Institution: University of Bath

Unit of Assessment:12: Aeronautical, Mechanical, Chemical and Manufacturing Engineering

a. Overview

The REF 2014 period has seen greater cohesion and standardisation of working practices across all Departments in the Faculty of Engineering and Design. An underpinning strategy has fostered a culture of interdisciplinary and inclusive working to deliver research of the highest excellence coupled with significant and measureable international impact. This unified submission encompasses the Departments of Mechanical and Chemical Engineering (MECE). The research structure is described below.

1. Research Centres are clusters of researchers providing critical mass in focused areas.
2. Research Units are smaller sub-groups of Centres having a deeper and narrower focus.
3. Research Groups have common and broader interests with greater collaborative interactions.

Individuals may be associated with more than one Research Centre/Unit/Group and are encouraged to do so, thereby promoting inclusiveness and interdisciplinary working. The research falls under 6 Themes, which define where core expertise lies:

Theme 1:	***Machine Systems***, including automotive engineering; power transmission; dynamics and control; fluid power; mechatronics; and active vibration control. → **Centre for Power Transmission and Motion Control (CPTMC)** → **Powertrain and Vehicle Research Centre (PVRC)**
Theme 2:	***Design and Manufacturing***, including engineering design; costing; manufacturing technology, machining processes; metrology; and product design. → **Innovative Design and Manufacturing Research Centre (IdMRC)** → **Laboratory for Integrated Metrology Applications (LIMA)**
Theme 3:	***Structures and Materials***, including computational methods; material processing; solid mechanics; nanomaterials; and failure analysis of composite structures. → **Materials Research Centre (MRC)** → **Composites Research Unit (CRU)** → **Advanced Materials and Porous Solids Research Group (AMPS)**
Theme 4:	***Aero, Thermo and Energy Engineering***, including acoustics; aerodynamics; fluid mechanics; thermodynamics; heat transfer; turbo-machinery; and energy systems. → **Aerospace Engineering Research Centre (AERC)** → **Gas Turbine Research Unit (GTRU)**
Theme 5:	***Healthcare Engineering***, including biomaterial structures; biomechanics; and tissue engineering. → **Centre for Orthopaedic Biomechanics (COB)** → **Centre for Regenerative Medicine (CRM)** → **Biochemical and Biomedical Engineering Research Group (BBERG)**
Theme 6:	***Process Engineering***, including catalysis; fuel technology; membranes; sustainable chemical technologies; and adsorption. → **Centre for Sustainable Chemical Technologies (CSCT)** → **Catalysis and Reaction Engineering Research Group (CARE)**

Over the assessment period a significant number of strategically important initiatives and developments have been fostered, with examples highlighted:

(a) A number of beacons of research excellence have emerged, e.g. Analysis Enabled Composites, recognised by the award of a RAEng/GKN Research Chair.

(b) Ten TSB industry collaborative R&D projects have been awarded, with a value to MECE of £3.7M, having a major influence on our impact agenda, forging new industrial partnerships with GKN, Ashwoods Automotive, Jaguar Land Rover, TATA Motors, and Shell, and deepening those with Ford, Renishaw, Johnson Matthey, Airbus, and Moog Controls.

(c) A new and major interdisciplinary research and innovation partnership has been forged with Wessex Water with initial direct investment of £2.7M and a University contribution of £1.4M.

b. Research Strategy

Vision and Strategic Research Plans

The vision of MECE is to undertake innovative fundamental and applied research of the highest quality that is recognised globally and capable of delivering ground-breaking impact.

To achieve our vision, a strategy was adopted to develop a culture of interdisciplinary and inclusive working in which research of the highest excellence can thrive. Five aims **S1**-**S5** were set within the REF 2014 period to enable this strategy to be realised and significant advances have followed:

S1. ***Grow and develop the research base in strategically important areas*****:** Strategically important areas are those: (a) having strong academic leadership; (b) having the capability to engage in a wide spectrum of current and future research funding opportunities; (c) that are capable of developing and supporting a critical mass of researchers; and (d) having strong industrial and end-user support to enable impact to be delivered. Examples include analysis enabled composites (CRU), gas turbine heat transfer engineering (GTRU), nanomaterials and nanofluidics (AMPS), high boosting next generation automotive engines and vehicle system integration and control (PVRC, CPTMC), and healthcare engineering (COB, CRM, BBERG).

S2. ***Diversify funding streams to underpin and provide sustainable research activity*****:** Traditionally, MECE has been largely reliant on RCUK funding. We have therefore sought to broaden our portfolio of funders (see **section d.**). We have had significant success with the Technology Strategy Board (TSB), the European Regional Development Fund (ERDF), the South West Regional Development Agency (SWRDA), philanthropic and charitable funding. Collaborative industry partnerships have been facilitated by the University EPSRC Knowledge Transfer Account (KTA) and the EPSRC Impact Acceleration Account (IAA). There has also been a focus on targeting and winning large grants, backed by significant University support, including the LIMA Business Technology Centre (BTC, £2.6M), a Wessex Water partnership (£4.1M), EPSRC awards including Sustainable Chemical Feedstocks (£2.7M with Chemistry); Manufacturing Metrology (£2.4M with Physics); and a major Equipment Grant (£2.0M) to create a national research Centre for Low Emission Vehicle Research (CLEVeR).

S3. ***Expand doctoral research student numbers and graduations*****:** We planned to increase our doctoral student numbers in line with our overall strategic aim to expand our research base. Over the last 5-year periods of the RAE 2008 and the REF 2014 our doctoral graduations increased from 1.5/FTE to 2.4/FTE, respectively. This has been accomplished through a number of initiatives, which include the EngD in Systems (with Bristol), the Doctoral Training Centre (DTC) in Sustainable Chemical Technologies (with Chemistry), a Marie Curie PhD Training Centre in Regenerative Medicine (with Biology and Pharmacy), philanthropic and charitable funding, direct industry funding, and University and Faculty Graduate School Scholarships.

S4. ***Form new partnerships with industry, having national and global reach*****:** Planned activities sought to forge and develop new partnerships with industry. The successful £3.39M EPSRC Knowledge Transfer Account (KTA) led to £1.34M being awarded to MECE for 15 partnership development awards with £1.14M of matched funding from industry. The successful £1.36M EPSRC Impact Acceleration Account (IAA) led to £750k for MECE with matched funding of £689k. Our research capability has therefore expanded in line with **S1**, our impact has been strengthened, and sustainable industrial funding has been secured. The emergence of the TSB has yielded more industrially led R&D projects, as highlighted in **section a.**, as well as new directly funded partnerships, especially with Wessex Water, Jaguar Land Rover, GKN Aerospace, Siemens (USA) and MAST Carbon International.

S5. ***Secure major investment for research: people, equipment and infrastructure*****:** We have secured investment for 2 new chairs, 2 readerships, 3 lectureships, and 4 University funded Prize Fellows (see **section c.**). Investment in specialist research equipment totals £2.1M and in infrastructure it is £1.6M. The details are presented in **sections c**. and **d**.

Current Position with Reference to the Research Position Described In RAE 2008

People**:** We have adopted a long term staffing plan, hence our position has changed significantly since the RAE 2008 as part of our plans to expand and develop our research base (**S1**). Appointments following retirements are now used strategically to enhance research capability and interdisciplinary working. We have appointed 20 new Early Career Researchers (ECRs) to provide

'new blood', 10 of these previously held Bath research positions, emphasising our commitment to career progression and retention. We have also had a significant number of new investment positions approved by the University to support our staffing plan (**S5**). We will only appoint researchers of the highest calibre to build capacity within our strategically defined areas. For submission to the RAE 2008, the numbers of FTE Category A staff for Chemical Engineering and Mechanical Engineering were 13.0 and 43.4, respectively, giving a total of 56.4. For this REF 2014 submission, there are 61.0 FTE Category A staff members.

***Doctoral students*:** MECE has benefitted from the award of EPSRC DTCs in Sustainable Chemical Technologies (PhD) with the Department of Chemistry, and in Systems (EngD) with the University of Bristol. Over the last 5 years of the RAE 2008 and the REF 2014, doctoral graduations increased from 84 (RAE 2008) to 145 (REF 2014).

***Research income*:** The research spends over the last 5 financial years of the RAE 2008 and REF 2014 assessment periods were £19.8M and £27.0M, respectively.

***Outputs*:** Research outputs include 1028 journal papers over the REF 2014 period, which is a pro rata increase of 28% compared with the RAE 2008 period.

Future Strategic Aims and Goals for Research

Over the 5 years from 2014, 5 future strategic aims (**FS1**-**FS5**) have been set:

FS1. ***New and expanded research capabilities***

- Launch a Water Innovation and Research Centre in 2014, spawning a new area of interdisciplinary research activity with investment secured for 4 new academic positions.
- Launch the EPSRC funded Centre for Low Emission Vehicle Research (CLEVeR) in 2015.
- Expand the gas turbine heat transfer engineering research, with further investment from General Electric, supported by further academic investment appointments.
- Expand machine systems (CPTMC, PVRC) by investing in key positions to support interdisciplinary research activity in intelligent machines, hybrid electric and electric vehicles.
- Expand nanotechnology, translating fundamental science into applications, e.g. waste water treatment, membranes for nanofiltration, supported by further academic appointments and the launch of a Nanotechnology Research Centre.
- Expand the composites research supporting future developments with GKN and the National Composites Centre (NCC).
- Realign engineering design with greater emphasis on integrated electro-mechanical systems.
- Align the PVRC to become a competence centre in the Department for Business, Innovation and Skills (BIS) £1bn Advanced Propulsion Centre to support the UK automotive sector.
- Launch two interdisciplinary research institutes in healthcare engineering, and advanced propulsion and power.

FS2. ***Investment in new build, research infrastructure and equipment***

- Two major new builds are planned. The University will invest £24M in a new Faculty of Engineering building to be opened in 2015, into which MECE research hubs will be located, e.g. the Water Innovation and Research Centre, and lead to further development of our investment in healthcare engineering. Advanced negotiations with the James Dyson Foundation are set to deliver a £10M philanthropic gift to create a state-of-the-art building, which will be a focus for a new era of integrated system design research.
- Investment of £5M of University funding in research infrastructure and laboratories, and further bids to EPSRC strategic equipment calls, the Wolfson Foundation, and the Local Enterprise Partnership (LEP) are planned.

FS3. ***Investment in new academic positions***

In order to realise and support **FS1** and **FS2** we will seek to strengthen and build capacity in our academic research base with the appointment of additional staff including 5 professorial positions, 4 readerships, 4 ECR lectureships, and 5 University funded Prize Fellows (**section c.**).

FS4. ***Future funding and expansion of doctoral student numbers***

Given the range, depth and scale of our planned activities under **FS1**, **FS2** and **FS3**, we are targeting future growth of grant capture at £140k/FTE/annum, a real-term increase of 40% over the next 5 years. Doctoral student graduations are targeted to increase to 1/FTE/annum, supported by the recently announced (November 2013) continuation of the Centre for Doctoral

Training (CDT) in Sustainable Chemical Technologies, and new CDTs in Water Informatics: Science and Engineering (WISE), (joint with Exeter, Cardiff and Bristol Universities), and in Catalysis, (joint with Cardiff and Bristol). MECE will engage in proposals for future CDT calls.

FS5. ***Form new research partnerships with leading international universities***

A number of new international partnerships have recently been formalised with leading universities. MECE is engaging with the National University of Singapore (engineering design, functional materials and nanoscience), Tshinghua University (biomedical and gas turbine engineering), Harbin Institute of Technology (fluid power and motion control), University of São Paulo (sustainable processes, catalysis and biotechnology), and Stellenbosch University (water engineering and membrane technology). These partnerships are expected to deliver jointly funded collaborative projects, jointly supervised PhD students, with significant University funding to support researcher mobility and sabbaticals.

c. People, including:

(i) Staffing Strategy and Staff Development

(a) Staffing strategy related to research strategy and physical infrastructure

Research excellence is a central expectation for all academic staff within MECE. Thus, MECE ensures that all staff have a supportive, inclusive and developmental environment in which to pursue their research and to progress their careers. Our staffing strategy is to recruit the highest quality researchers, to provide focus, fit and capacity building across our strategic research activities and to actively develop, support and monitor the careers of all staff. Our academic staff succession plans are central. Appointments following retirements are now used strategically to enhance research capability, interdisciplinarity and impact. Our 20 'new blood' ECRs have been appointed to support our research ambitions and strategy; six have already progressed in their careers over the assessment period. MECE ensures that opportunities, rewards and progression are available to high-achievers. All staff have access to individual office space, laboratories and specialised facilities. MECE has significant combined laboratory research space (4500 m^2) plus 45 technical support staff who are led by a Director of Technical Support Services.

The distribution of independent researchers across our research themes (at the census date of 31 October 2013) is shown in Table 1. There are currently 14 ECRs on Lecturer and Fellow grades.

Table 1. MECE staff as at 31 October 2013. Superscripts denote: directors of centres, units, or groups; 1- completion of probation; 2- promotion lecturer to senior lecturer; 3- translation senior lecturer to reader; 4- promotion to professor during the assessment period.

Grade	Theme 1	Theme 2	Theme 3	Theme 4	Theme 5	Theme 6
Professor (16)	Hawley[PVRC] Keogh Plummer[PTMC]	Culley[IdMRC] Maropoulos[LIMA] Mullineux Newman	Almond[MRC] Butler[CRU,3,4]	Gursul[AERC] Lock[GTRU,3,4]	Chaudhuri[BBERG] Gill[4] Miles[COB]	Crittenden[AMPS] Kola…ski[iCARE]
Reader (7)	Brace[3] Sahinkaya	Newnes[3]		Rees	Cunningham Turner[3]	Plucinski
Senior Lecturer (14)	Darling Johnston		Kim[2] Meo	Carley[2] Mays Robinson[2] Wilson	Ellis[2] Gheduzzi[2]	Bird Lukyanov Patterson Perera
Lecturer (11)	Akehurst[1] Cole Hillis[1]	Dekoninck[1] Nassehi[1]	Mattia[1]	Bannister[1] Wang Blenkinsopp		Chew[1] Torrente[1]
Prob. Lecturer ECR (9)	Copeland du Bois	Dhokia	Courtney Rhead	Cleaver Wain	Di Lorenzo Sharma	
Research Fellow ECR (5)	Burke		Dodwell	Sangan	Chuck	Ting
62	**13**	**8**	**8**	**13**	**10**	**10**

(b) Career development in research

The MECE workload model ensures a balance across research, teaching and management. It is

reviewed annually with Staff Development Performance Reviews (SDPRs), to set and monitor targets for research proposals, publications, and other longer term goals. The University Researcher Development Unit (RDU) supports all academic staff, provides development opportunities for research careers at Bath and beyond. The RDU embeds the national Researcher Development Framework (RDF) tool for planning, promoting and supporting personal, professional and career development. Over 30 training workshops are offered annually to cover the RDF.

ECR development strategy*:** Each ECR is allocated a fully funded doctoral research studentship from the Faculty's Graduate School, start-up funds are provided from the Faculty research investment account, and funding for travel and conferences is ring-fenced from Department budgets. Teaching and administrative loads of ECRs are introduced gradually and experienced mentors are assigned for guidance on research planning. An exciting feature has been the investment in ***University of Bath Prize Fellows to attract the highest calibre ECRs. These are 5-year posts that transition from research fellow to probationary lecturer after Year 2. All ECR lecturers are required to complete the Bath Course in Enhancing Academic Practice. The University's Academic Staff Committee approves successful completion of probation.

Our commitment to career progression is evidenced by examples where MECE ***Research Assistants*** have been appointed to ECR positions: Prize Fellowships were awarded to Burke, Sangan and Ting (2012); and Dodwell (2013). These appointments of MECE research assistants were won in externally-advertised open competition. Five-year RCUK Academic Fellowships were awarded to Bannister (2007) and Nassehi (2008), both of whom progressed to lectureships, in 2009 and 2010 respectively. Chuck was awarded a Whorrod Endowment Fellowship in 2010. In 2012, Cleaver, Rhead and Dhokia were appointed to probationary lectureships. A number of these researchers have been mentored through the Faculty Fellowship Academy (see section (d)).

Formal mentoring ceases at Senior Lecturer level as independent leadership is expected. ***Career promotions*** achieved by MECE staff over the assessment period are evidenced in Table 1.

(c) Personal research fellowships

Personal research fellowships are prestigious for both the individual and MECE. **Akehurst** held an EPSRC Advanced Fellowship (2005-2010) and associated research project funding under, 'Lean Powertrain Development' (valued at £553k). **Mattia** secured his RAEng/EPSRC Fellowship (2008-2013) to focus on 'Nanoparticle Factory-on-a-Chip' (£500k). **Butler** was awarded a RAEng Industrial Secondment (2010-2011) to GKN Aerospace in 2012, followed by his GKN Aerospace/Royal Academy of Engineering Research Chair (2013-2018) in 'Analysis Enabled Composites' (£532k).

(d) Concordat to Support the Career Development of Researchers

The University fully implements the ***Concordat***. In 2011, Bath was awarded an 'HR excellence in research' badge from the European Commission. The Research Staff Working Group, in consultation with the Pro-VC (Research), the Research and Development Support Office, and the Researcher Development Unit, developed an Implementation Strategy for the Concordat in 2011. In support, MECE has introduced initiatives: (A) Each new ECR lecturer within MECE is awarded a doctoral postgraduate studentship; and (B) In 2010, the Faculty created a ***Fellowship Academy*** as a unique venture to support and mentor our best doctoral students and ECR researchers, based on selective criteria, who wish to develop academic careers. Of the first 14 awardees, 10 were within MECE. Two have since been appointed to lectureships in MECE, 3 have won University Prize Fellowships (2 in MECE, 1 in School of Management), and 3 have taken up external postdoctoral positions. The University secured a £625k EPSRC small equipment grant in 2013 and 15 lecturers and ECRs from MECE gained £250k from this.

(e) International staff appointments, and visiting scholars

Incoming staff appointments as Visiting Professor include **Schmotzer** (Senior Partner at SigmaRC GmbH, Switzerland) from 2005; **Manley** (Chief Scientific Advisor, Stryker Orthopaedics, USA) from 2006; **Jones** (in Innovation, funded under RAEng Scheme) from 2008; **McFarland** (Group Engineering Director, Renishaw) from 2008; **Nuckols** (Senior Research Scientist, Mechanical Engineering and Material Science Department, Duke University) from 2009; **Brennan** (UNESP, Brasil) from 2012; **Tam** (Director, Engineering Design & Innovation Centre, National University of Singapore) from 2013; **Colton** (Professor of Mechanical Engineering, Georgia

Institute of Technology) from 2013; **Frise** (Scientific Director and CEO at AUTO21 Canadian Centre of Excellence Program) from 2013; **Pearson** (BP Global Formulated Products Group) from 2013; **Turner** (Principal Engineer for Petrol Engine Technology, Jaguar Land Rover) from 2013; **Dennis** (Ex-Director of Environment and Science at Wessex Water) from 2013; and **Weavers** (John C. Geupel Endowed Chair in the Department of Civil and Environmental Engineering at Ohio State University and the Co-Director of the Ohio Water Resources Centre) from 2013. **Sandborn** from the University of Maryland, was a RAEng Distinguished Visiting Fellow over 2010-11. Over 20 other international visiting scholars were hosted by MECE for 3-12 months during the REF 2014 assessment period, together with 12 Visiting Industrial Fellows and Researchers.

Outgoing staff appointments include **Gill**, as Visiting Professor, Ghent University, Belgium, since 2013; **Hawley**, as Adjunct Professor, University of Windsor, Canada, since 2008; **Kolaczkowski**, as Visiting Professor, Jagiellonian University in Krakow, Poland, since 2012; **Maropoulos**, as Visiting Professor, Nanjing University of Aeronautics and Astronautics, China, since 2011 and Guest Professor, Beijing University of Aeronautics and Astronautics, China, since 2012; **Rees**, as Visiting Professor, Université Paul Sabatier, France, since 2010; and **Kim**, as Affiliate, Los Alamos National Laboratory, USA, since 2009.

Outgoing sabbaticals were awarded to **Bird** (2009-10, 6 months, Universities of Canterbury and Auckland, NZ); and **Kim** (2012-13, 12 months, NASA Langley and Los Alamos National Laboratory, USA).

Numerous ***Outgoing visits*** were made, for example by **Burke** (TU Berlin, April 2013; Universidad Politécnica de Valencia, May-June 2013); **Chaudhuri** (Led a delegation to São Paulo, Nov 2012 and Sept 2013; A-Star, Singapore, Mar 2012); **Copeland** (UTM, Malaysia, Sept 2012); **Ellis** (IIT KanpurIndia, Sept 2010; Harvard University, Sept 2012); **Culley** (NUS, Sept 2012 and 2013); **Hawley** (Beihang (BUAA) University, China, Keynote address, Sept 2012; Tsinghua University, Sept 2012 and Sept 2013; UTM, Malaysia, Sept 2012; University of Stellenbosch, Feb 2013); **Keogh** (Tokyo Institute of Technology, Aug 2008); **Kolaczkowski** (sponsored research meeting with Office of Naval Research, US Navy Experimental Diving Unit, Panama City, Florida, US, June 2011); **Mattia** (NUS, NTU, Australia and New Zealand sponsored by BIS, Feb 2013); **Rees** (University of Bergen, Norway, Mar 2011); and **Lock** (Beihang University, China, May 2011). A MECE delegation to Stellenbosch In Sept 2013 included **Mattia**, **Patterson**, **Torrente** and **Wain**.

(f) Equality and diversity

All Equality and Diversity (E&D) HR policies are fully implemented and embedded in the research activities of MECE. Academic staff come from from diverse backgrounds, including 7 EU countries, Canada, China, India, Iran, Korea, New Zealand, South Africa, Russia, Turkey and the USA. Wherever possible we ensure a diversity balance on all our key committees. Formally, E&D is reported at the Executive Committees of MECE. Newnes (Mechanical Engineering) and Di Lorenzo (Chemical Engineering) are the Equality Co-ordinators. Departments submit an Annual Equality Return outlining the implementation of any equality actions and future plans. The University has an Athena SWAN Bronze Award, and the STEMM departments of MECE have actively pursued the Athena SWAN agenda since 2012 and will apply for individual Bronze Awards in November 2013.

(ii) Research Students

A Faculty ***Graduate School*** was created in 2010 to provide focused academic, administrative and careers support and co-ordinated skills training. Many doctoral students also profit from strong collaborative programmes and industrial links. MECE has benefitted from two EPSRC Doctoral Training Centres (DTCs): an industrially based 4-year EngD in Systems (£5.3M), which is jointly delivered with the University of Bristol; and a 4-year integrated Bath PhD (£7.5M) in Sustainable Chemical Technologies, centred in Chemical Engineering and Chemistry, with collaborators in Mechanical Engineering. Since October 2009, each DTC has been engaged in the training of 50-70 doctoral students in five cohorts. The large scale of the DTCs provides many collaboration and training opportunities, which are not always available for individual research projects.

Recruitment of research students is focused on research reputation to attract applicants having excellent undergraduate qualifications and research potential. Web-based visibility and links from the University postgraduate prospectus to our Graduate School and Departments and Research

Centres also attracts interest. Internal Graduate School showcases and Department presentations promote MECE research study to MSc students and final year undergraduates. Studentships are available to support outstanding candidates. Graduate School fees-only awards are used to attract outstanding overseas applicants.

Training and support mechanisms have been embedded in MECE for over 10 years to support research students. Following a week-long induction, doctoral students are offered targeted training under the PG Skills programme and must accumulate 10 days of training per year. In addition, the DTCs fund and embed their own credit based training units over the first two years. PhD students are assigned at least two supervisors (one identified as a lead), which allows for wider technical and interdisciplinary input and broader supervision. Similar support exists for EngD students, each having a lead academic supervisor, a systems (academic) supervisor, and an industrial supervisor. The Director of Postgraduate Studies will also guide students on expectations relating to their study. Representation of cohort issues is made through the Faculty of Engineering Postgraduate Staff Student Liaison Committee. A University Research Postgraduate Ombudsman is also available for consultation, in confidence, by any doctoral student.

Progress monitoring is reported through the Faculty Research Students' Committee (FRSC), which has been in place since 2010 (prior to this the Faculty Board of Studies was the formal vehicle). The FRSC, chaired by the Associate Dean for Graduate Studies, undertakes detailed monitoring of each student including candidature, confirmation of MPhil to PhD after Year 1, and of progress reports at 6, 12, 24, 30, 36, and 42 months. It seeks to ensure the provision of consistent, quality supervision for research students and promotes dissemination of good practice. The cohort of research students is monitored and reviewed annually using statistical performance indicators of completion, submission and attrition rates, systematic analysis of feedback from internal and external stakeholders, and the effectiveness of induction activities and skills training.

d. Income, Infrastructure and Facilities

Information on Provision and Operation of Specialist Infrastructure and Facilities

Maintaining and investing in appropriate research equipment and facilities is essential to the research vision. There is now a Research Equipment and Facilities Management Strategy in place, which is overseen by the Dean of the Faculty. It ensures that rigorous procurement, cataloguing, charging mechanisms for researchers and businesses, and maximum equipment usage through shared provision is applied.

Evidence of Investments in Infrastructure and Facilities

(a) Current

Clean Composites and Materials Research Laboratory**:** This laboratory offers inclusive accessibility to all researchers and has received major University investment to accelerate and energise research. This includes £260k in infrastructure improvement, and £618k to purchase a microCT scanner with high performance computing capability and a scanning laser vibrometer. Within its specialist nature, this facility also directly supports the RAEng/GKN Chair in Analysis Enabled Composites (Butler, 2013), including new academic appointments (Rhead and Dodwell).

Nanotechnology Research Facilities**:** Internal investment of £200k has been made in the areas of nanomaterials and nanofluidics, resulting in a nanoparticle manufacture and characterisation facility, comprising two microfluidic reactors, with the capability to carry out online nanoparticle synthesis. This also includes materials and catalysis characterisation capability and a dedicated gas phase catalysis testing system, with new academic appointments (Torrente and Ting).

Gas Turbine Heat Transfer Laboratory**:** Direct University investment of £300k has completely refurbished and extended this facility to support this expanding strategic research area, which is now the subject of a major industrial partnership with Siemens. Equipment funding of £750k from the EPSRC and Siemens has resulted in the design, development and build of new heat transfer emulation rigs with supporting ancillary equipment. This research is led by Lock, promoted to professor in 2012, and also includes new academic appointments (Sangan and Cleaver).

Machine Systems Laboratory**:** Internal investment of £500k has led to the co-location and expansion of equipment to create a showcase open-plan interdisciplinary research facility, which incorporates metrology, fluid power, advanced control, mechatronics, and machine design, accommodating LIMA, CPTMC and the IdMRC. This facility also houses specialist metrology

equipment supplied during the REF period by Renishaw, valued at £800k, and a 6-station knee joint wear simulator, valued at £150k, supplied by Smith and Nephew. This laboratory supports the research activities of new appointments (Gill, du Bois, Dhokia, Cole).

***Advanced Turbocharger Experimental Emulation Facility*:** This is a new facility that has been developed to support research in the area of extreme engine downsizing, where experimental emulation of turbocharger performance becomes critical. Capital investment of £300k to develop this facility has come from Ford, Jaguar Land Rover and the HEIF. This facility supports the research activity of new appointments (Copeland, Burke and Sangan).

***General Research Laboratory and Workshop Upgrades*:** There has been a £1M investment to upgrade and create high quality research laboratory space over that listed above.

(b) Planned

***New Faculty of Engineering Building*:** On 27 June 2013 the University Council approved the investment of £24M to create a new building for the Faculty of Engineering & Design. The building of 7,000 m^2 will allow the expansion of research across all disciplines within the Faculty. It will be operational by September 2015 and will feature a number of research hubs to allow continued expansion of our research activities in line with our future strategic aims (**FS1**-**FS5**)). High quality space for researchers and interdisciplinary showcase laboratories will be created in MECE-led research hubs for *Healthcare Engineering* and *Water Science and Engineering*. As regards the latter, the building will house the Water Innovation and Research Centre following the investment by Wessex Water. Researchers from MECE will benefit further due to their involvement in the other research hubs, including the *Built Environment* and *Smart Grid and Energy Storage*. Each hub will accommodate open-plan space for up to 30 PhD students and office space for academics and post-doctoral researchers, as well as showcase laboratory space.

***Engineering Design Research*:** Advanced negotiations with the James Dyson Foundation are set to deliver a £10M philanthropic gift to create a state-of-the-art building which will be a focus for a new era of design related research. This investment will lead to research in MECE with a focus on integrated systems design at the electro-mechanical interface and will lead to several new academic positions.

***Centre for Low Emission Vehicle Research (CLEVeR)*:** The current vehicle research facility is currently unique in the UK university sector. A successful proposal to the EPSRC has secured £2M to upgrade and expand the facility, with state-of-the-art research equipment. To be launched in 2015, this will establish a world-leading vehicle research facility (CLEVeR) that is able to address many of the future challenges associated with ultra-low carbon liquid fuelled vehicles and novel electric and hybrid electric vehicle (EV/HEV) platforms under real-world driving conditions. A further University contribution of £580k will upgrade the infrastructure around the facility, including an equipment contribution. A further £416k of University investment is committed over the first three years of operation into staff costs, which will ensure the facility is run effectively.

***Gas Turbine Heat Transfer Engineering*:** Secure major investment in new equipment to support this international research activity. We plan to extend the research facility, in collaboration with and funded by GE Aviation, initially at $830k. It will allow study of the fundamentals of buoyancy-induced flow for high-pressure compressors and will support research at the cutting-edge of technology.

***Rolling Investment into Research Facility Infrastructure*:** Over the next 5 years it is planned to upgrade the infrastructure of the remaining research laboratories in MECE at an estimated cost of £5M and will be met with direct investment from the University.

***Investment in New Research and Upgraded Facilities*:** Following the successful £2M EPSRC Strategic Equipment grant, CLEVeR, outlined above, further applications have and will continue to be made with significant funding support from the University. A £600k proposal has been submitted for a state-of-the-art volumetric velocity and concentration measurement system, which will be at the forefront of fluid dynamics research. Funding will continue to be sought direct from industry, philanthropic donations and other non-profit organisations such as the Wolfson Foundation.

Information on the Research Funding Portfolio: Current and Future Plans

Since 2008, we have sought to diversify our funding streams with a particular focus on large grant

awards as laid out in our **strategic aim S2**. Examples include the LIMA BTC (£1.2M ERDF, £0.5M SWRDA, and £0.9M Industry), the EPSRC KTA funding for partnership development resulted in £1.34M of awards for 15 projects with industry contributing £1.14M. Also, 10 TSB industry collaborative R&D projects have been awarded to the value of £3.7M. This has resulted in a portfolio of £27M over the REF 2014 assessment period, with 55% from the EPSRC/BBSRC, 22% from industry, 12% from government or health trusts, 7% from the EU, and 4% from other sources.

Future Plans

We have appointed 20 high calibre ECR staff, who we expect over the next 5 years will make significant headway in their careers. We also plan to recruit senior researchers with international reputations. The net effect is an expected further increase in research funding awards of a challenging 40%, maintaining, enhancing and diversifying further our portfolio supporting our future strategy (**FS1**-**FS5**).

We can already identify opportunities to increase the portfolio as in the examples:

1. PVRC will be engaged in future funding activity through the £1bn BIS led Advanced Propulsion Centre and proposals are already being developed with Jaguar Land Rover and Ford for the first call with projects to be launched in April 2014.
2. Building on successful engagement with the TSB, we foresee opportunities with our industrial collaborators.
3. LIMA will adopt a more commercial approach to support the business interests of local SMEs with planned relocation to the Bristol-Bath Science Park.
4. Discussions are underway with the West of England Local Enterprise Partnership (LEP) to secure funding up to £50M to create the West of England Centre for Power and Energy to support and expand our applied research in this area across the Faculty. This covers MECE research in the CPTMC, PVRC, AERC, and GTRU (see **section a.**).
5. Expand our EU project activity by having a significant presence in Horizon 2020 funding and academic partners are already being engaged in preparation for funding calls.
6. Continue to expand and deepen our engagement with key stakeholders, for example, the NCC and from industry, e.g. phase 2 of Wessex Water funding.
7. Engagement with catapults, e.g. Transport Systems, High Value Manufacturing and Offshore Renewable Energy.
8. Greater research activity in the healthcare sector in interdisciplinary projects, including that in soft/hard active materials and systems; tissue/system integration; and active mechatronic and polymer devices. The envisaged sources are the EPSRC, MRC, non-profit foundations and philanthropic gifts.
9. Expansion of Knowledge Transfer Partnerships as a result of the extensive engagement we have had supporting SMEs over the last 5 years.

Information on Consultancies and Professional Services

Over the period 2008-2013, these amounted to £1.5M. The typical arrangements are made through Consultancy Services with the University drawing 20%. The academic researcher may draw the remainder as a salary top-up and/or to supplement a personal research account that can support minor items of equipment and conference travel.

LIMA, since 2008, has undertaken £0.5M of work delivering consultancies and professional services to Airbus and Rolls-Royce. For Airbus, a major project has featured metrology enabled visual process control environment for the integrated equipping of aircraft wings. For Rolls-Royce, a major machine tool verification project has passed the Manufacturing Capability Readiness Level 4 (MCRL4) and the technology is being further developed with the NCC as part of the High Value Manufacturing Catapult. It comprises two major units, the Metrology Assisted Assembly (MAA) Hub of Airbus and the LIMA Business Technology Centre (LIMA BTC).

SMS Consultants has been an integral part of the Materials Research Centre delivering professional services for over 20 years. It provides expert advice in the many areas of materials associated with metals, polymers and ceramics, including mechanical testing, chemical and structural analysis, corrosion, friction and wear, failure analysis, and an expert witness service.

The Centre for Power Transmission and Motion Control undertakes consultancy projects with companies and organisations in a wide range of industrial sectors including aerospace,

automotive, manufacturing, marine, construction, and government. Activities include product development, detailed technical analysis and measurement, simulation studies, design appraisal, and training, especially CPD courses in the fields of hydraulics, electrical drives, and control.

Kolaczkowski's expertise in chemical reaction engineering is also recognised in his engagement by companies endeavouring to explore new opportunities for the conversion of biomass and waste into energy (e.g. Refgas Ltd, Blue-Ng Ltd). In addition, he has advised on the use of metal foams as a novel form of catalyst support (Alantum Europe GmbH), which has led to a recent patent application (March 2013, EP 13157642.3).

e. Collaboration and Contribution to the Discipline

Support for Research Collaborations and Interdisciplinary Research

Collaboration, especially interdisciplinary working, is central to the current and planned research and impact strategies and activities of MECE. We seek to support academics engaged in developing collaborations through our Faculty and Departmental research committees chaired by the Associate Dean for Research and by Directors of Research, respectively. These important forums allow two-way information exchange to inform, advise and guide staff on mechanisms and examples of opportunities for research engagement and collaboration, especially where impact can be nurtured. Engagement with the University's Research Development & Support Office (RDSO) through the specialist Research Development & Collaborations (RD&C) team provides expert advice to broker collaborative research. A structured programme of training events is aimed at developing the skills of staff to enable them to take advantage of collaborative opportunities.

Significant support has been available through the RDSO for staff to engage in collaborative working via EPSRC KTPs, a £3.39M EPSRC KTA (1 Oct 2009 to 30 Sept 2012) and a follow-on £1.36M EPSRC IAA. Awards are made on a competitive basis subject to a tendering process.

Exemplars of Research Collaboration

Over 2008-2013, exemplars include:

(a) 30 academics have been engaged in 25 KTP projects with 21 individual industrial partners to a value of £3.18M. There have also been 15 KTA projects with 22 academics engaged with 13 companies for partnership development (£1.34M KTA and £1.14M industry). An IAA award of £300k has assisted the forging of the Wessex Water collaboration.

(b) **Hawley**, **Brace** and **Akehurst** (PVRC) have led extensive industrial collaboration with Ford, Jaguar Land Rover, Ashwoods, Mahle Powertrain, BP, Shell and Castrol over 2008-2013. This has resulted in 6 TSB projects (£2.5M to PVRC) in the Low Carbon Vehicles: Integrated Delivery Programme, 4 KTA projects (£600k EPSRC, £630k industry), and a major EPSRC equipment grant (CLEVeR; £2.0M EPSRC, £580k University of Bath).

(c) **Meo** led a collaborative FP7 project 'A Life-cycle Autonomous Modular System for Aircraft Material State Evaluation and Restoring System' (ALAMSA, €4.3M total, with £750k to MECE). This involves a consortium of 10 academic and industrial partners. To support this complex network, Dr Denise Cooke from the RDSO is the part-time Project Manager. Meo is also involved in the FP7 project 'Smart Cylinders for Flexographic Printing Industry' in collaboration with 7 European academic, research and SME partners.

(d) **Kolaczkowski** and **Perera** have an international collaborative project funded by the US Office of Naval Research with Duke University into methods of removing CO_2 from submersible habitats, especially shallow water combat submersibles. The first grant (2009-2013) was successfully completed and a follow-on award (2013-2016) is focused on developing a prototype. Total grant value to date supporting this is $1M.

(e) **Mays** was Principal Investigator on the EPSRC SUPERGEN UK Sustainable Hydrogen Energy Consortium, UK-SHEC (2007-12, £5.9M, £770k to Bath) and is currently Co-Director of the EPSRC SUPERGEN Hydrogen and Fuel Cells Hub (2012-17, £4.1M, £250k to Bath) with lead responsibility for the Hub's hydrogen storage research. The current Hub is a consortium of 7 UK universities in collaboration with 13 industrial and international partners.

Contribution to the Discipline Base

An exemplar of a significant contribution to the discipline base is the LIMA BTC, led by **Maropoulos**. Between 2010 and 2013, the BTC worked with 193 SMEs in the South West region, in the area of metrology enabled manufacturing. The BTC addresses key industrial challenges and

the subsequent application of knowledge and technologies into SMEs and supply chain companies in order to improve their verification and process control capabilities, enhancing their competitiveness. These activities resulted in the safeguarding and generation of new Gross Value Added (GVA) of £11.5M (net).

Exemplars of Interdisciplinary Research
Interdisciplinary research is a key feature of our research strategy. Exemplars include:

(a) The notable appointment of Gill from Oxford to an investment post as ***Professor of Healthcare Engineering*** specifically to galvanise this area of activity and to launch a University-wide research institute that will focus on the challenges of healthcare research and innovation, especially unmet clinical needs.
(b) **Plucinski**, **Mattia**, **Patterson** and **Torrente** are investigators with the £2.7M EPSRC project 'Terpene-based Manufacturing for Sustainable Chemical Feedstocks'. This is interdisciplinary with researchers from MECE, Chemistry, and Biology & Biochemistry. It includes industrial collaborators Sasol (SA), Johnson Matthey, TMO Renewables, and Amyris (USA).
(c) The ***Institute for Sustainable Energy and the Environment (I-SEE)***, led by **Mays**, focuses on connecting and integrating fundamental and applied research on sustainable energy and the environment across all disciplines at the University. These include the natural, engineering, social, political and economic sciences, policy and international studies and business management.
(d) **Sahinkaya**, with **Keogh** and **Ellis**, secured a British Heart Foundation (BHF) grant to investigate the use of polymer actuation for a heart-assist medical device that generates controllable pulsatile action in blood flow. The project, with researchers from MECE, is being undertaken with consultant cardiologists from the University Hospitals in Bristol and Wales.
(e) The ***Wessex Water*** initiative launched in 2013 and led by MECE has five key and interlinked research areas. These are sustainable water treatment, analytical techniques for water quality, biogas recovery and generation, asset management and consumer engagement, involving other researchers from Chemistry, Biology, and Management.

Exemplars of Collaboration that has Informed Research Activities and Strategy
There are numerous cases of such collaboration within MECE. Exemplars include:

(a) **Butler's** engagement with GKN Aerospace has informed on the design of composite wing skins for optimised performance, and on the laminate consolidation process for the manufacture of composite wing spars. This collaboration has informed the design and manufacturing processes associated with all composite aircraft, particularly the A350-XWB.
(b) **Hawley**, with **Brace** and **Akehurst**, lead a 25-year partnership with Ford. They have developed procedures, techniques and tools to reduce variability in test measurements of fuel consumption and emissions. The Bath work was embedded into the Ford's vehicle emissions laboratory at the Dunton Technical Centre in 2012. Improvements have been carried over to laboratories in Germany and the USA, through multi-million pound investments.
(c) **Lock's** engagement with Siemens has informed engineers of the benefits of new rim seal designs that have reduced leakage paths and hence improved the efficiency of gas turbine engines. A carefully organised programme of interaction between Siemens and Bath was central to the Siemens strategy and design process.

Exemplars of Leadership Roles
There are 17 cases of leadership on ***Advisory Boards***, exemplified by **Chaudhuri** (BBSRC Committee (2009-11)), **Crittenden** (President, UK Heat Transfer Society since 2013), **Culley** (Chair, IMechE Manufacturing Industries Divisional Board; Chair, Advisory Board of the Design Society since 2009); **Hawley** (by invitation since 2001, on the International Scientific Advisory Committee of the Canadian AUTO21 Network Centres of Excellence), **Plummer** (Chair: UK Automatic Control Council since 2011; IMechE Mechatronics, Informatics and Control Group since 2009; Member, Technical Strategy Board since 2009). Leadership of international standards in demonstrated by ***Convenorships of ISO committees*** by **Johnston** (ISO/TC131/SC8/WG1 relating to Fluid Power Systems), **Keogh** (ISO/TC108/SC2/WG7 relating to Active Magnetic Bearing Systems), and **Newman** (ISO/TC183/SC4 relating to STEP-NC Manufacturing). There is significant engagement in leadership of ***Learned Societies***. For example, **Brace** has been Chair of the IMechE Automobile Division since 2012, while **Miles** has been an Executive Committee

Member of the British Orthopaedic Research Society since 2003.

Eleven MECE academics are/were members of the **EPSRC Peer Review College** and several acted as EPSRC Panel Members and Chairs.

Eleven MECE academics have acted as ***Conference Programme Chairs***, exemplified by **Brace** (IMechE Conference on Low Carbon Powertrains in 2009), **Culley** (ICED11; DESIGN 2010 and 2012), **Keogh** (Structures and Dynamics Track of the ASME/IGTI Turbo Expo conferences from 2008-2010), **Mays** (International Hydrogen Research Showcase in 2011); **Meo** (17th International Conference on Nonlinear Elasticity in Materials, 2012, and 9th International Conference on Composite Science and Technology, 2013), and **Plummer** (FPMC2008, FPMC2010 and FPMC2012).

Thirteen MECE academics were invited to give ***Keynote or Plenary Lectures***, including **Almond (**18th World Conference on Non-Destructive Testing, South Africa, 2012), **Brace** (SAE World Congress, USA, 2013), **Culley** (ICoord 2011, India), **Gill** (European Orthopaedic Research Society Annual Meeting, Austria, 2011), **Gursul** (ASME Fluids Division Summer Meeting, Canada, 2010), **Keogh** (8th IFToMM Int Conf on Rotor Dynamics, Korea, 2010), **Mattia** (XIV Int Conf on Surface Forces, Russia, 2010), **Mays** (Int Hydrogen Storage Conf's, Korea, 2008 and Japan, 2009, 2011), **Plummer** (8th Int Fluid Power Conf, Germany, 2012; 12th Scandinavian Conf on Fluid Power, Finland, 2011; Int Conf on Fluid Power Transmission and Control, China, 2009), **Rees** (3rd Int Conf on Porous Media and their Applications in Science, Engineering and Industry, Italy, 2010), and **Turner** (Gothenberg University Annual Biomaterials Conf, Sweden, 2009).

Journal Editorships are held by **Maropoulos** (Editor, IMechE, Part B, Journal of Engineering Manufacture) and **Newman** (Editor-in-Chief, International Journal of Computer Integrated Manufacturing). ***Associate Editors*** include **Cole** (IMechE, Part I), **Culley** (J Eng Des), **Gursul** (Aeronautical J; J Aerospace Science and Technology; and the AIAA J), **Keogh** (ASME JEGTP and ASME JVA), **Lock** (IMechE, Part C), **Miles (**Medical Eng and Phys), **Mullineux** (IMechE, Part C and IMechE, Part E), **Plummer** (Int J Fluid Power; IMechE, Part I), **Rees** (Trans Porous Media), and **Sahinkaya** (IMechE, Part I). ***Guest Editors*** include **Culley** (Art Int Eng Des, Anal and Man), **Butler** (Phil Trans Roy Soc A), **Meo** (Int J Non-Linear Mech), and **Patterson** (Chem Eng Res and Des). Members of MECE also held 15 learned journal ***Editorial Board*** positions.

Crittenden and **Keogh** are ***Fellows of the Royal Academy of Engineering***. MECE also has 14 academic staff with FIMechE and FIChemE status. A further 7 are Fellows of other learned societies and institutions.

Publication Awards and Prizes were made in 13 cases in recognition of the standard of publications or contributions to the field. They include: **Almond** (British Institute of NDT John Grimwade Medal for a Best Paper in 2011); **Copeland** (ASME/IGTI Best Technical Paper, 2010; ASME/IGTI Best Technical Paper, 2011); **Gill** (Otto Aufranc Award, The Hip Society, USA, 2012); **Johnston** and **Keogh** (Donald Julius Groen Prize for Best Paper, IMechE, Part I, 2011); **Keogh** (IMechE, Part C, Best Paper Award, 2008); **Lock**, **Sangan** and **Wilson** (ASME/IGTI Best Technical Paper, 2008; ASME/IGTI Best Technical Paper, 2013); **Maropoulos** (DET2009 Best Paper Award (2009); and Proc IMechE, Part B: Journal of Engineering Manufacture Best Paper Award, 2010); **Plummer** and **Sahinkaya** (Proc IMechE, Part A: Journal of Power and Energy Best Paper Award, 2009); **Rees** (Outstanding Paper of the Year award from the International Journal of Numerical Methods for Heat and Fluid Flow, 2008); and **Torrente** (Rushlight Carbon Capture and Storage Award, 2009). Additionally, **Brace** and **Hawley** were instrumental in securing the PraxisUnico Collaborative Impact Award (June 2012) for 25 years of collaborative research engagement the Ford on fuel efficient, low carbon cars. This award recognises collaborative projects that leverage the intellectual assets of the research base. They also received the BP Global Helios Progressive Award (November 2009) for a collaborative project to improve the fuel efficiency of diesel cars with BP and the Ford. It was one of four BP awards for the creation of new business opportunities. **Crittenden** also received the Petronas Award (highly commended) for Excellence in Education & Training from the Institution of Chemical Engineers in 2008. As an ECR, **Ting** received the Gold Award and the Westminster Medal at the 2013 SET for Britain event. She is also the recipient of the IChemE 2013 Sir Frederick Warner Prize.