

<b>Institution: Oxford Brookes University</b>
<b>Unit of Assessment: 12 Panel B</b>
<p><b>1. Unit context and structure, research and impact strategy</b></p> <p><b>Unit Context and Structure</b></p> <p>The UoA comprises staff from within the School of Engineering, Computing and Mathematics (ECM), which is part of the Faculty of Technology, Design and Environment. Research within ECM is organised into two subject areas: Engineering and Mathematics (UoA12), and Computing (UoA11), and each of these areas has a Research Lead (RL) and a Postgraduate Tutor (PGT), responsible for the PGR community. Research in Engineering and Mathematics is organised under seven research groups:</p> <ul style="list-style-type: none"> <li>• Engine Modelling Team (<b>EMT</b>) (Lead: <b>Bonatesta</b>);</li> <li>• High Voltage and Energy Storage (<b>HVES</b>) Group (Lead: <b>Morrey</b>);</li> <li>• Autonomous Vehicle and Human-Vehicle Interaction Group (Lead: <b>Bradley</b>);</li> <li>• Electronics and Communications Group (Lead: <b>Hayatleh</b>);</li> <li>• Mechanics, Materials and Design Group (Lead: <b>Fellows</b>);</li> <li>• Cycle Mobility Group (Lead: <b>Gerguri</b>);</li> <li>• Modelling, Risk and Design for Reliability Group (Lead: <b>Todinov</b>);</li> </ul> <p>and two research centres, which were originally more industrially facing, and undertook more contract testing:</p> <ul style="list-style-type: none"> <li>• Joining Technology Research Centre (JTRC) (Lead: <b>Broughton</b>), and</li> <li>• Sustainable Vehicle Engineering Centre (SVEC) (Lead: <b>Hutchinson</b>).</li> </ul> <p><b>Research Objectives</b></p> <p>The 2013-20 Strategy for this UoA (as described in the REF2014 submission) focused on achieving further increases in the quality and diversity of research and external funding, increasing the number of industrially funded PhD studentships, building on research on 'energy reduction in transport', and increasing the number of post-doctoral researchers.</p> <p>Specific outcomes of this strategy during the REF period, are as follows:</p> <ul style="list-style-type: none"> <li>• 71 external grant proposals were submitted, with a total value of £16.2M, and 23 (32 %) of these were awarded, with a value of c.£2,340,000, an increase from REF 2014;</li> <li>• Nine post-doctoral researchers were appointed (PI in brackets), in the areas of: Life Cycle Analysis (EU, EPSRC, Faraday) (<b>Hutchinson, Hayatleh</b>), Engine Modelling (APC) (<b>Bonatesta</b>), Engine Testing (<b>Bonatesta</b>), and Future of Transport (<b>Morrey</b>). Six of these have been externally funded;</li> <li>• Four industrially funded PhD students were awarded, from Williams Grand Prix Engineering, Norbar Torque Tools, ELG Carbon Fibre Ltd, and Oxfordshire County Council. Three of these studentships were part-funded through the University 150<sup>th</sup> Studentship Initiative, with matched funding from the collaborators, and one was fully funded externally.</li> </ul> <p><b>Inter-disciplinary research</b></p> <p>During the REF period, the Unit has established an interdisciplinary theme in the field of 'Future of Transport' (Lead: <b>Morrey</b>), which brings together the strong links that the School has with the Automotive and Motorsport Industries, their supply chains, and the development of low carbon vehicles and transport (<b>Morrey</b> and <b>Hutchinson</b>). The theme also includes staff who work in the area of transport planning (UoA13) and computing (UoA11), from elsewhere in the University. It builds on successful work with partners such as Mobility Oxford (MobOx) and Oxfordshire County Council, with</p>

a focus on addressing the 'Local Industrial Strategy' of the Oxford Local Enterprise Partnership (OxLEP), by working with 'Living Laboratories' as part of 'Living Oxford'. Initial work was undertaken through TSB and local authority funding. Part of the theme focuses on urban air quality, using expertise established through the DYNAMO (APC6) project, and battery recyclability as part of the Faraday ReLIB project. Internal funding has been used to establish a High Voltage and Energy Storage (HVES) Laboratory and Research Group (c.£162,000). Faculty and University Central Research Funds (CRF) has been provided for two, 2-year, Research Fellow (RF) posts to support the theme (c.£150,000). In addition, members of the HVES Group, and the theme are engaging with the very recently (post-census date due to COVID-19) formed, University network in 'Sustainable and Resilient Futures'.

### Collaboration and Impact

The majority of active projects are collaborative, including the ten-partner £22,000,000, APC6 DYNAMO project led by Ford (other partners include Siemens and Ricardo) on the 'Dynamic modelling and Optimisation of GDI Engines', focused on developing strategies to reduce soot and particulate emissions (PI: **Bonatesta**); the eight-partner, c.£9,000,000, Faraday ReLIB project, on the Reuse and Recycling of Lithium Ion Batteries, focused on tractive batteries (PI: **Hutchinson**); the three-partner, c.£1,200,000 EPSRC UltraMelt2 project examining changes in the formation of the crystal structure in metals, improving the mechanical properties of the end product through the formation of pressure bubbles (PI: **Tzanakis**); and the three-partner c.£1,900,000 EPSRC EcoUltra2D project, aimed at improving the quality and expediting the layers of exfoliation of 2D nano-materials such as graphene (PI: **Tzanakis**). The School has a strong history of successful knowledge transfer projects, particularly KTP projects, such as one recently with the Rooflight Company (PI: **Gerguri**), and two projects with YASA Motors (PI: **Broughton**).

Real world impact leads from all areas of our research activities and there is a clear strategy to ensure the vitality and sustainability of the UoA's impact in the future, including the employment of RAs and experienced post-docs to further embed this work in ongoing activity and projects. The UoA's long history of strong industrial engagement has provided the central pillar to enable impact from all its underpinning research. Although some of this has focused on achieving economic viability, such as in the Impact Case Study (ICS) with YASA Motors: *[Influencing the development of YASA high performance electric motors for sustainable mass production for next-generation vehicles (author: **Broughton**)]*, the other two ICSs concentrated on wider environmental and health benefits through achieving modal shift in transport. Development of cost-effective electric motors is vital for future electric transport. This ICS, which is based on two KTPs with YASA Motors, describes how polymer composite materials, injection moulding and multi-material adhesive bonding techniques were optimised to reduce production times and costs for high power density, low mass, electric motors.

Road transport is currently dominated by the internal combustion engine. However, this sector is responsible for the release of up to 20% of atmospheric carbon matter or soot, leading to large numbers of cardiovascular and respiratory diseases and cancers. As reported in the ICS *[Robust and reliable digitalisation of the automotive industry: improvements in 3D CFD modelling of particulate matter emissions (author: **Bonatesta**)]*, the Engine Modelling Team developed novel methods of 3D computational fluid dynamics modelling of engine emissions in collaboration with Ford, Siemens and Ricardo, to reduce particulates and soot in emissions.

Research in the UoA addresses issues of regional, national and global importance, and hence achieving impact is central to the way in which research is planned and supported. In particular individual Personal Research Plans (PRP) for the next three years, are updated and discussed with the RL, as part of the annual Performance Development Review (PDR) exercise, to consider how ongoing and new collaborations and future impact are identified and supported. Additionally funding allocations can be applied for, through the Research Groups, from Departmental QR, for travel and conference attendance, to ensure engagement with national, international and user communities. A good example of this is the steady building of research and impact in sustainable mobility reported in the ICS: *[Transitioning to the 'new normal' of electric vehicles (author: **Hutchinson**)]*. This ICS demonstrates how separate strands of research in electric vehicles, life cycle assessment and energy generation were combined to address solutions to the net zero emissions challenge. Additionally, **Hutchinson** was supported to serve as a Board Member of the Low Carbon Vehicle Partnership (LowCVP), a key body in shaping the future of sustainability by accelerating transport to zero emissions. This activity is central to the newly emerging interdisciplinary theme in 'Future of Transport'.

The theme includes work on reduction of emissions, particularly particulates, both through new approaches to powertrain design, and urban transport; new materials for light-weighting, including use of composites and recycling; autonomous vehicle implementation; and transport policy to promote modal shift, although this is not an exhaustive list.

### Future strategy

The 2020-25 Strategy for this UoA focuses on achieving further increases in the quality and diversity of research and impact, with the following specific objectives:

1. Focus on collaborative research topics of national and global importance, with a particular emphasis on the recently established inter-disciplinary 'Future of Transport' theme;
2. Increase the number of industrially funded PhD studentships through the UoA's strong network of industrial partnerships;
3. Maximise impact generated from research, and capture the benefits and outcomes particularly in the areas of Engine Modelling, Autonomous vehicles, Functional Materials, and Biomedical Instrumentation, by working in large-scale, industrially-led projects;
4. Establish a strong experimental presence in the area of electric vehicles, underpinned by the newly formed HVES Group and Lab. This reflects the modal shift towards the zero emissions agenda in our areas of strength in high performance and motorsport vehicles, development of our 'Future of Transport' theme, continuing work with Oxfordshire County Council and their commercial partners, and with Ford and BMW;
5. Continue to increase the number of post-doctoral researchers, and actively recruit early-career academic research staff;
6. Further expand collaborative research through engagement with high quality overseas institutions eg McMaster and Kyoto, and support joint research student training and exchange;
7. Sustain and diversify income from knowledge transfer activities;
8. Engage in further major 'breakthrough' projects, with the automotive and motorsport industry, in areas such as alternative power-plants, end-of-life vehicle issues, and materials sustainability;
9. Ensure that all future research engages with the 'Open Access' agenda, making more use of open source versions of software, depositing code, software and data on repositories such as GitHub, and working with software developers in open-access projects.

### Open access

As part of its drive towards open access, the UoA has provided funding for open access publication of a small number of key Gold-route journal papers. Additionally, some code and data generated through projects is being hosted on GitHub repositories. An example of this is **Mahak** who has developed RANS based CFD software using OpenFOAM.

### Research integrity

The University approval procedures for research grant applications require all PIs to assess and provide information on the ethical, legal and insurance implications of proposals and collaborations. In addition, internal reviewers for bids are responsible for considering the integrity of any proposals. PGR students with the support of supervisors are required to obtain ethical approval from the University Ethics Committee, if there is any involvement of human participants.

## 2. People

### Staffing Strategy and Staff Development

The UoA's strategy for staffing and staff development is supportive and aspirational with the aim to maximise the potentials of staff to generate excellence in research and impact. The strategy aligns with University's Research and Knowledge Exchange Strategies 2015-2020. Opportunity is taken when new staff are appointed to improve on metrics such as proportion of staff that are research active as well as equality opportunity and diversity. In the current REF period, nine new research active lecturing staff were employed (**Tzanakis, Barerra, Coco, Fresneda-Portillo, Ben-Esmael, Dimitrov, Yang, Mahak, and Azizi**).

**Staff grouping** - The 29 staff (27.9FTE) returned within the UoA are organised into groups, each with coherent research interests and activities. Each group has a lead. The overall RL for the UoA is **Morrey**. The composition of the groups is:

- **Engine Modelling Team (EMT)** (Lead: **Bonatesta**); **Yang, Mahak**, and **Rohani**; three post-graduate research assistants, one research technician, two research students.
- **High Voltage and Energy Storage (HVES)** (Lead: **Morrey**): **Dimitrov, Collier, Tajdaran, Yassine, Azizi**; one research fellow, one research technician, one research student;
- **Mechanics, Materials and Design** (Lead: **Fellows**); **Durodola, Thite, C Bell, Tzanakis, Barrera, Samuel and Raugei**, two post-doctoral research assistants, eight research students;
- **Modelling, Risk and Design for Reliability** (Lead: **Todinov**), **Coco** and **Fresneda-Portillo**;
- **Cycle Mobility Group** (Lead: **Gerguri**), **D Bell**;
- **Autonomous Vehicle and Human-Vehicle Interaction** (Lead: **Bradley**). This recent umbrella group comprises three associate members, and two research students.
- **Joining Technology Research Centre (JTRC)** (Lead: **Broughton**), one post-graduate research assistant, two research students;
- **Sustainable Vehicle Engineering Centre (SVEC)** (Lead: **Hutchinson**), one post-doctoral research assistant, one research student;
- **Electronics and Communications** (Lead: **Hayatleh**), **Barker, Ben-Esmael**; two research students.

Each group runs its own research activities to ensure progress and achievement of aims and objectives, including paper-reading meetings. The UoA runs a series of bi-weekly seminar series that all members are encouraged to attend. This provides opportunity for cross group support and collaboration. The UoA by virtue of its diversity encourages interdisciplinary research and addresses key issues of global significance, building on the UoA's history as a strong externally-facing entity. Although individual staff members belong principally to one of the groups, the structure is matrix-based. For example, **Hutchinson** leads the Sustainable Vehicle Engineering Centre but also contributes significantly to the Joining Technology Research Centre and the Mechanics, Materials and Design Group, through his work on structural adhesives and composites..

The recently established interdisciplinary theme in the 'Future of Transport' concentrates established areas of activity as well as providing an umbrella for new and emerging activity such as the HVES, Autonomous Vehicle and Human-Vehicle Interaction, and Cycle Mobility Groups. The theme members meet quarterly for seminar presentations and project updates, and plan future external activities including workshops.

**Staff recruitment** of all category A staff focuses on research performance and potential, through evidence of high quality outputs and experience of funding proposal preparation. A key consideration is the fit of individuals within the School's research culture and group structure, so that staff can be supported and developed. The UoA promoted two Professors (**Broughton, Tzanakis**) and three Readers (**Bonatesta, Gerguri, Samuel**) during the REF period. Succession planning is used as part of overall staffing strategy, to ensure the viability and development of research groups. Examples include **Tzanakis** and **Barrera** with **Hutchinson** in Materials, **Broughton** with **Hutchinson** in Joining Technology, and **Fellows** with **Durodola** in the field of Stress Analysis. Sustainability is also achieved by continuous staff training and development.

**Staff development** as it impacts research is identified and met in a number of ways. Individuals with significant responsibility for research (SRR) are allocated dedicated research time through the university workload planning system, and are supported by staff development funding (e.g. for research training and conference attendance). Identification of staff development needs are assessed through the annual PRP exercise, which runs in parallel with the PDR process. The PRP process requires all research active staff to prepare their individual plans detailing their proposed grant sourcing and output generation activities for a rolling three-year period which is updated annually. Examples of real success include research grants awarded to **Barrera, Bonatesta**, and **Tzanakis**, who have all won external funding through activities and plans identified as part of this process. These are monitored as part of the annual cycle of PDR meetings, and through regular monitoring meetings with the RL.

**Internal funding support** for research development is facilitated by the University through the CRF' of c.£1,000,000 per year which is accessed through a competitive bidding process to support projects

with staff development goals, as can QR funds from within the Faculty and the UoA. Examples of this latter use of QR are awards of studentships given to **Bonatesta** and **Tzanakis**. The Faculty's staff development programme, 'Next 10' instituted during the last REF period was a competitive call to allocate additional resource, senior mentoring and an associated PhD studentship (value £30,000), to increase the research capacity of mid-career research staff. **Broughton**, promoted to professorship in the current REF period, was a beneficiary of the scheme.

**External grant generation support** is offered by the University for preparation of bids and research contracts, through the Research and Business Development Office (RBDO), and the Faculty's Research support team. During the census period, the CRF also supported a Research Funding Officer for Mechanical Engineering and a Business Manager for Science and Technology (both based in RBDO). The Faculty has a Grants Panel, aimed at enhancing the quality of submitted proposals through internal review. All RLs are members of the Panel, and act as mentors to bid writers, along with other senior staff. Workload time is allocated for these roles. As an example, **Morrey** acted as mentor to **Bonatesta**, in the preparation of his EPSRC First Grant application, and on project management. **Morrey** and **Durodola** have acted as mentors for **Tzanakis** for EPSRC grant application and project implementation. Two EPSRC submissions (UltraMelt2 and EcoUltra2D) were awarded, and have needed support with staffing and project management.

### Early career staff support

Early career researchers have enhanced research workload allowances in the first three years of appointment, up to a maximum of 640 hours per year, in order to allow time for research development. They are included in research groups that enable mutual support for research, and access to existing infrastructure. For example, **Mahak** joined EMT which has 3 post-docs and five research students. **Mahak** has benefited from mentorship by **Morrey**.

The faculty and University provides competitive research funding for early and mid-career researchers. For example, **Tzanakis** who joined in 2015 has been awarded two research studentships that complemented his EPSRC research grant awards. Mentoring of early career researchers is supported by established members of staff. The mentoring process is overseen by the research lead in the school who makes every effort to link staff in similar research areas and interests. For example **Hutchinson** has been supporting **Raguei** on exposure to Sustainable Engineering and automotive communities. **Morrey** has been mentoring **Barrera** on research project development and execution. **Durodola** has been mentoring **Tzanakis** on research students and postdocs' supervision. **Barrera** joined the Materials Mechanics and Design group and her research work on orthopaedic biomechanics has benefited from support from **Fellows** and **Gerguri**. This allowed her research work to continue while she was away on her Marie Curie Fellowship, which resulted in a new collaboration with the University of Luxembourg, and at least two high quality journal outputs.

### Industry and academia exchange opportunities

Staff are encouraged to take exchange opportunities nationally and internationally, both within academia and industry. **Morrey** is a visiting professor at Murray Edwards College, University of Cambridge. **Samuel** welcomed Dr Rogelio from National Autonomous University of Mexico, an expert on engine emissions. **Durodola** was a Tan Chin Tuan Visiting Fellow at the Nanyang Technological University of Singapore. **Broughton** held a Cotutelle studentship with the University of Grenoble in France.

In addition, other staff external to the University are appointed to visiting posts. For example Prof Cary, Senior Engineer from Ford, was appointed as a Visiting Professor and Dr King, former CTO of YASA Motors, was appointed as a Royal Academy 'Entrepreneur in Residence'. Dr King helped to set up the 'ICE Qube' incubator space, to provide support for start-up and innovation activities, for staff and students, to complement existing innovation teaching which takes place within the curriculum in ECM. Prof Cary provides supervision for projects in EMT, and Dr King has worked with a number of researchers developing knowledge transfer activities.

### Research students

**i) Welcome, resources and administration** - All research students are members of the Graduate College which is led by the PVC Research and Global Partnerships. The College is student-focused



and oversees all matters related to the programmes and student experience. All research students have personal desk space, an individual networked personal computer, and access to dedicated research laboratories. Training for research students is provided at University, Faculty and School level. Research students are given a full induction covering policies, procedures and health and safety, on commencement of their studies. A PGT is responsible for overseeing recruitment, induction, registration, monitoring of progress, and examinations. Administrative support for these processes is provided by the Faculty and the Graduate College. The University has a Well-being Group that provides counselling and guidance support to ensure the wellness of students to function to their optimum.

**ii) Training** - Training of research students is carried out collaboratively at School, Faculty and University levels. These three levels meet research study methods, subject specific, interdisciplinary, career, and social and networking needs. Training within the School and Faculty is coordinated under a Doctoral Training Programme (DTP), which involves all four Schools in the Faculty. Research students benefit from all three subject strands available in the Faculty namely: Technology, Built Environment, and, Arts, Culture and Media. Each strand has its own programme covering theoretical and methodological issues that engender advanced critical thinking and professional values. The training includes regular seminars to facilitate opportunities for interactive discussions and feedback. Each student is expected to attend the UoA bi-weekly seminar series and also present at an annual Faculty wide Research Conference at which they acquire poster or oral presentation experience. Students have the opportunity to publish their work in the conference proceedings. In addition to grant funds, each student is also guaranteed a minimum sum of £600 towards external conference attendance to support their research career development. At the University level, workshops and writing retreats on topics such as writing proposals, analysing data and digital technologies are organised throughout the academic year.

**iii) Progress monitoring** - In addition to regular support from a team of supervisors, the progress of all research students is monitored annually and at each research progression stage. Annual progress is monitored through a report, or draft chapters of the thesis, and an interview carried out by at least two PGTs. Reports are written for registration, and MPhil to PhD transfer stages. The reports are reviewed at School level and through an interview. A University-wide RDC reviews the report and decides whether to accept or decline the student's application to progress.

#### **Equality and Diversity**

Details of staff development, recruitment and support for staff, which take into account protected characteristics, were discussed under **Staffing Strategy and Staff Development**. The University and the UoA take initiatives to achieve equality and diversity in recruitment and in the development of all researchers through university (Bronze-level since 2012) and faculty-wide (Bronze level 2017) Athena Swan action plans, and through our Race Equality Charter action plan to submit in 2021. The 29 staff returned with SRR represent 74% of those eligible for REF2021; 80% of women (4/5) and 73% (24/33) men. By ethnicity (of those who provided data), our UoA comprises 72% (17/24) White and 100% (8/8) BAME staff. There was no bias in staff selection for any other protected characteristics and our EIA also demonstrated no difference in the number of outputs submitted by women (2.5) or men (2.4) or by ethnicity (white 2.25, BAME 2.33). In order to increase the pipeline of women researchers the UoA sponsored two MSc by Research students under a 'Women in Engineering and Mathematics' initiative. One has gone on to obtain PhD Research Studentship at Dundee University and the other obtained an R&D position at Group Lotus.

### **3. Income, infrastructure and facilities**

#### **Strategy for generating Research Income**

The UoA has built on its success in REF2014 to further diversify its grant income over the REF period. This funding mainly comes from Research Councils (EPSRC), UK Government (Innovate UK/APC), Industry and EU Government.

A key strategy to maximise grant submission success has been to work as part of other large research consortia, addressing technological challenges of regional and national importance. Our success in joining, or being invited into, these consortia is because of the high-quality facilities, expertise and our extensive network of industrial partners. Examples of this follow.

Since 2014, the EMT at Oxford Brookes has been collaborating with Ford Motor Company and Siemens Software (formerly CD-Adapco) to improve modelling of combustion and PM/soot emissions in Gasoline Direct Injection (GDI) engines. In 2017, this collaboration led to EMT's inclusion in a 10-partner c.£22,000,000 Innovate UK project (Ford-led APC6 DYNAMO Project, Ref. 113130). EMT concentrated on 3D CFD modelling of GDI engines with a two-fold aim: an improved understanding of the mechanisms leading to PM formation; and developing a more robust, physics-based 'Digital Engineering' approach to support engine programs within the automotive industry. This work led to innovative engine control strategies which minimise PM emissions, e.g. new Piston Cooling Jet schedules to be implemented in the Eco-Boost range of Ford engines, presented in five journal papers, as well as new improved models and modelling methodologies for Siemens Star-CD CFD software and Ricardo Wave software (**Bonatesta**).

Building on our involvement in the TSB's Integrated Delivery Programme for low carbon vehicles, where we acted as BMW's research partner for the high impact c.£6,000,000 MINI Electric project (TSB TP11/LCV/6//BF045J, 2009-11), our Life Cycle Assessment expertise in sustainable future vehicles was extended to cover electric vehicle drivetrains. A TSB pilot and multi-partner EU MARS-EV project (2013-17) (FP7-NMPS-LA-2013-609201) assessed the feasibility of developing a circular economy for vehicle traction batteries. UK partners in MARS-EV, Axion and Johnson Matthey then helped to shape a focus on batteries by creating the Faraday Institution to exploit the Industrial Strategy Challenge Fund aimed at addressing Global priorities. We were invited into two competing consortia to tackle reuse and recycling of lithium batteries. Ultimately we became a partner in the c.£9,000,000 multi-partner ReLIB project (EPSRC EP/R041946/1) led by Birmingham University (**Hutchinson**).

**Tzanakis** was awarded two large inter-multidisciplinary EPSRC projects which focus on the fundamentals, applications and scaling up routes of ultrasonic cavitation processing in metals and 2D functional nanomaterials that are the promising and game-changing materials of the 21st century. One c.£1,200,000 EPSRC project (EP/R011044/1) on light metal alloys (UltraMelt2) received strong endorsement by our industrial partners Constelium, Kaizer Aluminium and Anton Paar Ltd (value £200,000). The other c.£1,900,000 EPSRC project (EP/R031401/1) on nanomaterials exfoliation (EcoUltra2D) came with an in-kind contribution from Designer Carbon Materials Ltd and Tata Graphite of £50,000. These research projects form a solid network of strategic collaborations with far reaching potential in terms of research output, income and visibility. Subsequently, an ultrasonic cavitation processing mini-hub was formed in partnership between Greenwich, Brunel, Birmingham and Oxford Universities. This hub is the first of its kind in the UK that enables sharing expertise, pooling of resources and providing us with a higher profile for future proposals. The research so far has led to 6 journal papers and 4 conference papers, new improved models for characterization of the acoustic pressure spectrum, novel insights on the fragmentation of metallic samples due to interaction with shock waves, and advanced numerical methodologies that for the first time couple acoustic cavitation and the complex multi-physics that are involved in casting processes.

#### **Significant investment in equipment and infrastructure (including specialist infrastructure, and in-kind or donated benefits)**

Investment in capital equipment has included the purchase of an Objet30 3D Printer for rapid prototyping (c.£50,000), which has been used to manufacture novel cycloidal gear trains for torque converters with NORBAR Torque Tools; a scanning electron microscope (c.£140,000), a donated Induction Heater and chiller (value c.£20,000), and a donated Differential Scanning Calorimeter (value c.£40,000), all of which are used to support materials based projects such as development of active disbonding mechanisms, which has supported ongoing industrially funded research eg with ELG, YASA Motors (KTP), and National Composites Centre (NCC); testing of CFRP composites, and development of high strength aluminium alloys for use as piston materials.

Since 2015, donations and in-kind contributions made by Ford have noticeably enhanced the research capabilities in our UoA. The first wave of this, valued at c.£146,000, consisted of an instrumented engine, a large set of engine data and Ford Technical Specialist time (Dr Cary, now a Visiting Professor) to support a collaborative PhD project on PM/soot formation and emissions from Gasoline Direct Injection engines, and a range of parallel spin-off studies. The state-of-the-art down-sized GDI instrumented engine, fitted in one of our test-cells, is used heavily to support parallel engine modelling

activities as well as to study the important, but currently still unqualified, correlation between fuel quality/composition and soot formation. Results are reviewed regularly, including with Ford in the DynAMO project, and the data from the engine and in-kind support from Ford staff have led to a number of journal outputs (**Bonatesta**).

The second wave of external in-kind support from Ford (2018-2020, valued at c.£126,000) includes two latest-generation fully-instrumented Ecoboost GDI 1.0-litre engines equipped with Bosch development ECU and ATI software licenses. There has been additional internal investment of c.£80,000 in supporting instrumentation and hardware. The availability of this new engine type, which features the latest technology such as a 300 bar direct injection system and cylinder deactivation, opens up a new dimension of research on combustion and PM emission-reduction, tailored to support actual engine programs run by Ford and its main suppliers. Initially, the new engine was used to further investigate the effects of fuel quality and to support the parallel modelling activities; subsequently, the engine was used to support an investigation in collaboration with Ford and Dong Yang Pistons on the effects of thermal coatings on soot emissions. The new piston sets, valued at c.£18,000 (3 sets with different coats), are part of a separate donation the EMT has received from Dong Yang. To further support the development of these two engine test cells, an internal technician post has been funded over 3 years at a cost of c.£60,000.

A driving simulator and associated sensors, including LIDAR sensors (value c.£40,000) have enabled work in the area of autonomous and connected vehicles to be developed (**Bradley**). This includes the modelling of intelligent and connected intersections, as well as work on driver safety and rehabilitation.

Our new interdisciplinary theme, the 'Future of Transport', includes the development of electric vehicles both for road and high performance markets. A critical development in this area has been funding, in cash and in-kind, of c.£162,000 to establish the HVES Group and Lab, with experimental facilities for cyclic testing and characterisation of cells, thermal and environmental degradation of single pouch cells and packs, impedance spectroscopy, pack storage and fire suppression, along with high performance electric in-wheel motors, and a high voltage supply. A new Technical Instructor post for this Lab has been funded by the Faculty, to establish health and safety protocols, and to support research and knowledge exchange activities. The development of this Group and Lab has been possible because of our strong network of industrial partners, and the strong integration with activities such as Formula Student, and our externally facing curriculum.

Three, one-year research technician posts have been funded internally, with matched funding from ELG Carbon Fibre Ltd. This has specifically supported PhD research on characterisation of recycled short-fibre CF composites, and the development of novel testing protocols to provide comprehensive design data for applications in certain transport sectors. This involved a huge body of experimental testing, including a large body of fatigue and durability data. These data are linked to the laminate production processing parameters. The research has supported conference presentations at SAMPE Europe; an overview of the research was published in *Composites World* (2019), *Composite Structures* (2020) and in a book 'Recycled Carbon Fibre for Composite Materials' (2021). The research technician posts have supported further research on disbonding of structural adhesive joints, including work on a technology pull-through project with the National Composites Centre (NCC). Discussions are continuing with ELG and NCC on future research on sustainable composite structures. They have also contributed significantly towards a major contract with the Health and Safety Executive on advanced composite repair systems for corroded steel pipes. This is an Industrial collaborative project to benchmark minimum surface preparation requirements within the industry (for off-shore and on-shore). The outcomes will influence future guidance on repairs and potentially provide benchmark data for H&S exec with any future issues.

There has also been Investment in test facilities to support the experimental work in the UltraMelt2 and EcoUltra2D projects (University Travel grant, and 2 PhD studentships – Faculty and School: value c.£145,000).

#### **Evidence of cross-HEI collaborative use of research infrastructure**

**Barrera** was awarded EU funding for two years as a Marie Skłodowska Curie Fellow at the University of Luxembourg. During this time she set up a group of international collaborators interested in knee menisci from the University of Luxembourg (Prof Seil), IIT Madras (Dr Natarajan), and the Universities



of Kyoto (Prof Vincenot) and Palermo (Prof Pittaresi). During her fellowship, she used experimental facilities at the Universities of Luxembourg and Palermo to further develop standards in the testing of biomaterials, which are already being used in the University of Oxford (Prof Murray), and the Rizzoli Orthopaedic Institute in Bologna, Italy.

As part of HEI infrastructure access, facilities in Greece (and elsewhere in Europe) have been used through a Horizon 2020 Grant by **Tzanakis**. This was directed at investigating the sono-exfoliation of 2D materials using ultrasound, which was in collaboration with FORTH (Prof Stratakis) in Greece (one of the leading top 50 research institutes in Europe). This was then complemented by two internal research travel awards (c.£6,000), with the aim of continuing this research collaboration with FORTH. It is intended that this collaboration will be strengthened in the future via the submission of a large-scale inter-disciplinary grant.

**Tzanakis** is an Academic Visitor in the Materials Department at the University of Oxford (UoO; since 2013). The post allows him to have access to all the state of the art experimental research facilities in the Materials Department and he is in charge of the PIV laser facility lab at the Begbroke Science Park for fluid flows visualization and characterisation of sonicated transparent liquids. The laser facility is frequently used by our research staff. This fruitful collaboration with UoO has already resulted in a number of joint outputs in the last couple of years. There is an ongoing collaboration with UoO on an EPSRC project on 2D nanomaterials (EcoUltra2D) project. This allows UoA research staff (PhD, PDRA) working on the project to use all the state of the art research facilities for the nano-characterisation (TEM, SEM, AFM, Raman, Uv-Vis etc.) of the produced 2D functional materials at Oxford University. He also has long-lasting and successful research collaboration with Brunel (Prof Eskin) and Greenwich (Prof Pericelous) Universities as part of the UltraMelt2 EPSRC research project, with a joint externally-funded PhD student based at Oxford Brookes on ultrasonic atomization of light metal alloys. This collaboration allows **Tzanakis** and his group to have full access to the advanced experimental and processing facilities at BCAST (Brunel), where liquid metal processing and structural characterization of the end cast products is performed. Additionally, Oxford Brookes has contributed to this work with the purchase of specialised research equipment such as the state of the art ultrasonic reactor worth c.£14,000, and an ultra-high speed camera with integrated acoustic sensors (calibrated to the National Physical Laboratory standards).

The EMT has also had access to STFC Hartree Cluster, used for CFD modelling, along with multiple licences of Siemens STAR-CD CFD software, as part of DYNAMO project – (equivalent value c.£100,000 per annum) (**Bonatesta**).

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

Collaboration and communication results in the greatest impact of our research outcomes on their practical application in society. We collaborate actively across disciplines, including a wide variety of external organisations, to maintain vitality and real world impact.

##### Collaborations with other disciplines:

**Barker** and **Hayatleh's** electronics research focuses on applications in biology and medicine, e.g. Electrical Impedance Tomography (EIT) systems for mammography, early cancer detection and heart conditions. **Barrera's** research on the soft meniscus in knee joints involves biomechanical modelling, design and medical validation testing. The team includes biophysicists, mathematicians, engineers and clinicians. **Bonatesta** and **Tajdaran** work with the Architectural Engineering Research Group (OISD) at Oxford Brookes in the area of 3D modelling of sustainable heating systems for buildings, focusing on optimisation of transpired solar collectors. **Hayatleh's** research on development of digital signal processing is applied to biomedical instrumentation, while **Hayatleh** and **Yassine's** research on driver fatigue combines psychological inputs with optical image processing. **Hutchinson's** work for BMW in the MINI E project involved social and psychological research that included questionnaire design, diary development, focus groups and interviews with drivers to analyse attitudes and experiences over time. **Hutchinson** and **Raugei's** use of whole life cycle assessment involves interfaces with the energy community and environmental researchers, e.g. EU MARS-EV, EU EV-WISE and ReLIB. **Hutchinson** and **Morrey** worked on social, community and local transport initiatives in the EU REPUTE project. **Raugei** works with environmental scientists on a fundamental understanding of energy generation and production, and climate science (documented in high quality,

high impact, journals: *Energy Policy* (2016), *Nature Energy* (2019) and *Joule* (2019)). **Tzanakis** works with materials scientists and physicists on the fundamentals and applications of ultrasonic cavitation processing for the production of high quality metallic alloys and 2D functional nanomaterials. **Tzanakis** also works in the area of bio-inspired self-healing coatings for protection against cavitation erosion and on the emerging field of engineering emulsions and additive manufacturing.

#### Collaborations with leading institutions

**Barker** and **Hayatleh's** design of EIT instrumentation amplifiers has resulted in patents/products in other areas of biomedical instrumentation in collaboration with the University of Mainz, Germany. **Barrera** holds appointments with the Nuffield Department of Orthopaedics at UoO for access to the cadavers lab and testing facilities, and the University of Luxembourg for expertise in mathematics and numerical modelling for bioengineering. The outputs have provided new insight and understanding of meniscus deformation and its role in knee movement. Collaborations with Oxford University Hospitals NHS Trust have facilitated building a knee implant wear testing rig. The objective is to reduce patient discomfort and provide robust clinical solutions for more durable implants. **Bonatesta** is a Visiting Research Fellow at NUMC, Nottingham University Malaysia Campus, in automotive engineering technology. He also collaborates with Loughborough, Bath and Sheffield Universities in the field of Digital Engineering and development of novel engine models and CAE methodologies in the field of soot formation and morphology in Gasoline Direct Injection engines. **Bonatesta, Durodola, Fellows** and **Gerguri** work with the Universities of Oxford and Buenos Aires on novel aluminium piston materials for high performance, high temperature, engine applications. **Bradley** is a visiting professor at University de los Andes in Bogota, Columbia, in the area of electric and autonomous vehicles.

**Broughton's** collaborative work with University of Bordeaux, DSTL and DGA (2016-19) investigated predictive modelling of Boron Carbide Polymers for ballistic armour. **Hutchinson** works with EV technologies, battery specialists, business modellers and LCA experts in the Faraday Institution ReLIB project at the universities of Birmingham, Cardiff, Edinburgh, Leicester, Liverpool and Newcastle. Additional inputs are from Diamond Light source and Johnson Matthey. **Gerguri's** design work on Paralympic wheelchair development involves the University of Loughborough for specialist testing. **Morrey** and **Hutchinson** work with UoO and Oxfordshire County Council on traffic flows and mobility systems for the City of Oxford, as an adjunct to MoBox. **Morrey** is a visiting professor at University of Cambridge for work on complex algorithms for dynamic modelling. **Raugei** worked alongside Manchester University on scenarios of photovoltaic energy deployment in the UK in EV-WISE. **Raugei** is Visiting Scientist at Columbia University, New York, on energy, solar energy systems and life cycle analysis. He also collaborates with Yale University on integration of renewable energy in buildings. He is a technical member of IEA's PVPS Task 12 on EH&S of PV electricity, and was a member of the UNEP-SETAC Global Warming Task Force to guide LCA impact factors. These collaborations produced 11 international journal papers, 4 official IEA reports and 5 conference presentations over the last four years. **Thite's** research on acoustic modelling involves the University of Southampton.

**Todinov** works with the Universities of Catania and Maryland, on advanced mathematical modelling and reliability and risk. **Tzanakis**, as part of the UK mini-hub in ultrasonic cavitation processing, works closely with Brunel, Birmingham, Oxford, Hull and Greenwich universities as well as companies including Constellium, Kaizer Aluminium, Anton Paar, Tata Graphite, Designer Carbon Materials Ltd, and DLR.

#### Collaborations with industry and public sector bodies

Interactions are focused largely within applied collaborative research projects and consultancy activities. ECM works with >200 industrial organisations, independent research organisations, institutes, local authorities, sustainable enterprise groups and charities. The particular collaborations below, stemming from the research groups and centres identified in Section 1, have resulted in significant impacts.

##### i) Future of Transport

- BMW selected us as their academic partner in the MINI E trials which also involved Scottish and Southern Energy who supplied the home/public charging technology and electricity, Oxford City

Council and Oxfordshire County Councils who provided infrastructure support, and the South East England Development Agency (SEEDA) who brokered local partnerships.

- We have worked with YASA Motors on materials selection, motor optimisation and design for manufacturing since 2010. Two KTPs have been completed. The innovative, energy-dense, electric motors have been continually refined for applications in automotive and aerospace.
- We were one of eight partners in a tractive battery recycling project under the Faraday Institution umbrella. ReLib (<https://relib.org.uk>) is a multi-partner project, described earlier, that includes Diamond Light Source and Johnson Matthey Battery Systems.
- In European research projects we worked on REPUTE (7 partners), MARSEV (17 partners) and WISE-PV (4 partners) which all involved large numbers of public and private sector collaborations and interactions.
- The Mobility Oxford (MoBox) Foundation (<https://mobilityoxford.com>) involves Oxford County Council, Preston IMC, Oxford Brookes, UoO, Streetdrone and Zeta Automotive. MobOx is research-led to promote urban mobility, transportation and innovation in Oxford City and Oxfordshire.
- We worked with the Regional Driving Centre and Dunhill Medical Trust for assessment tools associated with impaired and distracted drivers.

## ii) Engine Modelling

- The engine research group (EMT) has collaborated with Ford Motor Company since 2014 with the task of developing new fundamental knowledge and robust models for soot/PM formation mechanisms in modern Gasoline Direct Injection engines. This led to partnership in the large Ford-led APC6 DYNAMO project (Innovate UK, Project Ref. 113130), which comprises of four academic Institutions and six companies, and aims to deliver new Virtual Product Development capabilities to drastically reduce cost and time to get new powertrains to market.
- The EMT have a long-term active collaboration with Siemens Software (formerly CD-Adapco) to support the development and optimisation of physics-based models within CFD software STAR-CD and STAR-CCM+. Since 2018, the EMT have worked in collaboration with Ricardo Software on the development and optimisation of models with Wave 0D/1D engine modelling software.

## iii) Mechanics, Materials and Design

- ELG Carbon Fibre Ltd have sponsored research on characterisation of recycled CF composite materials since 2017, leading to numerous outputs (see earlier) and uptake of products in the automotive, railway and wind energy sectors.
- Collaborative research with 3M UK Plc (2016-19) investigated a novel test method for adhesive screening and selection. This resulted in a confidential development that 3M is looking to further extend the collaboration.
- We worked with SHAPE Machining on developing 3-D printing of components and embroidered CF composite materials for lightweight applications in transport.
- Building on the success of the bamboo bicycle, a joint project with Onbone sought to construct a bicycle using biodegradable material (2017). Woodcast is a re-mouldable and non-toxic material made from FSC certified wood and biodegradable plastic that is presently used for splints and casts in the medical sector. The collaboration opened up future research projects dealing with material development for alternative applications and joining technology. <http://www.woodcast.fi/en/company/>. We also worked with Ecobike Manufacturing Ltd in Ethiopia in 2018, in order to develop local manufacturing concepts for bamboo bikes to promote and enhance mobility in rural areas.
- We undertook collaborative research with National Composites Centre (NCC), University of Bristol (UoB), BAE Systems and Delta Motorsport Ltd (2019-20), extending significant research into disbondable adhesive systems for materials recovery. Outcomes are focused on the generation of transport demonstrators to encourage industry uptake, by increasing the TRL level from 3 to 4/5.
- We also work with Tisics in Farnborough who specialise in the development of MMC materials. They have been supplying MMCs for research that is comparing the residual stresses in manufactured materials with model predictions, to exploit in transport applications.

## Contributions to the economy, society and impact

### i) Future of Transport

Electric vehicles represent part of the solution to the net zero emissions challenge. The vehicle energy use and driver data from interdisciplinary research in the MINI E project allowed BMW Group to understand how people really respond to electric cars and technical factors necessary to support electric mobility. Key deliverables of our study were demographics of potential customers, in-depth understanding of their mobility needs and an analysis of underlying motivations for wanting to drive electric vehicles. Overall, the project was a real success for BMW Group *[Case Study: Transitioning to the 'new normal' of electric vehicles (author: **Hutchinson**)]*.

An award-winning KTP was completed in 2014 with YASA Motors, delivering significant savings and increased motor production throughput for small energy-dense electric motors for applications in automotive and aerospace. This innovative motor design won the research excellence prize at the Innovate UK 2014 awards and was runner up in the 'Best of the Best' category. A second KTP was undertaken on a novel heat exchange system for the motors (2014-16). *[Case Study: Influencing the development of YASA high performance electric motors for sustainable mass production for next-generation vehicles (author: **Broughton**)]*.

Public dissemination of practical outputs from the EU REPUTE project included our active participation in a low-carbon European road trip through Scotland, Ireland, France, Spain and Portugal in June 2015. Audiences at each venue included energy, transport, media, city mayors and local authority delegates. The events included public demonstrations of EVs. One meeting took place with EU officials at their regional HQ in Porto. Our output report (hard copy and web) was compiled in 4 languages (English, French, Spanish and Portuguese) and distributed widely.

## ii) Engine Modelling

Globally, too many high-emitting vehicles are still being made and sold. The large Ford-led APC6 DYNAMO project has contributed strongly to emissions reductions from engine combustion modelling in conjunction with software developers Siemens and Ricardo. Our research fundamentally transformed Ford's knowledge around the mechanisms of particulate matter formation, enabling them to comply with ever stricter emission regulations. It also enabled both Siemens and Ricardo to integrate new modelling approaches into versions of their market-leading software. For Ford, this led to a new proposed GDI engine control strategy with potential to reduce Particle Number emissions beyond the limitations of Euro 6 and forthcoming regulations. *[Case Study: Robust and reliable digitalisation of the automotive industry: improvements in 3D CFD modelling of particulate matter emissions (author: **Bonatesta**)]*.

## iii) Mechanics, Materials and Design

Research into the repair and restoration of historic timber structures was undertaken by JTRC through a European network COST action FP100: Enhanced mechanical properties of timber, engineered wood products and timber structures. This Action's aim, completed in 2015, was to create new opportunities for timber construction. The project outcomes included enhanced design guidance for strengthening, stiffening, improving toughening techniques, modelling and case studies relating the experience of practitioners that had worked on real projects. Fourteen European countries were involved and over 60 participants from leading research institutions and industrialists.

Our bamboo bike design, originally licensed for UK manufacture in 2012, was publicised through appearances and presentations, eg Oxford's Ashmolean museum 'Wisdom, Wonders and Widgets' (2015), 'Future of cycling' Exhibition at the Design Museum, London (2016), a SAMPE conference (2016), BBC World Service and local news.

Research on bamboo bikes was extended to hosting a sustainable enterprise from Ethiopia in July 2018. Staff worked on the design and manufacture of an Eco Bike made from bamboo, building on our previous success with the bamboo bike project, with a young African Leader supported by a Mandela Washington Fellowship. The sustainable enterprise will make use of Ethiopia's bamboo resources to create bikes that will be manufactured locally and provide transport for rural communities in Ethiopia to promote and enhance mobility, and empower women, low-income groups and isolated rural dwellers.



We also worked with Bromakin Wheelchairs to develop a lightweight CF racing wheelchair for star athlete Sammi Kinghorn in the 2021 Paralympics in Tokyo.

### Contributions to the research base

Many staff members hold editorships, and key positions on journal editorial boards, international conference committees and research grant panels.

### i) Examples of conference organisation, invited talks and appearances

Conference organisation: **Barker** and **Haytleh**: Oxford Circuits and Systems 2017. **Tzanakis**, with Prof Eskin (Brunel), the “Ultrasonic Processing of Liquid and Solidifying Alloys” symposium at the 2019 TMS Annual Meeting and Exhibition (4,500 participants).

Keynotes: **Raugei** at 13<sup>th</sup> Photovoltaic Science, Application and Technology Conference in Bangor, 2017; **Todinov** at 2<sup>nd</sup> International Conference on System Reliability and Safety in Milan, 2017; **Tzanakis** on ultrasonic melt processing technology such as at the ERC workshop on Cavitation Exploitation in Slovenia (2018), the 3rd International Conference of Ultrasonics in Portugal (2018) and in UWE (2018) and Warwick University (2019).

Invited presentations to government: **Raugei** at "Energy Return On Investment Workshop", BEIS, London, 2017.

Media and public citations: **Raugei** was interviewed about energy topics for the popular Italian television programme ‘Report’ on Rai 3 in 2015, and on Zetland, A Danish on-line magazine in 2020. **Raugei**’s work on the LCA of photovoltaics was cited by the European Commission EU Science Hub in 2017. In 2019, **Raugei**’s research was featured in ‘The Verge’ (an American technology news and media network operated by Vox Media), and in the ‘EOS’ Newsletter (EOS is a branch of the American Geophysical Union).

### ii) Examples of Board memberships

**Barrera** is an editorial Board member of *Computational Material Science*. **Broughton** is Board Member for the Society for Adhesion and Adhesives, which organizes bi-annual workshops and seminars on adhesive and sealant related topics. It also organizes the International Conference on Adhesion (e.g. Bristol, 2019) and co-organises the international conference EURADH. **Hutchinson** served on the Board of Directors for the Low Carbon Vehicle Partnership 2014-16, which included judging of the annual ‘Low carbon champions’ awards, and working on steering groups for reports, e.g. **Ricardo**’s ‘Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies’ (2018). Our urban mobility research and whole life cycle analysis outputs were included in reports and supporting recommendations for adoption of future urban transport: *Micro Vehicles - Challenges and Opportunities for L-Category Vehicles in the UK* (LowCVP, 2019). This report was launched at a London workshop held jointly with the MotorCycle Industry Association (MCIA). The MCIA is now leading urban mobility initiatives on powered light duty vehicles (PLVs) with further inputs from LowCVP and ourselves on life cycle analyses [Case Study: Transitioning to the ‘new normal’ of electric vehicles (author: **Hutchinson**)].

### iii) Examples of visiting positions

**Barrera** is Honorary Senior Research fellow, Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, UoO. Previously she was Marie Skłodowska Curie Fellow, University of Luxembourg, Luxembourg (see Section 3 for her research on knee implants). **Morrey** is Visiting Professor at Murray Edwards College, Cambridge University. **Raugei** is Visiting Scientist at the Center for Life Cycle Analysis, Columbia University (New York), where he collaborates on research initiatives on photovoltaics and renewable energy scenarios. Since 2008, **Raugei** has been a full member and technical representative of the International Energy Agency PhotoVoltaic Power Systems (IEA PVPS) Task 12. Within IEA PVPS, he contributed to official IEA outputs (six reports, four of which since 2014) and lead-authored one report on the Net Energy Analysis of PV (all reports at: <http://www.iea-pvps.org>). He was also a member of the Global Warming Task Force of the UNEP-SETAC Life Cycle Initiative (2014-2016) and contributed to multi-author expert outputs on global guidance on LCA impact



indicators (*Environmental Science and Technology* (2015), *Ecological Indicators* (2016), *Int J Life Cycle Assessment* (2016), and a presentation at a Net Energy Analysis workshop at Stanford University (2015)). **Tzanakis** is an Academic Visitor in the Materials Department at the UoO (see Section 3 for his research).

#### iv) Journal Guest Editorships

**Azizi** for Special Issues of: *Emerging Trends in Mechatronics* 'Complexity' (2021) and *Evolutionary Bioinformatics* 'Application of Artificial Intelligence Techniques to Bioinformatics Problems' (2021). **Durodola** for a Special Issue of *Materials* (2021), for Materials Simulation and Design section entitled 'Predictive Modelling for Mechanical Behaviour (PMMB) of Materials'. **Hutchinson** for a Special Issue of *Adhesion* 'Dismantlable Adhesive Joints' (2017); two papers were authored by Oxford Brookes. **Raugei** for Special Issues of: *Ecological Indicators* and *Energies* (2016), *Cleaner Production* (2018) and *Energy Technology* (2019). **Tzanakis** for a Special Issue of *Materials* (2017) 'Ultrasonic Cavitation Treatment of Metallic Alloys' (2019); two papers were authored by Oxford Brookes.

#### v) Books, personal awards and seminal journal articles

**Raugei's** chapters on photovoltaics in 'The Performance of Photovoltaic (PV) Systems: Modelling, measurement and assessment', 2016, and Springer's 'Encyclopedia of Sustainability Science and Technology', 2019. **Raugei's** paper on 'Net Energy Analysis' was published in *Nature Energy* (IF: 54) in 2019 and has been cited multiple times (Web of Science data). **Todinov** was awarded the IMechE award for Risk Reduction in Mechanical Engineering in 2017 and he produced 'Reliability and Safety', 2019. **Tzanakis** produced 'High-Frequency Vibration and Ultrasonic Processing', Springer, 2018.