Institution: Cardiff University

Unit of Assessment: 15 – General Engineering

a. Overview

Our Unit is part of the School of Engineering, one of seven Schools within Cardiff University's College of Physical Sciences and Engineering. We aim to be renowned for our innovation and deep-rooted international links with industry, built on fundamental and applied research of the highest quality. Our Unit's success since 2008 is evidenced by major increases in Research Council and industrial income, publication rates of high quality journal papers and postgraduate student numbers. This has been driven by our strategy of recruiting and developing high calibre academic staff (especially early career researchers) and major investments in infrastructure. This strategy for Research ***and*** Innovation is developed by our Senior Management Team, led by the Director of School (*Bowen*) and with major input from our Research and Innovation Committee via its chair, the Deputy Director for Research and Innovation (*Porch*). The Committee meets bimonthly and comprises our research leaders and senior members of our research and professional services. Our strategy is informed by our long-standing Industrial Advisory Board.

All our research staff have primary association with one of our three ***Research and Innovation Themes***. These provide an effective environment for researchers of all levels to interact, collaborate, develop and exploit funding opportunities. They have strong leadership and mentorship from the Professoriate and are structured as follows:

- ***Energy*** (led by *Jenkins*), incorporating the Centre for Integrated Renewable Energy Generation and Supply, the High Voltage Energy Systems Group, the Wolfson Centre for Magnetics and the Centre for Research into Energy, Waste and the Environment;
- ***Mechanics, Materials and Advanced Manufacturing*** (led by *Setchi*), incorporating the Computational Mechanics Group, the Tribology Group, the Mechanical and Structural Performance Group and the High Value Manufacturing Group;
- ***Health, Security and the Digital World*** (led by *Tasker*), incorporating the Biomedical Engineering Group and the Centre for High Frequency Engineering.

b. Research Strategy

Our ***vision*** is to be recognised as a leader in the Russell Group for driving and fully integrating innovation with outstanding research. We will deliver our vision through our five year strategic plan (2012-17), whose principal aims are to:

- Establish and grow our Research and Innovation Themes, each founded on our research strengths and underpinned by a strong, vibrant, multidisciplinary research culture;
- Continuously strengthen our academic base by promotion and strategic recruitment of outstanding leaders of research and innovation (for example, during this REF period, *Bordas* in Computational Mechanics), and early career academics (*Yang* in Medical Electronics);
- Invest strategically and continuously in our research and innovation infrastructure, in collaboration with our industrial partners and stakeholders;
- Promote collaborations across institutions, unrestricted by boundaries between disciplines, and develop further strategic alliances with top international institutions that support our vision;
- Set the agenda for future "Grand Challenges" in Engineering.

We aim to be at the forefront of policy advice to UK/EU governments for the integration of Research and Innovation, building on our past experience (for example, *Jenkins*, Co-Director of UK Energy Research Centre; *Bowen*, Member of Dods Westminster "Innovation Panel"). We will benefit directly from Cardiff University's new five-year strategy for delivering excellence in Research, Innovation and Impact, led by our new Vice-Chancellor *Professor Colin Riordan*. This involves a £250M "Innovation Fund" for investment in staff, research students and capital development, with ambitious plans for University Research Institutes which align with our Themes.

We believe that true innovation arises from gifted researchers who have sufficient freedom to explore their ideas. Our Themes are based on this principle, allowing us to embrace innovation, develop cross-disciplinary research and provide a vibrant environment to nurture the highly skilled graduates demanded by the UK's industry and economy. With this in mind, we have identified the

following strategic priorities, building on our strengths and identifying exciting new opportunities.

- In ***Energy*** – combined network analysis and smart grids; high voltage and lightning research; grid infrastructure and smart-grids; hazard analysis; unconventional fuels, CCS and "flexible" power plant; combustion diagnostics and control; emission characterisation; tidal energy.
- In ***Mechanics, Materials and Advanced Manufacturing*** – autonomous structural health monitoring; improving understanding of advanced materials through computational and experimental approaches; soft materials; sustainable manufacturing and product life cycle management; ICT tools for decision support; micro/nano technologies; high-value manufacturing; symbiotic human-robot interaction; prognostics; intelligent manufacturing and design informatics; smart systems.
- In ***Health, Security and the Digital World*** – new methods in biomechanics (such as biplanar dynamic fluoroscopy, with Arthritis Research UK); MRI for in-vivo studies of human joint loading; bio-mechanics of injury assessment (new centre, with FIFA and IRB); support for novel technology advancements and legislation in healthcare; new medical diagnostic devices; medical uses of solid-state microwave power; new avenues for microfluidics; synthetic biology; signal processing for secure communications; new high frequency devices and systems.

Evaluation of Current Position, with Reference to RAE2008

Our Unit has continued to experience major growth and research success since 2008, delivering the main research goals described for RAE2008. Our strategy has been to expand our staff base to establish critical mass in selected areas and move towards an integrated structure, resulting in our current interdisciplinary Themes. We have ensured sustainability by appointing outstanding early career researchers (ECRs), key senior researchers (for example, *Bordas* and *Jenkins*) and by making major investments in facilities. Evidence of our growth and vibrancy includes:

- 80% increase in journal papers published per year (up from 80 to 143 per year);
- Increase in income from RCUK (up over 100% to £10.1M):
- 92 new awards with Industrial, Commercial and Public partners (value £6.2M);
- 18 ECRs, who now make up 29% of our Unit's eligible staff (32% of those submitted);
- 14% increase in our PGR student population (up from 129 to 147 students enrolled).

In our Energy Theme – The ***Centre for Integrated Renewable Energy Generation and Supply*** (CIREGS) was established in 2008 through the EPSRC Science and Innovation Award in "Renewable Energy". It covers smart grids and integration of renewables, energy networks and infrastructure, with new research grants of over £6M since its inception. Research highlights include the effects of aggregating electrical loads (*Jenkins 3*), and the design and analysis of voltage source converters for HVDC grids (*Liang 2,4*). It leads a Marie Curie training network in HVDC offshore wind power (MEDOW, £1.3M). Our unique expertise in the ***High Voltage Energy Systems Group*** has been strengthened by an extended framework agreement with National Grid (one of four in the UK). A new high current laboratory (the Morgan-Botti Lightning Laboratory) was founded in partnership with EADS (£1.4M), to investigate lightning strikes on composite materials. Work on dryband discharges on polluted insulators was awarded the 2010 European Electrical Insulation Manufacturers' Prize (*Haddad 1*). The ***Centre for Research into Energy, Waste and the Environment*** (CREWE) has appointed four new ECRs. A Tata Centre of Excellence (£1.3M plus £0.8M from EPSRC, one of nine in the UK) was established in "Energy and Waste''. Key outputs include research on new, fundamental combustion diagnostics for blast furnace gases (ECR *Crayford 1*). Our strategic partnership with Ricardo has resulted in new optical diagnostic techniques (*Bowen 4, Case Study 4*), and is enhanced by a new ECR appointment enabling innovative free-boundary fluid simulation (ECR *Yokoi 1-4*). CREWE also hosted a Marie Curie training network. The ***Gas Turbine Research Centre*** (GTRC), created through funding of £7M from QinetiQ and the EU, has developed into a world-renowned centre. Research highlights include evaluation and model validation of turbulent combustion for unconventional fuels at raised ambient conditions (*Bowen 1*). New transient thermofluid structures have been discovered and studies of their influence on flame stability in gas turbines (*Bowen 2*, ECR *Valera-Medina 1*) have resulted in two "best paper" awards at a leading US conference (AIAA 2010, 2012). In partnership with Rolls-Royce, the GTRC led an EU consortium developing particulate emission measurement protocols (the SAMPLE project, funded by the European Aviation Safety Agency).

In our Mechanics, Materials and Advanced Manufacturing Theme **–** The ***Computational Mechanics Group*** was established in 2009 (led by *Bordas*), specialising in advanced computational models and methods for simulating natural and engineered materials and processes, over a range of spatial and temporal scales (outputs by *Bordas*, ECR *Kerfriden,* ECR *Beex,* ECR *Nguyen*). Its research is supported by a prestigious ERC independent research fellowship award (£1.1M, *Bordas*, *Kerfriden*) and an EU Marie Curie training network award (£1.2M), opening up exciting new application areas in surgical (haptic) simulators for the training of surgeons. The ***Tribology Group*** has maintained its outstanding record of having secured near continuous EPSRC/SERC funding over the last 38 years (19 grants). Research highlights include the impact of manufacturing processes on the performance of helical gears (*Evans HP 4*), and the effects of diamond-like coatings for improving scuffing capacity of aerospace gears (*Snidle 2*). Analysis of nano-scale contact and adhesion has led to new indentation test methods for contacting materials (*Borodich 2*). The group also hosted a Marie Curie training network during the REF period. In the ***High Value Manufacturing Group***, knowledge engineering has been expanded through a number of EU collaborative projects, such as the EU-FP7 project SRS to develop robotic solutions for independent living (*Setchi 4*). Micro and nano-technology research has created innovative platforms for product miniaturisation, such as diamond-like coatings of micro injection moulds for microfluidic components (*Brousseau 1*). The Group hosts the UK's only EU "Research Infrastructure" Network Facility in micro/nano manufacture. The ***Mechanics and Structural Performance Group*** has been expanded through the appointment of two ECRs, and has new systems for damage detection, structural health monitoring (including acoustic emission monitoring, *Case Study 2*) and energy harvesting. Its research portfolio includes major industrial collaborations, including Airbus (seven years of continuous funding), Boeing, Marshall and SKF. Research on detecting fatigue cracks on aircraft landing gear (with Messier-Dowty) won the Charles Sharpe Beecher Prize for best paper in Journal of Aerospace Engineering (*Holford 3*).

In our Health, Security and Digital World Theme – The ***Centre for High Frequency Engineering*** (CHFE) has recruited *Professor Steve Cripps*, a world authority on microwave power amplifiers. New design methodologies for power amplifiers have been developed (*Cripps 2, Tasker 1,3, Benedikt 4*) with the aid of a £1.8M EPSRC research grant, including the new concept of "continuous modes" (*Cripps 1*). CHFE's concept of Practical Waveform Engineering led to the formation of the successful spin-out company Mesuro Ltd., and major impact on the practice of leading international companies such as CREE, M/A-COM and National Instruments (*Case Study 3*). New algorithms have been developed for digital communication channels (*McWhirter 1-2*). In healthcare, non-invasive blood glucose monitors using microwave technology have been invented, patented and are in clinical trials (supported by over £1M funding, including a major Wellcome Trust Translation Award). A new type of astrophysical sensor based on a superconducting microwave circuit has been invented and demonstrated, offering unparalleled performance for long wavelength photon detection (*Doyle 1*). Highlights in the ***Biomedical Engineering Group*** include a patented new bone cement, novel mechanical measurements of human skin (*Evans SL 4*), the development of new ultrasound imaging techniques (ECR *Yang 1, Wells 1-3*) and new methods of biomechanical data analysis (*Holt 1,4*). The strategically important interface between electronics and medical engineering has been strengthened by the appointment of *Yang*. The Arthritis Research UK Biomechanics and Bioengineering Centre was established in 2009 with £2.5M funding. It combines novel joint imaging and modelling studies with patient biology, gene expression and clinical factors to unlock the disease mechanisms for mechanically regulated osteoarthritis. Our microfluidics research has become highly interdisciplinary, with diverse projects on stem cell encapsulation, microparticle synthesis, nuclear fusion target synthesis (with Thermofisher, STFC and AWE) and graphitic microchip chromatography (*Barrow 1*). The successful biopharmaceutical spin-out company Q Chip Ltd. was developed, using microfluidic encapsulation technologies for manufacturing injectable therapeutics *(Case Study 1).*

c. People – Staffing Strategy and Staff Development

Our ***staffing strategy*** relies on the recruitment, development and retention of outstanding research staff. We help ensure the vitality and sustainability of our environment by: (i) recruiting high calibre ECRs, (ii) developing ECRs into research leaders (for example, through the "Cardiff Futures" programme, completed by *Pullin*), and (iii) appointing senior staff, in key research areas. Since 2008, ***new appointments*** have been made in: integrated and renewable energy

generation and supply (eight staff); low carbon, fuels and emission (four staff); composite materials, devices and performance (four staff), and computational mechanics (three staff). Research in high frequency engineering has been boosted by two staff. There have been three promotions to Professor, four to Reader and 11 to Senior Lecturer. Senior promotions are *Holford* to College Pro-Vice Chancellor, *Bowen* to Director of School, *Porch* to Deputy Director for Research and Innovation, and Haddad to Deputy Director for International and Engagement.

We are deeply committed to the ***career development*** of all staff through training and development, in accordance with the Investors in People framework. We gained full accreditation in 2011, Cardiff University being the first in the Russell Group to achieve feat this over the whole institution. Our staff utilise Cardiff University's comprehensive suite of staff development courses, including workshops on postgraduate supervision, leadership, project management and performance management. The University's Research Leadership course won the Times Higher Education Award for Outstanding Contribution to Leadership Development (2010).

Mentors are assigned to all new academic staff, whose integration is also supported by our Theme leaders. All staff benefit from appraisal procedures, which facilitate the regular review of research progress against agreed objectives and are used to identify future objectives, as well as training and development needs. The School's workload model includes factors such as publication of research outputs, grant applications awarded and postgraduate students supervised, as well as research-related management and citizenship roles. New staff are allocated reduced teaching loads during their first two years to allow them more time to establish their research activities.

We support staff in preparing high quality research applications via rigorous internal peer review (since 2011), co-ordinated by our Research Office, which consists of five full time staff and a Research Development Manager. This environment has helped boost success rates (for example, 67% success rate for EPSRC first grants). PhD studentships have been created for first grant holders to maximise their value. New staff are supported by seedcorn funding of £150k/year, used for studentships, academic travel and start-up activities. Our study leave scheme has funded, for example, *Holt* (next phase planning for our Arthritis Research UK Centre, 2012/13), *Setchi* (to develop relationships with China, Japan and Singapore, 2010) and *Snidle* (University of Cape Town, 2012/13). We distribute 40% of indirect project costs to investigators, giving them a high incentive to seek external funding and empowering them to develop their research.

Cardiff's commitment to enhancing the environment and career development for research staff has been recognised (2010) and reaffirmed (2012) by the award of "HR Excellence in Research" accreditation. The Cardiff Researcher Programme offers workshops, training, careers advice and coaching in over 100 topics. In 2010 we conducted a benchmarking exercise aimed at achieving compliance with Vitae's ***Concordat to Support the Career Development of Researchers*** (www.vitae.ac.uk)***.*** Our Research Staff Coordinator ensures continued compliance and manages research staff activities, including an annual conference (since 2005), where research staff can showcase their work, build collaborations and undertake innovation and impact training.

We pride ourselves on providing an ***international environment*** which attracts the best research staff and students from around the world, and our ambition is to be a partner of choice. 40% of our academic staff are originally non-UK nationals, and 24% are non-EU. Likewise, the international ethos is also prevalent in our postgraduate student body, where 45% are non-EU. We actively encourage international collaboration by providing strategic funding to facilitate staff travel and visits from overseas scholars, proving an excellent incentive to promote international activity. For example, *Jenkins* was Shimizu Visiting Professor at Stanford University from 2009-11, spending each Winter Quarter there. Since 2008 we have hosted more than 60 visiting academics. Our Iraqi Presidents Programme has provided senior management training to up-skill Iraqi academics (including staff from the Universities of Basra and Baghdad), as part of the Rebuilding of Iraq Programme. Propagation of our research and innovation culture is aided by monthly Theme seminars, often by esteemed visiting academics from prestigious universities (such as Northwestern, Georgia Tech., Peking, Kyoto and Singapore), and industry (such as Rolls Royce, Airbus, Tata Steel, Panasonic, Agilent and General Dynamics). Some Groups (Computational Mechanics, Wolfson Centre for Magnetics) have their own distinguished lecture series.

We promote ***Equality and Diversity*** (E&D) in all aspects of our work. Our School of Engineering attained an Athena Swan Award (Bronze) in 2013 in recognition of its commitment to the careers of

women in Science, Engineering and Technology (one of seven in Engineering nationally). Significant activity takes place under the Women into Science, Engineering and Construction (WISE) initiative. For example, *Holford* (the first female School Director, now PVC for the College of Physical Sciences and Engineering) was a recipient of the UK WISE Excellence Award. Cardiff appears consistently on Stonewall's "Top 100 Employers" (one of six Universities on the 2013 list), recognising our commitment to LGBT Equality, and also funds staff development activities for LGBT members. All staff undertake mandatory E&D training and E&D initiatives and activities are actively supported, such as the College network for female researchers.

c. People – Research Students

Our ***postgraduate (PGR) recruitment strategy*** is to recruit high calibre students and to develop skilled postgraduate researchers to contribute to the research base and workforce. Since 2008 we have increased our full-time PGR student population from 129 to 147 students. Our Recruitment Committee ensures that PGR recruitment is responsive to our research agenda. It works closely with the School's PGR Tutors Committee, which oversees all other aspects of PGR activity and is chaired by the Director of Postgraduate Studies, with student representation from all of the Themes. The Unit promotes impact and leverages additional research funding through collaboratively funded studentships, including 15 of the flagship, University-funded President's Research Scholarships, and 30 EPSRC Doctoral Training Grant and CASE/iCASE awards. Supporting companies include Airbus, Cogent, EADS, Merck, NASA, NXP Semiconductors, Selex, Tata Steel, Toshiba, Renishaw, Rolls Royce and Ricardo. The Unit has hosted four prestigious Marie Curie training networks over the period, facilitating recruitment and development of high-quality EU PGR students. We also invest strategically in multi-/cross- disciplinary studentships (12 since 2008) and studentships in support of EPSRC First Grant Holders (five since 2008).

We place great emphasis on ***PGR student training and support***, integrating students into the research community, aiding them to successful completion and providing high quality personal, professional and career development opportunities. ***PGR student training*** has three concurrent strands, namely, transferrable skills, technical training and mentoring to achieve chartered status (optional). The training programme is structured on the four domains of Vitae's Researcher Development Framework (RDF). A managed professional development scheme is available to any member of staff interested in becoming a chartered engineer. We have developed a programme of core compulsory courses, designed to develop competences recognised by the RDF, covering essential skills including research methods, technical writing, intellectual property, innovation and commercialisation, working safely and risk assessment. Cardiff University's Graduate College (UGC) also offers students and supervisors over 300 training opportunities annually to develop immediately applicable skills and also focuses on broader issues such as impact, engagement and enterprise. This was recognised when Cardiff was shortlisted in the 2010 Times Higher Education Award for "Outstanding Support for Early Career Researchers". Our students have bid successfully for six interdisciplinary awards from the UGC since 2008, enabling them to work with students from other disciplines to develop activities to enhance our research environment.

PGR student support is provided by our PGR tutors, who oversee progress and give pastoral care, and our dedicated Research Office. A residential, three-day PGR conference is held annually in Mid-Wales, and another one-day conference is organised by the students. Each student controls their individual student account (£2.4k each), independent of accounts linked to their research project, which they can use to develop wider networks through national/international conferences and training courses. The PGR Student/Staff Panel is student-chaired and includes representatives from each Theme, overseas students, PGR Tutors, library, safety and Research Office staff. It enables students to become more involved in the research environment and develop new initiatives, as well as providing a mechanism to respond effectively to any problems.

PGR progress monitoring in ensuring support for students to timely completion is a high priority for the PGR Tutors Committee. A new progress monitoring system was implemented in 2011, which has been well received by students, who appreciate the regular feedback and the opportunity to raise concerns. Progress is reviewed through six monthly reviews and annual meetings with internal examiners, and is assessed independently by members of the PGR Tutors Committee. Administrative support from the Research Office ensures that the progress review paperwork is completed on time.

d. Income, Infrastructure and Facilities

Our Unit has achieved major research grant success from a wide range of sources (RCUK, EU, industry and charities), now giving us a balanced portfolio of awards in support of the strategic priorities described for RAE2008. Since 2008 we have increased the number and value of our RCUK awards (50 new awards of total £10.1M, up by over 100%). Our focus on ECR support has contributed to successful EPSRC First Grants for 6 staff. Specific funding highlights include:

- Multi-terminal DC grid for offshore wind, MEDOW (EC, £1.3M);
- Integrating numerical simulation and geometric design technology, INSIST (EC, £1.2M);
- Towards real time multi-scale simulation of cutting in non-linear materials with applications to surgical simulation and computer guided surgery, RealTcut (ERC, £1.1M);
- Power amplifiers for future wireless systems (EPSRC, £1.8M, Cardiff share £1.1M);
- Shadow robotic systems, SRS (EC, Cardiff-led, total budget £4.3M, Cardiff share £0.65M);
- Printable, organic, large-area integrated circuits, POLARIC (EC, £8.7M, Cardiff share £0.75);
- Centralised power and steam distribution versus local generation (EPSRC, £0.8M);
- Non-invasive blood glucose meters (Wellcome Trust, £0.9M, Cardiff share £0.7M);
- SUPERGEN: FLEXNET (EPSRC, £0.7M);
- UKERC 2 'Energy Supply' (NERC, £0.6M);
- Signal processing solutions for the networked battlespace (EPSRC, £5M, Cardiff share £0.5M);
- SUPERGEN: Effects of realistic flows on tidal stream turbines (EPSRC, £1.4M, Cardiff £0.5M).

We have maintained our ***strong industrial links***, undertaking 92 research contracts since 2008 with industrial sponsors (total value of £6.2M). Our diverse portfolio of partners includes Rolls-Royce, Selex Sensors, EADS, Cogent Power, Westland, QinetiQ, Tata Steel, Airbus, National Grid, Merck and BP Amoco; projects include measurement of aircraft panel displacements due to lightning strikes (EADS). The vibrancy of our ***commercial, consultancy and professional services*** is evidenced by 3489 contracts for business undertaken since 2008 (total value of £7.6M); an example project is damage detection in composite missile structures (QinetiQ).

We have a strong commitment to ensuring that our infrastructure anticipates and meets the needs of our expanding research base. Accordingly, we maintain a range of ***high quality facilities and equipment*** in support of our research, next described in more detail for each of our Themes.

In our ***Energy*** Theme our infrastructure includes:

- ***High-Voltage Laboratory:*** supports Cardiff's National Grid Centre for research into new materials and systems for power transmission (outputs of *Haddad* and *Griffiths*);
- ***Morgan-Botti Lightning Laboratory*****:** a unique facility for collaborative research with EADS, for studies of direct strike effects on carbon composite materials and aerospace components;
- ***Gas Turbine Research Centre (GTRC)***: a suite of rigs for research into safe, low-carbon power and emission reduction (outputs of *Bowen, Crayford* and *Valera Medina; Case Study 4*);
- ***Centre for Integrated Renewable Energy Generation and Supply (CIREGS) Laboratories:*** for interdisciplinary energy research on gas/electricity systems to maximise distribution efficiency and resource diversity (outputs of *Jenkins, Wu* and *Liang*);
- ***Wolfson Magnetic Laboratories*****:** for high sensitivity magnetometry for the characterisation of ferrites, steels and magnetocaloric materials, for memory storage, refrigeration and MRI;
- ***Laser Ablation Laboratory*****:** for depositing thin films of electronic and magnetic materials;
- ***Infrared Microscopy Suite:*** for rapid thermal imaging and object profiling on a micro-scale, used for studying heat-recovery by thermoelectric devices.

In our ***Mechanics, Materials and Advanced Manufacturing*** Theme, our infrastructure includes:

- ***Structural Performance Laboratory and Tribology Laboratory*****:** for new testing and diagnostics across all engineering, including acoustic emission testing of aircraft structures (*Holford 1-4, Pullin 1*) and bridges (*Case Study 2*), and soft tissue mechanics (*Evans SL 3,4*);
- ***Micro/Nano Manufacturing Centre:*** for length-scale integration and replication, including a combination focused ion beam/SEM for nanomachining, nano imprint lithography, micro EDM, laser micromachining and micro-injection moulding (*Brousseau 1-3, Bigot 1-3*). An atomic force microscope is being used for new nanomachining processes (*Brousseau 4*).

In our ***Health, Security and the Digital World*** Theme, our infrastructure includes:

- ***Centre for High Frequency Engineering:*** unique microwave measurement facilities for power amplifier design and evaluation (outputs of *Tasker, Cripps, Benedikt*), sensor design and evaluation (*Porch 2,3*), and spin-out company development (Mesuro Ltd., *Case Study 3*);
- ***Femtosecond and Laser Micromachining Laboratory****:* for new graphitic (*Barrow 1*) and fluoropolymer (*Barrow 2*) microfluidics and spin-out company (Q Chip Ltd., *Case Study 1*);
- ***Motion Analysis Laboratory:*** part of the Arthritis Research UK Biomechanics and Bioengineering Centre, for 3D motion measurements for dynamic gait modelling and classification focused on musculoskeletal disorders (*Holt 1-4*):
- ***Medical Diagnostic Laboratories:*** our research partnership with Cardiff and Vale UHB provides MRI, X-ray, Ultrasound, DEXA scan and whole-body radiation counter facilities.

Our Unit hosted a UK facility in Nanoscience and Nanotechnology Equipment, founded using a £500k EPSRC grant, enabling access to UK academics. We also host two prestigious EU-FP 'Research Infrastructure' (EU-RI) Network Facilities, unique to the UK, funded to enable researcher access to rare/unique facilities in Europe in areas of strategic importance, namely:

- ***EUMinaFab Network***: a €1.8M, 12 partner, EU-RI network providing academic and industrial access to novel Micro-Nano Manufacturing facilities and expertise;
- ***BRISK Network***: a €10.9M, 25 partner, 2nd Generation Biofuels EU-RI network developing innovative processes to convert and utilise sustainable agro-environmental feedstocks.

We have enhanced our ***investments in infrastructure and facilities*** through a combination of securing external investments and University investment. Investment decisions are taken in line with our overarching research and innovation strategy, and since 2008 these have included:

- The Morgan-Botti Lightning Laboratory (£1.4M, relocated from EADS Paris);
- A £400k power grid simulator in the CIREGS laboratory enables studies and training on the influence of renewables integration on the electrical grid;
- Investment of over £1M from EPSRC/Wellcome Trust has enhanced equipment in the Centre for High Frequency Engineering, for broadband waveform and device studies to 67 GHz;
- An £800k WEFO investment in the GTRC to develop a 5-gas fuel-mixing plant, enhancing this unique UK capability for the study of sustainable energy systems;
- An EPSRC award of £500k (£200k to Engineering) for small equipment for a multidisciplinary network of ECRs in areas such as nano-fabrication, metrology and biomedical engineering;
- A rare, re-commissioned "Drop-Tube" Furnace (donated by RWE), used within our Tata Centre of Excellence for characterising coals and biomass for local fuel supply potential;
- A £2.5M investment from Cardiff University to enhance library and study resources for researchers, including a total rebuild of the Engineering library;
- Cardiff University's Advanced Research Computing facility (ARCCA), to which all staff have access and which provides HPC capacity with a "Raven" cluster of 2048 Intel Xeon 2.6 GHz cores (each with 4Gb memory per core), as well as small, higher throughput clusters. ARCCA delivers capability and capacity for large scale simulations, data analysis, storage and visualisation and is one of the largest and most efficient supercomputer facilities in the UK.

Strategic planned investments in new facilities (from 2014 onwards) will benefit from Cardiff University's £250M Innovation Fund, to provide an even broader range of expertise and capital equipment to boost the capabilities of our Themes. Additional, immediate enhancements include:

- Relocation and further development of the High Voltage Laboratory (£700k);
- 3D Scanning Laser Vibrometer (£500k), unique in the UK and capable of measuring in-plane and out-of-plane vibrations across large structures over a wide range of frequencies;
- Advanced Metrology Laboratory (£500k), world-class facilities for 3D scanning, imaging and reconstruction of complex surfaces (co-funded by Renishaw plc);
- Advanced facilities (£350k) for multi-material and mobile robotic 3D printing;
- Biplanar, dynamic fluoroscopy and motion analysis laboratory (£400k) for 3D characterisation and classification of joint function and biological factors for improved interventions for arthritis.

e. Collaboration or Contribution to the Discipline or Research Base

Research Collaborations – We are engaged in a diverse range of research collaborations with academia and industry, many of which are highly interdisciplinary and involve major UK and international consortia. Some of our main collaborative research projects since 2008 are:

- FP7 AccMet, involving 31 partners from 11 countries with a total budget of €22M, to accelerate development of high-order alloys based on high-throughput characterisation techniques, with partners including ESA, EADS, Rolls-Royce, Fiat and Johnson Matthey;
- FP7 H2-IGCC, involving 24 partners from 10 countries with a total budget of €17.8M, to provide technical solutions which will allow the use of state-of-the-art highly efficient, reliable gas turbines in the next generation of Integrated Gasification Combined Cycle (IGCC) plants;
- FP7 COTECH, involving 23 partners with a total budget of €8.5M, focused on the production of polymer-based miniaturised parts; COTECH and another of our FP7 projects MULTILAYER have been chosen by the EU as exemplar FP7 collaborations to publicise Horizon 2020;
- FP7 ThermoMag, involving 14 partners with a total budget of €6.3M, using 3D nanocrystalline thermoelectric materials for transformational generators in the energy and transport sectors;
- EPSRC SUPERGEN, for marine energy technology and sustainable power generation, involving 15 UK HEIs and over 20 international marine/electrical energy companies;
- EPSRC "Signal Processing Solutions for the Networked Battlespace", £5M budget over 5 years, in collaboration with Loughborough, Surrey, Strathclyde and Surrey Universities, whose results are communicated directly to the Defence Science and Technology Laboratory (Dstl);
- EPSRC FLEXEPLANT Consortium (£5M total, £2M from EPSRC) for "Future Conventional Powerplant" with Loughborough, Imperial, Nottingham, Cranfield, Warwick and major industrial partners in the power sector (16 in total, including EON, Rolls-Royce, Siemens and Alstom).

Examples of Interdisciplinary Research – Since 2008 our Unit has seen a growth in projects across the full spectrum of the sciences, also including archaeology, psychology, business and social sciences. These projects have led to new capability, innovation and impact, such as:

- In Computational Mechanics, where we collaborate with mathematicians, computer scientists and clinicians, e.g. in surgical simulators with haptic feedback (Marie Curie training network);
- Shadow Robotic System (SRS), a Cardiff-led FP7 project for domestic support for the elderly, involving 12 partners with expertise in engineering, physical, social and life sciences;
- Microwave sensors for non-invasive diabetes monitoring, with the potential to transform the lives of millions, in collaboration with clinical diabetes specialists at Swansea University;
- High power microwaves in the detection of pathogenic bacteria, with Cardiff's School of Pharmacy; detection time is reduced to seconds (rather than days), with dramatic potential healthcare benefits; other projects with Pharmacy include microneedles for drug delivery;
- Assessing risk perception within the EPSRC project "Transformation of Energy Networks", in collaboration with psychologists (such as *Prof. Nick Pigeon*, Cardiff's School of Psychology);
- Multiphase microfluidics, which has provided new fabrication routes for nanostructured stem-cell scaffolds (with Cardiff's Dental School), inertial fusion energy targets (with STFC-RAL) and artificial cell-like constructs in synthetic biology (with Cardiff's School of Pharmacy);
- Our Arthritis Research UK Biomechanics and Bioengineering Centre, which brings together researchers from engineering and across the whole of the life sciences to understand the biomechanical basis of osteoarthritis and develop new treatments;
- The NICE external assessment centre "Cedar", a £2.5M collaboration with the NHS for medical devices and treatments, providing access to clinical experts and patient groups.

How Research User Collaborations Inform Our Research – A major advantage for our end-user collaborations is that over 60% of our staff have over 2 years of industrial experience. The credibility that this brings has helped us to develop and sustain many successful partnerships, including our strategic industrial partnerships with Ford, EADS, Tata Steel, Renishaw, Ricardo, National Grid, Cogent and National Instruments. Regular and direct engagement of our key research leaders with our Industrial Advisory Board (five annual meetings) informs and focusses our research activities. Specific research user collaborations which inform our research include:

- Research topics in High Voltage Multi-Terminal DC for offshore wind farms, Smart Grid/Metering and Renewable Heat, which are driven by decarbonisation of the energy sector and are guided by close collaboration with National Grid, Alstom, Bglobal and UKERC;
- Our National Grid framework agreement, which led us to focus on transmission networks,

including earthing and safety, overvoltages, insulation coordination and system compaction;
- Our collaboration with EADS/AIRBUS, which has established the Morgan-Botti Lightning Laboratory; EADS's CTO (*Dr Jean Botti*) contributes to the laboratory's strategic development;
- Research in the Arthritis Research UK Biomechanics and Bioengineering Centre, which is informed by close collaboration with clinicians (orthopaedics, rheumatology, physiotherapy);
- Collaborations with Nokia-Siemens Networks, M/A-COM and Freescale Semiconductors, which have defined our research and strategy for small-cell transmitters for new 4G/5G mobile communications systems, and miniaturised high-power oscillators for medical applications.

Exemplars of Leadership in the Academic Community

Fellowships include two Fellows of the Royal Society (*McWhirter, Wells*); five Fellows of the Royal Academy of Engineering (*Jenkins, McWhirter, Snidle, Watton, Wells*); Life Fellow of American Society of Mechanical Engineers (*Snidle*); two Fellows of the IEEE (*Cripps, Jenkins*); six Fellows of the Learned Society of Wales (*Bowen, Holford, Jenkins, McWhirter, Tasker, Wells*); funded Fellowships for *Bordas* (Leverhulme/RAEng), *Bigot* (RCUK) and *Brousseau* (RCUK).

Awards and Prizes include The Royal Society's "Royal Medal" (*Wells*, 2013) for work in clinical ultrasound; Tribology Trust Silver Medal (*Evans HP*, 2009); IMechE Water Arbitration Prize (*Evans HP*, 2010); ASME Westinghouse Gold Medal in Power Generation (*Syred*, 2011); L Kegg Outstanding Young Manufacturing Engineer Award (*Brousseau*, 2011); Karen Burt Memorial Award (*Watling*, 2011); Biezeno Solid Mechanics Award (*Beex*, 2012); IEEE Distinguished Microwave Lecturer (*Tasker*, 2008-11); AIAA Best Paper Award in Terrestrial Energy Systems (*Valero-Medina*, *Bowen* 2010 and 2012); Charles Sharpe Beecher IMechE prize for best Aerospace paper (*Holford*, 2009); IMechE Best Paper in Process Engineering (*O'Doherty T*, 2009); most cited paper in Journal of Mathematics and Computers in Simulation (*Bordas,* 2008), best paper in Engineering Computation (*Bordas*, 2013); best paper awards at International Conference on Knowledge Expert Systems (*Setchi*, 2012, 2013); best paper at International Microwave Symposium (*Cripps*, 2009).

Expert Advisory Roles and Standards Committees include Council of the Royal Society (*McWhirter*); Sectional Committee 4, Royal Society, and Sectional Committee 1, Academy of Medical Sciences (*Wells*); Co-Director (for Energy Supply) of UKERC, Member OFGEM Low Carbon Network Fund Panel and Distinguished Member of CIGRE (*Jenkins*); Chair UHVnet (*Haddad*); Member of EU-Biofuels Technology Platform Steering Committee, Member of Dods Westminster "Innovation Panel" (*Bowen*); IEC International Standards Committee for Explosive Area Classification (*Bowen*); BSi Committee CH/205/1/2 on test methods for hip protectors (*Evans SL*); Chair, BSi committee GEL/600 (Earthing); member BSi committee PEL/99 (Erection and operation of power installations), IEC:TC99/MT4 (*Griffiths*); member of BSi committee PEL37 and IEC:TC37 MT4 and MT10 (*Haddad*); W3C Protocols and Formats Working Group (*Setchi*); IMechE, BmEA Board Vice Chair and Orthopaedic TAC Chair (*Holt*); Member of SAE-31 (USA) Aircraft Emission Measurement Committee (*Crayford*).

Editorial Board Memberships include major international journals such as Advances in Applied Mechanics (Editor, *Bordas*); ICE Energy Journal (Chair, *Jenkins*); IEEE Transactions on Microwave Theory and Techniques (*Cripps*); STLE Tribology Transactions and IMechE Journal of Engineering Tribology (*Evans HP*); Journal of Mechanical Engineering and Automation (*Brousseau*); Computer Methods in Biomechanics and Biomedical Engineering, Journal of the Mechanical Behaviour of Biomedical Materials (*Evans SL*); Journal of Acoustic Emission (*Holford*); Journal of Adaptive Control and Signal Processing (*McWhirter*); International Journal of Systems Science, International Journal of Knowledge & Systems Science (*Setchi*).

Keynote Addresses include World Congress on Computational Mechanics, Venice, 2008 (*Borodich*); China International Symposium on Tribology, Beijing, 2008 (*Evans HP*); International Symposium for Micro Manufacturing & Nano Materials, Portugal 2008 (*Brousseau*); International Conference on Damage Assessment of Structures, Beijing, 2009 (*Holford*); World Conference on Acoustic Emission, Beijing, 2011 (*Holford*); European Conference on Tribology, Vienna, 2011 (*Borodich*); European Conference on Computational Methods in Applied Science & Engineering, Vienna, 2012 (*Bordas*); International Conference on Mathematics in Signal Processing, Birmingham, 2012 (*McWhirter*); International Microwave Symposium, Seattle, 2013 (*Cripps*).

Major Conferences Hosted (of over 300 delegates) include 5th European Combustion Meeting (2011), 5th European Rheology Conference (2009), 14th Knowledge-Based Intelligent Information & Engineering Systems (2010), 45th International Universities Power Engineering Conference (2010).