Institution: University of Brighton

Unit of Assessment: UoA12 – Engineering

1. Unit context and structure, research and impact strategy

1.1. Context and structure

Driven by our vision to be recognised as a foremost academic partner for internationally leading companies from the transport, energy and construction sectors, UoA12 has more than doubled its staff, income, outputs and postgraduate researchers (PGRs) since 2014. By addressing the mobility and clean growth Grand Challenges through rigorous science and applied innovation, we have improved the energy efficiency of vehicles and buildings and delivered cleaner air in cities. Our distinctive approach is to closely integrate in-house *theoretical physics* and *numerical simulation* with *advanced experiments*.

Since 2014 we have strategically recruited high-calibre scientists, moved our laboratories into a new £14m building, invested £3m in our instruments and infrastructure, and restructured our research community to nurture interdisciplinary collaborations. These investments have underpinned significant growth in quality and volume of research, enabled our teams to join major international consortia and secure leadership roles that define research priorities across the transport sector.

The research of our 29 staff (including 5 Professors, 6 Early Career Researchers (ECRs)) and PGRs (40 FTE completed + 36 current) spans two thematic areas:

- ***Applied Thermal Fluids****:* multiphase flows; heat and mass transfer; optical diagnostic techniques; reacting flows; theoretical models and numerical simulation
- ***Structures and Construction****:* materials; structural dynamics; soil-structure interaction; earthquake engineering; energy efficiency; construction and project management

UoA12 has evolved significantly since 2014, with the boundaries of our research growing beyond its automotive engineering roots: the *Vetronics Research Centre* moved to Coventry University, and in 2015 the *Centre for Automotive Engineering* was relaunched as the *Advanced Engineering Centre* (AEC) to emphasise the broadening of our capabilities and growth of our research base. Our researchers belong to two Schools: CEM (*Computing, Engineering and Mathematics*, 20 FTE) and SET (*School of Environment and Technology*, 9 FTE), which will merge in August 2021 to bring together overlapping research structures and expertise.

Most UoA12 staff are affiliated to the AEC (26 out of 29 FTE), which is led by **Marengo** and renowned for fundamental and applied research. Following a 25-year growth focused on building a critical mass of expertise in heat transfer and fluid dynamics, the AEC has been collaborating with Structures and Construction researchers who contribute to two newly-formed groups: Sustainability and Resilience Engineering (SuRE) led by **Cacciola** and established in 2016 to develop knowledge on the behaviour of new materials and structures; and Construction Engineering & Management (ConEM) led by **Alam** and formed in 2015 to improve energy and resource efficiency in construction. The AEC also has a history of supporting a niche experimental nuclear physics team led by **Bruce**, who is networked with a larger consortium through sustained funding from STFC consolidated grants with the University of Surrey since 2011.

1.2. Research and impact strategy

While our core mission has remained to deliver real-world energy-efficient technologies, since 2014 we have expanded our focus beyond vehicles and into thermal management, insulation materials, energy recovery and storage. To achieve this, we significantly broadened our research capability and capacity (from 8.5 to 29 FTE), whilst also increasing the quality of our research, as evidenced by our Research Council income increasing more than fivefold compared to REF2014 to exceed £4.2m.

1.2.1. Delivering our strategic aims since REF2014

Our overarching ambition since 2014 has been to continue dominating a specialised research market with high potential for academic, economic and societal gains. Our leadership role in novel low-carbon internal combustion systems has been further consolidated through the award of agenda-setting positions at the Advanced Propulsion Centre (APC) and the UnICEG (Universities' Internal Combustion Engines Group), described in Section 4.

The vitality of our research environment has enabled us to make strategic appointments of research leaders (**Marengo**) and talented ECRs (**Georgoulas, Magaletti, Rybdylova, Vogiatzaki, Zaripov**) to rejuvenate our Unit (17% are Professors compared to 33% in REF2014) and more than doubling our income within the census period (from £6m to £13.3m). This acceleration stems from large investments in support and funding for our teams and infrastructure, including a new Advanced Engineering Building in 2018 that forms our innovation hub for collaboration between researchers, students and business partners.

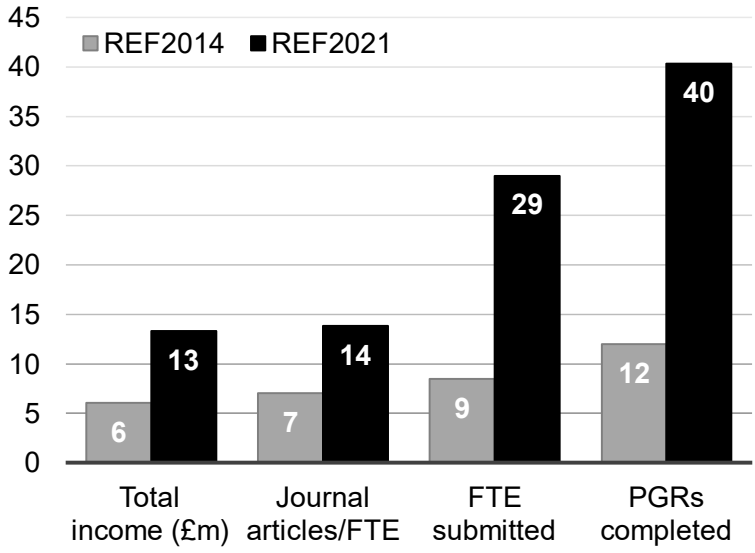

Figure 1. Comparison of REF2014 and REF2021

This rapid growth (Figure 1) has enabled our teams to significantly exceed the ambitious goals they had set for this census period. We attribute this success to the nurturing and retention of talented researchers, and a vibrant environment that promotes academic excellence.

Evaluating our performance against the research goals set in REF2014:

***RG1 Design efficient and clean combustion systems**:* We led the £3m EPSRC-funded *Ultra Efficient Engines and Fuels* consortium (EP/M009424/1), in collaboration with 10 industrial and academic partners. **Morgan**'s research on the split cycle combustion engine delivered a world leading 60% brake thermal efficiency. This proof of concept we co-delivered with global engineering consultant Ricardo plc generated a new spin-out company (Dolphin N2) in 2018, and £6m of further funding from Innovate UK and APC (STEPCO2). The global Fiat Powertrain Technologies group acquired Dolphin N2 in 2019 to take the engine concept to commercialisation. This major progress towards next-generation powertrain systems is detailed in our Impact Case Study [ICS_Ricardo]. We delivered cleaner biofuels (**Saeed**), and partnered with the global oil company bp to identify mechanisms that lead to fuel films on injector nozzles as potential foundations for the growth of deposits (**Crua**). By removing harmful deposits, bp fuels now help engines maintain optimal performance and increase fuel economy across the light and heavy-duty transport sectors [ICS_bp].

***RG2 Nurture close collaborations with industry and government to manage and exploit impact**:* The AEC was selected as one of six national Spokes for the APC, a £1bn venture founded in 2013 between UK Government and the automotive industry to develop low emission powertrain technologies, reinforcing our position as a recognised leader in propulsion. As the Spoke for *Thermal Propulsion System Thermal Efficiency*, we encourage and nurture cross-sector collaborations to keep the UK at the forefront of low-carbon high-efficiency engine research and development. We have strengthened our capability to build industrial partnerships by recruiting high-calibre researchers from Ricardo (**Atkins**) and Highview Power (**Morgan**); developed new standards with BSI to support remanufacturing in the UK and China (**Wang**); and co-established a

research impact accelerator hub with Ricardo. This *Impact Factory* investigates long-term disruptive technologies, hosting Ricardo's Global Technical Lead (Professor Andrew Atkins) within our laboratories.

***RG3 Increase interdisciplinary research**:* We collaborate with biomedical and clinical scientists from UoA3, applying expertise in fluid dynamics and energy efficiency to produce new knowledge in the cross-themes of pharmaceutical sprays (**Rybdylova**'s UKRI Fellowship; PhD co-supervised by **Crua, Marengo**; Royal Society grant - **Rybdylova, Sazhin**), 3D bioprinting (UKRI I3 award - **Marengo**), biofluid dynamics (PhD co-supervised by **Vogiatzaki** and Brighton and Sussex Medical School (BSMS) on tuberculosis and pulmonary airflow; PhD co-supervised by **Crua** on flow optimisation in bioartificial organs), plasma-assisted chemical vapour deposition (KTP – **Rybdylova**), manufacture of medical devices (KTP – **Wang, Covill**) and manufacturing data analytics (Innovate UK grant – **Wang**).

***RG4 Develop the leaders of tomorrow**:* Through targeted support and mentoring our ECRs have secured prestigious fellowships and leadership roles, such as UKRI Future Leaders Fellow **Rybdylova**, EPSRC-UKRI Innovation Fellow **Vogiatzaki**, Marie Skłodowska-Curie Fellow **Magaletti**, and Director of APC Spoke **Atkins**. Mid-career staff have been promoted to Professors (**Crua, Morgan**) in recognition of their leadership of research consortia and influence on national and international agendas.

***RG5 Invest in infrastructure to enhance academic-industrial collaboration**:* We built a new £14m Advanced Engineering Building in 2018, funded by the Coast to Capital Local Enterprise Partnership and the Wolfson Foundation, in close partnership with our strategic partner Ricardo. This building hosts 15 of our research laboratories along with dedicated machining workshops, rapid prototyping and metrology instruments. It acts as an engineering hub to promote three-way communication across industry, research and education, and hosts staff from Ricardo, which provided engine test beds and equipment, and invested £940k in cash to develop our laboratories over the census period.

1.2.2. Delivering our strategic impact aims since REF2014

Our strategy for achieving economic and societal impact centres on maintaining and building long-term collaborations and strategic alliances with industrial partners and governmental bodies. In 2014 our impact goals were to:

***IG1 Disseminate and publicise the impact of our research**:* New Research Leads engage with the University Impact Manager and the central Research Services team to capture and support impact across UoA12 and identify new areas for impact generation. The dissemination of impact is led by AEC Deputy Director **Atkins**, former Head of Technology Strategy at Ricardo with extensive industrial experience (13 years Ricardo; 4 years Jaguar Land Rover). This has increased participation with industry and public-facing events, such as prize-winning contributions to the Future Powertrain Conference by some of our PGRs, TV news features, and brought academics, industry figures and environmentalists together (eg 2016 workshop co-organised with the APC and EPSRC to discuss the future of combustion engines).

***IG2 Increase engagement and generate links with new partners**:* We collaborate with more than 160 groups from 50 countries, all evidenced by 400+ co-authored journal articles and >100 projects since 2014, in partnership with global corporations (eg EDF, Siemens, GA Drilling, Quaker Houghton, Tullow Oil) and leading regional technology innovators (eg Bloc Digital, Ceres Power, Highview Power). Since 2014 we have taken a leadership role at the APC, created an 'Impact Factory', launched an Engineering Doctorate programme, and led projects through Clean Growth UK – the £3.5m University of Brighton (UoB)-led national innovation consortium of 1,800+ SMEs (see REF5a). This has resulted in new collaborations such as with London EV Company (£44m APC-funded programme to deliver zero-emission vehicles); Jaguar Land Rover, Daimler and Bosch (€12.1m Horizon 2020 collaborative project to develop new gasoline engines); EDF to develop new seismic protections for nuclear plants; Tata Motors to research new heat pipe

technology to control the thermal loading of batteries in electric vehicles; Highview Power to accelerate the commercialisation of liquid air energy storage [ICS_HighviewPower].

1.3. Research and impact strategy to 2026

Our ambition is to strengthen and expand our international influence in highly specialised research areas that have strong potential for academic, economic and societal gains. Over the next five years our strategic goals will be to:

***SG1 Build interdisciplinarity**:* We will exploit complementary expertise in fluid dynamics, materials, heat transfer, optics and mathematical modelling in growth areas: biofluid dynamics, superinsulation materials, structural resilience, and digital manufacturing (**KPI**: to double interdisciplinary collaborations, outputs and income).

***SG2 Grow industry partnerships**:* We will use Brighton's new innovation hubs from our ongoing £85m campus redevelopment (see 3.2 and REF5a) as a platform to increase industry collaborations (**KPI**: +50%), targeting and prioritising areas of strategic growth identified in SG1. *Structures and Construction* will deepen relationships with key partners across industry and academia to create a centre of excellence for digital construction.

***SG3 Ensure vitality and sustainability by nurturing future leaders**:* We will increase our PGR community (**KPI**: +30%) through targeted investments and training grant/network applications, and exploit activities in SG2 to increase the number of PGR secondments to leading industry and international laboratories. We will target investments and mentoring towards early and mid-career staff to increase funded fellowships (**KPI**: +50%).

***SG4 Strengthen our global reputation in highly specialised areas**:* We will invest Quality-related Research (QR) funds in networking with international research leaders from prestigious laboratories (**KPI**: double incoming/outgoing research exchanges). *Applied Thermal Fluids* will grow UKRI grant income (**KPI**: +50%), focusing on areas with high potential for impact: energy storage/recovery, cryogenics, and green manufacturing. We will seek opportunities to combine and share facilities and expertise with other institutions in our two thematic areas through international funding schemes.

1.4. Research ethics and integrity

Ethics and integrity are integrated within our processes to ensure that all researchers engage with University-wide policies and ethics management systems (described in REF5a). Best practices for research ethics are communicated through school-led training workshops for staff and PGRs, which cover all research from undergraduate student projects to major research programmes. Training in research integrity is compulsory for all PGRs, and part of the induction process for new academic staff.

Our researchers have embraced open access (79% of all articles produced during this REF cycle are open access), and UoA12 staff have produced more than 12% of all datasets deposited on Brighton's Open Research Data repository. Data from our nuclear physics experiments are stored at each host laboratory and are open to all members of the collaboration to analyse, thus encouraging results and interpretations to be cross-checked before publication. We aim to go beyond normal expectations for open science in our fields. For example, in 2014 we were the first UK academics to join and contribute to the Engine Combustion Network (ECN) open initiative founded by Sandia National Laboratories, where datasets, research methods and data processing codes are shared freely online. We participate in ECN's international meetings and collaborative publications (eg **Crua, Rybdylova, Sazhin, Vogiatzaki**) where the issues of reproducibility of measurements and simulations are openly discussed to actively eliminate errors in the ECN members' research methods. Participating in such open initiatives has significantly increased the quality of our sprays and combustion research over the return period by enabling our PGRs and academics to 'debug' their methods alongside world leaders in the field.

2. People

Our ambition is to provide an inspiring and inclusive environment for staff and PGRs (Table 1), where they can rapidly generate and transform novel ideas into applied solutions in close partnership with industry leaders from the transport, energy and construction sectors.

Table 1. Overview of UoA12 career grades, experience, and characteristics for this REF cycle

	Headcount	% Cat. A
Career grades		
Professors	5	17%
Emeritus Professors (Cat. B)	1	-
Mid-career academics[1]	16	55%
Early career academics[2]	8	28%
Experience		
Principal Investigators	15	52%
Co-Investigators	17	59%
Early-Career Researchers (REF definition)	6	21%
PGRs (Completed, Active[3], External[4])	48, 36, 22	
Characteristics		
Gender balance (Female, Male)		28%, 72%
Ethnicity (BAME, White)		28%, 72%
Permanent employment contracts	28	97%
Staff recruited	13	45%
Staff promoted	20	69%

[1] *Readers, Principal Lecturers, Principal Research Fellows*
[2] *Senior Lecturers, Lecturers, Research Fellows*
[3] *PGRs active at submission*
[4] *Completions at other universities with co-supervision by UoA12 staff*

2.1. Staffing strategy and staff development

Our recruitment plans during this assessment period (13 staff, at a steady rate of 2 FTE/year, 46% women) have been targeted at: planning the succession of the AEC's leadership, supporting our impact strategy, improving our gender profile, and expanding our research capability.

Our succession plans delivered a smooth transition for the leadership of the AEC: **Marengo** was appointed in 2014 and became Director of the AEC following the retirement of **Heikal** in 2019 (who now contributes as Emeritus Professor). The leadership of UoA12 is strengthened by 3 Professors (**Crua, Morgan, Sazhin**, combining 60+ years of research within UoA12) and 4 Readers (**Begg, Cacciola, Piroozfar, Vogiatzaki**).

We have supported our impact strategy by increasing capacity for building industrial partnerships, with **Atkins** (former Head of Technology Strategy at Ricardo) joining our team with **Morgan** (former Senior Manager, Ricardo, and Chief Technical Officer, Highview Power). We have expanded our ability to respond to commercial research demands by funding dedicated technicians using the AEC's own investment account. We use this account to invest in projects with long-term potential for impact through internal competitive schemes and to support, for example, bridging PGR/ECR contracts, work with SMEs on spray cooling (**Begg**), expanding research capability in energy harvesting and nano-refrigerants (**Fenercioglu-Aydin, Panesar**), and growing partnerships with international universities (**Georgoulas, Sazhin, Wang**).

We have expanded capacity and capability by increasing staff numbers in *experimental thermal fluids* (**Atkins, Marengo**) and *computational fluid dynamics* (**Georgoulas, Magaletti, Vogiatzaki, Zaripov, Zubkov**), while building upon optical and numerical capabilities to expand into *aeronautics* (**Fenercioglu Aydin, Kwiek**) and *remanufacturing* (**Wang**). We have grown capacity

in *structure and materials* (**Tombari, Tsioulou**) and the *energy and environmental performance of buildings* (**Alam**).

***University-wide processes promote fairness within UoA12**:* the University adheres to the Concordat to Support the Development of Researchers, and in May 2020 retained its 'HR Excellence in Research' award following the eight-year review. The institutional workload allocation model offers all staff 0.2 FTE pro rata for research and/or scholarly activity. Our researchers benefit from long-term contracts by default, with only one Category-A staff being on a fixed-term contract (employed on an Individual Fellowship).

Investment in the development of staff is evidenced by career progressions: 20 staff (69% of UoA12) were promoted 23 times, including 7 to Senior Lecturers, 10 Principal Lecturers, 3 Readers, and 2 Professors. Contribution to research leadership is a key promotion criterion, with impact engagement and delivery being essential for Professorship. The support we offer staff to achieve this includes incoming/outgoing secondments with industry and academia, for example: **Morgan** and **Crua** were seconded (1 day/ week) at Ricardo to plan joint research; Visiting Professor Atkins participates in impact activities and planning (1 day/week); **Heikal** was seconded for 2 years to develop UTP's (Malaysia) research and impact strategy with Petronas.

2.2. Developing the research leaders of the future

By fostering a vibrant and supportive environment we have been able to attract new talented academics and retain experienced staff (55% were employed before 2014). Examples of support and successes include:

Crua, mentored by **Heikal** since joining Brighton as an undergraduate (1997), completed a PhD (1999 – 2002) supervised by **Heikal, Sazhin** and **Morgan** (then employed at Ricardo) before being recruited as postdoctoral Research Fellow (PDRF). Supported through a research-focused career pathway under the mentorship of Visiting Professor Monaghan (Ricardo's Technology Director 1990 – 2000), he established new partnerships (eg bp in 2006, Sandia National Laboratories in 2014), securing £4.7m through industry contracts and 11 UKRI grants. Promoted to Reader (2014) and Professor (2016) he is Research Lead for Engineering, Deputy Director of the AEC, has led this REF submission to UoA12, and mentors researchers at all career stages.

Rybdylova (Principal Lecturer), UKRI Future Leaders Fellow, with a PhD from the Moscow State University where she was awarded a Young Scientists Award, and mentored by **Sazhin** since joining Brighton as a PDRF (2013), **Rybdylova** simulated droplet entrainment in flows with vortex ring structures for projects led by **Sazhin** (EP/K005758/1, EP/M002608/1). After becoming a permanent member of staff, she secured an EPSRC First Grant (EP/R012024/1), and centrally funded investments that laid the foundations for her UKRI Fellowship (2020, MR/T043326/1) to direct research on droplet flows relevant to the spread of COVID-19 and the mixing of fuels.

Vogiatzaki (Reader), EPSRC-UKRI Innovation Fellow, mentored by **Crua** since joining Brighton as a Senior Lecturer (2016), she secured an EPSRC First Grant (EP/P012744/1) the same year and further funding to rapidly build a team of 9 researchers. **Vogiatzaki** received targeted support to construct grant proposals, meet new industry collaborators and prepare for panel interviews. These support mechanisms helped secure her EPSRC-UKRI Innovation Fellowship (EP/S001824/1), which aims to create new fundamental knowledge and advanced numerical tools for liquefied gases and their integration in future energy systems, in collaboration with Ricardo and Libertine FPE.

***Mentoring and supporting researchers at all stages of their careers**:* All new staff are allocated a research mentor, given workload relief to establish their research (0.1 FTE for 2 years), and assigned a yearly appraisal review to reflect on achievements and set goals. All PDRFs are mentored to develop their research specialism and become principal investigators. UoA12 introduced additional mentorship processes for long- and short-term support of our ECRs, including targeted help with the development of grant proposals (eg **Georgoulas, Wang**), responses to funder reviews and mock interview training. ECRs are routinely supported by senior staff to win central funds, for example the University's 'Rising Stars' ECR funding was awarded to:

Rybdylova (then secured EP/R012024/1), **Vogiatzaki** (then secured EP/P012744/1), and, more recently, **Georgoulas** and **Tombari** (to develop their first UKRI proposals as principal investigators). Industry leaders (eg Visiting Professors Atkins, Jackson, Monaghan) contribute to mentoring mid-career and senior staff to broaden horizons and grow their collaboration networks.

***Using QR funds strategically, we promote PDRFs to permanent staff**:* 28% of returned staff previously held a PDRF position within UoA12 (eg **Begg, Miché, Panesar, Zubkov**). We achieve this by ensuring PGRs and PDRFs contribute to undergraduate teaching, which helps them secure permanent lectureships at Brighton and other universities (eg Coventry, Surrey, Egypt-Japan University of Science and Technology). We prioritise QR funds for ECRs and staff returning to research (eg 10% additional research time to **Begg, Covill, Wang, Zubkov**), supporting staff with sabbatical leave and pump-priming funds to underpin grant proposals and high-quality outputs, including: **Georgoulas** (to build an optical flow boiling facility for an EPSRC proposal), **Panesar** (to build an Organic Rankine Cycle experiment for leading energy recovery research), **Lampropoulos** (thermal conductivity analyser for construction materials), **Cacciola** (laser vibrometer for AHRC-funded seismic protection research), **Rafiq** and **Alam** (vacuum sealing chamber for an EPSRC proposal).

ECRs and PGRs contribute to leadership both across the University and this Unit: **Vogiatzaki** represents ECRs at her school's Research and Enterprise Committee; **Rybdylova** contributed to the construction of this submission as a full member of UoA12's REF Leadership Team; PGR Gander represents research students on the AEC Steering Board.

2.3. Postgraduate research students

Our staff's success at securing EPSRC projects, combined with £1.4m strategic investment in UoA12's PGR studentships, has led to significant increases in Doctoral Training Grants over this REF cycle (Table 2). We received EPSRC DTP formula allocation, 4 EPSRC Industrial CASE awards (£320k bp, Delphi, Ricardo), and 4 STFC-funded quota and project studentships. Industry-funded studentships are also increasing through 4 direct contracts and 5 EngD (described in 3.2). We have worked with the Iraqi Cultural Attaché in London and the Ministry of Higher Education and Scientific Research as a partner in the Iraqi PhD Scholarship Scheme, hosting 17 PGRs.

Table 2. Overview of funding type by PGR headcount ('Active' PGRs at submission date)

	Completed	Active	Total
Doctoral Training Grants (EPSRC, ESRC, STFC)	1	11	**12**
Industry (EngD, contracts)	2	7	**9**
Middle East and North Africa (MENA) governments	15	2	**17**
Self-funded PGRs	10	8	**18**
UK/EU grants (STFC, H2020)	4	0	**4**
University strategic investment	16	8	**24**

We provide interdisciplinary PGR training with the University of Oxford and UCL through a £4.7m joint EPSRC DTP '*Science and Engineering in Arts, Heritage, and Archaeology*' (SEAHA). As members of the University Alliance our researchers have secured studentships within the Doctoral Training Alliance Energy programme to research green maritime shipping (**Panesar**) and fundamental thermal fluids (**Georgoulas**).

In addition to our own 48 completions (40 FTE) and 36 active PGRs, in this REF cycle UoA12 staff have co-supervised 22 PGR completions at other universities including Stuttgart, UTP (Malaysia), Bergamo (Italy), Imperial College and UCL. These external supervisions promote an international outlook in our supervisors, expand the collaboration networks of our own PGRs, bring back good practice to UoA12 and contribute to research across the world.

PGR recruitment, administration and core training are conducted centrally through the Brighton Doctoral College (described in REF5a). We use our QR allocation to extend studentships and fund

conference travel to help PGRs present their research and integrate with the international community. We complement central training for research methodology and impact delivery through our industry partners and government links to further the student experience, skills, and knowledge. For example, Ricardo hosts 5 EngD researchers on a weekly basis, STFC PGRs participate in national graduate schools and attend a summer school. PGRs are members of our research centres and groups, participating in internal and external meetings. We train PGRs for academic success by mentoring them to apply for competitive internal and external funding schemes (eg PGR Gander securing a UKRI-Mitacs Globalink grant, one of only two awarded to post-1992 universities).

Our approach to training and development has prepared PGRs for success both in academia (eg Professors at Alexandria University; Egypt-Japan University of Science and Technology; University of Western Cape) and industry (eg Innovation Manager at the PSA Group; Global Technical Expert at Ricardo; Formula 1 Trackside Engineer at Scuderia Ferrari; ExoMars and Solar Orbiter Engineer at Airbus Defence and Space). Our close working relationships with technology innovators help PGRs secure their first employment (eg 3 PGRs at Highview Power; 2 at Ricardo/Dolphin N2) while supporting our partners in recruiting highly trained engineers.

2.4. Ensuring equality, diversity and inclusion

We form an inclusive multinational community of staff/PGRs with regular visits (>32/year) to/from international research laboratories such as UTP (Malaysia), Tsinghua University (China), ISAT, INSA, CORIA (France), and University of Bergamo (Italy). Moreover, the proportion of staff from BAME/ethnic minority backgrounds is in proportion to the UK population, but significantly better than the average UK Engineering workforce (Table 3).

Table 3. Equality and diversity characteristics for UoA12 compared to UK Engineering

Characteristic	UoA12	UK Eng.	Source
Women staff	28%	10%	WISE 2019 Workforce Statistics
Ethnic minorities	28%	8%	Engineering UK 2018: The state of engineering
Permanent contract	97%	51%	UCU Precarious work in higher education

Our processes embed charter principles to ensure fairness and work-life balance in our community (UoA12 Schools hold bronze Athena SWAN awards; UoB holds a bronze Race Equality award). We promote the University's employment protocols with all UoA12 staff having completed training on 'unconscious bias', 'equality and diversity', GDPR, and 'managing diversity' for line managers. Our core hours policy supports staff with parental/caring responsibilities to participate fully in all activities and meetings. We prioritise QR funds for staff returning to research after parental leave (eg **Tsioulou** who subsequently published journal articles and secured a Royal Society grant).

UoA12's inclusive culture contributed to significantly reducing ethnicity and gender gaps. We attribute some of this success to women holding visible leadership roles across the institution (eg VC, Pro-VC for Research) and in UoA12's environment via the Head of Research and Enterprise (**Bruce**), Mentoring Lead (Belz until 2020), Deputy Director of the AEC and Director of APC Spoke (**Atkins**), and being celebrated as female role models (**Bruce, Vogiatzaki** at University-wide celebration of International Women's Day). We contribute to building gender balance and setting high EDI standards across the UK engineering community, such as **Atkins** co-authoring a policy report on decarbonising transport where gender balance and inclusiveness were embedded from the outset.

Our recruitment plans to improve UoA12's gender distribution have resulted in a positive impact on the gender profile of our Principal Investigators since 2016 – 17 (Figure 2). Our success rate at securing external funding is equal across genders (average: 43%, women: 42%).

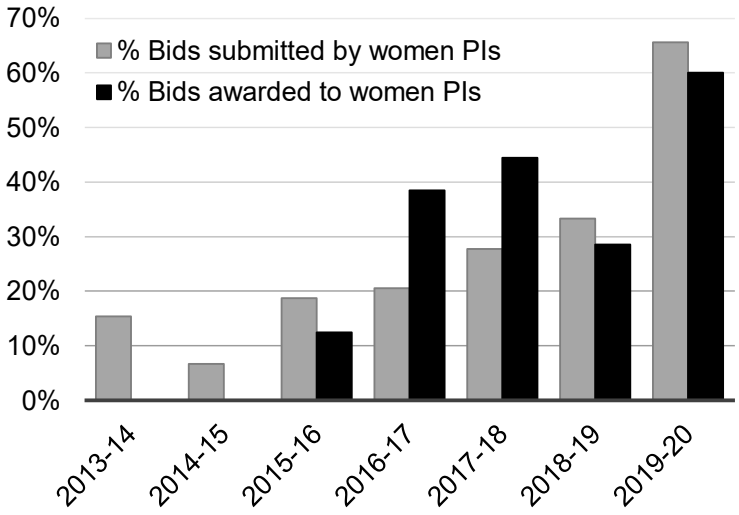

Figure 2. Gender profiles for Principal Investigators

This REF submission was constructed by a diverse Leadership Team, with a representative gender balance, drawn from all main disciplines in the submission. The Output Review panel and UoA Leadership Team completed REF-specific training on 'equality and diversity' and 'information security awareness'. UoA12 held a mock output selection to identify potential EDI biases, and subsequently inform the final output selection. An equality impact assessment demonstrated that our selection and attribution of outputs were proportional to gender and ethnicity profiles.

3. Income, infrastructure and facilities

3.1. Research portfolio and strategies

In REF2014 our research income was dependent upon a small number of senior staff securing Research Council and EU grants. Since REF2014, a broader range of Principal Investigators (52% of UoA12) across the full career spectrum have secured over £13.3m (~£459k per FTE) in competitive research income from a wider range of funding bodies. Our focus on high quality research in close partnership with industry is reflected in UoA12's portfolio (Table 4). Over the census period, the academics from UoA12 have generated an average of approximately ~£2m per year, maintaining at least £1.2m per year over the REF cycle.

Table 4. Research projects and their funding streams over the census period

Funding stream	Projects
UK grants (eg UKRI, Royal Society, British Council)	45
Industry (eg Ricardo, bp, Delphi, PETRONAS, Johnson Matthey)	35
EU grants (eg H2020, European Space Agency, Interreg)	13
In-kind contributions (eg UK Space Agency, STFC, CERN)	10

EPSRC funding from UoA12 alone places Brighton as a top performing post-1992 university (total grant awarded during census), demonstrating our ability to lead partnerships and deliver impactful research for our industry collaborators. Our increased EPSRC grant portfolio was instrumental in securing DTP formula allocation (UoA12 generated 99% of Brighton's EPSRC funding at the time of DTP allocation). We have increased the number of staff who receive continuous long-term EPSRC funding as Principal Investigators (eg **Sazhin** continuous PI on EPSRC grants 2007-19; **Crua** 2013 – 23; **Morgan** 2015 – 22; **Vogiatzaki** 2016-23). Our plans for the coming years are to continue growing this strategically important funding stream by further expanding the mentoring activities of early- and mid-career researchers. These targeted activities include close support with writing competitive grant proposals, engaging new staff with our long-term collaboration networks (eg APC, ECN) to promote the development of new cross-sector partnerships, and strategic QR investments into fundamental research areas.

In addition to the UKRI Fellowships described in 2.2, examples of competitive awards include:

- ***ULTRA*** (£770k, EPSRC, 2015), Brighton-led £3m consortium delivered new combustion engines that can achieve up to 33% reduction in fuel consumption at near zero emissions, in

collaboration with Delphi, Ricardo, bp, Imperial College, Brunel University, University of Oxford, and UCL. This research was instrumental to the Dolphin N2 spin-out and acquisition by the Fiat group [ICS_Ricardo].

- ***Design Service Capability Fund*** (£2.1m, UK Government, 2013-16) for classified research funded by the Ministry of Defence.
- ***PaREGEn*** (£437k, Horizon 2020, 2016), €12.1m collaborative programme with 16 partners including Daimler, Siemens, Bosch, Jaguar Land Rover, Aachen University and ETH Zurich. PaREGEn delivered a demonstrator vehicle with a new generation of gasoline direct injection engines achieving a 15% reduction in CO_2 emissions.
- ***HyHP*** (£722k, EPSRC, 2017), developed a novel wickless heat transfer device capable of operating both on the ground and in space, in collaboration with Kayser Space, Libertine FPE and Sustainable Engine Systems. This technology will be deployed on the International Space Station in 2023.

Our external funding portfolio is supplemented by central investments (£540k from QR and capital funds, excluding PGR studentships), which we used to develop new research areas and expand exchanges with industry, for example: **Covill** to build on his KTP with OSET Bikes and produce an interactive test rig to showcase at public events; **Marengo** to develop a modelling platform for simulating energy consumption and comfort in buildings, which led to the FREDS spin out in 2019; **Wang** to set up an online remanufacturing platform which led to a £320k Innovate UK project to develop an electronic marketplace for remanufactured products.

3.2. Intellectual infrastructure for research and impact

Through the University's 2016 review of its research, we delivered strategic change in the internal organisation of our Unit. New leadership and management roles were established to support our teams, including Research Leads for Engineering and for Impact, Mentoring Lead, and four Deputy Directors for the AEC. These roles focus on supporting our staff to construct funding proposals and build new partnerships with industry. In addition to these structural changes, we lead and contribute to research impact through innovative mechanisms such as:

Impact Factory*:* co-founded in 2017 with Ricardo using funds from HEIF and the Royal Academy of Engineering, this impact accelerator is based in our Advanced Engineering Building laboratories to promote high impact collaboration between students, business and academics. The Impact Factory has generated research grants (£627k), while supporting undergraduates and PGRs in understanding their roles in industry, particularly in developing innovative solutions for complex problems. This initiative is championed by **Morgan** and Visiting Professor Atkins (Global Technology Lead at Ricardo), who brings significant intellectual property (33 patents) in the areas of energy generation, transmission, medical engineering, energy conversion and transport.

Clean Growth UK / Green Growth Platform*:* Since launching in 2014 with £3m funding from HEFCE, the Green Growth Platform (GGP), that is led by UoB, has attracted a membership of over 1,800 businesses, helped business raise over £2m in R&D funding, created over 248 green economy jobs and helped develop over 70 new products and services. In 2018, the GGP was awarded £3.5m from Research England to link with two other university-led business-innovation hubs and create the national Clean Growth UK network. Through this innovative collaboration platform, academics from UoA12 have generated 15 industrial projects with a total value of £2m. These include: **Covill** who supported OSET Bikes, leading manufacturer of electric trials and motocross motorcycles, to develop new electronic interfaces for the high-performance bikes (£224k); **Wang** worked with ATC Ltd, one of the UK's largest contract medical device manufacturers of orthopaedics, to enhance productivity by linking simulations, automatic machining code generation and inspection to CAD models to significantly reduce machine setting times, facilitating rapid reaction to patient needs (£217k); **Marengo** and **Miché** who work with European Thermodynamics Ltd to bring to market novel heat pipes and optimise the thermal management of electronic or mechanical systems, including electric vehicles (£192k).

***Engineering Doctorate (EngD)**:* This industry-sponsored programme prepares talented engineers and scientists for advanced careers in engineering and provides an intellectual challenge at PhD level through four-year full-time doctoral training. Our 5 EngD students spend up to 75% of their time at the sponsoring company with an industrial supervisor, and the remaining time at the University to attend taught modules covering research methods, business, and specialist technical subjects relevant to their research. A recent demonstration of the ability of this programme to prepare scientists for industrial challenges is Dr Rota, who completed his EngD in January 2020 in collaboration with Ricardo, then worked with us as a PDRF on cryogenic energy storage (funded by Highview Power) and moved to Dolphin N2 as a Development Engineer in August 2020 to contribute to our split-cycle engine research [ICS_Ricardo].

***Brighton Research Innovation Technology Exchange (BRITE)**:* This business innovation programme facilitates collaboration between academics and industry innovators. Recently launched through a £10.5m partnership between Plus X business incubator and the University, BRITE supplements our impact facilities and gives new opportunities for staff and PGRs to expand research and development collaborations with start-ups, scale-ups and SMEs.

3.3. Infrastructure and facilities for research

To achieve the ambition outlined in REF2014, our research environment was significantly upgraded over the assessment period. We have invested a total of £14.7m in a new building and research equipment. Our staff and PGR offices provide a modern academic and learning environment through a £26m refurbishment in 2015, which won an *Architects' Journal Retrofit Award*. Research is supported by 5 FTE of highly skilled technical staff, 1 FTE per annum being supported by QR funds.

***Advanced Engineering Building (AEB)**:* The AEB is our brand new 2,770m^2 three-storey building (opened in 2018) which serves as a hub for engineering knowledge exchange across our research, teaching and enterprise activities. This £14m build was funded by the Coast to Capital Local Enterprise Partnership and the Higher Education Funding Council. Research in the AEB has been supported by Ricardo (£940k) to upgrade our test cells instrumentation and engine emissions measurements, the Wolfson Foundation (£500k) for a new fully automated multi-cylinder engine test cell capable of running transient vehicle cycles, HEFCE's Research Capital Investment Fund for a high-speed infrared camera (£147k) and relocating an engine test cell to the AEB (£42k). The AEB hosts our Applied Thermal Fluids laboratories, two manufacturing workshops, rapid prototyping facilities, lecturing and meeting spaces.

Engine research laboratories comprise a new multi-cylinder engine with automated running capability and full emissions measurement, 2 single-cylinder engines and 3 optically-accessible engines to support fundamental combustion research. We host 6 optical flow laboratories (including cryogenics, flow boiling, pulsating heat pipes) that have produced and applied new optical diagnostic techniques such as ultra-high-speed (200MHz) Time-Resolved Laser-Induced Incandescence for soot formation, high-speed (10kHz) Laser-Induced Grating Spectroscopy for high-precision gas thermometry, time-resolved 1D Phase Rainbow Refractometry for droplet evaporation rate and temperature, high-speed (10kHz) Laser-Induced Fluorescence and Phosphorescence for full field gas thermometry, and 200MHz long-distance microscopy to characterise non-spherical droplet shapes and velocities inside engines. For these we use 7 laser systems, 4 high-speed video cameras (including one infrared for thermal imaging), 3 gated CCD cameras, 3 gated intensifiers, LDA/PDA system for dense spray analysis, and heavy-duty programmable 3D traverses. All our work is underpinned by computational fluid dynamics, which run on a dedicated high-performance cluster, supported with QR funds.

The high-speed spin test facility is the first and most advanced flywheel test facility in the world, capable of spinning flywheels and e-machines at up to 80,000 rev/min in vacuum while providing optical access. Jointly developed with Ricardo as part of the Innovate UK 'FlySafe' consortium, it enables high-speed laser illumination and imaging to investigate the behaviour of carbon fibre reinforced polymer flywheels when they fail at high-speed, releasing up to 1MJ of energy. Each destructive test costs ~£12k in replacement parts, optics and instrumentation. This world-leading

facility, which was widely reported in the specialised press, helps understand the rate of energy release during flywheel failure. This enabled the project partners (Ricardo, GKN, Torotrak, PUNCH Flybrid) to design safety containment systems that are compact, lightweight, and low cost, while effective in providing flywheel safety for applications in the off-highway, power generation, and automotive sectors.

Structures and Construction laboratories support research on geotechnical simulation of seismic activity, superinsulation materials for buildings, novel cement-free concretes, and the development of monopiled gravity base structures. Our suite of five laboratories includes a concrete 3D printer, laser vibrometer for dynamic modelling and testing, shaker table, thermal imaging cameras, point-cloud laser scanner, survey drones, five different AR/VR technologies, and geotechnical centrifuge which enabled Tullow Oil to model seismic faults on well casings (**Stone**). The laboratories are being upgraded with a world-unique 36m^3 thermal environmental chamber (£215k from UKRI capital funds) to design anti-vibration technology for ageing structures exposed to extreme temperatures (4,500kg payload vibrated up to 300Hz under -30 to +60°C).

During this REF period our specialist laboratories have hosted and supported >120 incoming researchers from >50 international institutions, typically for 3-12 months, including 15 industry visitors (eg Ricardo, Dolphin N2), >30 academic staff and >80 research students from institutes based in countries including China, France, Italy, Malaysia and Russia.

3.4. Accessing world-leading infrastructure and facilities

Our researchers access world-class facilities that both complement Brighton's infrastructure and build a global perspective to our PGRs and academics. Some of the unique research facilities we use are highlighted below.

Airbus A310 Zero-G and International Space Station*:* ***Marengo***'s thermal management research supported by EPSRC (EP/P013112/1) led to a new concept for hybrid pulsating heat pipes that enables efficient thermal control under terrestrial and microgravity conditions. The European Space Agency and the UK Space Agency have supported our technology development through grants, as well as continued access to parabolic flights since 2013 (£1.2m total in-kind value). These experiments demonstrated that our hybrid pulsating heat pipe concept could successfully and efficiently transfer heat in short-term microgravity. This technological breakthrough enabled the Brighton team to secure time on board the International Space Station in 2023 that will prepare it for implementation for satellite and space exploration.

Working across global state-of-the-art laboratories*:* ECR **Li** visited MIT's Gas Turbine Laboratory (USA) to work with Professor Ghoniem and model the mechanisms that drive the transitional process of transcritical atomisation. 1st year PGR student Gander secured a joint UKRI-Mitacs grant (NE/T014431/1) to be seconded to the University of British Columbia and collaborate with experts in engine combustion diagnostics. **Crua** has worked at Sandia National Laboratories (USA) for a combined total of 6 months since 2014 as part of the Engine Combustion Network to investigate the microscale transition of fluids from liquid to supercritical state.

bp's Centre for High-Performance Computing*:* This industry-leading supercomputer is equipped with over 16 petaflops of processing speed, making it one of the world's largest supercomputers for commercial research. Our fuel spray researchers (**Crua, Sazhin, Vogiatzaki**) have received access to bp's supercomputer in Houston to perform high-resolution direct numerical simulations of heat and mass transfer, unveiling some of the complex physics involved in the heating and evaporation of fuel droplets and sprays. This research contributed to supporting bp's fuel development, as detailed in an Impact Case Study [ICS_bp].

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

4.1. Fostering a vibrant and diverse research community

Our staff have demonstrated national and international academic leadership, including **Heikal** (Emeritus Professor, Ricardo Professor of Automotive Engineering) who was elected Fellow of the Royal Academy of Engineering, Fellow of the IMechE, and served as a member of the REF2014

Assessment Panel B12. **Bruce** and **Sazhin** have been Fellows of the Institute of Physics since 2005 and 1994, respectively. Our researchers are members of the EPSRC's Peer Review College (**Atkins, Cacciola, Crua, Georgoulas, Marengo, Vogiatzaki**). **Bruce** was a member (2007 – 2015) and chair (2012 – 2015) of the STFC nuclear physics funding panel. She has recently been elected as the chair of the European Physical Society's Nuclear Physics Division and will serve a 2-year term starting in 2022. Our members have given 32 invited keynotes and plenaries, hold 15 editorships and editorial board memberships. These international recognitions have enabled us to actively engage with the global research community, and provide new opportunities for our PGRs and academics, such as:

Setting research priorities with international leaders*:* We contribute to setting the UK's agenda for engine research through **Morgan**'s role as joint secretary of the Universities' Internal Combustion Engines Group (UnICEG) and **Atkins**' leadership of APC Spoke. We host **Magaletti** (Marie Skłodowska-Curie Individual Fellow) whose leading expertise in the modelling of flow boiling and cavitation contributes to our simulation team. We have hosted 14 visiting scholars to promote academic excellence and set research directions, including: Professor Osiptsov (Laboratory Head at Moscow State University, Russia) worked with **Sazhin** on new mathematical models for multiphase flows; Professor Danaila (University of Rouen, France) and Dr Kaplanski (Tallinn Technical University, Estonia) visited **Sazhin** to create new mathematical models for vortex rings; Professor Payri (CMT Valencia, Spain) visited **Crua** to develop optical diagnostics for engines; Dr Santisi D'Avila (University of Nice, France) visited **Cacciola** to build novel simulation techniques for earthquake-induced ground motion; Professor Zaripov and Dr Gilfanov (Kazan Federal University, Russia) developed new mathematical models for medical sprays with **Sazhin**; Dr Kyriakides (Cyprus University of Technology) developed innovative one-part green concretes with **Tsioulou** and **Lampropoulos** supported by Royal Society funding and patented by Zicon Ltd.

Establishing long-term partnerships*:* We have formalised our cooperation with partners in China (Fudan University), Japan (Tokyo University of Agricultural Technology), Italy (University of Bergamo) and Malaysia (Universiti Teknologi PETRONAS) to exchange PGRs and staff. These have enabled Dr Firmansiah (UTP, Malaysia) to visit **Heikal** and work on new combustion systems for PETRONAS; Professor Cossali and Dr Tonini (Bergamo, Italy) to work with **Sazhin** on new mathematical models for droplet heating and evaporation; **Heikal, Crua, Sazhin** to spend more than 30 months at Universiti Teknologi PETRONAS to research new fuel emulsions; **Crua, Rybdylova, Sazhin, Vogiatzaki** to collaborate with the Engine Combustion Network to perform ground-breaking research on the mixing of fuel sprays under extreme pressures and temperatures (which was awarded the triennial ICLASS Tanasawa award in 2015); and **Bruce** to work alongside the University of Surrey's nuclear physics group at international experimental facilities such as CERN (£268k in-kind value). **Sazhin** led the 'Sprays in Engineering Applications' Special Interest Group for the EPSRC's UK Fluids Network as a platform for the exchange of ideas between researchers working across 12 UK universities.

4.2. Understanding and responding to industrial priorities

By embedding industry leaders within our teams, we have access to the latest market intelligence and can influence international research agendas. For example, the AEC's Steering Committee includes senior industry figures, such as Visiting Professor Jackson who brings nearly 40 years of experience and insight from his senior executive roles in the automotive industry (eg Chair of the RAC Foundation, advisory board member of the European Green Vehicles Initiative, founder board member of the European Automotive Research Partners Association (EARPA), member of the EPSRC's Strategic Advisory Network, non-executive Director of the APC, deputy chair of the UK Automotive Technology Council). Close dialogue with Ricardo Innovations' team has enabled early recognition of market trends and technological challenges (eg the development of new engine cycles, described in [ICS_Ricardo]).

We develop and maximise interactions with key end-users and audiences through other routes besides our formal Steering Committees and impact facilities (described in 3.4), including:

***Advanced Propulsion Centre (APC)**:* Following an assessment process undertaken by independent industry experts, the AEC was selected to host the APC's Spoke for *Thermal Propulsion System Thermal Efficiency*. Through this role we supported the APC to develop the Automotive Council's 2017 and 2020 roadmaps, with our researchers being at the heart of the process helping to shape the technology roadmaps before and after the stakeholder workshops. As an APC Spoke, we also worked on improving the accuracy and granularity of the modelling work of the Energy System Catapult, to identify cost-effective transition pathways to low carbon energy systems. These simulations then inform the Climate Change Committee to model energy system decarbonisation.

***Knowledge Transfer Partnerships (KTPs)**:* We secured 15 KTP projects funded by Innovate UK and SMEs, ranking in the top 10 across the UK for KTP funding in Energy Generation. Our collaborations include: **Morgan** worked with Libertine FPE to develop free piston power generation technology; **Crua** supported Rivertrace Ltd to design a new range of sensors to measure water contamination in the marine and offshore market; **Miché** developed a validated test-rig for cooling system leak repair additives with Kalimex. Our collaboration with Highview Power grew from a KTP project to an Impact Case Study [ICS_HighviewPower], transferring thermal fluid modelling expertise which supported the development of scalable liquid air energy storage solutions.

***Co-supervision of PGRs**:* We steer the direction of PGRs alongside industrial partners through our EngD programme, and through directly funded studentships including the joint supervision of 4 EPSRC Industrial CASE awards (eg bp, Delphi), 4 industry-funded studentships (eg bp, Ricardo UK) and SEAHA studentships with external heritage (Diocese of Chichester) and industry (Soenecs) partners. By co-supervising external PGRs at international institutions we further contribute to the discipline across the world and bring new expertise to Brighton.

***Collaboration networks and industry-focused workshops**:* Our researchers are active members of multi-sector international organisations, including EARPA, IMechE's Powertrain Systems and Fuels Group (previously chaired by **Heikal**), the Engine Combustion Network (includes GM, Bosch, Delphi), and UnICEG (co-organised by **Morgan**). Our teams have hosted industry-focused workshops and specialist training courses involving industrial delegates and guest speakers from companies such as Caterpillar, Ceres Power, CNH, E4tech, Shell and Toyota.

4.3. Interdisciplinary collaborations

Having identified a strategic area for expansion into biomedical fluid dynamics, we developed new capabilities through internally funded research collaborations and are now able to secure major grants. Examples of this multidisciplinary expansion include:

***3DMed – 3D bio-printing with York University (Canada)**:* One of 8 projects supported by the UKRI International Investment Initiative (I3) Fund in 2020, 3DMed (£455k) builds upon an established strategic collaboration between **Marengo**'s team and York University (Canada). The project combines engineering and biomedicine to develop novel research skills in additive biomedical manufacturing technologies. 3DMed develops methodological expertise in droplet architecture that will revolutionise bio-printing of individually tailored medicines through personalised pills, cell therapy, tissue engineering, and biochips for in vitro drug testing/dosage.

***Pulmonary fluid dynamics**:* With BSMS (medical imaging expert Professor Cercignani, microbiologist Dr Waddell), and Professor Parker (Manchester University, Head of the Quantitative Biomedical Imaging Lab) we identify signatures of pulmonary lesions caused by tuberculosis, to correlate the disease with pulmonary airflow characteristics in a non-invasive sensor that could transform the diagnosis of tuberculosis (PhD co-supervised by **Vogiatzaki**).

***Bioartificial organs**:* Working with biomaterial experts Sandeman and Savina (UoA3) we research and optimise the microscale flow through cryogel cell scaffolds used for bioartificial liver devices (PhD co-supervised by **Crua**). Using optical measurements, we improved internal flow patterns and generated significant improvements in cell colonisation.

***New electrochemical biosensors**:* **Covill** works with bioanalytical chemist Patel (UoA3) to design and validate drug-eluting in vivo biosensors, which contributed towards EPSRC grants (EP/N027345/1; EP/V028391/1) and adoption by the NIHR Med-Tech Cooperative.

4.4. Contributions to policy and public engagement

We featured throughout the 2017 British Science Festival (co-hosted by UoB, attracting 18,490 attendees), showcasing our latest engine research and heat transfer technology. Our researchers also engage with international public and decision makers, including:

***Remanufacturing with China**:* **Wang**, selected as one of 30 inspiring women by the KTN/The Manufacturer magazine, has been working with the BEIS manufacturing policy team, the Department for International Trade (DIT), and as a BSI Committee Member to support UK remanufacturing and promote links between the UK government and industry in China. Since 2016, **Wang** has led 4 UK-China workshops attended by senior government policymakers from the UK (eg BEIS, DIT, UKRI) and China (eg Yu Hu Gao, director of Energy Conservation and Waste Reduction department, Ministry of Industry and Information Technology (MIIT)). These supported a G7 'Value Retention Policies' workshop (Montreal, 2018) with advice on international standards (eg BSI standard BS-8887) and the state of remanufacturing in China. A 2017 workshop on Green Manufacturing Innovation contributed to a policy outcome report and initiated closer collaboration between BEIS and MIIT for industry and research. In partnership with the University of Sussex, these activities are funded until 2025 by a multilateral programme between the British Council and China's Ministry of Education, with research exchanges and multi-stakeholder events with universities across China (Jinan, Hefei, Zhejiang) and Singapore.

***Producing expert evidence for decision makers**:* Our position as APC Thermal Efficiency Spoke has placed us as a national influencer of policy makers. **Morgan**'s recent workshop 'RIP ICE?', organised at the Royal Institution, provided a forum to review the future of internal combustion engines with a broad range of stakeholders. Our researchers contribute expert knowledge on energy and transport to develop policy, for example **Atkins** led the Cross Sector Energy and Propulsion Roadmaps for the Transport Energy Network, co-authored Decarbonising Road Freight for the Energy Systems Catapult, and contributed to the Sustainable Synthetic Fuels for Transport policy briefing for the Royal Society; **Morgan** contributed to a DfT stakeholder consultation for their Future of Transport programme; **Lampropoulos** chaired a working group (2017 – 2018) on Earthquake Resistant Structures for the International Association for Bridge and Structural Engineering, and is currently chair of two of their Task Groups; **Piroozfar** authored UoB's written evidence to the House of Lords' Science and Technology Committee, which was used by the House for the Building for change report.

***Supporting the global MATLAB community**:* **de Sercey** was selected by MathWorks, the leading developer of mathematical computing software for engineers and scientists, to be one of eleven international Community Advisors for his outstanding contribution to MATLAB. His role on the Community Advisory Board involves working with MathWorks to advance the MATLAB community and to propose enhancements and new features. **de Sercey**, the only Community Advisor in Europe, is invited by MathWorks to travel and participate in their confidential Advisory Board, thus informing the development of MATLAB based on the needs of our researchers and their collaboration networks.

***International space agencies**:* **Marengo** contributed to the UK Space Agency's review of its support for developing commercial microgravity opportunities in the UK, and the 'Investing in UK Aerospace Forum' led by the All-Party Parliamentary Group on Aerospace, Innovate UK and UKspace. PGR Pietrasanta was invited to talk at NASA's SLPSRA Fluid Physics Workshop at the Glenn Research Center. **Miché** delivered ESA's Gravity-Related Research Summer School, and helped our team of MEng researchers win the European-wide 'Fly Your Thesis' competition to test nanosatellite thermal management technology in a Zero-G aircraft.

4.5. Contributions to society

Our research impacts societies across the globe by improving air quality through better engines and fuels, safeguarding cultural heritage and protecting populations, while developing next generation energy efficient technologies and fundamental knowledge. Examples include:

***Addressing UN Sustainable Development Goals**:* In 2018, **Bruce** obtained UKRI-GCRF funding to initiate a series of annual workshops on Advanced Nuclear Science and Technology Techniques (ANSTT) at iThemba LABS (Cape Town, South Africa) that then assembled a UK-African and inter-Africa network focussing on applications in the areas of nuclear medicine and environmental radiation, thus addressing five Sustainable Development Goals.

***Management of risk and safety during the Hajj**:* **Gidado**'s team secured unprecedented access to the Holy Mosque in Makkah during the annual Hajj pilgrimage. Their report to the Custodians of the Holy Mosques (King Crown Prince and Government Ministers) provided expert advice for monitoring the flow of over 2m pilgrims per year and implementing new technological measures to help reduce the risk of heatstroke and exhaustion.

***Earthquake defence technology**:* **Cacciola**'s EPSRC-funded (EP/K004867/1) Vibrating Barrier developed in collaboration with EDF/LAMSID to protect nuclear power plants against seismic damage, featured in high profile press (eg Forbes, World Economic Forum) and led to a motion for a European Parliament resolution on the importance of protecting cities from earthquake damage (B8-0964/2015). **Cacciola** and **Tombari** are adapting the technology for World Heritage Sites (SEAHA studentship) and secured AHRC funding (£207k, AH/R007934/1) in collaboration with Cairo University and City University London to help protect Egyptian pyramids and the Cairo citadel without the need to alter ancient structures.