategy</b>

### 1.1 Unit context and structure

Engineering at Imperial College London (referred to here as the Unit) consists of 9 academic departments (420 FTE – see Table 1), which together with Computing (submitted to UoA11) make up the Faculty of Engineering (FoE). Although these departments are organisationally distinct, they operate within a shared strategic management framework for teaching, research and enterprise.

**Table 1 Academic departments within the Unit and number of submitted FTE staff**

Department	Abbreviation	Submitted FTE
Department of Aeronautics	AER	33.13
Department of Bioengineering	BIO	54.0
Department of Chemical Engineering	CHE	44.1
Department of Civil and Environmental Engineering	CIV	58.9
Department of Earth Science & Engineering	ESE	45.79
Department of Electrical and Electronic Engineering	EEE	54.7
Department of Materials	MAT	47.15
Department of Mechanical Engineering	MEC	56.2
Dyson School of Design Engineering	DES	26.0
	<b>Total</b>	<b>419.97</b>

**The strategic vision for the Unit** is “to perform world-leading fundamental research in core engineering disciplines, supported by computation and experiments, that addresses the most challenging problems facing the world, and to translate the results into sustainable solutions and practical applications”. We do this across length and time scales – from the atomic and molecular to the industrial scale, and from picosecond measurements of reactions to understanding the Earth’s behaviour over millions of years.

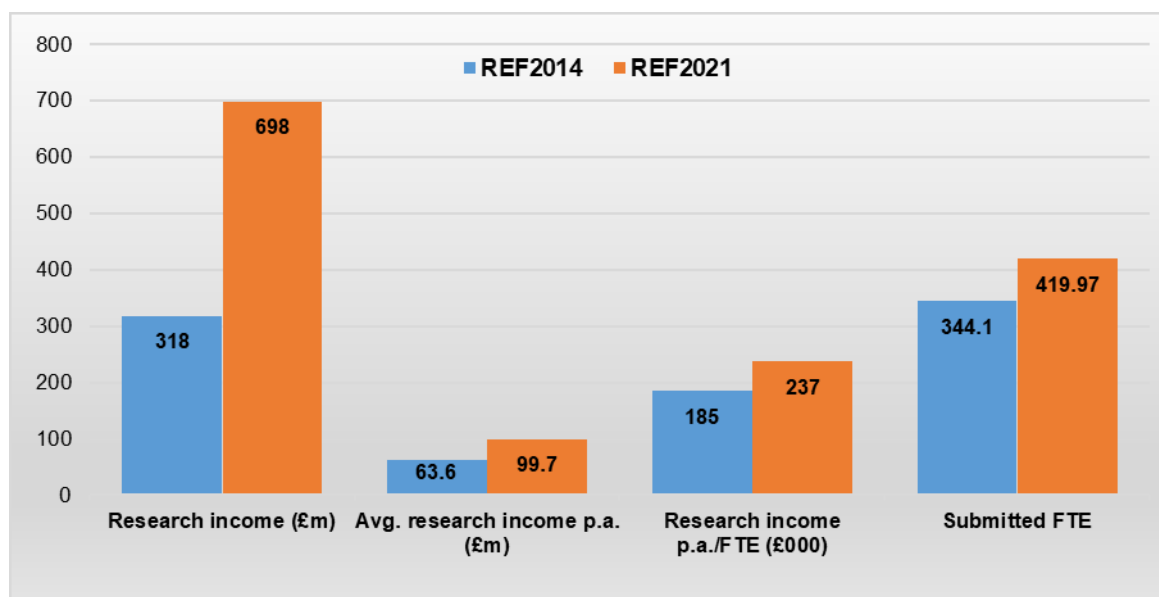
The quality and vibrancy of our research is reflected in the award of 5 Royal Academy of Engineering Emerging Technology Chairs since 2018 (*Titirici, Greenhalgh, Stan, Stevens and Demiris*). Our strategy of sustainable growth in new and emerging areas of engineering, combined with continued support of core engineering disciplines, has been enabled by a total research income of £698m over the REF2021 period, compared with £318m for REF2014. The annual average research income increased by 57% to £99.7m and the annual research income per FTE by 28% to £237,000 (see Figure 1). Research translation achievements over the REF period include the formation of 23 new startup companies, 97 licence agreements, filing of 227 patent applications and 218 patents granted.

The vitality of our research environment has resulted in an enormous array of achievements, substantial growth in strategic priority areas and the launch of a new academic department – the Dyson School of Design Engineering (DES).

Our research highlights include:

- A new turbine design for Mitsubishi Heavy Industries (MHI) which began series production in 2016 with 2.2 million units produced to date, and which received MHI’s Best Innovation Award (Impact Case Study [ICS] 14 Low Emission Road Vehicles).

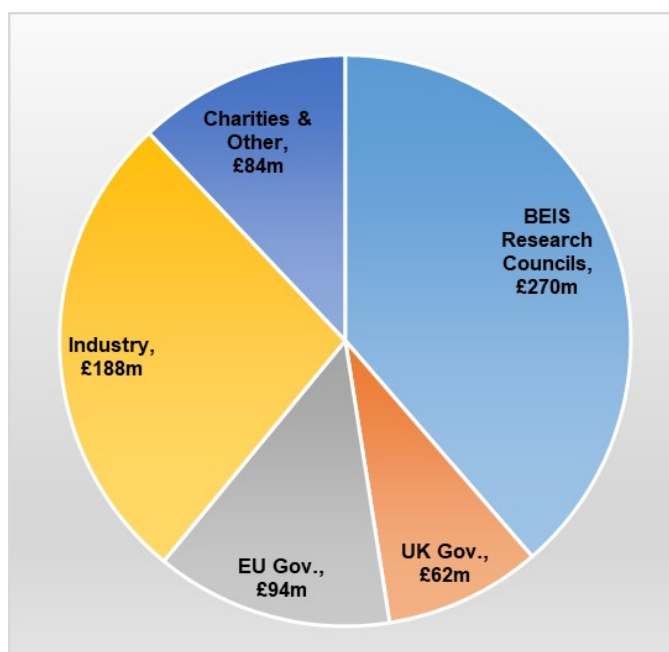
- A novel extrusion process for producing curved, lightweight structural components, helping to reduce the carbon footprint for many forms of transport, including automotive and aerospace.
- Launch of the PharmaSEL Prosperity partnership with Eli Lilly supporting research into improving efficiency and reliability in the manufacture of medicines.
- A lab-free test for Covid-19, which after validation in a clinical trial, was rolled out across the UK NHS and is now routinely used in 500 hospitals (ICS03 Bioelectronics).
- New surface engineering strategies to significantly increase the thermal stability of therapeutic proteins: which are applicable to producing heat-stable vaccines, including the Covid RNA vaccine.
- Bouncy Bioglass – a new self-healing material for cartilage regeneration: this is 3D printed into a device for regenerating torn cartilage in sports injury patients and is currently in pre-clinical trials.
- The Personal Robotics Lab, supported by an RAEng Chair in Emerging Technologies, has developed perception and control algorithms for personalising robot assistance to humans in need. Targeted domains include personal mobility (smart wheelchairs) and activities of daily living, such as assistance with dressing.
- Conceiving and demonstrating a structural material that has the capacity to store and deliver electrical energy providing the potential for structural power applications in an enormous range of products, including phones, cars, computers, aircraft, medical devices and infrastructure.
- Providing leadership to NASA's Mars Science Laboratory Curiosity rover mission, including the protocols for life detection in the solar system, influencing the strategy for its exploration, and supplying microseismometers for the first investigation of the internal structure of another planet (ICS11 Mars Exploration).



**Figure 1 Comparison of REF2014 and REF2021**

The number of staff FTE submitted rose from 344 to 420, including 73 early-career researchers (ECRs). The number of postdoctoral research assistants/associates (PDRAs) increased by 28% to 542, and the postgraduate research student (PGR) population rose by 35% to 1,493, equivalent to 3.6 per staff FTE. Over the REF period, we hired 82 new academic staff, 49 from internal research fellows or postdoctoral positions. This growth in research activity was underpinned by significant investment in facilities, particularly in DES and at the College's new White City Campus, a research and innovation ecosystem with an emphasis on co-location of academic and commercial research (see Section 3.2.a and institutional environment statement). Our efforts to increase diversity within our academic staff, including the introduction of design engineering as a key focus

for the Faculty, have resulted in the proportion of submitted female staff increasing from 15.6% to 18.1%, and the proportion of BAME staff rising from 13.4% to 17.2%.



**Figure 2 REF2021 research income by source**

Over the REF period, we have developed a sustainable and diversified research income portfolio of UKRI, EU and charitable funding (see Figure 2) that supports fundamental research and advances the intellectual boundaries of engineering disciplines. Our reputation for rigorous, fundamental research in turn attracts high-quality industrial sponsors. Industrial funding forms a significant proportion (27%, £188m) of our research income.

## 1.2 Research strategy

The Faculty's guiding strategy at the time of the REF2014 submission was driven by "targeted sustainable growth" (2015-18 strategic plan), involving growth in emerging and multidisciplinary research, combined with continued support of core engineering disciplines. Key growth areas included advanced materials, artificial intelligence and machine learning, bioengineering (including engineering biology), design engineering, fluid and solid mechanics, sensing and detection, robotics, and systems engineering. The strategy was achieved through:

- expanding academic staff numbers in key multidisciplinary growth areas and maintaining strength in breadth and depth of core engineering disciplines;
- investing in new and upgraded facilities;
- diversifying funders and consolidating major programme research;
- building on and deepening our strategic partnerships with industry;
- developing and supporting future research leaders.

To consolidate achievements in these areas, the strategy from 2019 onwards has had a particular focus on "delivering impact and excellence in research and translation". The Faculty has engaged fully with the wider College strategy, in particular through the Global Institutes (see Section 4.5). It has also worked closely with other College Faculties (Medicine, Natural Sciences and the Business School); collaborative research with Medicine has been particularly productive, exemplified by the Unit's role in the Dementia Research Institute (for this and other examples see Section 1.2.a).

Major milestones towards implementing the strategy have included the launch of a new academic department, the Dyson School of Design Engineering (26 submitted FTE, 268 undergraduates, 182 PGT students and a research team of 53 PGR students and 18 PDRAs). In addition, expansion of the Department of Bioengineering (from 33.5 submitted FTE in REF2014 to 54 in REF2021) has provided new state-of-the-art laboratory space at the White City Campus in the £130m Sir Michael Uren Biomedical Engineering Research Hub (part funded by a £40m donation from Sir Michael Uren). Creation of the Dyson School realised a major strategic objective of embedding design thinking, creativity and innovation throughout the Faculty of Engineering's research and educational programmes. The period also saw: completion of the refurbishment of the City and Guilds building housing the Departments of Aeronautics and Mechanical Engineering with new state-of-the-art research facilities; construction of new research facilities in Department of Materials (1,000m<sup>2</sup> as part of the Henry Royce Institute at White City, total investment £10m); and a complete overhaul of the research translation and commercialisation arrangements (see Section 1.3).

## Unit-level environment template (REF5b)

The Faculty's research strategy is overseen by the Faculty Research Committee (FRC). The FRC consists of the Directors of Research from each department and the Global Institute Directors and is chaired by the Vice-Dean for Research. The committee advises on new strategic initiatives (detailed below), shares best practice in support of research (e.g. policies for support of ECRs) and serves as a forum for discussing research matters across the constituent departments, e.g. sharing best practice regarding on-campus research during the Covid-19 pandemic.

In early 2019, following cross-department away-days and workshop discussions on future strategic initiatives, the Faculty launched 4 new themes, embracing cross-cutting interdisciplinary research spanning departments and focusing on major global challenges:

- Transition to a sustainable zero-pollution economy;
- Engineering resilient and secure infrastructure;
- AI and machine learning for engineering applications;
- Affordable technologies for an ageing society.

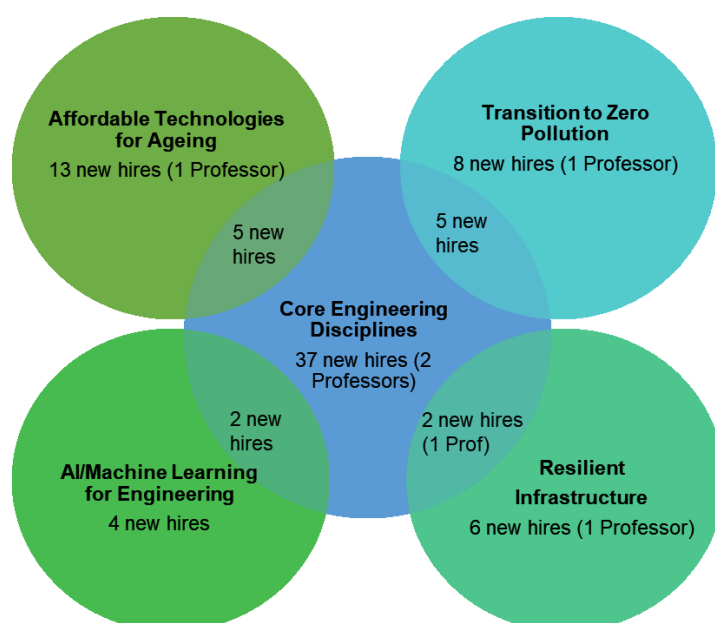


Figure 3 Recruitment by strategic priority area

These themes map on to the College's Academic Strategy areas of Sustainable Society, Resilient Society, Smart Society and Healthy Society (see the institutional environment statement). Researchers from across the 9 departments are supported through networks and research facilitation workshops in these thematic areas, and early-career academics are given opportunities to take leadership roles, for example through participation in College Networks of Excellence, Centres and Institutes (see Section 4.5). The Unit has also influenced the College's strategic priorities and "Transition to a sustainable zero-pollution economy" is the first major initiative launched under Imperial's new Academic Strategy.

Recruitment of the 82 new academic appointments was achieved through a combination of "growing our own" and hiring internationally (see Figure 3).

In terms of research management, the 9 departments share a common high-level strategy: to encourage sustainable growth and to achieve critical mass in targeted research areas, through 3 levels of increasing scope and scale:

- **Exploratory research** with departmental support for new ideas and research areas (typically 1-3 years duration, <£100,000 p.a.; 830 awards amounting to about £40m in the REF period), by internally funded PhD scholarships, PDRAs and Imperial College Research Fellows (ICRFs), leading to:
- **Developmental research:** larger projects, in or between research groups, funded by industrial consortia, UKRI or other sources (typically 3-5 years duration, £100,000-£1m p.a.; 1,025 awards amounting to about £350m), with UKRI studentships and Research Fellowships, for example from Royal Academy of Engineering, Royal Society or UKRI. This research level is supported by investment to enhance research facilities. From this project scale, targeted, strategic activities grow into:
- **Programme research:** large and long-term (typically 5 years or longer, >£1m p.a.; 143 awards amounting to about £300m) industrial research centres or UKRI Programme-type activities within or across departments, and beyond the College. At this scale, departmental

and College support includes significant strategic investment in staff, space and new laboratories, for example, the Faraday Lab (see Section 3.2.b[v]).

### 1.2.a Achievement of strategic aims since REF2014

The achievements described below are structured according to the Unit's strategic aims.

Achievements relating to the aim of "delivering impact and excellence in research and translation" (2019 onwards) are described in Section 1.3, "developing and supporting future research leaders" is addressed in Section 2.1, and "investment in new facilities" in Section 3.2.

#### (i) Growth in key areas of multidisciplinary research and maintaining breadth and depth in core disciplines

- Bioengineering:** We have recruited 21 new academics in this department since 2014; this rapid growth was accommodated in the new Sir Michael Uren Biomedical Engineering Research Hub at the White City Campus. Growth areas included **Implants and regenerative medicine** (4 new appointments) and establishment of the UK Regenerative Medicine Platform (UKRMP2) Smart Materials Hub (co-led by *Stevens*), as well as 2 Imperial College Networks of Excellence (see Section 4.5), the Stem Cell Regenerative Medicine and the Wound Healing and Regeneration Networks. **Neurotechnology** research was expanded through founding the EPSRC Centre for Doctoral Training in Neurotechnology for Life and Health (led by *Schultz*), which helped to establish the UK Dementia Research Initiative Centre and the UK Dementia Research Initiative Care Research & Technology Centre (DRI-CRT, £20m from Dementia Research Institute). The DRI-CRT combines artificial intelligence, engineering, robotics and sleep science to create new technologies that will deliver the highest quality dementia care in the home. **Engineering biology** (Synthetic Biology) was grown by hiring 2 new academic staff, establishing the Imperial College Centre of Excellence for Synthetic Biology, renewal of SynbiCITE (EPSRC/Innovate UK) and an RAEng Emerging Technologies Chair (*Stan*). **Cancer engineering**, the embryonic IBME Network in Cancer Engineering, was expanded into an Imperial College Network of Excellence (co-led by *Tang*) and funds around 10 PhD studentships a year, as well as research training fellowships, at the interface between engineering/physics and cancer biology/oncology.
- The Dyson School of Design Engineering:** A new academic department, established in the Faculty of Engineering during the REF period, is submitted to REF for the first time. The School grew out of the Innovation Design Engineering MSc (running for more than 30 years in collaboration with the Royal College of Art) and research in MEC. During the REF period, the key goals for DES, which have all been achieved, were to establish the School, generate sustainable research activities, and build the facilities required to support them. DES was conceptualised and proposed in September 2013 and launched in 2014. A £12m donation from the James Dyson Foundation and £43m from Imperial enabled the purchase and refurbishment of the 7,000m<sup>2</sup> Dyson Building on Exhibition Road, South Kensington, adjacent to the Science Museum and the College.
- Key applications of fluid and solid mechanics:** Six specialised appointments were made focusing on reductions in aircraft emissions, noise and weight, 3 appointments were made in BIO, on fluid and solid biomechanics, and CIV made 7 appointments in fluid mechanics, allowing expansion of research activities in strategically important areas including coastal engineering, large-scale ocean mixing, marine renewables, urban fluid mechanics and building optimisation. *Jardine* developed new paradigms in the design of offshore wind turbine monopile foundations, receiving the prestigious 2017 BGA Fleming Award for research, and having a substantial impact on the design of a number of the world's largest offshore wind farms (see ICS02 Geotechnics). The EPSRC Programme grant "Multi-scale Exploration of MultiPhase Physics In FlowS (MEMPHIS)" led by *Matar*, resulted in 112 publications and an Imperial College President's Award and Medal for Excellence in Research 2016.



- Advanced materials:** Sixteen new appointments (15 in MAT, including 1 professor, and 1 professor in CHE) in Ceramics, Nano, Biomaterials and Sustainable Materials were made and associated lab space increased by 1,000m<sup>2</sup> by using new space at the White City Campus. Programme research developed includes: the Shell-Imperial Advanced Interfacial Materials Science (AIMS) Centre (March 2016 with £3.2m, see Section 4.4.a); EPSRC SUPERGEN Fuel Cells Challenge “Control of structure, strain and chemistry: A route to designer fuel cell interfaces” (*Skinner*, £1.1m); a nuclear engineering EPSRC Programme “MIDAS – Mechanistic understanding of irradiation damage in fuel assemblies” (*Dunne, Balint*, led by Manchester, £7.2m); EPSRC “Designing alloys for resource efficiency” (DARE) project (*Dye* is Imperial lead on £3.2m award); EPSRC grant (with Manchester and Oxford) on “Heterogeneous mechanics in hexagonal alloys across length and time scales” (Principal Investigator [PI], *Dunne*, £5m) with Rolls-Royce, TIMET, Westinghouse, EDF and Magnesium Elektron. Programme research in materials testing and processing, particularly aluminium forming, was expanded, building on the £5m investment from the Aviation Industry Corporation of China (AVIC), generating a further £8.4m for research on creep age metal forming, additive manufacturing of metallic structures, state-of-the-art welding technologies, lightweight transparent materials for aircraft, high-speed trains and other vehicles, impact-resistant composite materials for aircraft, including fibre metal laminate materials and fundamental research on batteries. The EPSRC CDT in Advanced Characterisation of Materials (Director, *Skinner*, joint with UCL) was renewed in 2019 providing essential research training in this area. Research facilities were upgraded with cutting-edge equipment supported by EPSRC and the Unit (see Section 3.2).
- Robotics:** Research across the Unit (and in UoA11) was expanded, for example through the Hamlyn Centre (Medical Robotics, Co-director *Baena*, £27.9m total funding including an EPSRC Programme grant and strategic equipment for a College micro-robotics facility) and consolidated through the Robotics Forum, whose members include 44 research groups and labs across the College. Aerial robotics research was grown with support for new research projects from EPSRC, ONR, The Royal Society, CEC, UKAEA and completion of the Micro-robot flight arena (see Section 3.2.b.iv). Additional growth was achieved through leadership of an EU H2020 (EDEN, €8.3m) Research and Innovation Action for robotic-assisted precision neurosurgery, developed directly from an ERC grant (*Baena*) and the development of a total shoulder replacement system (Wellcome Trust funded, £1.4m). Programme-level research grants include, *Jeffers* (PI on £4.8m funding and £2m NIHR professorship – the first engineer to win this award), 2 RAEng Emerging Technology Chairs (*Demiris*, human-centred robotics and *Lomuscio* [submitted to UoA11]). Three startup companies were established: Additive Instruments Ltd (2019), Athletec Ltd (2018) and Serg Technologies Ltd (2019). Within DES, the Robot Intelligence Lab (lead *Kormushev*) was set up specialising in research at the intersection of Robotics and Machine Learning, focusing on the design, control and intelligence of autonomous robotic systems (see Section 3.2 on research facilities).
- Sensing and detection:** An Electromagnetic and Biochemical Sensors Network was established to contribute to sensor research and development in these areas (the value of this was highlighted in the past year with the need for Covid-19 testing). We increased work on permanently installed monitoring systems for non-destructive evaluation (NDE): the NDE group expanded its work with permanently installed monitoring systems and monitoring technology, which was taken up by industry as a key research theme within the UK Research Centre in NDE (RCNDE: industry–university research centre, led from MEC, renewed in 2014, £5.3m EPSRC, £3.5m industry). The NDE group also led the multi-university CDT in NDE (EPSRC, £3.3m, renewed 2014). We hired a new lecturer in NDE and 2 early-career lecturers won EPSRC fellowships: an £11m EPSRC Interdisciplinary Research Collaboration in Early-Warning Sensing Systems for Infectious Diseases (renewed in 2018 for £3.9m, in addition to follow-on Programme-level projects involving Imperial worth £2.4m); work in *Stevens’* group produced the first class of biodegradable silica-based “nanoneedles” capable of penetrating cell membranes efficiently and safely to deliver sensitive biocargoes or monitor intracellular pH and enzyme activities. *Rodriguez*

*Villegas's* work on wearable sensors for diagnosis and management of respiratory conditions, and other applications, led to 2 startup companies (Acurable and Tainitec) and an award of the RAEng Silver Medal. ABB funded a 3-department collaboration (CHE, EEE, DES) on future sensors for the water industry (£900,000).

- **Systems engineering:** Research in the **Centre for Process Systems Engineering** (CPSE) has flourished during the REF period covering design, control and optimisation accounting for safety, sustainability, uncertainty and emission reduction utilising robust multi-parametric control techniques, sophisticated multi-objective optimisation algorithms, as well as novel dynamic simulation methods that leverage the use of hybrid and machine-learning approaches. This has been extended to cover molecular systems engineering through the establishment of a College Institute co-directed by *Adjiman* (resulted in an £11m programme funded by Eli Lilly and UKRI Prosperity Partnership for systems-based methods for innovation in the pharmaceutical industry). CPSE research has also been recognised through the award of the IChemE Sargent Medal to *Shah* (2019). Furthermore, the company spun out from CPSE research, Process Systems Enterprise, was acquired by Siemens for more than £100m in 2019 (see ICS15 Process System Engineering). The **Centre for Systems Engineering and Innovation** (CSEI, Co-directors *Whyte* and *Mijic*), established in 2010 to provide a hub for work that brought systems approaches to civil infrastructure, has developed research on cyber-physical complexity, interdependencies between infrastructure systems in water and transport, and the potential for projects to act as interventions and a catalyst for change in infrastructure.

## (ii) Investing in new and upgraded facilities

This is covered in detail in Section 3.

## (iii) Diversifying funders and consolidating major programme research

Although the overall profile of our funding is similar to that for REF2014 (see Section 3.1.a), the period saw increases in funding from the EU (from 11% to 13%), UK Government (7% to 9%) and charities (10% to 12%). The increasingly multidisciplinary nature of the Unit's research opened up new funding streams, including in the healthcare field (NIHR, Royal British Legion, Wellcome Trust, MRC and BBSRC), industry (AVIC, Dyson Ltd, P&G and Eli Lilly) and private donations (e.g. James Dyson Foundation, Sir Michael Uren). Some key highlights are given below.

- **Energy:** The award of the 5-year EPSRC Programme grant, IDLES (PI *Green*), coordinated by the Energy Futures Lab (see Section 4.5), combined with 3 new academic appointments in the field, is providing the evidence needed to facilitate a cost-effective and secure transition to a low-carbon future. It has also enabled major international collaborations with partners in India and China (Section 4.3).
- **Transport:** We grew and diversified Programme-scale research grants in transportation engineering and its effects, for example:
  - A 4-year project on developing smart sensing, analytics and predictive modelling to aid planning and optimisation for the urban habitat, funded by the Singapore National Research Foundation (*Sivakumar* with *McCann* [submitted to UoA11] £2.5m).
  - £1.1m from Innovate UK, Department for Transport, Met Office, NERC and EU H2020 for road transport and aviation pollution.
  - Research on public transport system performance within the Transport Strategy Centre has led to substantial improvements in the design, management and operations of mass transit systems in the world's largest cities (see ICS09 Mass Transport).

- **Materials:** Composite materials research has grown to Programme level (>£10m) with 3 related grants addressing improved mechanical performance:
  - EPSRC NextCOMP Programme grant £6.2m (*Robinson*) targeting improved compression strength.
  - Multifunctional composites (RAEng Emerging Technologies Chair in Structural Power, *Greenhalgh*), and several research grants (EPSRC, Clean Sky, EOARD, £1.7m).
  - EPSRC Engineering Fellowship for Growth (*Pinho*) for toughness and manufacturing challenges in composites.

Research on metals and alloys was grown through:

- EPSRC Programme grant, “Heterogeneous mechanics in hexagonal alloys across length and time scales” (*Dunne*, £5m) with Rolls-Royce, AWE and SERCO.

And functional materials research expanded and consolidated through:

- SPIN-Lab, an EPSRC underpinning equipment grant (*Heutz*, £1.9m).
- The team (*Breeze*, *Alford*) that developed the first room temperature MASER (2012) progressed the technology to demonstrate a *continuous-wave* oscillator which is optically pumped, opening up the possibility of a new generation of microwave devices for applications in medicine, sensing and quantum technologies.

- **Engineering biology:** Growth and consolidation was achieved through establishment of the Imperial College Centre of Excellence for Synthetic Biology. The Centre (36 research groups across 6 departments from the Faculties of Engineering, Life Sciences and Medicine) is the largest critical mass of world-class synthetic biology academics in the UK. Funding includes: UKRI investment of £21.4m and RAEng funding of £2.7m. It jointly leads the DHSC-funded Future Vaccines Manufacturing Hub with the Faculty of Medicine. In line with ambitions to increase our capabilities in biotechnology and engineering biology, new hires included *Ouldrige*, *Polizzi*, *Ceroni*, *Papathanasiou* and *Elani* (UKRI FL Fellowship) and a new EPSRC CDT was launched (Co-I, *Stan*, £6.67m). *Stan* was awarded an RAEng Emerging Technologies Chair in this area.
- **Blast injury research:** We have developed the Royal British Legion Centre for Blast Injury Studies (£6.8m over REF period) to address the disabling injuries of conflict with a clinically-led approach. The Centre is led by *Bull* and comprises unique multidisciplinary collaborations of military medical officers and civilian engineers and scientists from around the world, all of whom are dedicated to investigating the difficult research issues surrounding blast injury. The Centre attracted major new funding of £5.2m in 2016 from the Royal British Legion as well as from EPSRC (Injury & Reconstruction Biomechanics Test Suite, PI *Masouros*, £1.3m) (ICS07 Blast Injuries).

#### (iv) Building on and deepening our strategic partnerships with industry

As described in more detail in Section 4, enterprise culture is deeply embedded across the Unit and this has enabled a substantial growth in industry-sponsored research (total research income from industry has grown from £96m in REF2014 to £188m in REF2021). Our strategy has been to grow and deepen long-term strategic partnerships, building on strong relationships with a collaborative, solution-focused approach to addressing the major challenges facing companies. There are now strategic partnerships with 24 companies and managed relationships with a further 11 companies. Some key developments are summarised below:

- Industrial collaborations have been converted into more strategic partnerships: for example, ABB funded programme research on water industry sensors and co-funds the IDLES Programme grant, and Huawei-funded projects culminated in a 10-year funded Chair (*G. Li*). Imagination Technology funded an RAEng Research Chair (2014) and PETRONAS now sponsors the Centre for Engineering of Multiphase Systems.
- Three new industry-University Technology Centres (UTCs) have been established in engine research with Caterpillar (2015, £1.2m), Mitsubishi Heavy Industries (2016, £1.7m) and Jaguar Land Rover (2017, £1.7m).



## Unit-level environment template (REF5b)

- The Vibration UTC joined the Cornerstone Prosperity Partnership with Rolls-Royce and Oxford and Nottingham UTCs (£13.5m, £3.1m to MEC).
- Tribology research has been expanded significantly: the SKF and Shell UTCs were renewed (total £5.8m). Other industrial support in the area now exceeds £3.5m in total. A startup company, TriboSim, was incorporated in 2018.
- The Resource Geophysics Academy was established in 2019 with Programme research funding (£11.3m) from China Petroleum and Chemical Corporation (SINOPEC). This will support 40 PGR students over 5 years.
- The 10-year \$70m Qatar-Shell QCCSRC project was concluded, followed by launch of the £7.8m Shell-funded Digital Rocks Lab.
- ABB donated the ABB Imperial Digital Energy Demonstrator (>£1m), a combined research and teaching facility for future low-carbon energy systems.

## (v) Developing and supporting future research leaders

The Unit has given a high priority to developing the next generation of research leaders. Details are provided in Section 2.

### 1.2.b Future strategic aims and goals for research

The future strategic aims of Engineering at Imperial build on the vision described in Section 1.1 with a focus on:

- maintaining world-class excellence in core engineering disciplines;
- supporting multidisciplinary research to address global challenges;
- maintaining existing and establishing new world-class research facilities;
- growing and consolidating our translational research;
- continuing to develop and support future leaders in engineering research.

The depth of our disciplinary research, together with the infrastructure for transdisciplinary collaboration through Institutes, Centres and Networks, means that Engineering at Imperial is well placed to tackle major research challenges. Central support and facilitation of new initiatives is provided through the Faculty Research Committee and the Research Strategy, and Industry Partnerships and Commercialisation teams.

Future plans involve developing our major research priorities into cross-Unit developmental- and programme-level research activities.

Specific goals for the next REF period are described below, structured by the Unit's strategic aims.

### (i) Maintain world-class excellence in core engineering disciplines

A thriving body of research in core engineering disciplines provides the fundamental advances needed to drive innovation and provide solutions to major societal challenges. We will continue to support excellent core discipline research across all fields of engineering; the following are *just a few* examples of planned new developments:

- In **materials** research within the Henry Royce Institute (EPSRC, £10m), we will foster collaborative cross-disciplinary research by consolidating groups into a single, multidisciplinary, functional- and nano-materials activity including 3 teams, each led by European Research Council (ERC) award recipients.
- Increase significantly exploratory and developmental research in **aeronautical sciences**: personal and aerial robotics, machine-learning, sensing and AI for enhanced urban environments. Grow significantly research in space engineering, including satellite propulsion, deployable space structures and space resource utilisation.

- Build on the Programme research (£11m, Eli Lilly–UKRI Prosperity Partnership) in **molecular systems** to develop novel, difficult-to-manufacture medicines such as peptides. Diversify catalysis-, reaction- and electrochemical engineering research by leveraging the rEaCt CDT and the White City Campus Molecular Sciences Research Hub.
- Develop research **modelling geotechnical infrastructure** incorporating big data analytics to produce design guidance for industry (e.g. road/rail embankments and cuttings, geological disposal facilities for nuclear waste and thermo-active structures) incorporating climate change and soil behaviour.
- Evolve **seismic processing methods** using full-wave seismic inversion to better image the Earth's subsurface at high resolution. The work will utilise an industrial research grant from Sub Salt Solutions of £1.6m to advance understanding of the generation of fracturing and the fate of fractured rocks. These techniques are being translated to application in brain imaging with support from the President's Excellence Fund for Frontier Research and are the subject of ICS05 Full-Waveform Inversion.

## (ii) Support multidisciplinary research to address global challenges

- **Affordable technologies for an ageing society**
  - Consolidate research that improves quality of life for an ageing society, supporting the College and Faculty strategies. We will grow further funding for biomechanics and robotics, specifically for orthopaedics, medical procedure robotics, and robot–human interfaces. BIO has established a new research group in this area – Perioperative and Ageing Group – with a founding philanthropic donation of £1.25m.
  - Further grow engineering biology, building on the RAEng Emerging Technologies Chair (“Accelerating engineering biology: Efficient engineering of reliable and high-performance biosystems” [PI *Stan*, £2.7m]). And also expand application-focused research on bio-processing and bio-medical applications carried out by *Ceroni* (“Synthetic biology for bio-medicine and bio-production”), *Polizzi* (“Biosensors, biopharma and ageing”) and *Yetisen* (“Medical bio-materials for diagnostics, therapeutics, and imaging”).
  - Grow the Hamlyn Centre’s collaborative research with Medicine on clinical applications of robotics and maintain support for biomechanics, specifically for orthopaedics, medical procedure robotics, and robot–human interfaces.
  - Grow research in very-low-power electronics and algorithms for personalised medicine, supported by communications systems for ubiquitous, secure, private and sustainable connectivity.
- **AI and machine learning for engineering**
  - Grow further computational methods for novel solutions to transition to a low-carbon energy future. This will build on the hybrid/multi-fidelity and data-driven models for managing fully renewable electricity systems across the manufacturing, energy and healthcare sectors (EPSRC Programme PREMIERE, £6.56m) integrating provision of heat, electricity and transport.
  - Grow research on personal assistive robots, building on the RAEng Emerging Technologies Chair in this area (*Demiris*).
  - Expand EEE’s work in applied AI and robotics by making at least 2 new academic appointments in these fields. Develop applications of AI in wireless communications and in energy systems by establishing new research groups in each of these areas.
  - Launch a major new multi-department research hub (Imperial-X) on the White City Campus, building on opportunities from the convergence of new digital and computing technologies, and bringing together staff, students and researchers from industry (Imperial-X is covered in more detail in Section 3.2.a).

- **Zero pollution**

- Energy Futures Lab's forward-looking research strategy is to develop and support research of societal benefit that enables the transition to a sustainable and low-carbon energy system, in line with the Unit's strategy for sustainable and resilient infrastructure and the transition to a zero-pollution economy. Decarbonisation is a major challenge in energy systems and must be tackled under the framework of sustainability. Our goals for research development match this level of ambition. To this end we have identified 3 areas of focus that we view as vital: i) net zero carbon emissions across all energy sectors; ii) sustainability in energy technologies and systems; and iii) digitalisation of energy systems through cross-cutting research to support advanced digital technologies that will underpin the energy transition.
- Respond to the challenging environmental demands facing aviation, refocus hybrid transport/aircraft gas turbine research by integrating current research into reducing emissions, friction and weight, and optimising aerodynamics, power-train and transmission efficiency (by leveraging established UTCs: Rolls-Royce Vibration, Shell, SKF and AVIC, and the new Caterpillar and Mitsubishi UTCs). Develop exploratory and developmental research in fundamental technologies and system-level optimisation required for electric and hybrid electric aircraft, building on our world-leading research on structural batteries and higher-order methods for fluid mechanics; this will be complemented by new targeted appointments in this incipient domain. Align activities with the UK Fly Zero programme by engaging with Airbus (via *Iannucci's* RAEng Research Chair) and related supply chain companies, and developing a Structural Power Storage programme through *Greenhalgh's* RAEng Emerging Technology Chair.
- We will expand integrated Programme research in alternative and synthetic fuels, nuclear power, battery technology and waste heat recovery. We will recruit a new lecturer to research in fluid mechanics related to energy efficiency and the reduction of CO<sub>2</sub>, and further develop computational tools for offshore wind turbine array modelling through an EPSRC Fellowship (*Buxton*, £1.29m).
- Grow sustainable battery manufacturing research (*Titirici*, RAEng Research Chair in Emerging Technologies, *Payne*, EPSRC grant £1.3m, Reduced Energy Recycling of Lead Acid Batteries) leveraging current Faraday Institution projects (*Offer*, Li-STAR, "Extending battery performance past the limits of Li-ion batteries", £9.86m), Royal Academy of Engineering and industry funding, and integrating with research into electric/hybrid electric aircraft, and sustainable biomass and waste conversion processes.
- Build on EPSRC-supported Sustainable Plastics Network award (PI *Hallett*), developing collaborative Programme-scale research activities across the Unit, for example between CHE and DES on the design for a greener plastic future (*Baxter*, *Hallett*).
- Launch new research programmes on urban ecosystems services, systems approaches to zero pollution, and plastics sedimentology.

- **Resilient infrastructure**

- Grow research into advanced construction materials and structural analysis, targeting enhanced technical performance, greater efficiency, new methods of design and manufacture, longer life, and reduced greenhouse gas footprint for lower initial and whole-life cost infrastructure. This will leverage the 2016-21 £9m EPSRC equipment grant for an Advanced Infrastructure Materials Lab and 4 new academic appointments (*Buchanan*, *Martinez-Paneda*, *Myers* and *Wu*).
- Combine our diverse smart cities research (planning, design, development, testing and inter-mobility) into an integrated research programme to address the capacity, safety, security, and environmental and economic requirements of future cities.
- Expand our research into sustainable and resilient water systems by developing new and optimising existing treatment technologies, distribution systems, mathematical

**Unit-level environment template (REF5b)**

modelling tools and land management practices. We will apply these to resolve global water supply problems in urban, remote and economically developing regions.

- Grow resilient and sustainable transport activities with a focus on urban transport systems as a service, reducing carbon emissions and optimising user experience. We plan to expand our benchmarking of mass transit systems to include environmental performance and to grow our research into tackling air pollution, for example through Imperial's NExAir air quality network.

**(iii) Maintain existing and establishing new world-class research facilities**

The Unit's plans under this heading are described in Sections 3.2 to 3.5.

**(iv) Grow and consolidate translational research**

The support described below (Section 1.3.a) for building our relationships with industry will enable growth of translational research across the Unit. A few specific examples are highlighted here:

- The new translation facilities at the White City Campus will allow the co-location of research and industry partner offices, enabling new academic–industrial collaborations, creating new opportunities for joint ventures and startups, and consolidating multi-department digital activities into a single research hub (Imperial-X).
- Translation of the full-wave seismic geological imaging research to medical imaging applications in complex physiological settings (links to ICS05 Full Waveform Inversion).
- Develop and implement the translation pathway for process engineering research from the experience of CPSE startups, Lixea Ltd (formerly Chrysalix Technologies), Quaisr, Exactmer and AlphaCells Biotechnologies Ltd.
- Utilise Digital Rocks' imaging methods to optimise exploitation of existing oil and gas reserves during the net zero transition and enable subsurface storage of carbon dioxide (CCS) by investigating a range of rock-fluid imaging techniques linked to modelling at multiple length scales. The work builds on the £8m research grant (2016–20) provided by Shell: a further £3.2m has been committed for Digital Rocks Phase 2 (2021–24).

**(v) Develop and support future leaders**

Recruiting and developing outstanding staff, particularly ECRs who have the potential to become international leaders in their field, is a central goal of our people strategy, which is described in detail in Section 2.

**1.2.c Delivery of strategic aims and research goals**

Collectively, the Faculty of Engineering Directors of Research form the FRC, which is responsible for advising the Faculty Management Committee (FMC) on research matters. At a departmental level, progress and delivery of the research strategy is overseen by the Director of Research (DoR) supported by a departmental Research Committee made up of senior, research-leading academics.

These committees:

- promote a vibrant and positive research culture across the department;
- keep abreast of emerging trends in the disciplines and funding opportunities;
- monitor large proposals in preparation to ensure the necessary support is made available;
- make recommendations to the departmental executives on shared capital equipment expenditure;
- work with the departmental services and safety managers to align the provision of technical services with the research needs;
- make recommendations to the Heads of Department on strategic recruitment of new staff;



- oversee support of early-career academic staff and postdoctoral staff.

The DoRs and Global Institute Directors serve as a conduit for information and strategic advice between the FRC and the departmental Research Committees, and with College-level initiatives and the College Research Committee (CRC). They also take the lead in publicising research opportunities, monitoring industrial interactions and funding opportunities, organising research away-days and co-ordinating the communication of the department's research activities to potential sponsors. The DoRs are members of academic staff appointment panels; the recruitment of excellent research staff at all levels and their effective support (see Section 2.1.b) is a crucial mechanism for the successful delivery of our strategic goals.

### 1.3 Enabling and facilitating impact

A key priority for the Unit is to maximise the impact achieved by its research on industry, government and broader society. This is in line with Imperial's overall founding mission "to provide the highest specialised instruction and the most advanced training, education, research and scholarship in science, technology and medicine, especially in their application to industry". We generate impact via:

- direct industrial application of research findings, often coming from industry-funded research contracts;
- the formation of startup companies to commercialise the intellectual property generated by research;
- third party licensing;
- improvement of health outcomes by the application of research findings, either directly by clinicians or via industrial products;
- consultancy;
- the establishment of standards;
- influence on government or agency policy;
- outreach activities encouraging interest in science and engineering and appreciation of the value of investment in research.

The reach and significance of the Unit's impact is illustrated by the summary of Impact Case Studies in Table 2.

**Table 2 How ICSs submitted exemplify different industry sectors and routes to impact**

ICS no.	Short title	Direct industry use	Industry-research partnership	Startup	Licence	Healthcare	Consultancy	Government/regulatory/standards	Outreach	Main sector
01	Building resilience	•	•					•	o	Construction
02	Geotechnics	•	•				o	•		Energy
03	Bioelectronics			•	o	•	o	o		Healthcare
04	Corrosion monitoring	o	o	•				•		Oil and gas
05	Full-waveform inversion	•	•	o	•				o	Oil and gas
06	Aero-engine performance	•	•				o			Aerospace
07	Blast injuries	•				•				Healthcare
08	Digital rock	•	•	o						Oil and gas
09	Mass transport	•	•				o	o		Transport

## Unit-level environment template (REF5b)

10	Bioglasses and toothpaste	•				•	o	•		Healthcare
11	Mars exploration							•	•	Space
12	Instantaneous wave-free ratio				•	•		o		Healthcare
13	Energy system	o					o	•		Energy
14	Low-emission road vehicles	•	•	•			o			Transport
15	Process system engineering	o		•						Chemicals

(• primary route; o additional route)

We have in place specific mechanisms that support our staff to generate impact from their work. Perhaps the most fundamental component of our approach to impact is the creation of a culture within the Unit in which the importance of impact is fully understood by all staff and is fully reflected in our processes of staff recruitment, development, promotion and reward. This is complemented by training programmes in translation and commercialisation.

The specific mechanisms used to create and promote impact include:

- (i) **Reorganisation of industry partnerships and technology transfer support:** Imperial took advantage of the end of the intellectual property pipeline agreement with AIM-listed Imperial Innovations Ltd (now part of IP Group) to take the technology transfer office back in-house in 2019 under the College's Enterprise Division, expanding support from the Faculty-based Industry Partnerships and Commercialisation (IPC) teams and building on our highly successful record of industry-funded research. This means industry and academics have one point of contact for research partnerships and technology licensing. The team support academic staff to maximise the impact of Imperial's research and technologies, promote Imperial's research capabilities, manage relationships with strategic partners, and negotiate research partnerships and commercialisation agreements. The team now comprises 11.8 FTE (4.5 FTE partnerships, 6.5 FTE tech transfer, 0.8 FTE admin support).
- (ii) The College encourages entrepreneurship through the **Founders Choice scheme** and has recently reduced the equity it takes in startups from 50% to 5-10%. This has led to 8 companies being formed from the Unit in the past 18 months (CURVEX, Sonobotics, Biomex, Additive Instruments, Breathe, SERG, TOffeeAM and Quair), compared with 15 over the previous 6 years. We have also created a new role of Associate Dean for Enterprise covering the whole Faculty to encourage technology transfer activity and to be the academic lead in tailoring support from the IPC team to meet the needs of staff; the inaugural post-holder, *Cawley*, has founded 3 startups from his research, one of which was a case study in REF2014 and another is a case study in this submission (ICS04 Corrosion Monitoring).
- (iii) **Engagement and collaboration with industry:** Consistent with the College mission, worldwide industry – and hence the global economy – is the major beneficiary of our research. We recognise that the probability of research outcomes being translated to industry is greatly increased if the relevant companies have co-created the programme, either funding it directly themselves or jointly with government agencies. Therefore, our strategy is to seek industrial engagement in our research. This has raised £166m in new research contracts from industry over the REF period from a wide spread of industry sectors (the £166m comprises new awards rather than income which is returned in REF4). Strategic partnerships with key industry players are a particularly effective means of translating research to industrial practice because these long-term relationships foster trust, and many of the researchers involved go on to work for the companies. This is also helped when Doctoral Training Centres operate in parallel with the research relationship. For example, over the REF period, 7 PhD graduates and PDRAs have joined the company staff from the Rolls-Royce University Technology Centres. There are 14 industry-funded centres in this Unit with annual funding of >£500,000 per centre. As shown in

Table 2, 7 of the submitted case studies originate from substantial industrial research partnerships.

**(iv) Intellectual property and commercialisation:** Academic staff are supported to create, build and invest in pioneering technologies, combining the activities of technology transfer, company incubation and investment. Staff disclose inventions to the IPC team (Imperial Innovations Ltd pre-2019) prior to publication; the IPC team then discuss the best route to impact and whether patenting is appropriate and, if so, they manage the process and cover the costs on behalf of College. They discuss the most appropriate exploitation route, which is usually a licence agreement with an existing company or creation of a new startup company. This mechanism has been very successful with 227 patents filed from research in the Unit over the REF period and 97 new licence agreements signed. Staff from the Unit are involved in 23 startup companies formed over the REF period; these are not yet mature enough to warrant individual case studies in this submission, but startup companies formed in the period 2000–13 form the basis of 4 case studies and contribute to a further 2, as shown in Table 2. Staff are encouraged to undertake up to 1 day a week consultancy work, and this is a key means of ensuring that our research work is used by industry. Imperial Consultants Ltd is wholly owned by the College and is the vehicle by which most consultancy work is undertaken. A total of 351 staff from the Unit have undertaken 2,560 consultancy projects with industry over the REF period at a value of more than £38m. Consultancy has assisted the generation of the impact described in 7 case studies, as shown in Table 2.

**(v) Management and incentives:** Leadership is crucial to the promotion of impact and the Dean of Engineering (*Brandon*), Associate Dean for Enterprise (*Cawley*) and Heads of BIO (*Bull*) and ESE (*Sephton*) have each contributed to case studies (ICS14, 04, 07 and 11 respectively). They will continue to strongly encourage research translation to industry via a variety of mechanisms:

- each department has an academic enterprise champion whose role is to discuss potential routes to technology transfer with staff in the department and to link with the Associate Dean for Enterprise and the IPC team;
- impact is a major criterion for promotion, alongside research papers and teaching;
- Chemical Engineering has established an internal translation seed fund;
- impact is discussed at all annual appraisals, together with an exploration of the extent of industry contacts, what key industrial problems to address have been identified, what avenues to impact are being explored, what consultancy work is being done;
- impact is a standing agenda item at all departmental management committee and staff meetings;
- consultancy, particularly that associated with technology transfer, is actively encouraged.

Staff are financially incentivised to generate impact through the College's Reward to Inventors policies. Intellectual property (IP) generated by staff is owned by the College and upon successful commercialisation and generation of revenue streams the Reward to Inventors scheme ensures the individuals involved in creating the IP receive a share of the revenue (see Table 3). In 2020, the reward scheme was updated to better incentivise serial inventors, several of whom are based in this Unit. The review of the reward scheme also led to the reduction in startup equity taken by College, as discussed above.

**Table 3 Revised Reward to Inventors scheme (2020)**

Cumulative College revenue	Inventors	Department/Faculty
Up to £50,000	100%	0%
£51,000-£999,000	80%	20%
>£1m	60%	40%

## 1.4 Research impact outcomes

Over the REF period, the Unit's contributions to impact have been substantial, and reach beyond the Impact Case Studies included in our submission. For example, 16 startups founded within the Unit were sold generating about £30.5m of income to the College (the total return to shareholders generated is much larger; we have records relating only to the College's equity). Students (PGR and MSc) are fully engaged in the Unit's enterprise culture and 135 student entrepreneurs formed 118 startup companies during the REF period. Startups involving PGR students include: Aeropowder Ltd (2018), the world's first feather-based thermal packaging material under the brand "pluumo"; and The Tyre Collective (2020), a mitigation solution for tyre particulate pollution.

In many instances, impact has been enabled and facilitated through the UKRI-funded Impact Acceleration Accounts (IAAs). The Unit supported 166 IAA projects during the period with nearly £9m. Some of these have produced impressive results, demonstrated by the examples below:

- [Lixea Ltd](#) (formerly Chrysalix Technologies), co-founded by *Brandt-Talbot* (Chemistry), *Gschwend* (CHE) and *Hallett* (CHE), commercialised a process that enables wood waste to be used for the production of renewable chemicals, materials and fuels, with £78,000 feasibility study funding from the EPSRC IAA. Lixea has developed a low-cost ionic liquid to enable large-scale production of bio-derived materials, paving the way for a greener alternative to the petrochemical industry. The company has been recognised with funding from the Royal Academy of Engineering Enterprise Fellowship, the EU's H2020, the European Clean Technology Business Prize (2016) and was a finalist in the IChemE Business Startup Awards (October 2020).
- [Serg Technologies](#) (*Vaidyanathan*, MEC) was founded in 2019 and centres on a wearable neuromuscular sensor which it is commercialising for treatment of Parkinson's disease, control of artificial limbs, and gesture recognition for next-generation computer interface. Drawing from £127,000 in EPSRC IAA support, the development team has filed for 3 patents (1 issued, 2 pending), secured pre-seed venture investment, and won research awards from the NIHR, Innovate UK and MedTec Superconnector. Current income exceeds £1.7m with valuation several times greater. The core technology was further awarded the National Health Service (NHS) Innovation Challenge Award and has been featured for innovation by the BBC and ITV. It was also invited for presentation at 10 Downing Street and the New Scientist Festival.
- [Bumblebee Power](#) (*Mitcheson*, EEE) developed a 700W wireless charging prototype for a Govecs ride-on electric scooter in 2018, building on 6 years of wireless power research. The demonstrator was exhibited at IEEE Wireless Power Week 2019, and was the main demonstrator for our startup, Bumblebee Power Ltd, when talking to investors. Bumblebee is currently finalising its seed round and has developed a partnership with Voi, an electric scooter operator in Europe with the intent to perform field trials of the technology by summer 2021.

## 1.5 Open research environment

Imperial is committed to promoting an open research environment and has played a leading role in open access (OA) discussions with publishers (see institutional environment statement). Each department within the Unit has a designated OA champion who serves as a local point of advice within the framework of the College's Open Access and Research Data Management policies, which are overseen by the Scholarly Communications Office. The OA champions have promoted an open research environment which has contributed to the Unit's vibrant research culture, evidenced by the high level of OA compliance for our research outputs (96.4% of in-scope outputs submitted are OA compliant). Open research has been promoted, for example, by: *C. Jackson* (ESE) using EarthArXiv for rapid dissemination of Earth science and planetary science research,



## Unit-level environment template (REF5b)

which provides a preprint server and has created a volunteer community devoted to open scholarly communication; and the KIOS Centre of Excellence has developed experimental testbeds on power, transportation, water and cyber-security systems that are open and accessible to third parties (academic and industrial) to experimentally assess their solutions.

In addition, *Haynes, Alford* (MAT) and *Gorman* (ESE) served on the Research Data Management working group that established College policy and supported research data infrastructure. *Sherwin* (AER) is Director of the Research Computing Service established during the REF period. This service includes a Data Repository, which provides long-term curation of datasets with a persistent DOI suitable for citation in academic literature.

### 1.6 Research integrity

Oversight of research integrity at an institutional level is the responsibility of the Vice-Provost for Research, advised by the College Research Committee, on which the Faculty's Vice-Dean for Research sits, and supported by the Research Office (see institutional environment statement). Each academic department within the Unit is governed by the College's Research Integrity policy, and policy matters are the responsibility of the FMC (with advice from the FRC), with individual cases being handled by the relevant Head of Department (HoD).

The College is a signatory to the Concordat to Support Research Integrity and is committed to maintaining the highest standards of rigour and integrity in all aspects of research, including support for the professional development of postdoctoral researchers. Directors of Research in each department are kept up-to-date on Concordat policies via presentations at the FRC.

Ethical review of research proposals takes place within Imperial's [Ethics Code](#) of practice; any research involving human subjects, animals or human tissue is reviewed by the Research Ethics Committee. To address technology-focused research involving human subjects, a second Research Ethics Committee was established in 2018 (the Science, Engineering and Technology Ethics Committee) and a communications strategy implemented across the and Faculty to raise awareness of the need for ethics approval in non-medical research involving human subjects. The new committee and awareness campaign was highly successful, resulting in an increase in all ethics applications from an average of 16 p.a. to 67 p.a. in 2019–20.

Imperial is a signatory to the [San Francisco Declaration on Research Assessment](#) (DORA) and has introduced policies to further its implementation across the institution, including ensuring that our recruitment and promotion procedures do not use journal-based metrics in assessing individual researchers. Two members of the Unit served on the College DORA Advisory Group (*C. Jackson, Xu*) established in 2017 to provide guidance on implementing DORA within the College, and DORA has been discussed by both the FMC and FRC (which supported the College in becoming a signatory).

## 2. People

The Faculty of Engineering's (submission made to UoAs 11 and 12) people strategy has been developed under the Faculty's 5-year (2018–23) plan and aims to recruit and develop the best researchers internationally, developing our own future leaders, combined with selective recruitment to grow new priority areas. Our strategy:

- builds an inclusive culture in which everybody in our community can be their authentic selves, and are supported to create a flourishing, vibrant and diverse research community;
- identifies, cultivates and empowers emerging leaders to develop and deliver major research programmes;
- develops staff to support effectively the people they lead.

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To ensure that we reflect the value of our staff in our remuneration packages, we benchmark against the world's top engineering schools, provide a transparent and fair pay review process overseen by the Dean to ensure equity across all departments in the Faculty, and offer competitive pay and benefits packages. We recognise specific financial challenges for ECRs in London and offer assistance with relocation and housing, as well as College-based nursery provision. In addition, staff are supported in applying for, and have been successful in winning, the President's Awards (see Section 2.1.f) and prestigious fellowships and prizes (see Section 4.6.a).

### 2.1 Staff development

The Faculty of Engineering at Imperial College London recognises that staff development at all levels is core to sustained delivery of research excellence. Our commitment is fully aligned to the 3 principles of the Concordat to Support the Career Development of Researchers (of which we are a signatory) and their obligations: environment and culture; employment; professional and career development. We have committed to implement actions that satisfy (and go beyond) our obligations as defined in the Concordat. The College Committee for Researcher Development is chaired by the Vice-Dean for Research for Engineering and works to support Faculties and departments in creating the best culture for its researchers to thrive and to implement the Concordat action plan. Career development of academic staff, research fellows and students is managed through consistent and transparent processes at department level and supported by Faculty and College professional development programmes and the Graduate School (see Section 2.2.d) and are detailed below.

#### 2.1.a Development of academic staff and research fellows

##### (i) Mentoring and support

All academics and research fellows have an academic line manager plus an independent mentor to support and advise on their career development. They are given access to a wide range of professional development and coaching provision, tailored to their needs throughout their career. The College's award-winning Postdoctoral and Fellows Development Centre (PFDC) has created a suite of bespoke training for our ECRs including career planning, professional development and advisory services for research fellows. The PFDC supports the Imperial College Research Fellows (ICRFs) through additional cohort activity and training (see Section 2.1.c).

Specific coaching for leadership and developing confidence has included sessions with a trained drama and vocal coach: following this support several academics went on to secure ERC grant or EPSRC fellowship funding.

##### (ii) Training and appraisal

All staff discuss their career development at an annual meeting with their line manager. This includes: creating a Personal Review and Development Plan (PRDP); discussing their overall performance; setting agreed targets for the forthcoming year; and ensuring that support and training is in place to help meet those targets. This encourages recognition of achievement as well as guidance for addressing any weaknesses for promotion or development. This may include, for example, professional development courses, enhanced mentoring, financial support or reallocation of duties. The PRDP process is independent of, but informs, the annual salary review and promotions processes.

##### (iii) Promotions

Over the REF period, 370 promotions were made within the Unit. Female staff (18.1% of the submitted staff, details below) account for about 27% of annual promotions. Promotion cases start within departments; each department has a committee made of representative staff who consider the cases and all eligible staff are discussed. Constructive feedback is provided on each case

## Unit-level environment template (REF5b)

which may include improvements to the case or delaying the application with specific guidance for strengthening the case.

Mock interviews are provided, with feedback to prepare candidates for promotion. All applications for promotion are considered annually by an independent promotions panel to ensure equal treatment across the College. Following the formal College interview, an interview is held with the HoD to give feedback. This supportive process means that few applications are unsuccessful, but any unsuccessful candidates are supported at departmental, Faculty and College level, and guided with a personal development plan discussed and agreed through the PRDP process.

Personal fellowships are an important route to permanent positions, and research associates are supported to apply for these highly competitive schemes. Over the REF period, 58 research associates were promoted to research fellow. Recognising this strength in our postdoctoral community, we encourage suitably qualified research staff to apply for available permanent academic positions; 49 such internal appointments were made during the REF period. We actively support the careers of promising postdoctoral researchers through mentoring and training.

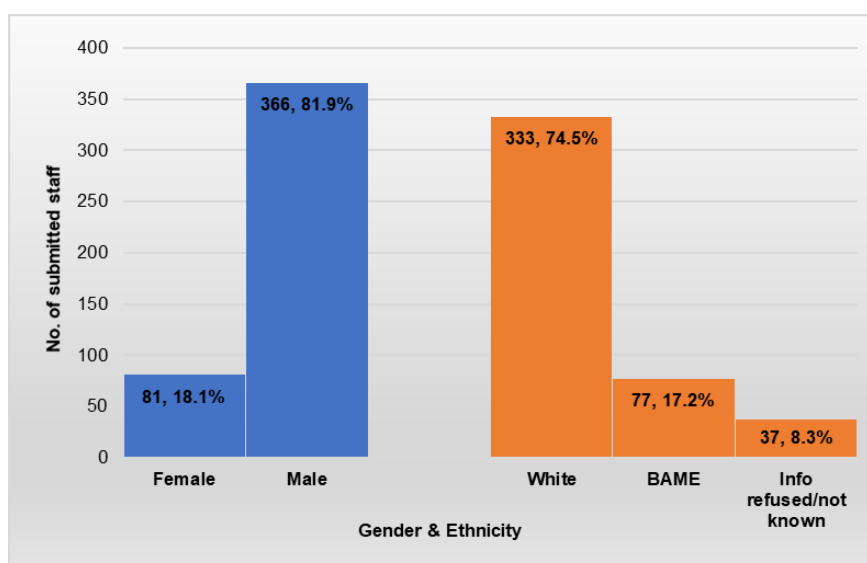
Other promotions over the REF period were:

- 98 Lecturers were promoted (currently among the REF submitted staff within the Unit, there are 66 lecturers, of which 27% are female) to Senior Lecturer (currently 87, 23% are female);
- 77 staff promoted to Reader (currently 78 Readers, 14% are female);
- 55 staff promoted to Professor (currently 172 Professors, 15% are female).

### 2.1.b Staffing and recruitment policy

The key priorities of our staffing policy are: to attract a diverse community of the highest-calibre staff from around the world; to develop the potential of staff at all career stages; and to foster a stimulating environment that enables world-class research and training. Recruitment of academic staff and fellows focuses on our strategic priorities (see Section 1.2) including multidisciplinary research to address global challenges.

#### (i) Demographic profile



**Figure 4 Demographic profile of submitted staff by gender and ethnicity**

The demographic profile of submitted staff in the Unit is shown in Figure 4. The Faculty of Engineering recognises that it has a lower proportion of female staff (18.1%) than the College submitted female staff (23.8%) and is taking active steps to increase the proportion of female

## Unit-level environment template (REF5b)

academics appointed. These include identifying and contacting potential female applicants; providing compulsory unconscious bias training for the selection and interview panel members; ensuring the use of gender-neutral language in communications and adverts; and taking into account known under-claiming of competencies in female applications through the shortlisting process.

As a result, the staff gender balance has improved steadily during the REF period from 15.5% to 18.1% submitted female staff. It should be noted that the staff turnover is relatively low, only about 16 people (<5%) retire or leave each year, which doesn't allow rapid changes in the demographic distribution. The Faculty encourages strong research staff to apply for available permanent academic positions, and 12 of the 49 (25%) internal appointments were female.

The HoDs are appointed for an extendable term of 5 years and are generally appointed from within departments following consultation with staff.

### (ii) Contract distributions

Our submitted staff are predominantly on full-time open-ended contracts (91% of male staff and 86% of female staff), but part-time working to support work-life balance and creating time for translation or impact-generating activities is fully supported when requested. The breakdown of submitted staff by contract level is: professor 40.7%; reader 17.4%; senior lecturer 19.5%; lecturer 14.8% and researchers who are on research only contract 7.6%.

### (iii) Staff recruitment and retention

Staff recruitment and retention are planned strategically to maintain international excellence in current activities and allow for expansion into new priority areas. In each department, strategic investment in salaries and facilities allows recruitment and retention of internationally leading researchers. Start-up support includes fully funded PhD studentships, provision of specialised labs and facilities, and departmental funding of £2.6m over the REF period.

### (iv) Key joint appointments

Joint appointments are used to promote interdisciplinarity and links to our key stakeholders including in industry and policy. There are 5 joint appointments between departments within this Unit, and a further 6 with other submitting Units in the College. Five joint appointments with other universities, of which 2 are international, connect our research to key partners worldwide. As well as joint appointments of our staff we also have a significant number (103) of Visiting Professors, 19 of whom bring direct industrial expertise and strengthen key partnerships (for example with Rolls-Royce, National Grid and Arm) and 44 of whom are engaged in collaborative research (for example, with UC Berkeley and Dstl). These appointments help to ensure that both our education and research are connected with current industrial needs.

## 2.1.c Development of early-career researchers

### (i) New academic staff

New lecturers are appointed for a 3-year probationary period and are assigned an academic mentor – a senior member of staff who provides career advice and guidance on preparation of research grant applications, management of research projects and good teaching practice. The academic mentor meets regularly with the new lecturer and prepares a report for their line manager and the HoD at the end of each term. Progress is assessed formally at a mid-probation review (fifth term of service) and a final review in the penultimate term. Review panels typically consist of the HoD, line manager, academic mentor and additional academic staff from a relevant research area. New lecturers are assigned no substantive administrative duties and a reduced teaching load to enable them to secure funding and build a strong research programme. New lecturers also complete a Learning and Teaching Programme, usually within the first 2 years of



## Unit-level environment template (REF5b)

appointment, and are offered a range of courses via our academic development programme, including aspects of student supervision and communication skills. Within the FoE, we have created bespoke “research funding and management” workshops to ensure that new hires are introduced to key staff across the Faculty and to help them build peer networks. In addition to being given start-up funding, new staff are prioritised in the allocation of PhD studentships.

Early-career academic staff are encouraged and supported to apply for various prestigious fellowships (e.g. Research Council Fellowships, ERC Grants) and the success rates are typically high (about 40% for UKRI schemes). Departments organise internal proposal reviews and the Faculty Research Strategy Office organises mock interviews. Successful outcomes include 15 EPSRC Early Career Fellowships and 20 ERC Starting or Consolidator grants during the REF period.

### (ii) Research fellows

There are currently 73 ECRs (by REF ECR definition) in the Unit who started their careers as independent researchers on or after 1 August 2016.

To attract internationally leading ECRs, the College awards 4-year Imperial College Research Fellowships to outstanding researchers who are on the pathway to independence (20 awarded p.a.). The ICRFs are supported via a cohort-based training programme, an academic mentor and with up to £45,000 p.a. research expenses. The Faculty has been successful in the ICRF scheme with a total of 42 ICRFs appointed in the 9 departments of the Unit during the REF period (69% male and 31% female) and all current ICRFs (10) are now research independent and submitted to REF2021. A significant proportion of ICRFs (59%) move on to permanent academic contracts either within the College or elsewhere.

ECRs were also successful in winning other prestigious fellowships: Royal Academy of Engineering Research Fellowships (8); Royal Society (47 in total across various schemes, 28 URF); and UKRI Future Leaders Fellowships (3 in 2020).

### (iii) Postdoctoral researchers

All postdoctoral researchers (postdocs) and fellows are entitled to 10 professional development days a year and are encouraged to use this time to develop key skills to support them in their long-term careers. The College's [Postdoc and Fellows Development Centre](#) provides a bespoke programme of development opportunities that focus on multiple pathways for success. Its support is targeted at postdocs, independent and other research fellows; all researchers within the Faculty are encouraged to engage with the Centre.

The PFDC also provides individual support ranging from guidance with interviews to conversations about development opportunities. During the Covid-19 pandemic, the PFDC's support programme was adapted to provide development opportunities and mock interviews online.

“The expert-run mock interview and support from PFDC was integral to the success of my RAEng Research Fellowship application, and the Bioengineering grant-writing workshop provided valuable feedback...this support formed the basis for the launch of my independent research programme and of my appointment to Lecturer in 2018.”

*Quote from a female lecturer*

During the REF period, 744 individuals within the Unit benefited from the one-to-one support provided by the PFDC (58.7% male, 36.3% female, 4.7% undisclosed). The PFDC also offers a wide range of courses grouped under the themes: Postdoc Essentials, Communication and Presentation Skills, Leadership and Management, Succeeding Now, Planning for Success and Next Steps. The courses are free to Imperial postdocs and fellows including residential courses lasting 2–3 days; 670 postdocs and fellows from the Unit attended PFDC courses during the REF period.

## Unit-level environment template (REF5b)

The PFDC is critical in ensuring that the ECR voice is represented at College: each department appoints postdoctoral staff representatives and a local academic champion who meet regularly with departmental, Faculty and College management, including the Dean, to discuss staff development. Currently there are 24 postdoc representatives and 19 postdoc and fellows champions across the 9 departments in the Unit.

PDRAs are integrated into Imperial's research culture and are encouraged to develop independent ideas, organise and co-host seminar series and events, and co-supervise project students. The Faculty of Engineering runs a successful seed-funding programme (Dame Julia Higgins Postdoctoral Research Fund) for postdoctoral researchers to develop new ideas with colleagues across the College. Following an "ideas" workshop, pairs of PDRAs (from different disciplines) submit proposals that are reviewed by the FRC and the PFDC. This provides experience of idea-generation, improves networking and allows valuable experience of proposal writing and feedback. Successful teams are awarded funding to cover research expenses, and PIs commit to allowing time for them to pursue the ideas. PDRAs are also invited to join mock interview panels for academic grants (e.g. Programme grants, ERC) giving them insights into the process of developing and leading large strategic grants.

Departments take a proactive approach to the redeployment of research staff at the end of fixed-term contracts. Staff are contacted 3 months before the contract ends and liaise with their departmental manager, HR and PI to explore funding routes, move to another position within College (open positions are discussed) or support a move to another position outside College.

### 2.1.d Policy for sabbatical leave

Sabbaticals allow staff to pursue dedicated research in academia or industry and provide an opportunity for new collaborations and fresh perspectives. Sabbaticals are financed by the department, through learned societies or by industry; 60 academic staff took sabbaticals during the REF period. We recognise that "traditional" sabbaticals are challenging for academics with caring responsibilities and so encourage "mini" or "staggered" sabbaticals where staff can take shorter or serial visits and have the benefit of release from academic duties to explore new areas of research.

### 2.1.e Exchanges between academia and industry

The Faculty has more than 20 industry-funded Research Centres (see Section 4.4.b) that act as a natural focus for inward secondments from industry and visiting academic positions with industry partners. These interactions enable valuable industry experience for both academic staff and PGR researchers. We provide support to staff seeking joint and collaborative appointments with industry through the Research Strategy and IPC teams.

Industry fellowships and chairs awarded include:

- RAEng [Enterprise Fellowships](#): *Montomoli, Shao, Ahlfeld, Abo-Hamed, Popa, Kingsbury*
- RAEng Research Chairs:
  - Professor *Joao Cabral*: Procter & Gamble / Soft Matter Microflow Engineering
  - Professor *Amparo Galindo*: Lilly / Pharmaceutical Molecular Systems
  - Professor *Fionn Dunne* FREng: Rolls-Royce / Integrative Mechanistic Design
  - Professor *Omar Matar* FREng: Petronas / Multiphase Fluid Dynamics
  - Professor *Mary Ryan* FREng: Shell / Interfacial Nanoscience
  - Professor *Jennifer Whyte*: Laing O'Rourke / Systems Integration
  - Professor *George Constantinides*: Imagination Technologies / Digital Computation
  - Professor *Jianguo Lin* FREng: TATA Steel / Multidisciplinary Studies of Hot Stamping
  - Professor *Lorenzo Iannucci*: AIRBUS / Advanced Airframe Design
  - Professor *Spencer Sherwin* FREng: McLaren Racing / Computational Fluid Mechanics

Several company-sponsored Chairs reinforce our close links with industry and provide opportunities for further individual professional development (e.g. Total, ABB and Shell Chairs).

## Unit-level environment template (REF5b)

### 2.1.f Recognition and rewards for research achievements

#### (i) Recognition for research achievements

Achievements in research and impact activities are recognised under the Faculty's reward and recognition policies discussed in Section 2.1. In addition to pay, specific achievements are recognised through prizes and medals (Imperial College President's Awards for Research Excellence, which includes categories for ECRs, external collaboration, innovation and entrepreneurship, and research supervision). Over the REF period, staff within the Unit received 46 such awards.

Research achievements are recognised through the President's Excellence Fund for Frontier Research, which invests up to £750,000 a year of College funds in high-risk fundamental research. Both individuals and teams can apply and the Unit has received 8 such awards involving 20 people since 2017.

The Faculty Awards Committee proactively solicits and reviews nominations for external honours and awards (National and College honours, Regius Professorships). Achievements in this category are covered in Section 4.6.

Individual and group achievements are also recognised annually in the Faculty Rewards & Recognition scheme and celebrated at the annual Faculty barbeque, an event to which all staff across the Faculty are invited and during which the awards are announced. The scheme provides a platform to anonymously nominate academic, professional and support staff and recognise individuals and teams for outstanding contributions to the Faculty.

#### (ii) Support for achieving impact

The Unit has an extensive range of support and rewards for researchers translating their research into tangible impact that benefits society (see Section 1.3).

### 2.2 Development of research students

#### 2.2.a Recruitment

The recruitment of postgraduate research (PGR) students has increased year-on-year growing by 27% over the REF period (Figure 5). The total enrolment of PGRs over REF2021 is 35% greater than REF2014 and the current average PGR enrolment per FTE is 3.6.

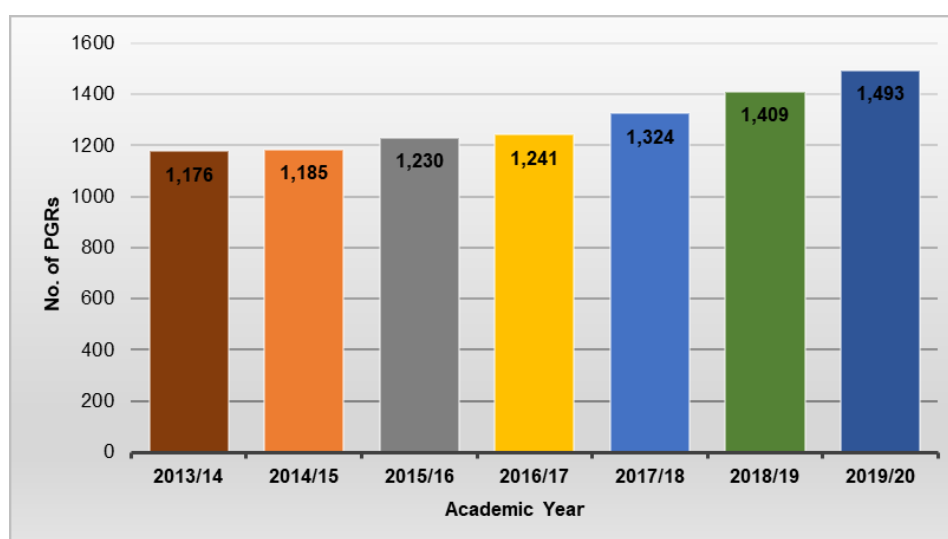


Figure 5 PGR students enrolment trend, academic years 2013–20

## Unit-level environment template (REF5b)

There has been a concerted effort to recruit from a broader demographic base and as a result the gender balance for PGRs has improved year-on-year. The PGR female population (28.8%) is significantly higher than that of the submitted female staff in the Unit (18.1%), and with appropriate support mechanisms as described below, this should help improve the staff gender balance in the future.

### 2.2.b Funding

The largest proportion of PGR students in the Unit are funded from UKRI Research Training Grants (41%, largely from EPSRC), while 24% are supported by College or departmental funds (data for 2019/20). Only a small proportion are funded by industry or employers directly rather than through industrial research grants (these are categorised as College or departmental funds in Figure 6). About 1 in 10 students are funded from overseas sources.

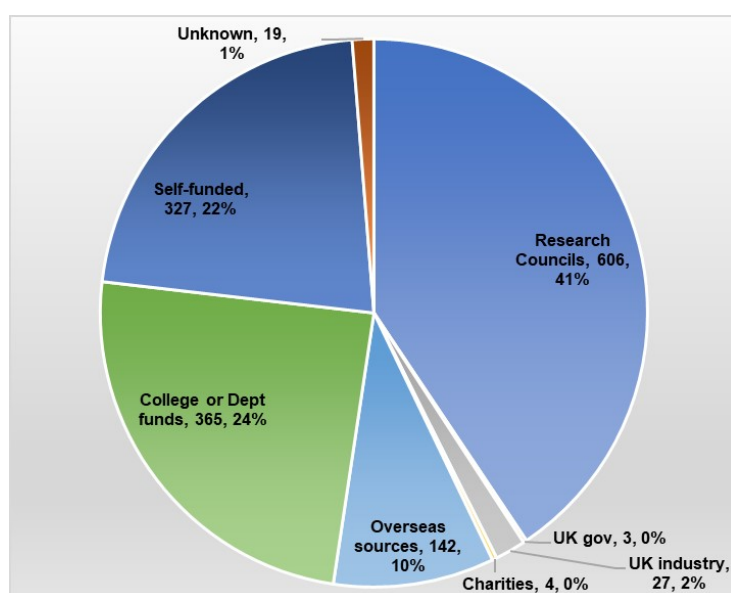


Figure 6 Source of PGR tuition fees, academic year 2019–20

The College offers prestigious President's PhD Scholarships to attract the most talented students worldwide. There are no restrictions on nationality, project supervisor or topic area. Successful candidates are granted full tuition fees and stipend for up to 3.5 years. In the REF period, a total of 137 students have been offered the scholarship to study across the 9 departments in the Unit.

The Unit hosted 9 EPSRC Centres for Doctoral Training (CDTs) from 2014, and partnered in a further 12 (including 2 NERC CDTs), training 359 CDT PGR students. The high-quality research training and cohort approaches employed by the CDTs proved highly popular with students, attracting exceptionally high-quality candidates.

### 2.2.c Monitoring and support

The monitoring of PGR student progress is through a series of independent reviews. Each student must prepare a research plan for independent assessment within 9 weeks of starting, followed by an Early Stage Assessment at 9 months and a Late Stage Review at 18–24 months. The Early Stage Assessment features a written report accompanied by a short presentation and viva and is conducted by an independent member of staff approved by the Director of Postgraduate Studies. At the Late Stage Review, sufficient progress is equivalent to being the major contributor to, and oral presenter of, a peer-reviewed archival paper at a conference. All PGR students are expected to submit their theses within 4 years and 87% achieved this for the REF period.

PGR student performance and feedback on their research experience are monitored via twice-yearly progress reports. Departments also participate in, and take action on, research student experience surveys run by the College and nationally (via the Postgraduate Research Experience Survey).

The completion rate for PGR students at the end of REF2014 (2013–14) was 83.6%. By taking positive action, the average completion rate has increased to 86.7% during the REF period. This significant improvement was achieved through:

- stricter admissions processes and criteria, including significantly raising the entrance bar across the board. Particular attention is given to self-funded applicants, who have a



## Unit-level environment template (REF5b)

- significantly poorer completion record, to ensure that they are sufficiently motivated and are able to focus on their work;
- the introduction and expansion of President's Scholarships, which have enabled more of the very best international students to conduct PhDs at Imperial;
- the introduction of cohort approaches in CDTs and the expansion of this approach to most PGR students, either by aligning them to CDTs or through the use of cohort mentors;
- the Graduate School's courses now provide a greater focus on writing up and completion, for example through the [Finish Up and Move On](#) course;
- the period allowed for (reduced fee) writing-up status has been increased from 6 months to a year and, concomitantly, this defines clearly the point for completion of lab work and research (after 3 years), and has resulted in earlier and timely PhD submissions.

Research students are given working space, separate from their laboratory, and a computer. They are encouraged to attend any relevant lectures in the College. Vibrant seminar programmes, held weekly in each department expose all students to the very best researchers from around the world and attendance of at least 50% of these seminars is a formal requirement for progression. Attendance and presentation at external conferences is actively encouraged and funded by the departments.

PGR students have a structured first-year training programme in research skills, planning, presentation, technical writing and other transferable skills, delivered through the Graduate School. Each research group also provides specialist skills training and knowledge modules, details of which are compiled for safety and training records. Students that are deemed to require English tuition, through a rigorous test, receive the necessary help through the Language Support Unit. Safety training is given and recorded, both general and specific to the project, supported by the departmental and Faculty safety officers.

The Graduate School delivers a number of high-profile events each year that increase the visibility of postgraduate students across the College. These offer the opportunity to network and to showcase the research being undertaken by research students. Events include the 4 Cs (Communication, Content, Charisma, Clarity) Science Communication event and the Annual PhD Summer Showcase which features a College-wide post symposium and *Research as Art* competition.

### 2.2.d Skills development and preparation for future careers

The Graduate School's [Professional Development Programme](#) is designed to ensure that students acquire the basic research skills and attributes at the start of their doctoral studies and continue to develop professionally throughout their studies. The programme also provides all postgraduate students with the opportunity to meet students from across College, promoting interdisciplinary discussions, helping to create a sense of community and giving students the opportunity to share good practice and to network.

All research students are required to attend a minimum number of Graduate School courses by their Late Stage Review, choosing from a range of programmes including: Research Impact, Research Communication, Research Computing and Data Science, Professional Effectiveness, Professional Progression, Professional Business Skills, Industry and Enterprise, Teaching and Research Integrity. In addition, the College requires all doctoral students to complete mandatory plagiarism awareness training by the Early Stage Assessment.

In addition to this wide range of short courses, students have the opportunity to develop global leadership skills and intercultural awareness through the School's Global Fellows Programmes. In order to ensure that the Graduate School's provision is inclusive, courses are delivered in a number of different ways including face-to-face workshops, online courses and webinars. Students are able to access professional development opportunities wherever they are in the world.

**(i) Cohort building**

Using the good practice demonstrated by CDTs, the Graduate School's Cohort Building programme aims to enhance support for doctoral researchers and help improve the research environment. One of the key philosophies of the programme is to promote student cohort development by delivering cohort-based skills training. The School also makes available a Research Community Fund for student-organised cohort building activities. Students from several Engineering CDTs have organised such events, for example, a cross-CDT trip to the West of England, an "escape room" activity and a Cross-CDT reunion. Students have commented on how beneficial they have found the opportunity to meet students from other disciplines and how it enhanced their sense of community within the College (reports of these activities are posted to the [Graduate School student blog](#)). In 2015, the Graduate School's Cohort Building programme was shortlisted in the Outstanding Student Services category in the *Times Higher Education* Leadership and Management Awards.

The Graduate School hosts an annual CDT Festival of Science & Engineering, organised by the students, giving them valuable experience and opportunities to meet students from CDTs. In addition, transferable skills training courses are organised across CDTs, enriching the students' experience. Examples of courses include Writing Anxiety, Career Development, Active Bystander training and Unconscious Bias training, where students from different CDTs mingle, bringing diversity and interest to the training sessions and raising awareness of these subjects across the student body.

**(ii) Wellbeing support for postgraduate research students**

In line with Imperial's Strategy 2015–20 to "prioritise the mental wellbeing of the student body, recognising this as both a moral imperative and a pre-requisite of academic success", the Graduate School's remit includes the support and wellbeing of research students. The Graduate School leads institutional discussions in this area, complementing the support provided to students via the College's Student Counselling and Mental Health Service. Over the past 2 years, the Graduate School has developed a package of support, the key elements of which include: a range of 2-day residential retreats; a coaching programme; and new online resources for supervisors.

The doctoral student coaching programme is open to all research students and is designed to focus on self-development issues and support students to develop effective partnerships with supervisors. It provides students with the space and opportunity to talk, independently from their academic department, about challenges they may be experiencing as they study towards their doctorate. Details of specific support provided by the Unit to disadvantaged students is provided in Section 2.3.

During the Covid-19 pandemic, PGR students' wellbeing has been a priority. All students affected by the pandemic (except for those in their writing-up period) are entitled to an automatic extension of up to 6 months, depending on the level of disruption experienced. Tuition fees associated with the extension are waived if not covered by an external funder.

**2.3 Unit's commitment to equality and diversity**

The Unit's commitment to equality, diversity and inclusion (EDI) is central to our mission to create a positive research culture that is supportive of all staff regardless of their gender, ethnic background, sexual orientation, disability or health status. Progress on this front since 2014 is reflected in our demographic profile: the proportion of female staff submitted to REF has increased from 15.6% in 2014 to 18.1% in 2021; and the proportion of BAME staff from 13.4% to 17.2%. The effectiveness of the Unit's EDI policies is evidenced by the proportion of female and BAME staff who have the maximum of 5 attributed outputs submitted to REF: 20% of staff with 5 attributed outputs are female compared with the expected proportion of 18%; for BAME staff 18% have 5 attributed outputs (compared with 17.2% BAME staff submitted).

## Unit-level environment template (REF5b)

The selection of submitted outputs for Unit staff took place within the framework of the College's REF2021 Code of Practice (CoP) and was overseen by the Faculty of Engineering REF Advisory Group (4 senior staff members, including the Vice-Dean for Research, and chaired by the Associate Dean for REF) and the REF Planning Group (composed of all departmental REF leads and chaired by the Associate Dean for REF), with the REF Advisory Group being responsible for making final decisions regarding the submission and ensuring compliance with the College REF CoP.

The framework for the Unit's equality and diversity policies is the [College's EDI Strategy](#) and the organisational support put in place to deliver it (see institutional environment statement). Within the Unit, this commitment is implemented through our Faculty people strategy, which commits us to:

- promoting workplace wellbeing through positive mental and physical health approaches and building on the Faculty "Have Your Say" initiative, and Unconscious Bias and Active Bystander training initiatives;
- supporting the growth of College-wide initiatives such as Mental Health First Aid, which promotes mental health awareness with a network of Mental Health First Aiders;
- providing a supportive and flexible work environment that supports people with caring responsibilities, enabling and empowering all staff to work productively.

The Faculty of Engineering's Equality, Diversity, Inclusion and Culture Committee meets termly and is chaired by the Dean, and has representatives from all departments. The Committee's remit is to act as a conduit for disseminating information and gathering feedback, and to identify potential equality, diversity and departmental culture issues, and to ensure that they are addressed. Further, each department has established an Equality, Diversity and Departmental Culture Committee (EDDCC) to discuss and address equality and diversity, culture-related issues, and to take ownership of the department's Athena Swan submission (see Section 2.3.a).

To support female research and academic staff, the Faculty has established a Women in Engineering Network (WiN), led by our current Women's Ambassador, Professor *Mary Ryan* FEng (who is also Vice-Dean for Research). WiN provides an environment for women across the Faculty to network and discuss topics such as career progression, overcoming obstacles and recognising achievements. It is an inclusive network, engaging all research-related roles in the Unit. Termly events are organised by the network and are aimed at female staff and students in particular. Events include workshops (e.g. assertiveness, personal branding, work-life balance), external speakers and panel discussions with colleagues in College (our most recent event celebrated the 20th anniversary of the Elsie Widdowson Fellowship with panellists who had received the funding – see Section 2.3.e).

The Faculty of Engineering introduced Active Bystander training to the College, which won the 2018 Universities Human Resources award in the category of Organisational Development and Culture Change for an initiative that achieved transformational culture change. This training is delivered to staff and students across the Faculty, and all new PGR students attend the training during their first year. In addition, Unconscious Bias training is compulsory for managers and strongly encouraged for all students and staff.

Specific EDI policies introduced by departments include:

- MAT established 3 annual prizes to recognise valuable contributions to mentoring, inclusion, support and outreach, all of which help to create a supportive environment. They include the Materials Community Champion prize for exceptional contributions by staff to improve our workplace culture and improving inclusivity. The first staff awardee was Dr *Andrew Cairns* who spearheaded the creation of rainbow lanyards, which signified support for LGBT+ inclusivity at Imperial, which were rolled out across Imperial.

## Unit-level environment template (REF5b)

- CIV has adopted a measure to facilitate inter-group communication. For example, during the summer of 2020 it ran biweekly virtual research seminars, each involving staff from 3 different sections and attracting up to 65 participants (these will start again in 2021).

The Faculty is looking at the lessons it can learn from remote working during the Covid lockdown that will enhance accessibility and inclusion in all aspects of research, for example, continuing to support remote participation in meetings and seminars.

### 2.3.a Athena Swan

Athena Swan certification is recognised as a framework to drive cultural change and all departments hold, or are working towards, accreditation. The College holds a Silver institutional award; details of individual department awards are shown in Table 4. During the REF period, 7 of the 9 departments in the Unit obtained or renewed their Athena Swan Award; ESE's Bronze renewal submission was delayed due to Covid-19 and DES will submit its first application during the next REF period.

**Table 4 Athena Swan award levels achieved by departments over REF period**

Department	Current award level	Submission date
Department of Aeronautics (AER)	Bronze	Nov 2019
Department of Bioengineering (BIO)	Silver	Nov 2018
Department of Chemical Engineering (CHE)	Silver	Nov 2017
Department of Civil and Environmental Engineering (CIV)	Bronze	Nov 2017
Department of Electrical and Electronic Engineering (EEE)	Bronze	Nov 2017
Department of Materials (MAT)	Silver	Apr 2017
Department of Mechanical Engineering (MEC)	Bronze	Apr 2019

### 2.3.b Flexible working arrangements

The College has a Flexible Working policy that recognises that the case for flexible working is strong; it improves morale, motivation, productivity, staff recruitment and retention. Flexible working and encouraging the sharing of caring responsibilities will ultimately result in better workplace productivity and improved gender equality.

Staff can apply formally for flexible working arrangements but the Faculty also supports informal flexible working arrangements. Faculty and departments are especially sympathetic to flexible working requests from staff with caring responsibilities, and are cognisant of specific travel challenges into London. Departments support staff with caring responsibilities by allowing them to block certain periods or informally request restrictions to teaching hours as part of the annual timetabling exercise. Both male and female staff have taken advantage of this to enable them to balance domestic and childcare responsibilities with workload demands.

Staff on academic contracts are able to work flexibly around teaching commitments and meetings. Meetings are usually arranged within the core hours of 10.00–16.00 and lunch meetings are either avoided or lunch is provided. Where possible, seminars and events start no later than 16.00 so all staff can attend, and events are recorded for remote/late viewing. We also support additional childcare costs for staff to attend events (or in some cases organise an onsite creche). The sabbatical leave policy (Section 2.1.d) is implemented in line with the College's EDI policies.

## Unit-level environment template (REF5b)

During the Covid-19 pandemic, the majority of staff have been working from home. The College has a dedicated webpage, Imperial@home (<https://www.imperial.ac.uk/about/covid-19/home/>), to provide resources, guidance and wellbeing advice.

### 2.3.c Support for research staff and students with caring responsibilities or ill health

#### (i) Support for staff

Staff who need to take leave for reasons of ill health or caring responsibilities are supported during their leave and on their return to work. The College's sick pay entitlement allows staff time off work to recuperate or return to work on a gradual basis following sick leave without worrying about the financial implications. Sick pay ranges from 1 month to 6 months' full pay, followed by half pay for up to 6 months, depending on length of service.

Staff returning from long-term absence are encouraged to adopt a phased return to work depending on an assessment and recommendation by Imperial's Occupational Health office.

The College recognises the demands of family life and is committed to supporting members of staff to obtain a good work-life balance. A wide range of family leave is offered, including maternity/paternity leave, adoption, surrogacy leave and shared parental leave. Family leave guidance has been designed to support both staff and managers by guiding them through the procedures for the various family leave types, covering what needs to be considered and the steps that need to be completed. All family leave policies apply to staff irrespective of gender identity, sexual orientation, gender expression, biological sex or if transitioning. In 2017, after the extension of the Elsie Widdowson Fellowships (see Section 2.3.e) to fathers, the College won the Best for all Stages of Fatherhood Award in the annual Top Employers for Working Families Special Awards run by the charity Working Families. The national awards recognise the most family-friendly and flexible employers.

#### (ii) Support for PGR students

For UKRI-funded PGR students, we follow the UKRI's policy and allow students to take maternity, paternity, shared parental and adoption leave and make provision for additional stipends to be paid where appropriate, e.g. up to 26 weeks of maternity leave on full stipend and a further 26 weeks of unpaid maternity leave. Students are also allowed and supported to study on a part-time basis.

The College Student Support Fund provides discretionary payments to students facing hardship. The Fund, which started in 2015, has made awards to 77 PGR students in Engineering (over £141,000). Specific support measures in Engineering include the Dean's Fund, established in 2015 with donations from alumni. The student support element of the Dean's Fund is open to students at all levels of study, and enables the Faculty to help alleviate financial burden as a result of unexpected hardship, or contributes towards specialist medical treatment for both physical and mental health issues. The College understands that this is a challenging time for our student community due to the impact of the Covid-19 pandemic and this fund has now been expanded with support from the Covid-19 hardship funds provided by the College.

Since 2018, the fund has supported 47 postgraduate research students in Engineering (see box on the right).

Support through the Dean's Fund (in 2020) included:

- £2,550 towards long-term therapeutic support for a PGR student suffering from mental health issues
- £800 towards specialist therapeutic support for a PGR student who recently lost immediate members of their family and has caring responsibilities
- £1,500 towards specialist medical tests and treatment for a PGR student suffering from ongoing physical health issues
- £3,000 towards long-term physiotherapy for a PGR student seriously injured in a road accident
- £1,000 support for a PGR student facing immediate financial hardship who is the primary caregiver for a parent, or is a refugee.



### 2.3.d Equality, diversity and inclusion considerations in research funding

Considerations of equality, diversity and inclusion are built into support for funding applications at Faculty and department levels. At the Faculty level, all candidates, and particularly early-career applicants, are supported in making grant and fellowship applications. All applicants invited to interview by the sponsor are offered mock interviews with experienced academic staff. Support at department level includes mentoring and advice on funding strategy, review of draft proposals, and in 3 departments, support from dedicated research development staff. Our commitment is demonstrated by the following specific examples (but there are many more across the Unit):

- MAT exemplifies the several layers of support available to under-represented staff applying for research grants and fellowships. Fellowship opportunities are publicised and workshops are held by experienced staff, outlining the schemes' assessment criteria and any internal selection processes. This demystifying of the process is an important step in encouraging participation from under-represented groups. Potential applicants are identified, encouraged and assisted with scoping and writing applications. Staff liaise with their mentor on developing proposals and the Director of Research reviews drafts.
- BIO and MEC also offer Grant Writing workshops providing constructive feedback in a supportive and confidential environment. All staff are supported in the administration of research applications and grant editorial services are also available. The Research Development Manager assists in writing and preparing large grant applications with multiple investigators. Recently a female research fellow (fixed-term contract) received positive feedback and benefited from 3 mock interviews, increasing her confidence and communication skills, which led to the award of a Royal Academy of Engineering Fellowship. She was subsequently awarded a Lectureship in the department.
- CHE also holds a Research Forum once a term, where large initiatives and applications are discussed collectively. In CHE, female and male staff achieve the same success rate in funding applications, and 3 female academics – 1 Lecturer, 1 Senior Lecturer and 1 Professor – have been Principal Investigators on awards >£1m.

Staff are also supported by the College Corporate Partnerships team who make industry contacts, and by the Faculty Research Strategy office, which organises mock interviews. For strategically important proposals, departments pay for external coaching support. For example, MAT's first female Professor benefited in 2017 from such coaching for a (successful) €2m European Research Council grant interview.

All departments have schemes for **conference attendance and training** that include support beyond attendance costs. Schemes are advertised and regularly communicated to staff. As an example, MAT has a fund for staff with caring responsibilities to enable them to attend conferences and training programmes. This covers the extra costs associated with childcare and caring support. These small grants have been helpful for staff returning from maternity leave and caring for elderly relatives. Staff are supported to travel but not expected to travel excessively. Promotion cases are not built around simple "numbers of talks" which may disadvantage staff with caring responsibilities.

### 2.3.e Support for staff and research students returning from periods of leave

Imperial has a range of initiatives to support families including a campus nursery, childcare vouchers, a parents' network and workshops for new parents. Departments within the Faculty automatically support all academics returning from maternity or parental leave with Elsie Widdowson Fellowships, a College-funded fellowship that covers 50% of the salary costs for 12 months and relieves the holder from teaching and administrative responsibilities to focus on research and professional activities.

## Unit-level environment template (REF5b)

Over the REF period, 28 staff (23 female, 5 male) have benefited from this fellowship, with 40 fellowships being awarded (8 people received it more than once). CHE was the first department in the College to support a male academic who took shared parental leave and received the Elsie Widdowson Fellowship. Support of both men and women for these fellowships is now College policy. In 2020, we celebrated 20 years of this pioneering Fellowship which has supported many female staff who are now Professors in the Faculty. The event was chaired by one of our PGR students from CHE, with panellists including senior colleagues (*Higgins, McCann, Cabral*). This quote illustrates how valuable recipients find these fellowships: "...given the much greater demands of bringing up twin babies – that I had completely underestimated – I could not have developed my research agenda so quickly without the fellowship...[which] has since generated 3 journal papers. And [it] was instrumental in my promotion to Senior Lecturer in 2017."

### 2.3.f Support for staff with protected characteristics

Imperial is committed to providing equality of opportunity to all staff and is a Disability Confident employer. Where possible, we make workplace adjustments to enable disabled staff and students to successfully carry out their work and study. Line managers have primary responsibility for ensuring that the necessary adjustments are in place for the disabled staff they manage, with support provided by department teams and College Occupational Health.

We recognise that disabilities can be physical or mental, visible or invisible, and that mental ill health is an under-reported but common issue. The College's Equality, Diversity and Inclusion Centre (EDIC) provides information, advice and guidance for disabled staff and their managers. This includes reasonable adjustments and support available within and outside the College. All discussions are held in confidence. The EDIC also has a process to screen and assess staff who think they may have dyslexia or other specific learning differences.

"Calibre" is a specialised talent development and leadership programme for staff who identify as neurodiverse or disabled, or who have a long-term physical or mental health condition. Calibre helps people develop strategies for the unique challenges and experiences of disabled staff, addresses the barriers faced by disabled staff, and implements techniques to overcome those barriers in the workplace.

The EDIC also offers a range of training throughout the academic year to educate and develop staff including "EDI at Imperial", Unconscious Bias, and various workshops including Active Bystander training and IMPACT (Imperial Positive About Cultural Talent), a talent development programme for BAME staff. Over the REF period, more than 450 staff in the Unit participated in these training programmes.

### 2.3.g Approach to supporting wellbeing

#### (i) Staff wellbeing

The College recognises that, across the community, staff have different experiences, depending on the nature of their role, their domestic situation, caring responsibilities, their health and that of their families. To address this, the College carries out biannual staff wellbeing surveys and from the feedback has implemented: new online meeting protocols; no expectation that staff respond to emails outside of normal working hours; home working guidance; a Wellbeing Day during the first Covid-19 lockdown in July 2020; and new guidance supporting maximum flexibility for those with caring responsibilities.

Across the Unit, workload allocation for academic staff is discussed and agreed by a committee at the departmental level which comprises Head of Department, Directors of Teaching and Research and line managers, with input from local EDICs to ensure that the policies in place are fair and transparent. The College does not have a universal workload allocation model; each department implements their workload distribution in a manner that accounts for all the factors involved, such as teaching reduction due to fellowships and recognition of different contributions of staff.

## Unit-level environment template (REF5b)

Departments regularly analyse the data and speak to staff members to ensure a balanced allocation. Staff are encouraged to raise issues related to workload allocation, and individual workloads are discussed as part of the annual PRDP process.

To better understand staff support needs during the Covid-19 lockdown, the May 2020 staff wellbeing survey was repeated in September 2020 with additional questions to understand how staff were feeling about safety and returning to campuses. Results suggest that people are coping well in these extraordinary times, but identified some areas of concern: managing workload; returning to more regular work on campus; travelling to work safely; and remote working in the longer term. Each department in the Unit is developing actions to address concerns, and the Faculty has developed a Remote Working Development Hub, providing our people managers and all staff with advice sheets and bespoke training courses.

### (ii) Student wellbeing

Each department within the Unit has a dedicated Senior Tutor for postgraduate research students who has overall responsibility for the academic and pastoral care of that group of students. After a successful pilot of a Student Wellbeing Adviser role in the MEC in 2018, wellbeing support for students across the Faculty was enhanced through the appointment of additional Student Wellbeing Advisers across the majority of departments in the FoE. The role of the Student Wellbeing Adviser is to provide wellbeing and mentoring support to both undergraduate and postgraduate students, typically through one-to-one advice and support sessions, and they will signpost students to specialist support such as Student Counselling & Mental Health Advice, the Disability Advisory Service or the Imperial College Health Centre, as appropriate. The Student Wellbeing Advisers also develop and deliver resources, activities and training to support students' wellbeing. The Faculty has also made available mindfulness and resilience training sessions to students in Engineering departments, including a specialist workshop for PGR students focused on values, purpose and resilience. Support measures have also been put in place for students with caring responsibilities or ill health (Section 2.3.c).

## 3. Income, infrastructure and facilities

### 3.1 Research funding strategy

As described in Section 1, the Unit's research strategy has evolved over the period from "targeted, sustainable growth" to "delivering impact and excellence in research and translation". The research we perform reflects developments in national and international environments, notably responding to global climate change and the UK Government's commitment to net zero carbon by 2050.

Concerns about global environmental pollution resulted in the Faculty and College launching the "Transition to a sustainable zero-pollution economy" initiative, which has been led by Engineering. Funders have responded to these developments; for example, we have been working with companies in the oil and gas sector to support them in the transition to low-carbon technologies. A key example is the Qatar Carbon Capture and Storage Research Centre (funded by Qatar Petroleum and Shell, ~£25m during REF2021), dedicated explicitly to understanding the safe capture and storage of CO<sub>2</sub> as part of a lower carbon energy transition. It provided the underlying science and engineering to enable large-scale storage in Qatar, where 5 million tonnes of CO<sub>2</sub> will be sequestered annually. Other work on energy storage is developing capabilities that will underpin a sustainable net zero society, such as new types of batteries to replace lithium, clean and low-cost production of hydrogen from biomass or plastic waste and its use in fuel cells free from precious metals (*Titirici*, RAEng Chair in Emerging Technologies).

At the time of submission, we are still assessing the impact of Covid-19 on the Unit's research strategy, but we believe that our strong presence in healthcare and associated technologies, including vaccine manufacture, measurement and sensing, and medtech, position us well for future growth in these areas. We are also exploring the increased role of digital technologies in conducting research, through data-centric engineering and related approaches.

## Unit-level environment template (REF5b)

The research funding strategies of the Unit and the Faculty are both vertical and horizontal. They grow in scale and duration as topics and projects develop, and the funding base has broadened correspondingly. The research funding portfolio is described here both in terms of research income and grants awarded, demonstrating the breadth, vibrancy and sustainability of our research.

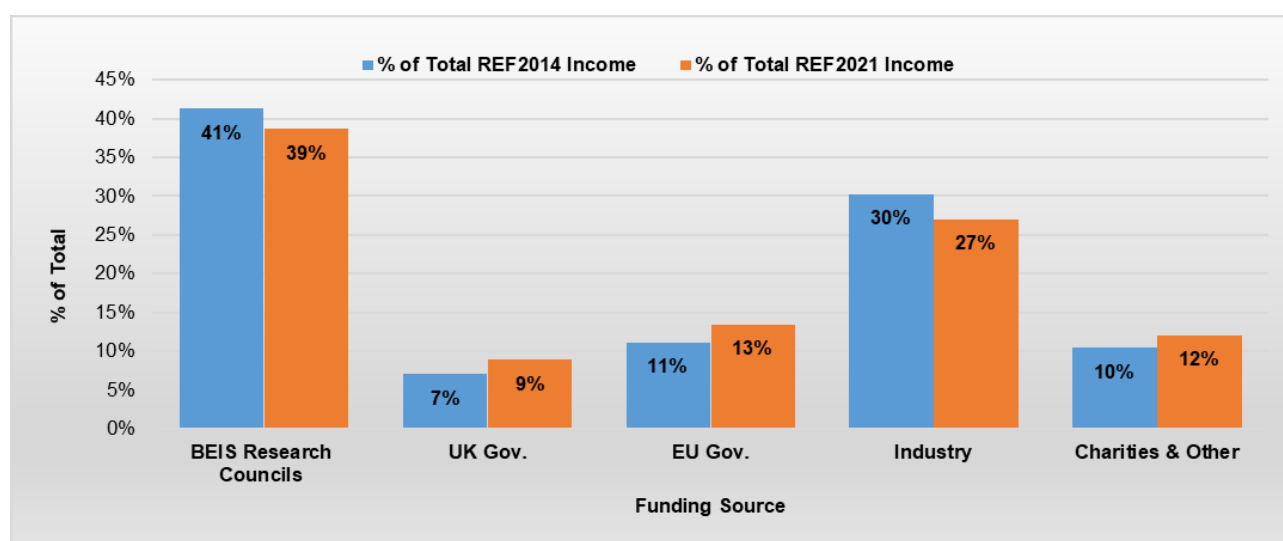
The Unit's EDI policies and Athena Swan principles (Section 2.3) are implemented throughout our support processes for: attracting research funding; enabling impact; providing access to research facilities; and support for research-related travel. This includes support for engagement in research leadership roles (e.g. *Ryan* and *Adjiman* are members of the EPSRC SAN; *Whyte* serves on the EPSRC Engineering SAT; *Heutz* chairs the EPSRC Physical Sciences SAT; and *Ryan* serves on the Diamond Scientific Advisory Committee).

### 3.1.a Portfolio balance and distribution

The Unit has a large and vibrant research funding portfolio that has continued to grow over the REF period. Total research income for the 7 years of REF2021 was £698m (£99.7m p.a.) compared with £318m (£63.6m p.a.) for the 5 years of REF2014, a 57% rise in average income per annum.

The REF period saw a significant increase in research income productivity; in the REF2021 period, annual research income per FTE was £237,000, compared with £185,000 over REF2014, an increase of 28%. A simultaneous and planned increase in FTE (from 344 to 420) contributed further to the increase in total research volume.

The research portfolio is similarly distributed across funding sources in REF2021 and REF2014 and continues to be well balanced between UK, EU public funding and industrial support, as shown in Figure 7.



**Figure 7 REF2014 vs REF2021 research income distribution**

The research portfolio has a broad distribution of sources, which spreads the risk should developments reduce funding availability from any one source. Income from BEIS Research Councils, academies and societies remains the largest proportion of the Unit's research funding (39%, £270m), which, together with UK Government bodies, totals 48% of research income. EU research funding has grown from 11% to 13% of the total income, reflecting our success in winning ERC awards.

Industry research funding remains about 27% of the total research income (£188m). Half comes from the UK, 11% from the EU and 41% (£76.4m) from the rest of the world, confirming the strength and international reach of the Unit's research.

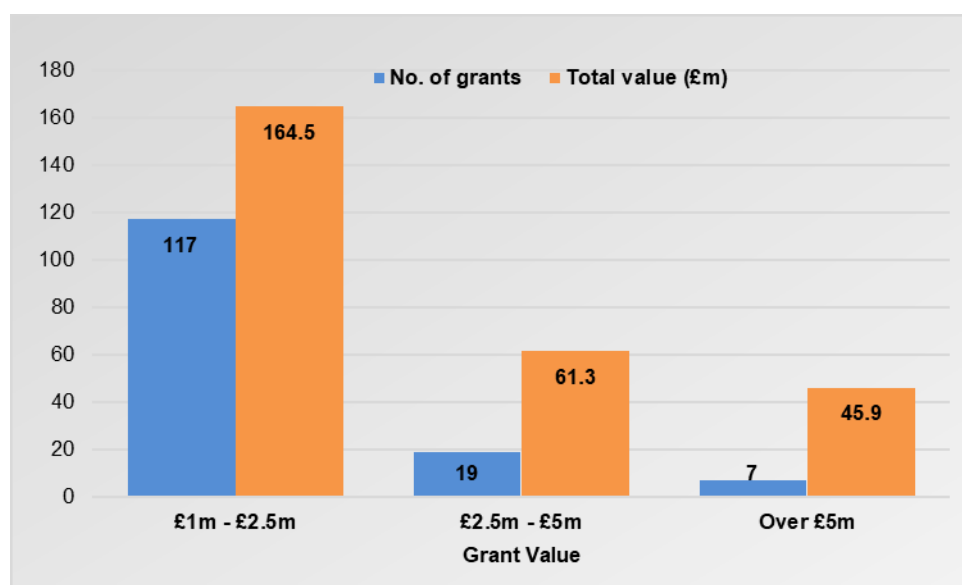
## Unit-level environment template (REF5b)

In line with the Unit's strategy of sustainable growth, the number of long-term strategic partnerships with companies grew to 24 in 2020 (from about 10 in 2014). A further 11 companies were engaged in managed relationships and many more are under development.

Of our UKRI funding, by far the largest proportion is from EPSRC (84% over the REF period), as is to be expected for engineering research. Industry funding has grown and consolidated, with 32 partnerships of more than £1m in the REF period. The period also saw growth in new sectors such as pharma (Eli Lilly £4.8m, GSK £2m), Chinese industry (AVIC £3m, Beijing Aeronautical S&T Research £3m) and sustained activity with the manufacturing sector and OEMs (Rolls-Royce £10.5m, MHI £4.8m, Caterpillar £2m, JLR £2m). Overall, there were 143 research grants greater than £1m, totalling £271.7m (40% of the total). These large awards have facilitated sustainable research activity and enabled long-term support of a critical mass of researchers and facilities across the Unit. Figure 8 shows the distribution of these large grants, with the vast majority (82%) in the £1m to £2.5m class.

The 26 grants awarded that were greater than £2.5m are distributed across all departments, cover a wide range of topics and a broad range of funding sources and geographies. This exemplifies the breadth and reach of the Unit's research.

Of the 7 grants of more than £5m, 4 from EPSRC contributed half of the value, 3 industrial grants amounted to 40% and charity awards contributed 10%. The success in attracting a significant number of very large, long-term research grants from a range of funding sources demonstrates the vitality and sustainability of the Unit's research portfolio.



**Figure 8 Number and size of large grants (over £1m) awarded over REF period**

### 3.1.b Organisational infrastructure supporting research and impact

The Faculty of Engineering has a well-developed administrative infrastructure to support academic staff applying for and managing research funding, as follows:

- The Faculty Research Strategy office (2.4 FTE) provides guidance on funding opportunities, funding organisation strategies, support for large and/or complex multi-department bids and for internally managed calls.
- There is well-developed support for industry partnerships, commercialisation and research impact, provided through the Industry Partnerships and Commercialisation team (11.8 FTE) as described in Section 1.3.
- The Research Services Pre-award Team (8.8 FTE) work with the investigators to develop clear resource planning for the proposals in line with sponsor guidelines. They also assist



## Unit-level environment template (REF5b)

and advise investigators in completing sponsor documentation, allowing PIs to focus on the research aspects. This office was restructured in 2019–20, introducing department-facing teams to streamline support and ensure consistency across the Faculty.

- The Research Services Post-award Team (14.6 FTE) support financial and compliance administration for all grants and contracts.
- The Contracts Team (5 FTE) handle all contractual and legal aspects of grant administration across the Unit.
- Each department has a dedicated Research Operations Manager (ROM) to support grant applicants in costing and preparing proposals. ROMs work closely with Research Services to help PIs manage their research portfolios and in particular help ensure that funding is used to deliver the proposal commitments to sponsors.
- 3 departments (BIO, CEE and MAT) employ Research Development Managers to support preparation of large bids; other departments are planning similar appointments.

At an institutional level, the College's Research Office oversees major sponsor relationships and compliance with sponsor guidelines and regulations. Post-award support is managed centrally through the Faculty Research Services team and at department level by ROMs and departmental finance and human resource support managers.

### 3.2 Research facilities

#### 3.2.a New research facilities at the White City Campus

A key element of the Faculty's ambitious plans for strategic growth is the new research and innovation space at Imperial's White City Campus (see institutional environment statement). During REF period, new facilities were created at White City allowing growth (in headcount and lab space) in the Unit's strategic priority areas. The White City Campus epitomises the approach of developing research clusters, each focusing on distinctive areas of work, delivering highly impactful research as described below.

The most significant new facility at White City is the **Sir Michael Uren Biomedical Engineering Research Hub** (BmE Hub), co-developed with the Faculty of Medicine. This unique and spacious (21,000m<sup>2</sup>, 5,000m<sup>2</sup> for BIO, 1,000m<sup>2</sup> for MAT) facility was enabled by a £40m donation from Sir Michael Uren, £20m investment from UKRPIF and £70m of College funding. The BmE Hub has allowed a major expansion of laboratory and office space, co-located with startup incubator space (the I-HUB, see section 3.5) to help foster partnerships with industry and enable rapid translation of research outcomes.

BmE Hub facilities include: a bio-nano-fabrication suite established with support from the Wolfson Foundation (£1m) and EPSRC (£1.3m), which is used for the design of nanometer-scale biomedical devices; a medical device prototyping and manufacture unit (EPSRC, £1.7m); and also houses the £1m industry-funded Leica-Imperial Imaging Hub for advanced imaging.

The Faculty of Engineering is a founding partner in the **Henry Royce Institute for Advanced Materials**. The mission of Royce@Imperial includes accelerating commercial exploitation of materials research and delivering economic and societal impact for the UK. The College received £10m capital funding from EPSRC (matched with a £5m College contribution). Royce@Imperial is located on level 8 of the BmE Hub, and includes a complementary suite of equipment for "atoms to devices" research (funded by £5m of the EPSRC award). Specialised equipment acquired for this facility includes: electron beam lithography (£996,000); Empyrean X-ray diffractometer (£384,000); X-ray system (£408,000); dual-beam FIB (£796,000); PLD upgrade (£250,000); FEG-SEM (£192,000); 3D laser microscope (£142,000), ultra-sensitive on-chip mass spectrometry, plus state-of-the-art clean rooms (£400,000).

This facility is available to users from other academic institutions and industry across the UK via the Henry Royce Institute.

### Unit-level environment template (REF5b)

The other substantial White City development is the **Molecular Sciences Research Hub**, opened in 2019, which is designed to break down traditional barriers between scientific disciplines. Total investment in this cutting-edge facility was £170m, underpinned by £80m from UKRPIF. Two research groups from MAT and part of SynbiCITE (the BIO-led Innovation and Knowledge Centre) have relocated to space alongside colleagues from the Department of Chemistry to promote cross-disciplinary research addressing energy and sustainability in line with the Faculty strategic research theme “Transition to a sustainable zero-pollution economy”.

Planned future activities at White City include the launch of **Imperial-X**, which will provide a new co-discovery and co-creation working model for staff, students and industry partners that will bring together research, teaching and innovation. Imperial-X will realise opportunities created from the convergence of new digital and information technologies, convening staff, students and researchers from industry in a co-located space to deliver research, innovation and education for a digital world. The longer-term aim is to create a research and education activity similar in scale to one of the College’s larger academic departments, graduating 50 or more PhDs a year. This will be not just a physical space – we will build a strong digital presence and an environment for virtual collaboration.

Imperial-X will embrace a cohort of 20–30 academics and their research teams, collaborating with researchers from industry and other parts of Imperial, on idea-driven research addressing major scientific and technical challenges. A key aim is to embed industry deep into our research and education activities.

Following the severe disruptions caused by the Covid-19 pandemic, the need for universities to adapt and change has become clearer and more urgent. Imperial-X will be a Laboratory of the University of the Future, in which we will develop new approaches to research, teaching and innovation that can spread throughout and beyond Imperial.

### 3.2.b Developments at South Kensington Campus

The South Kensington Campus remains the heart of research in the Faculty of Engineering, and is extremely well equipped with a large range of high-quality laboratories to support novel engineering research. There were 3 significant developments of facilities during REF2021:

- The City and Guilds building refurbishment project (£100m) was started during REF2014 (£37m), comprising research laboratories (2,700m<sup>2</sup>), teaching areas and office space (1,600m<sup>2</sup>) and was completed (£63m) in the REF period.
- Additional laboratory and office space for BIO (>£30m, 1,900m<sup>2</sup>) was funded by EPSRC, ERC, MRC, NIHR, Royal Academy of Engineering and the Royal British Legion.
- The Dyson Building was purchased and completely refurbished for new use (£55m).

The major new laboratories in these facilities and other refurbishments across South Kensington align with our strategic themes and are described below (Bioengineering is covered under White City Campus in Section 3.2.a).

#### (i) Design engineering

Establishment of the new **Dyson School of Design Engineering** involved complete refurbishment of the old Post Office building on Exhibition Road to create teaching and research facilities including 800m<sup>2</sup> of design engineering studios, 600m<sup>2</sup> of manufacturing workshops and 600m<sup>2</sup> of research laboratories. The School also hosts the **Dyson Battery Facility** (created as part of the UK Faraday Institution), which provides labs for extended and stressed state battery testing of fast-charge, high-load and extreme-temperature operation, and the Dyson Robotics Lab (see Section 3.2.b.[iv]).

## Unit-level environment template (REF5b)

### (ii) Fluid and solid mechanics

Key investments in AER and MEC include:

- A **Hydrodynamics Laboratory** (£1.7m) for offshore, coastal and built-environmental engineering.
- An **Aerosol Laboratory** for in-situ characterisation of aerosols (EPSRC Core Equipment, 2019, £245,600) and links to the CDT in Aerosol Science (Bristol-led, EPSRC, 2019–27, £6.7m). The Covid-19 pandemic has increased the relevance of research on movement of air and aerosols in the built environment.
- The **National Wind Tunnel Facility**: two low-speed wind tunnels (£5.4m, department funded), a supersonic wind tunnel (£1.8m) and a 10ft x 5ft wind tunnel (£3.8m), the latter two supported by EPSRC.

### (iii) Advanced materials

Major investments in materials characterisation and testing facilities in AER, CIV, MAT and MEC include:

- **SPIN-Lab** for magnetic characterisation of materials (EPSRC “Underpinning multi-user equipment”, £1.9m and £878,000 refurbishment) with Superconducting Quantum Interference Device (SQUID) and Electron Paramagnetic Resonance (EPR) technologies.
- **Structures Laboratories** (>£6.8m) for structures manufacture, testing and health monitoring including static, dynamic and impact-loading servo-hydraulic equipment.
- **Material Synthesis and Multifunctional Materials Laboratory** (£1.5m) and **Composites Suite** (£4.8m) refurbishments.
- **Composites Suite and associated labs in the Composites Centre** were upgraded (£4.8m), Structures Testing laboratory (£5.4m, shared with MEC), Material Synthesis and Multifunctional Materials Laboratories (£1.5m, includes manufacturing facilities for metal matrix composites).
- **Advanced Infrastructure Materials Lab** (528m<sup>2</sup>, £9m UKCRIC EPSRC equipment grant, 2016, EP/R010161) for civil infrastructure materials.

Additionally, large equipment purchases and upgrades since 2014 include:

- High Five: A unique combination of plasma focused ion beam and secondary ion mass spectroscopy (£1.8m, EPSRC Strategic Equipment).
- High Throughput X-ray Photoemission Spectroscopy (£402,000, EPSRC).
- JEOL JEM-2100 TEM (£434,000, EPSRC).
- Nu Plasma II MC-ICPMS (£510,000, Unit funds).
- Industry funded equipment for new measurement approaches for fundamental research: an environmental SEM and Raman facility (£1.2m, Shell UTC in Advanced Interfacial Materials Science) and a high temperature high pressure AFM (£200,000), which is unique worldwide.

### (iv) AI and robotics

Growth in the number of academics and researchers in AI and robotics (Section 1.2.a.[i]) has been supported by investments in the following new facilities.

- **Personal Robotics Laboratory** for assistive robots that personalise behaviour to assist mobility-impaired people. The lab has 5 robots (valued at £750,000) including a £350,000 humanoid robot (iCub) and an ABB donation of a YuMi robot.
- **Dyson Robotics Lab** (210m<sup>2</sup>) with facilities for: quadruped, biped and humanoid robot function; mechanical intelligence for in-hand manipulation and validation of healthcare

## Unit-level environment template (REF5b)

- robotics (Robo-patient). Facilities include the robots DE NIRO, DE VITO Exoskeleton, REsQbot, plus several other robots.
- **Micro-robot flight arena** (£2.1m with a £1.25m alumnus donation) used in EPSRC grant (Imperial, UCL and the University of Bath) on the development of aerial additive manufacturing (EPSRC), and the EPSRC Programme grant CASCADE (Imperial, Southampton, Cranfield and Bristol) investigating complex autonomous aircraft systems, and the Industrial Strategy Challenge Fund ORCA project (Imperial, Heriot Watt, Oxford, Liverpool and Edinburgh) on the use of robotics for certification of offshore assets.
- **IOT Lab** (60m<sup>2</sup>) with extended testing of Internet of Things devices, data tracking and diagnostics facilities.

## (v) Core engineering research facilities

Other investments to support growth areas such as battery research, the smart grid, water and waste management, and new hires in Space Engineering include:

- **Faraday Lab** 540m<sup>2</sup> of dedicated research laboratory and office space, newly refurbished at a cost of more than £2.5m plus £900,000 for new equipment. This is in addition to Faraday facilities in the Dyson School (78m<sup>2</sup> for a new electrochemistry lab, £140,000).
- **Environmental Chemistry, Microbiology and Waste Management Labs** (450m<sup>2</sup>) provide extensive, state-of-the-art chemical and microbiological facilities. Since 2014, more than £750,000 has been invested in equipment (£430,000, NERC; £220,000, EPSRC; £100,000, Industry).
- **Digital Energy Demonstrator** for smart grid development (£1.6m, ABB substation and control-room donation).
- **Space Research Laboratory** (£1.7m, funded by AER departmental funds)

## 3.2.c Shared facilities

The Unit benefits from the extensive range of materials characterisation facilities hosted by MAT and shared with London universities via the London Centre for Nanotechnology. These include the Harvey Flower Electron Microscopy suite, surface analysis, the Thin Film Technology laboratory, X-ray diffraction and X-ray photoemission spectroscopy. The new SQUID equipment in MAT is shared with ESE for paleo-magnetometry research, and ESE provides mass spectroscopy in return. All departments in the Unit have access to MEC's state-of-the-art mechanical testing facilities, the composites processing equipment in AER and soil testing in CIV.

The Unit also contributes to specialist infrastructure provided at College level through user charges or direct funding (e.g. computing and HPC infrastructure described in Section 3.3) and we make good use of the central College research facilities described in the institutional environment statement. The proximity of the equipment, high levels of technical support and a College-wide booking system ensure that internal and external users can easily access these facilities, which are administered using established TRAC "charge-out" costing methodology.

## 3.2.d Planned future investments

Future plans will focus on enhancing and consolidating key facilities, for example to support strategic priorities in "Transition to zero pollution" and "Resilient infrastructure", and include:

- A new **Cryo-EPS** facility (£10.3m, EPSRC): a unique cryo-enabled, multi-microscopy facility enables quantitative atomic- to micro-scale investigation of light elements, critical to net zero carbon technologies. This award was made shortly after the REF2021 cut-off, and will form a cornerstone of our zero-pollution research during the next REF.
- An environmental chamber and near-field EMC scanner will be added to **The Wireless Power Laboratory**.
- The **ABB control room** will be expanded to support digital twins for grid control.

## Unit-level environment template (REF5b)

- Modifying the single cylinder advanced spark and **compression ignition engines and gas turbine combustion systems for operation with low carbon fuels** (hydrogen, ammonia, synthetic) to support net zero carbon marine and heavy duty transport, aviation and land power generation.
- **Automated Fibre Placement** (AFP) for producing lightweight flight designs.
- **Robotic WAAM** (wire and arc additive manufacturing) for 3D metal printing for the construction industry.

## 3.3 Research Computing and High-Performance Computing

Imperial has invested £25m over the REF period in its Research Computing Service, which currently has 4,600 users. Support for research includes High-Performance Computing (HPC) facilities and a Research Data Store. The Research Computing Service is available to departments free at the point of use and they can invest in additional services for preferential access. Since 2014 we have invested £13m in hardware alone with an additional investment of £2m a year in hosting. Imperial currently operates one of the largest facilities in the UK that is solely used by the institution and currently has 72k x86 CPU cores and 500TB of memory. There is a commitment to spend a further £3m a year for the next 4 years. Funding priorities are agreed in close consultation with the academic community and the Director of Research Computing regularly attends Engineering FRC meetings.

Engineering co-hosts the Materials and Molecular Modelling Hub, a National Tier 2 HPC facility for the UK materials and molecular modelling community. Within this, the “Thomas” HPC system was established in 2017 with a £4m capital investment from EPSRC and is run by a consortium of 8 universities led by the London institutions that form the Thomas Young Centre (UCL, Imperial, King’s College London and Queen Mary University of London). Thomas has 17k x86 cluster with 92TB of memory. To enhance the UK’s Tier 2 HPC capability, EPSRC (January 2020) awarded a further £4.5m to renew the Materials and Molecular Modelling Hub for a further 3.5 years, and establish a new HPC facility named “Young”. This successor to Thomas has 23k x86 cores of Cascade Lake processors connected by 100Gb Omnipath. This system is complemented by 6 high-memory nodes for single-node workloads, identified by users as necessary additional functionality. The running costs of Thomas and Young are part-funded by the Unit (about £120,000 p.a.).

Licensed software suites are available to all researchers, and in particular, a number of open-source codes, some of which were created in the Unit. Examples are Nektar++, PyFr, Incompact3D, Fluidity and Devito.

## 3.4 National and international research facilities

The Unit is embedded in, and in many areas provides leadership to, national and international research communities in engineering (see Section 4). As would be expected, staff make extensive use of national and international research facilities. Major STFC facilities used include a microgravity experiment performed on board China’s SJ-10 Shi Jian spacecraft in 2016 (*Vesovic* in a partnership between the European Space Agency and China’s National Space Science Center) and use of the Diamond facility, which had 24 users from the Unit, particularly from MAT, over the REF period. Use was also made of the ISIS Neutron and Muon Source (11 users) and ILL (4 users).

Examples of national and other major shared facilities employed in our research include:

- The Unit’s large wind tunnel (part of the UKRI supported National Wind Tunnel facility, 10ft x 5ft working section) is being used in the EPSRC Programme grant “Transpiration cooling systems for jet engine turbines and hypersonic flight” led by the University of Oxford and in the EPSRC project “Understanding and exploiting non-equilibrium effects on turbulent boundary layers: Towards realisable drag reduction strategies” with the University of



## Unit-level environment template (REF5b)

Southampton. In addition to research council projects, this tunnel is also being used by Boeing for testing of its High-lift common research model as part of a project funded by Boeing, QinetiQ and the ATI.

- We also partner in establishing collaborative facilities at other institutions. For example, BIO is a lead development partner of the £10m clinical imaging research facility at St Thomas' Hospital in London that includes a state-of-the-art 7T MRI scanner.
- The Unit houses the UKCRIC Advanced Structural Materials Lab (EPSRC, £9m, PI *Buenfeld*) focusing on producing, processing, imaging, analysing and testing infrastructure materials, as part of the UKCRIC national facility, which includes natural exposure facilities (University of Leeds) and extreme exposure facilities (University of Manchester).
- Materials characterisation shared facilities include the Royce@Imperial facilities described in Section 3.2.a.

### 3.5 Facilities supporting impact activities

A major focus for the Unit's support of impact is the Translation & Innovation Hub (I-HUB) at the White City Campus. The I-HUB provides translation facilities and support co-located with research labs. Facilities include:

- research clusters in biomedical engineering, synthetic biology, robotics, data sciences, autonomous systems, design engineering and plastic electronics;
- analysis and testing equipment and prototyping facilities;
- advisory and incubator support within a community of like-minded entrepreneurs.

The I-HUB hosts the SynbiCITE Synthetic Biology research and innovation centre, plus startups originating from within the Unit, such as RFC Power. Future plans for the I-HUB include expanding into digital tech areas through Imperial-X as described in Section 3.2.a.

The extensive support for impact provided by the IPC office (see Section 1.3) is complemented by departmental support. For example, BIO has hired 2 Entrepreneurs-in-Residence, who provide commercialisation advice to academic staff, and the department set up the Imperial MedTechLinks programme for corporate partnerships. A new MRes programme on Medical Device Design and Entrepreneurship has been launched and has already led to 8 startups that were created by its alumni (e.g. PathFinder Medical, founded in 2014, commercialises new technology for minimally invasive surgery and attracted more than £3m in funding and investment).

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

### 4.1 Approach to research partnerships

The College's structure of Global Institutes and Centres of Excellence (see institutional environment statement) provides the framework for internal and external collaborations. The Energy Futures Lab, Grantham Institute for Climate Change and Environment, Institute for Security Science and Technology, Data Science Institute and Institute for Molecular Science and Engineering span the College and support interactions with key industry and government partners. They showcase the Unit's sector-facing research capabilities and provide a conduit for collaborative research with end users.

In parallel, the 9 departments in the Unit have extensive collaborations with academic institutions in the UK (Section 4.2), institutions internationally (Section 4.3) and industry (Section 4.4) and also through research centres, industry sponsored research chairs, and department-level external advisory boards.

## Unit-level environment template (REF5b)

### 4.2 Partnerships with academic institutions

Collaborative partnerships with academic institutions are at the heart of the Unit's vibrant research activities. These include long-term strategic partnerships through centres, collaboration through major awards such as EPSRC Programme grants and CDTs, industry initiatives (e.g. Shell AIMS Centre and Eli Lilly; see Section 4.4) and individual investigator-to-investigator collaborations.

At a national level, as part of the College's wider relationship with UKRI institutes, the academic staff in the Unit have had formative and ongoing research roles in the following institutes:

#### Faraday Institution

- The Multi-Scale Modelling team (5 academic staff, 7 postdoctoral researchers and 4 PGR students) lead a major interdisciplinary project on the modelling of lithium ion batteries. Total funding is more than £76m, and includes a £12m EPSRC award in collaboration with 8 other UK universities: Oxford, UCL, Warwick, Southampton, Lancaster, Birmingham, Portsmouth and Bath, plus industry partners including JLR, Shell, BMW, Delta Motorsports and WAE.
- We are a partner in the "Towards a Comprehensive Understanding of Degradation Processes in EV Batteries" project (*Ryan*, Cambridge lead £10m, £1m to Imperial).
- The Faraday Li-STAR project (Faraday Challenge, "Extending battery performance past the limits of Li-ion batteries", £9.86m) involves 4 academics from the Unit.

#### Henry Royce Institute for Advanced Materials

- The Henry Royce Institute is an EPSRC-funded collaboration, jointly with the universities of Manchester, Cambridge, Leeds, Liverpool, Oxford, Sheffield, UKAEA and the Culham Centre for Fusion Energy. Investment at Imperial is a £10m EPSRC capital grant (£5m clean room, £5m equipment) plus recurrent £1.3m from EPSRC. Royce@Imperial involves 8 academics, 8 facility managers and 6 support staff within the Unit, plus about 100 PGR students, 7 PDRA's and 10 external academics.

#### Dementia Research Institute

- The Unit (BIO and MEC) helped to establish the UK Dementia Research Initiative Centre and the UK Dementia Research Initiative Care Research & Technology Centre (with EEE and Medicine, DRI-CRT, £20m from Dementia Research Institute).

#### Rosalind Franklin Institute

- Professor *Livingston* was the founding director.
- Professor *Porter* is collaborating with Angus Kirkland (RFI, University of Oxford) and Zeiss on "Developing multiscale microscopy techniques to understand how leukaemia alters bone remodelling".

#### Francis Crick Institute

- Professor *Molly Stevens* leads a Crick Satellite on designing smart materials for applications in disease diagnostics and regenerative medicine (2017–present), collaborating with Professors Briscoe and Malanchi at Crick. The team use Crick's state-of-the-art facilities to characterise smart materials' function and application.

#### Alan Turing Institute

- Engagement has focused on data-centric engineering research in the construction sector (*Gardner* and *Whyte*) and process industries (*Matar*). We anticipate that new interactions will develop through the Imperial-X initiative.

There is also an extensive range of collaborations through **joint research centres** with other institutions, including:

## Unit-level environment template (REF5b)

- **UK Research Centre in NDE:** (PI *Cawley*) >£10m industry and EPSRC funding plus associated CDT. Imperial leads with universities of Bristol, Warwick, Manchester, Nottingham and Strathclyde and 16 full industry members (2014–20).
- **EPSRC Future Vaccine Manufacturing Hub:** Advancing the manufacture and deployment of cost-effective vaccines £10m (Co-I, *R. Chen*) with King's College London, universities of Bristol, Nottingham, Cambridge and Leeds (2017–21).
- Imperial (PI *Brandon*) leads the **EPSRC Hydrogen and Fuel Cell SUPERGEN Hub**, the national programme in the field.
- **SynbiCITE** comprises the co-location of 3 foci of activity: (i) SynbiCITE technical facilities, including the Biofoundry; (ii) a joint metrology and standards centre with the NPL; and (iii) the co-location of companies. SynbiCITE started in 2013 and public investment to date is about £13m, plus matching funds from collaborating universities and companies. It works with all the main synthetic biology research centres in the UK including the universities of Bristol, Cambridge, Edinburgh, Manchester, Nottingham and Warwick and the main UK Biofoundries in Earlham, Edinburgh, Liverpool and Manchester.
- **Active Building Centre Research Programme:** Swansea University lead, Imperial Co-Is, *Strbac, Kerrigan, Shah* with universities of Bath, Cardiff, Loughborough, Newcastle, Nottingham and Sheffield (total EPSRC funding £9.2m, Imperial £1.6m).
- **UK Collaboratorium for Research on Infrastructure (UKCRIC):** Imperial leads the Advanced Structural Materials Lab (*Buenfeld*, £9m, 2016–21) and UKCRIC-PLEXUS (£1m, *Tarborda*) with universities of Birmingham, Cambridge, Cranfield, Leeds, Newcastle, Sheffield, Southampton, Manchester, Loughborough and Bristol.

Beyond research centres, other major collaborations with UK partners, for example through Programme grants and similar awards, include:

- **Transforming synthetic drug manufacturing: novel processes, methods and tools, Prosperity Partnership** grant with UCL & Eli Lilly (*Gallindo, Adjiman*, £3.5m).
- EPSRC Programme grants, **MEMPHIS** (PI *Matar*, £5m) with Birmingham, Nottingham, UCL; and **PREMIERE** (PREdictive Modelling with Quantification of UncERtainty for MultiphasE Systems, PI *Matar*, £6.5m) with Birmingham, Cambridge, UCL and the Alan Turing Institute.
- EPSRC Programme grant **Next Generation Fibre-Reinforced Composites: a Full-Scale Redesign for Compression**, jointly held with University of Bristol (PI, *Shaffer*, 2020–25, £6.25m).
- **LightForm: Embedding Materials Engineering in Manufacturing with Light Alloys**, EPSRC grant (PI *Lin*, with Manchester, Imperial, Cambridge, 2017–22, £5.88m), plus related joint awards with Cambridge (lead), EPSRC UKFIRES; £4.3m, 2019–24); Strathclyde University and Birmingham University (EC LoCoMaTech, €8m, 2016–19; and €6.08m, 2013–16).

### 4.3 International collaborations

International collaboration is embedded throughout our research and is regarded as essential to our thriving and vibrant research culture. Across the Unit there are 88 substantial international collaborations (each over £1m in value), most of them involving multiple countries, either in Europe or globally. The majority of these are driven by individual members of academic staff through research networks.

Strategic international university collaborations (e.g. with MIT, Tsinghua and Technical University of Munich) are supported at College and Faculty level through the International Relations Office. While there is insufficient space to do justice to the full range of the Unit's international links, the following examples illustrate their strength and diversity.

#### Europe

- EuPOLIS: H2020 (€11.2m, 2020–24) “Integrated NBS-based Urban Planning Methodology for Enhancing the Health and Well-being of Citizens: the euPOLIS Approach”.

**Unit-level environment template (REF5b)**

- Villum Centre for Sustainable Fuels and Chemicals' (£18m, 2015) collaboration with Technical University of Denmark, University of Copenhagen and Stanford University.
- PERFORM: H2020 (€17m, 2016–20) "Personalised Risk Assessment in Febrile Illness to Optimise Real-life Management across the European Union".
- Research Council of Norway (£14m, 2017–27) "Hybrid Technology Hub – Developing an Integrated Open Access Organ on a Chip Platform for Drug Discovery".
- TUM-Imperial College Joint Academic Doctoral School partnership for cross-disciplinary PGR cohorts (*Faisal* through the UKRI AI for Health CDT).
- The KIOS Research and Innovation Centre of Excellence (KIOS CoE), a strategic partnership between the University of Cyprus, the leading university in Cyprus, and Imperial, is co-funded by the flagship EU Teaming Programme with an overall budget of >€40m (€3.5m for Imperial). The CoE conducts multidisciplinary research and innovation in ICT with emphasis on monitoring, control, security and management of critical infrastructure systems.

**Multinational**

- Future Vaccine Manufacturing Research Hub, CHE (*Hallett, Shah, Polizzi, Chen, Stevens, Kontoravdi*) partnering with Professor *Shattock* (PI, Medicine) on £10m MRC grant with the following partners: Hilleman Labs (India), MRC Ugandan Virus Research Institute, Dalian Hissen Bio-pharm, China, Incepta, Bangladesh and VABIOTECH (Vietnam).

**China**

- UK–China award: "Role of Energy Storage in Enhancing Operation and Stability Performance of Sustainable Power Systems" (RESTORES, Co-Investigators *Strbac* and *Green*), a consortium of Manchester, Imperial and Cardiff with 3 Chinese partners. RCUK Energy Programme contribution of £1m. Partners are Tsinghua University, China Electric Power Research Institute and Huazhong University of Science and Technology (2014–17).
- Tsinghua–Imperial Joint Research Centre on Intelligent Energy Systems (PI *Green*, £600,000).
- "Interface and Network Infrastructure to Support EV Participation in Smart Grids" (*Green*), a consortium of Strathclyde and Imperial with Zhejiang University and Huazhong University of Science and Technology. RCUK Energy Programme contribution of £940,000 (2013–17).
- "Enhanced Renewable Integration through Flexible Transmission Options", a consortium of Imperial, Cardiff and Birmingham with China Electric Power Research Institute, Northeast China Dianli University and Xi'an Jiaotong. RCUK Energy Programme contribution of £1m, 2013–15.

**India**

- Joint UK India Clean Energy centre (JUICE): £5m, 5 Imperial academics, led by Loughborough with more than 10 international industrial partners for sustainable energy systems. The project has already made a substantial impact in building research capacity: 55 researcher exchanges and 10 research appointments to academic or industry positions in the UK alone.

**Africa**

- Water treatment research into neglected tropical disease significantly expanded through a £1.48m EPSRC GCRF grant with partners in Tanzania and Ethiopia (*Templeton*, 2017–21). Research into water treatment for the prevention of neglected tropical diseases expanded significantly; a £1.4m EPSRC GCRF grant, a state-of-the-art technology stack for operating water sensing networks supported by a >£5m research portfolio, and grants (>£2m) for technologies to generate value from complex waste streams.
- RENGAs: (Total funding at Imperial £1m, 2018–20) "Resilient Electricity Networks for a Productive Grid Architecture", collaboration with universities in Rwanda and Kenya.
- "Transforming Weather Water Data into Value-added Information Services for Sustainable Growth in Africa" (H2020, €4.9m, 2018–22).

## Unit-level environment template (REF5b)

**Brazil**

- Sustainable gas pathways for Brazil Consortium (NERC, £986,000, 2016–19) Imperial, UCL, universities of Leeds Cardiff and Sao Paolo, and Federal University of Rio de Janeiro.

**Other**

- Regenerative biomaterial patches for failing hearts (PI *Celiz*), UKRI Future Leaders Fellowship, £1.5m, 2020–24. Collaborators: Harvard, USA and EPFL, Switzerland.
- Universiti Teknologi Malaysia (*Martinez-Botas*), Centre for Low Carbon Transport in Cooperation with Imperial College London (£1.5m).
- The only UK academic group to be involved in the US Materials Acceleration Initiative (MAI) is led by *Dunne*, who is collaborating with USAFRL, Ohio, with partners GE, Pratt & Whitney, IHI, RR, USAF, FAA on addressing aeroengine titanium component susceptibility to dwell fatigue.

**4.4 Partnerships with industry**

The Faculty of Engineering is the focus for the majority of industry partnerships within the College. As a measure of the scale, over the REF period the Unit generated £188m of industry research income, 47.5% of the College's industry income (£396m).

Our partnerships with industry are structured according to the following partnership levels:

- Long-term, strategic partnerships with industry with substantial programmes of work covering multiple strands of research, over 5 years or more (£2.5m to £10m).
- Industry Research Centres – major managed research collaborations on partner-defined priorities and research challenges (£500,000 to £2.5m).
- Research Centre–Industry Membership programmes.

In addition, many collaborations are led by individual investigators, and these often grow into larger, managed or strategic partnerships. Support for all these partnership levels is provided by the Faculty-facing Industry Partnerships and Commercialisation team (see Section 1.3).

Details for each of the above types of partnerships are provided below.

**4.4.a Long-term, strategic partnerships with industry**

The Unit has major strategic partnerships (>£2.5m) with 16 companies, i.e. Shell, Sinopec, Rolls-Royce, BG International Ltd (now Shell), BP, PETRONAS, Eli Lilly, Mitsubishi Heavy Industries, Huawei Technologies, AstraZeneca, AVIC Manufacturing Technology Institute, Beijing Aeronautical Science & Technology Research, ABB, EDF, Total, and Beijing Institute of Aeronautical Materials.

These partnerships form the cornerstone of our portfolio of industry-funded research, with £101m of research income over REF2021.

The range and diversity of strategic partnerships is illustrated by the following examples:

- The **Mitsubishi Heavy Industries (MHI)** partnership started in 2005, and supports research to improve turbocharger design. The partnership (£4.8m during REF2021) has resulted in significant impact (see ICS14) from a new turbine design with a modified turbine blade in a new volute. A joint patent on the volute was filed in 2013 and series production began in 2016, now reaching 2.2 million units produced. This partnership has led to further new concepts for MHI, including a new turbine nozzle and compressor volute.
- The Unit has a longstanding relationship with **Shell** (£26.6m over REF2021), including work at the [Sustainable Gas Institute \(SGI\)](#), the fuels and lubricants University Technology Centre (UTC) and the [Qatar Carbonate and Carbon Storage Research Centre](#).
- The [Shell–Imperial Advanced Interfacial Materials Science \(AIMS\) Centre](#) (2016 to present, led by *Ryan*) delivers new insights into materials behaviour and enables optimal materials



## Unit-level environment template (REF5b)

selection, design and enhanced predicative capabilities for both structural and functional materials. The Centre links nanoscale processes to large-scale materials behaviour, exploiting developments in new ambient pressure systems for spectroscopy and microscopy, as well as central synchrotron facilities to develop in-situ approaches to study complex systems over length and timescales relevant to industrial processes.

- The partnership with **Eli Lilly** supports research into efficient medicine manufacture (total £4.8m over REF2021). The company funded a virtual lab, Pharmaceutical Systems Engineering Lab (PharmaSEL), in the Imperial/UCL Centre for Process Systems Engineering (CPSE). Improving the modelling of pharmaceutical compounds will reduce the time to market and the quality and effectiveness of drugs.
- **ABB** in 2019 renewed the collaborative research partnership with Imperial with a digital substation demonstrator facility in the Energy Futures Lab, and continued its Research Chair (£2.8m over REF2021).
- **PETRONAS** funds a 5-year (2019–24, 15 researchers) £2.5m Centre for Engineering of Multiphase Systems (PETCEMS) for research into multiphase flows with energy applications.

### 4.4.b Industry-sponsored Research Centres

Engineering at Imperial has established more than 20 Industry-sponsored Research Centres (IRCs) in the past 5 years. There is a Faculty-wide Industry Research Centres policy, overseen by the FRC, which reviews Centres every 2 years to ensure that they remain productive, thriving and mutually beneficial partnerships. IRCs are cross-departmental in their activities and research, but managed by a single department or institute to ensure clear lines of accountability.

Major collaborative industry support for IRCs during REF2021 includes:

- The Vibration UTC received >£7m from Rolls-Royce over the REF period and more than £6m additional leveraged funding from UKRI/EU, part of which is from the Cornerstone Prosperity Partnership between Rolls-Royce and Imperial, Oxford and Nottingham.
- The Nuclear UTC received >£4m from Rolls-Royce over the REF period plus >£3m leveraged funds.
- Aircraft Strength Research Institute (AVIC), £1m.
- Beijing Aeronautical Science & Technology Research, £3m.
- Caterpillar Innovation and Research Centre, £1.1m.
- SKF UTC for Tribology, £2m.

### 4.4.c Industry membership programmes

The Unit operates a number of industry membership programmes that enable businesses to access our academic and research expertise and recruit our top graduates for a relatively small memberships fees.

Examples include:

- Centre for Process Systems Engineering: a multi-institutional research centre involving 26 academic staff from Imperial and UCL (portfolio of grants worth more than £20m).
- Centre for Systems Engineering and Innovation: provides a research hub for systems approaches to the civil infrastructure sector.

## 4.5 Inter-departmental research collaborations: Institutes, Centres and Networks

Imperial College London supports cross-disciplinary research and translation through 7 thematic Global Institutes, as well as topic-specific Networks. The 7 Global Institutes are the: Data Science Institute; Grantham Institute for Climate Change and Environment; Institute of Global Health

## Unit-level environment template (REF5b)

Innovation; Institute for Security Science and Technology (*Ochieng*, Co-Director) ; Energy Futures Lab (*Green* and *Korre*, Co-Directors); Institute for Molecular Science and Engineering (*Galindo*, Co-Director); and Institute of Infection (see institutional environment statement). Together with Centres and Networks they provide a framework for fostering inter-departmental collaborations across the Unit.

Three illustrative examples are:

- **Centre for Blast Injury Studies** (see Section 1.2.a[iii]) addresses the disabling injuries of conflict with a clinically led approach. The Centre, which is based in BIO (with cross-Unit collaborations in CEE, DES and MEC, plus Brain Sciences, NHLI, Surgery & Cancer and Physics outside of the Unit), comprises the unique multidisciplinary collaborations of military medical officers and civilian engineers and scientists from around the world to investigate blast injury. Outcomes include: (i) a Paediatric Blast Injury Field Manual; (ii) a CBIS podcast run by PGR students entitled “Fragments”; and (iii) new designs for protective equipment (see ICS07 Blast Injuries).
- **Integrated Development of Low-Carbon Energy Systems (IDLES): A Whole-System Paradigm for Creating a National Strategy** (EPSRC, £6m, 2018–23) is co-ordinated through the **Energy Futures Lab**. IDLES involves the Unit, with Mathematics, Centre for Environmental Policy and the Business School from outside the Unit. The IDLES programme aims to provide evidence for cost-effective and secure transitions to a low-carbon future. Outcomes to date include: (i) Drax Electric Insights Quarterly Report – Q4 2019, *What Drove Britain's Decarbonisation?* (*Green et al*); (ii) outreach publication, *How do we prepare the UK for a zero-carbon future?*, aimed at 15 to 19-year-olds; and (iii) BEIS & OFGEM Electricity Engineering Standards Review Panel (*Strbac* is a member).
- The **Institute for Security Science and Technology** created a unique, co-located security and defence Innovation Ecosystem, which embeds government, industry, academia and SMEs/startups in the I-HUB building on the White City Campus, co-located with the UK Ministry of Defence and its Defence and Security Accelerator Fund (DASA) and the US Air Force, Army and Navy (Tri-services) international research offices. Research projects include: (i) the Security, Privacy, Identity and Trust Engagement NetworkPlus (SPRITE+), a £1.36m EPSRC-funded consortium led by University of Manchester for a new digital security network; and (ii) the Research Institute in Trustworthy Inter-connected Cyber-physical Systems (RITICS) that studies security of cyber-physical, critical systems.

## 4.6 Contributions to the research base and indicators of wider influence

Staff in the Unit have made substantial contributions to the health of the research base by participating in funding body policy boards, standards committees and as regulator advisers (more than 120 people), grant review committees for funding bodies (more than 140 people), Government or international advisory boards (more than 85 activities over the period). More than 170 staff hold research leadership roles in professional bodies.

### 4.6.a Fellowships and Honours

All staff are encouraged to become fellows of the relevant professional body. The Unit has 48 staff elected as Fellows of the Royal Academy of Engineering (10% of the headcount). Of these, 22 became Fellows during the REF period (*Stevens, Ochieng, Grimes, J. Lin, Bull, Amis, Lowe, Adjiman, Shah, Ryan, Elghazouli, Hui, W. Jones, Green, Martinez-Botas, Childs, Blunt, Gast, Gardner, Macchietto, Rodriguez-Villegas* and *Matar*) of which 6 (27%) are female.

Seven staff in the Unit are Fellows of the Royal Society. Three were elected as FRS during the REF period (*Grimes, G. Jackson, Stevens*). *Molly Stevens* was elected to both the Royal Society and the Royal Academy of Engineering.

### Unit-level environment template (REF5b)

The Unit has 16 fellows of the IEEE, of which 8 were elected during the period and one (*Parisini*) currently serves as President of the IEEE Control Systems Society.

National honours awarded in the REF period were: *Alford* MBE (2013) for Services to Engineering; *Richardson* CBE (2015) for Services to Chemical Engineering Education and Safety; and *Maitland* CBE (2019) for Services to Chemical Engineering.

### 4.6.b Journal editorships, keynotes and plenary lectures

Staff submitted to the Unit held more than 200 journal editorial positions, and presented more than 1,000 keynote or plenary lectures. More than 130 publications won “best paper” awards. Space constraints do not allow us to do justice to the full range and significance of these contributions, but as an indication of their importance, at least 20 staff hold or held the position of Editor in Chief (Table 5).

**Table 5 Staff holding position of Editor in Chief**

Editor in Chief	Journal
<i>Astolfi</i>	<i>IEEE Transactions on Automatic Control</i>
<i>Dragotti</i>	<i>IEEE Transactions on Signal Processing</i>
<i>Pal</i>	<i>IEEE Transactions on Sustainable Energy</i>
<i>Parisini</i>	<i>IEEE Transactions on Control Systems Technology</i>
<i>Pitt</i>	<i>IEEE Technology and Society Magazine</i>
<i>Aliabadi</i>	<i>Computational and Experimental Measurements in Structures</i>
<i>Bearman</i>	<i>The Aeronautical Journal</i>
<i>Brandon</i>	<i>Progress in Energy</i>
<i>Bull</i>	<i>International Biomechanics</i>
<i>Cann</i>	<i>Tribology International</i>
<i>Gardner</i>	<i>Proceedings of the Institution of Civil Engineers – Structures and Buildings</i>
<i>Gardner</i>	<i>International Journal of Steel Structures</i>
<i>Gardner</i>	<i>Structures</i>
<i>Heng</i>	<i>Chemical Engineering Research and Design</i>
<i>Kazarian</i>	<i>Applied Spectroscopy</i>
<i>Lin</i>	<i>International Journal of Lightweight Materials and Manufacturing</i>
<i>Markides</i>	<i>Applied Thermal Engineering, Elsevier</i>
<i>Matar</i>	<i>Multiphase Science and Technology</i>
<i>Matar</i>	<i>Journal of Engineering Mathematics</i>
<i>Muller</i>	<i>Adsorption Science and Technology</i>
<i>Parisini</i>	<i>European Journal of Control</i>
<i>Potts</i>	<i>Geotechnique</i>
<i>Rein</i>	<i>Fire Technology</i>

### 4.6.c Prestigious prizes and awards

The Unit's contributions to the Engineering research base over the REF period have been recognised by many medals, prizes and awards. Table 6 provides a small selection.

Table 6 Staff in receipt of medals and awards

<b>Medals</b>	
<i>Higgins</i>	Sir Frank Whittle Medal of the Royal Academy of Engineering, 2020
<i>Alford</i>	IOM3 Platinum Metal, 2018 Royal Society Armourers and Brasiers Medal and Prize, 2016
<i>Whatmore</i>	IOM3 Platinum Medal, 2019
<i>Petit</i>	IOM3 Silver Medal, 2017
<i>Cilliers</i>	IOM3 Futers Gold Medal, 2016
<i>Titirici</i>	IOM3 Rosenhein Medal and Price, 2015 Chinese Academy of Science President's Award, 2016
<i>Vandeperre</i>	IOM3 Veralum Medal, 2019
<i>Livingston</i>	ICChemE Underwood Medal, 2016
<i>Matar</i>	ICChemE Bird, Stewart and Lightfoot Medal, 2019
<i>Trusler</i>	ICChemE Guggenheim Medal, 2017
<i>Song</i>	ICChemE Nicklin Medal awarded for early-career researchers, 2016
<i>Kazarian</i>	Royal Society of Chemistry: The Sir George Stokes Medal and Award, 2015
<i>Maitland</i>	SCI Leverhulme Medal and Lecture, 2017 Imperial College Medal, 2017
<i>Spikes</i>	Tribology Trust Gold Medal, 2014
<i>Standing</i>	ICE Telford Gold Medal, 2020, 2018
<i>Jones</i>	Combustion Institute: Alfred C. Egerton Gold Medal, 2020
<b>Prizes and awards</b>	
<i>Zdravkovic, Potts, Taborda, Jardine</i>	BGA Fleming Award Awarded to PISA (Pile Soil Interaction) project for excellence in geotechnical design and construction, 2017
<i>Mandic</i>	Dennis Gabor Award, International Neural Networks Society (INNS), 2019
<i>Gardner</i>	International Association for Bridge and Structural Engineering (IABSE) Prize, 2017
<i>Grimes</i>	Japanese Foreign Minister's Commendation for promotion of scientific and technological co-operation between Japan, Japanese Foreign Ministry, 2019
<i>Walsh</i>	Philip Leverhulme Prize, 2017
<i>Vincent</i>	Philip Leverhulme Prize, 2016
<i>Petit</i>	Philip Leverhulme Prize for Engineering, 2017 AIChE 35 Under 35 Award, 2017
<i>Shorten</i>	NovaUCD Consultancy of the Year Award UCD Consultancy for Toyota, 2020 (with Russo and Timoney).
<i>Jardine</i>	Rankine Lecturer British Geotechnical Society, 2016
<i>Bearman</i>	Royal Aeronautical Society Specialist Silver Award, 2014
<i>Finnis</i>	Sir Neville Mott Medal and Prize of the Institute of Physics, 2017

#### 4.6.d Membership of advisory bodies

Staff in the Unit are members of a substantial number of Government policy advisory bodies and international advisory boards. The size of the Unit makes it impossible to do full justice to the enormous range and the strength of its contributions, but the examples provided below give an indication of their breadth and scale.

- Scientific Advisory Board of the Max-Planck-Gesellschaft, Germany, since 2014, Chair of Board from 2021, *Adjiman*

## Unit-level environment template (REF5b)

- Member of the Advanced Materials Leadership Council, *Alford*
- Expert Panel Maritime 2050 – Department for Transport (2018–19), *Angeloudis*
- Nuclear Technologies Trajectory Review Group (2016) advising the Government Office for Science; adviser on the UK JCPOA (Iran nuclear deal) (2019-present), *Bluck*
- Scientific Council member, Institut Laue-Langevin (Grenoble, France), 2009–18, member and chair of soft matter college ('9'), Institut Laue-Langevin (Grenoble, France) (2008–13), *Cabral*
- Member of Scientific and Technical Advisory Panel (STAP) for European Spallation Source (ESS), *Cabral*
- Member of Science Board, Science and Technology Facilities Council (STFC) (2015–18), *Cabral*
- UK lead on UK government TTCP Material Group until 2017 (collaboration between USA, Canada, Australia, New Zealand), *Curtis*
- Member, Research Programmes Group, Ministry of Defence, *Dunne*
- Member of SACGM (The UK Scientific Advisory Committee on Genetic Modification), *Ellis*
- Royal Society Covid-19 Rapid Assistance in Modelling the Pandemic (RAMP) Committee (2020), *Graham*
- Department for Transport / Highways England Expert Analytical Advice and Challenge Panel (2019–21), *Graham*
- High Speed two Ltd Analytics Panel (2016, 2017–18), *Graham*
- Expert Witness to the Treasury Select Committee (2014), *Graham*
- Ministry of Defence, Nuclear Chief Scientific Adviser (from April 2017), Foreign and Commonwealth Office, Chief Scientific Adviser (2013–18) *Grimes*
- AstraZeneca Scientific Advisory Board (2015), *Heng*
- 'New Materials Board' Member for the Home Office, *Kinloch*
- Trustee of Rosalind Franklin Institute (2018–20), *Livingston*
- Member UK Government CCUS Cost Challenge Taskforce (under BEIS) (2018), *Maitland*
- Member of the Science Advisory Council for the Department for Transport (UK), *Martinez-Botas*
- Vice-Chair, Basic Science Division, American Ceramic Society (2013–14), *Saiz Gutierrez*
- CCS Development Forum (2014–16), *Shah*
- UK Government Hydrogen Advisory Council (2020-), *Shah*
- Member of Blackett Review on Computational Modelling (2018), *Sherwin*
- Member of Technical Independent Review Panel, Joint Air Quality Unit (JAQU), DEFRA (2018–19), *Sivakumar*
- Chairman of International Advisory Board of Tsinghua State Key Laboratory of Tribology (2014–19), *Spikes*
- Nurse Review of Research Councils, Royal Society, *Stevens*
- Construction Leadership Council main board member (2019–20), *Whyte*
- United Nations Sustainable Development Goals Impact Finance (UNSIF) Research Council Member, (September 2017), *Cardin*.

## 4.7 Public engagement

### 4.7.a Public engagement events

Public engagement with a diverse range of communities is central to the Faculty of Engineering's mission with activities being supported both centrally and at department level. Our strategy for public engagement is to promote in-person participation on our campuses through events such as the Imperial Festival and the "Imperial Lates" events which run monthly from October through to March on workday evenings. These attract significant attendance: the Imperial Festivals in 2017 and 2018 had 20,000 visitors each, and as part of the Great Exhibition Road Festival in 2019 had 60,000 visitors.



## Unit-level environment template (REF5b)

Over the REF period, about 250 staff from the Unit participated in more than 450 public engagement activities, many of which were organised by the College's Public Engagement team. Examples include:

- **Future Commuter** (Imperial Lates event, February 2020): The Centre for Transport Studies worked with Imperial's Public Engagement team to create an adult-focused Lates evening encouraging discussion around the future of transport and mobility. A total of 65 members of staff and students took part in the 3-hour event that attracted close to 1,000 attendees. The programme included a panel discussion on the merits and drawbacks of autonomous vehicles. The debate featured audience questions put to a selection of Imperial researchers and representatives from Transport for London, investigating the technology from an engineering, economic, environmental and safety design perspective.
- **Enginuity Zone** (Imperial Festival, June 2018): To mark the Year of Engineering in 2018, Imperial Festival showcased the variety of novel solutions, inventions and new technologies developed by our engineering researchers, students and alumni. More than 100 staff and students contributed demonstrations, workshops and installations to the Enginuity Zone and discussed their research with visitors. Around 20,000 members of the public joined the Festival over the weekend and more than a quarter of those engaged with the zone's content. This included opportunities to perform robotic surgery, make music with our minds, play quantum bingo and learn how physics might improve our future phones, tablet and laptops. Participants were invited to sit in a zero-carbon racing car or control car-manufacturing robots, while fans of games were entertained with computer games that could be controlled with the user's body, having been adapted by our mobility and next-generation prosthetics engineers.

### 4.7.b Media and social media

In order to reach a wider range of audiences the Unit actively promotes public engagement in its research through both traditional and social media. Examples include:

- **Fire and combustion research Rein** (MEC) organised the fire science booth at 3 Imperial Festivals (2017–19) and took part in "New Scientist Live London" in 2018 and 2019 (40,000 visitors). His work has also featured prominently in a wide range of media including BBC Two *Newsnight*, Channel 4, Channel 5, Sky News, *The Economist* (2019), *The New York Times* (twice in 2019), *Evening Standard* (2017), *The New York Times* (2017), *Scientific American* (2016), *Financial Times* (2014) and many other outlets.
- **Technology and psychology** In February 2015, *Calvo* (DES) described research and methods on design for wellbeing (keynote at Google Wellbeing day, online ~3,500 views), TedX in April 2017 "Time for technologies to respect our psychological needs" (~1,100 online views, 200 live audience).
- **Human-robot interface Vaidyanathan** (MEC) was 1 of 7 presenters invited to showcase "top British Technology" at the Prime Minister's technology roundtable (June 2018). His work featured twice in the RAEng "This is Engineering" campaign – "Human-robotic assist/interface" and "This is Engineering, Sports training" (his group provided 2 of the 5 projects selected across the UK). His work has also been covered widely in the media including BBC *Facebook News*, *LIVE Broadcast* from Biomechatronics Lab (250,000 views in 24 hours), September 2017, *The Gadget Show* (2017) and BBC *Click Live* (2016).

### 4.7.c Outreach activities

We regularly engage in schools outreach activities to promote engineering as an exciting career choice to young people. Outreach work has included:

## Unit-level environment template (REF5b)

- *Heutz* (MAT) developed a resource with the Royal Academy of Engineering to enrich the secondary-school STEM curriculum (2018); this was distributed to 900 schools. The resource focused on Materials Science, with activities on the materials needed to address pressing sustainability challenges, e.g. circular economy and cleaning up the plastic from the oceans.
- *Ryan* (MAT) led the ‘All aboard the Mary Rose’ activity demonstrating new ways to think about science and what scientists do as part of a programme for teachers to bring science into the classroom (2016).
- *Popo-Ola* (CIV) won a President’s Award for Excellence for successfully establishing the Creative Futures programme, which aims to inspire under-represented pupils from BAME backgrounds to consider careers in STEM subjects.
- *Chen* (CHE) and 2 PGR students designed and presented an outreach and classroom activity, “Fats’ Love–Hate Relationships”, in 10 events held in the UK and Spain.
- *Sivakumar* (CIV) has been a STEMNet Ambassador since 2015, contributed to several career events in high schools across London, and presented lectures on transport economics and travel demand modelling to high school science clubs (e.g. Lancing College).
- *Pimenta* (MEC) presented her composites research at a composites-themed stand at Imperial Festivals (2016-18), an Imperial Festival Schools Day in April 2018 (students and teachers from 9 invited primary schools), as well as at poster exhibitions at the House of Commons (UK Parliament) in “STEM for Britain” (2016, 2017 and 2019).

This section has highlighted the wide range of communities that Engineering at Imperial has engaged with over the REF period. Our aims in doing this have been to serve as an ambassador and gain public support for Engineering, and to attract young people from diverse backgrounds to become the engineering researchers of the future.

## 4.8 Conclusion

This document has described the resources, policies and facilities that make up the research environment of Engineering at Imperial College London. The achievements contained in the research outputs and impact components of our submission have been made possible by this environment, and together they reflect the quality, breadth and depth of our research across core engineering disciplines. This research environment has underpinned our ability to tackle the most challenging problems facing the world, and to translate the results into practical applications with real-world impact.