Institution: University of Bradford

Unit of Assessment: B12 Aeronautical, Mechanical, Chemical and Manufacturing Engineering

a. Overview

Two strategic research areas are presented: (1) **Advanced Materials Engineering** (AME, led by ***Coates***) and (2) **Mechanical and Process Engineering** (MPE, led by ***Mujtaba***). These build on the RAE2008 submission, and reflect a vision for modern engineering research, pursuing top quality fundamental research with a strong emphasis on application, in line with our University motto, *Making Knowledge Work*. This requires ongoing development of strengths, and crossing of discipline boundaries, such as the incorporation of significantly more advanced materials for healthcare research in our expanding RCUK Science Bridges China, medical engineering and Centre for Innovative Manufacturing in Medical Devices programmes, and the widening of our RAE2008 automotive engineering area to Mechanical and Process Engineering, reflecting the renewal of chemical engineering research. There are clearly links between our strategic research areas, which we will foster.

Our vision is underlined by our strong track record with RCUK at the same time as active collaboration with over 100 companies, many of them 'blue-chip'. Indeed, the two strategic research areas have attracted strong internal and external investment in the UK and abroad, via their constituent parts. AME is the home of the world-leading Polymer IRC laboratories, which hosts two highly successful University focal points for investment (of eight) for research and knowledge transfer (RKT) delivery formed in 2010, namely the Polymer Micro & Nano Technology and the Advanced Materials Engineering RKT Centres. We also host part of the Pharmaceutical Engineering Sciences RKT Centre and the Visual Computing RKT Centre, both across the engineering-life sciences boundary. These RKT Centres have joint projects with the Centres for Skin Sciences and Sustainable Environments. MPE hosts the successful Automotive Engineering RKT Centre. The mission for all such Centres is to encourage the interface between top quality research and industry; ours are certainly achieving this goal, with significant support from a range of global companies including Jaguar Land Rover, BAE Systems, Ford, Smith & Nephew, Dow, DePuy Synthe (Johnson & Johnson), Tata, and Sinopec, together with excellent SME engagement that includes a leading contribution to Nanofactory, a six regional university consortium aimed at promoting nanotechnology.

Our delivery against this vision, *Making Knowledge Work*, has been strong. It includes fundamental, interdisciplinary research through to joint IP with industry with commercial demonstration and implementation, for example, building products (Dow/Eovations), orthodontic products (DRFP, Smartpoint), shape memory tissue fixations (Smith & Nephew), enhanced braking systems (Jaguar Land Rover, Bentley) as exemplified in our submitted Impact Case studies. These reflect one part of our deepening relationship with industry, in effective research collaboration and delivery of high added value products.

b. Research Strategy

We pursue research excellence that has application to society, taking fundamental research through to applications in the UK and worldwide strategic areas of advanced materials (one of the 'Eight Great Technologies' identified by the UK government), healthcare, and resource efficiency (the latter are two of the three major ministerially-agreed focal points for UK-China co-operation). We have consistently pursued interdisciplinarity as a strategy, which is increasingly recognized as vital for fruitful modern engineering and science research.

The strategy and plans of the Unit aligns with the University's Corporate Plan 2009-2014: To deliver leading-edge collaborative research with academe, industry, government and NHS, from world-class facilities, building upon core research strengths and developing themes emerging from these (smart materials, healthcare, biomedical engineering, automotive engineering, process engineering) to deliver world-leading *applied* engineering research, underpinned by rigorous

science and mathematics.

To support this we aim to sustain and expand the leading edge facilities in our laboratories and to build research capability and capacity. We have significantly achieved both aims in the period, with extensive development of all of our key areas. These, together with unique skills in micromoulding, solid phase orientation of polymers, and automotive emissions control and braking technology, help to attract Research Council funding and worldwide industry support. Research capability and capacity has been, and continues to be, built particularly through offering our strength in collaboration with external and internal strengths. We have achieved significant external success: (i) via the Polymer IRC (Leeds, Bradford, Durham, Sheffield Universities; Coates is the Director, 2011 onwards); (ii) through leading and coordinating the RCUK Bradford Science Bridges China/ ESPRC Global Engagements programmes (~£2m), actively involving some 28 Chinese institutions with a vibrant researcher exchange programme and strong leverage of funding (~£8m) in China; (iii) through a range of EPSRC grants in collaboration with research intensive universities, the latest of which was announced in May 2013, the new EPSRC Centre for Innovative Manufacturing in Medical Devices (£5.7m, involving Leeds, Bradford, Newcastle, Nottingham, Sheffield). We have achieved strong interdisciplinary collaborations internally in the University through our RKT Centres linking with other RKT Centres and leading groups (Skin Sciences, Sustainable Environments; Archaeological Sciences). Our extensive industry collaborations increase research capacity and capability (over 100 companies are involved with our research teams, adding theoretical, practical and commercial dimensions to our research, including 12 joint patents).

During the census period the Unit's combined research areas attracted £12.5m external RKT funding, graduated 102 PhD students, and published a significant number of high quality outputs, increasingly with international co-authors.

Advanced Materials Engineering (AME) (***Coates***, ***Abd-Alhameed***, ***Beggs***, ***Benkreira***, ***Buckley***, ***Gough***, ***Grant***, ***Kelly***, ***Twigg***, ***Ugail***, ***Youseffi***)

This group focuses on structuring advanced polymeric and biomedical materials via processing, with associated modelling, for (i) high added-value products and methodologies and therapies aimed primarily at health and wellbeing, and (ii) resource efficient materials, enhancing the value of feedstocks. Advanced Materials is one of the UK's 'Eight Great Technologies', and healthcare and resource efficiency are strategic areas of investment in the UK. Our 4000m^2 Polymer IRC laboratories support world-leading, extensive 2D and 3D processing facilities, with unique capabilities in micromoulding and solid phase orientation together with clean room reactive and pharmaceuticals processing, complemented by leading edge in-process measurements, and extensive characterisation and computer modelling over the length scales.

Medical/biomedical research targets include bioresorbable and non-resorbable materials, often with tailored properties or property gradients, for orthopaedic components in joint repair or replacement and tissue fixation devices (***Coates***, ***Twigg***), including shape memory bioresorbable polymers (Smith & Nephew Ltd - oriented polymers Impact Case Study: ***Coates*** plus *Caton-Rose* and *Sweeney*); oriented polymer stents for vascular repair (Arterius), orthodontic products (DRFP; Smartpoint root canal Impact Case Study: ***Coates*** plus *Whiteside* (Director of Polymer MNT RKT Centre)), spinal braces (Invibio), structured films for wound dressing. We research drug delivery technologies including micro-needles (Renefra), together with a range of medical devices for minimally invasive surgery (Surgical Innovations) and clinical biomechanics and gait analysis (***Buckley***, ***Twigg***; Blatchfords). This research interfaces closely with clinically oriented translational research in haemodynamics, bioinformatics, infection control, and epidemiological modelling (***Beggs***, ***Abd-Alhameed***, *Shepherd*; Dyson, NHS).

A particular strength of our team is in-process measurements, including novel rheo-optical and thermal sensors techniques which have been developed to measure real process histories (stress, velocity and temperature fields) of polymers during melt and solid phase deformation processing. This is complemented by off-line characterisation of structured polymers and biomaterials, including tissue, exploring and bulk and surface feature characterisations, using a range of state-

of-the-art measurements, which we also develop through our research, including rheo-optical, thermal, ultrasonic, IR/UV/Raman spectroscopic, 3D AFM, confocal laser microscopy, micro-mechanical and electromagnetic techniques (***Coates***, ***Abd-Alhameed***, ***Benkreira***, ***Gough***, ***Grant***, ***Kelly***, ***Twigg***, ***Ugail***, ***Youseffi***), and by finite element modelling of interfacial interactions, including novel constitutive equations, and property development associated with microstructure, across length scales from nanofiller surface interactions to bulk performance of multicomponent products (one of the few groups with this capability in the UK).

We have a strong track record of successful collaborations with industrial partners (including Dow; Smith & Nephew; De Puy Synthe; Autodesk Moldflow; Johnson-Matthey; Invibio; Surgical Innovations; Sinopec; Victrex; Dyson; Biomet, Trauson; Blatchfords) in the UK and overseas; and with clinical partners (Vascular Diseases Centre, University of Ferrara, Italy; Buffalo Neuroimaging Analysis Center, University at Buffalo, USA; NHS: Bradford Teaching Hospitals; Harrogate; St James University Hospital, Leeds; South Manchester Hospital; Northern General Hospital Sheffield; Huaxi Hospital, Sichuan).

'Resource Efficiency' includes enhancing polymer product properties and quality, enhancing the re-use of materials, or 'green' processing. Our world-leading research into process-structure-property relationships in solid phase orientation of polymers has led to exploitation of novel processes (variants of the die drawing process, invented by ***Coates***) and unique enhanced property products, including low density high stiffness polymer composites for building applications and shape memory polymers for cementless soft and hard tissue fixation devices (Dow, Eovations) both illustrated in the oriented polymers Impact Case Study. A significant range of research associated with advanced materials with enhanced properties for healthcare technologies has been progressed with leading Chinese partners, via the highly successful and visible RCUK Bradford Science Bridges China and EPSRC Global Engagements programmes.

Sustainable material products (***Coates***, ***Benkreira***, ***Gough***, ***Kelly***) have arisen from our underpinning polymer processing research and include novel acoustic and thermal insulation materials made from recycled polymers, elastomeric residues, thin film coating applications and smart incorporation of recyclates into conventional products for lower carbon footprint. Research into advanced materials in fuel cells has been pursued with Johnson-Matthey, and novel solids-containing hydrogen fuel research with Cella Energy. Our co-operation with a Chinese group (BUCT) is world leading in obtaining bioengineered elastomers from biomass – non-crystalline polyesters outperforming all other elastomers. We collaborate with ICT Mumbai, the leading Chemical Engineering institute in India, on solvent-free pharmaceuticals processing, exploiting our hot-melt technology and process structuring for co-crystallisation of drugs for enhanced bioavailability (with our Pharmaceutical Engineering Science RKT Centre).

Mechanical and Process Engineering (MPE) (***Mujtaba***, ***Arellano-Garcia***, ***Bryant***, ***Hussain***, ***Rahmanian***, ***Wood***)

The area reflects a strong track record in modelling and simulation of manufacturing, particularly in automotive engineering (*Day*, ***Hussain***, ***Bryant***) with growing application to industrial chemical process engineering. The automotive engineering focus is on fundamental and commercial RKT projects including the science of complex devices such as turbochargers (innovative experimental 250k/rpm tip-timing procedures have been developed through industrial collaboration to support fatigue understanding), active filtration systems, regenerative braking and control devices that underpin low-carbon transport policy (*Day*, ***Hussain***, ***Bryant***) together with systems approaches to engineering design and manufacturing (including unique fundamental empirical investigations aimed at understanding brake squeal and judder that is reducing warranty costs and improving performance, with several leading automotive companies). We have a very strong track record of successful collaborative research with industrial partnerships with major UK and global companies (JLR, Cummins, BAE Systems, Ford, Tata): systems engineering paradigms are being embedded within major automotive companies through bespoke CPD activities (TAS Scheme with JLR, SEED Programme with Ford).

Resource efficiency is employed for industrial fluids process modelling (***Mujtaba***, ***Arellano-Garcia***, ***Rahmanian***). This includes novel designs (optimisation of engine management for emissions reduction, brakes), systems (design optimisation, functional robustness, failure mode avoidance), products, and processes to enhance their competitiveness and sustainability, focussing particularly on efficiency improvements and CO2 reduction in the road transport sector. Dynamics, control, identification, validation studies of powertrains and drivelines of mechatronic systems have been carried out using mathematical model based techniques and using short distance telemetry. A condition monitoring system has been developed for energy recovery. This is complemented by our research into associated systems aspects of manufacturing: strategy, planning, control, maintenance, supply chain, process/technology improvement and scheduling through the use of Artificial Intelligence tools. This has targeted applied research design and development of systems for specific areas of automotive manufacturing (high and low volume environments, performance measurement, optimisation of supply chains) in order to assist in decision-making for achieving benchmark standards.

Process Systems Engineering and Computer Aided Process Engineering approaches have been adopted in addressing water and energy issues. Minimisation of energy consumption and environmental impact have been the key driving factors in novel design, operation, and control and enhanced productivity in a number of process engineering applications. Recently, strategies for significant thermal energy savings in reactive distillation (in collaboration with Libya), energy recovery in milk processing industries via novel heat exchanger design (in collaboration with Thailand), sustainable (low energy and low environmental impact) production of freshwater by desalination (***Mujtaba***) have been extended to sustainable production of quality (enhanced thermophysical properties with low environmental impact) fuels (including transportation fuels) by whole crude oil hydrotreating and by oxidative desulphurisation of heavy gas oil (***Mujtaba***, ***Wood***).

Model-based experimental analysis, modelling and optimization of complex process engineering and energy systems with large structural diversity and a high number of elements have been considered. Particular attention has been paid to the holistic view of the involved processes phenomena, micro and macro processes, process design and the final experimental verification including improved monitoring (***Arellano-Garcia***).

c. People

Staffing strategy and staff development: the spirit in our academic teams is first class, which we believe to be crucial to exemplary delivery in research, knowledge transfer, and teaching. We will build on this: our staffing strategy is to sustain and develop vibrant teams with clear leadership and commitment, working in a supportive but stretching environment, able to share and work across discipline boundaries and so deliver our vision. We have talented Early Career staff whose development is of first order importance (including support for professional development and professional qualifications), with very high quality senior staff, and leading professors (a progression requiring excellence at all stages, and addressing retention, succession planning, and sustainable team development).

During the period, the **AME research group** has been strengthened by the addition of several University research investment scheme 'Career Development Lectureship' appointments (***Gough***, ***Kelly*****,** ***Grant*****,** *Brown, Caton-Rose* (oriented polymers Impact Case Study), *Mulvaney-Johnson, Martyn, Whiteside* (Smartpoint root canal Impact Case Study) which has contributed to the generation of research outputs and external income of over £2m (including from EPSRC, European Union, several industries). Professor *Day****,*** who led the AMSO area, retired in 2013, but investment in a new generation of researchers (***Bryant*****,** *Mason*) has been made during the period. We have strategically invested in staff with a chemical engineering background (*Patel*, ***Rahmanian***, ***Arellano-Garcia***) to strengthen existing research concerning water, energy and polymers. Further investment in staff (lecturer to professor) in Automotive and Process Engineering (reflecting Chemical Engineering discipline growth) is in the School's 5-year strategic plan.

Our current team comprises a dynamic blend of senior staff (11 professors: in AME, ***Abd-***

Alhameed, ***Beggs***, ***Benkreira***, ***Coates***, ***Ugail***, *Shepherd*, *Sweeney;* in MPE, *Campean*, *Ebrahimi*, ***Mujtaba*****,** ***Wood***), providing research leadership, and high-calibre Early Career staff working together in a highly collaborative environment. New lecturers and PDRAs have reduced teaching and administrative duties and prepare a research development plan, supported by an experienced mentor. All staff commit to the University's *Equality and Diversity Strategy 2011-14* (which also underpins practice in recruitment and selection), and complete a *Diversity in the Workplace* e-Learning module and have access to an ongoing programme of staff training courses.

Visiting Professors: in the review period a number of visiting professors (IM Ward FRS, Speight in AME; Henshall, Allport, Davies, Fieldhouse in AMSO) and Research Fellow (Jupp), mainly from industry, have contributed significantly to our research environment.

Post-Doctoral Researchers: in the review period, eleven externally funded post-doctoral researchers, including an RCUK Fellow, have contributed significantly to our research.

Research Students: during the census period, the team has supervised to graduation 102 PhD research students, which includes a significant number of students holding prestigious Research Council awards, and international government funding (Greece, Egypt, Libya, Iraq, Iran, China, India, Malaysia, Nigeria, Saudi Arabia, Thailand). All PGR students have a support committee with a Principal and 1-2 Associate Supervisors, and regular contact includes formal monthly meetings and annual progress monitoring. The University Graduate School provides a programme of research and transferable skills training (including employability skills). Formal MPhil-PhD transfer occurs after 12 months. Research students participate in and organise seminars, workshops and conferences. Early Career staff are enabled to progress to principal supervisor status through initial involvement as Associate Supervisors.

d. Income, Infrastructure and Facilities

Income: during the review period, this Unit has won external research funding totalling £12.5m from a range of sources including UK and European research councils, charities, government agencies and commercial companies. This represents a more than doubling of the income per fte in the RAE2008 period. Looking forward, we will build on strategic collaborations with other strong UK research groups, internal and external, (the most recent award of £5.7m for the EPSRC CIM in Medical Devices is an example of such cooperation). RCUK bids with Warwick and Queen's Belfast are under discussion. We will bid into strategic areas or lead consortia where this is appropriate. Two ~£1m EPSRC bids have recently been submitted (each with ~£200k industry support), and a £3.4m EPSRC capital bid for advanced materials is pending decision. In addition we will develop further our international success with China (where we have already leveraged some £8m investment in Chinese groups), potentially expanding this to increased collaborations with leading Indian research groups with whom we have begun to build capacity (such as ICT Mumbai, through UKIERI initially, and through research studentships).

Infrastructure, Resources and Facilities: research activity is overseen by an Associate Dean for Research who chairs an internal Research and Knowledge Transfer Committee that includes senior colleagues (professors, readers), RKT Centre Directors and other Research Group leaders, Director of PG Research and postgraduate research student representation. RKT Centres, as focal points for University investment and key drivers of external funding for research and knowledge transfer, have become the main vehicles for progress, with critical mass of researchers and facilities. They have permeable boundaries, to incorporate more isolated researchers where possible. This helps to avoid spreading resources too thinly, and helps to build interdisciplinarity (teams indicated in this submission include a wide range of disciplines, which we have successfully drawn together to address modern research problems). The University's Research and Knowledge Transfer Strategy Committee promotes and monitors campus-wide research activity, and the Research & Knowledge Transfer Support offices provide assistance for grant applications, contract negotiations and IP/ commercialisation.

The **AME research area** forms the core of our world-class Polymer IRC laboratories**,** hosting the

Advanced Materials Engineering (AME) and Polymer Micro and Nano Technology (Polymer MNT) RKT Centres, and part hosting the Pharmaceutical Engineering Sciences and the Visual Computing RKT Centres, both across the engineering-life sciences boundary. These Centres have received over £3.2m funding, including around £1m capital investment from the University in an initial three year period from 2010-11, used in advanced processing, characterisation, and 80m^2 clean room facilities. Further investment is expected, based on the successful performance of these Centres. The funding complements externally won funding for projects, which include facilities (around £2m in the period), and SRIF (£1.25m estates support) and additional HEIF support (~£200k). The laboratories occupy ~4000m^2, with some 40 processing lines from nanoscale to macro (small industrial) scale. These include unique solid phase orientation processing (die drawing) in batch and continuous forms, from micro to macro scale - a precursor of the manufacturing line in Eovations LLC (oriented polymers Impact Case Study), and an extensive range of high precision injection moulding facilities (collaborations with Wittman Battenfeld, Austria and Fanuc, Japan), and single and twin screw extrusion (collaborations with Thermo Scientific) for polymers, polymer nanocomposites and pharmaceuticals; all processing lines have detailed computer monitoring of machine parameters and process variables including temperature, pressure, rheo-optical and spectroscopic, using in-process sensors, many of which we have pioneered - particularly thermal meshes, ultrasound and in-process IR, UV and Raman spectroscopic probes. We have developed and implemented wireless networks and protocols for remote process monitoring. Additive Layer Manufacturing facilities (five 3D printers) forms a recent expansion of our processing capabilities - we have strong interests in the basics of this technology and its feed materials, from our polymer materials and processing expertise, as well as its applications in, for example, medical devices. We shall link with strengths in Nottingham (CIM Additive Manufacturing), Newcastle and Sheffield in our Medical Devices CIM.

The trend to miniaturisation and the high cost of advanced materials have driven a need for novel small scale processing, and we have developed in our research small scale solid phase orientation processing (e.g. ~100μm wall thickness biaxially oriented novel stents), mini-mixing for polymer nanocomposite evaluations, and micromoulding technologies and control strategies in collaboration with a leading technology supplier (Wittman Battenfeld).

Our team has unusual levels of characterisation for an engineering department: these reflect the growing push towards miniaturisation and the engineering/life sciences interface, and also our expertise in computational characterisation of surfaces and modelling which is allowing significant synergy between experiment and modelling across a range of physical phenomena and length scales, for which top level characterisation is required for validation. This includes 3D Atomic Force Microscopy for polymers, nanomaterials and tissue, for property mapping and surface feature characterisation, complemented by White Light Interferometry and Confocal Laser Microscopy; larger scale laser scanning is used with our modelling and reverse engineering. Bose micro testing and Hitachi bench top SEM allow rapid evaluation of microscale products, complemented by full-scale physical, rheological, and chemical testing (in addition to the University central Analytical Centre available to us). Collaboration with leading Chinese groups has given us very substantial access to major beam line characterisation (in Shanghai and Beijing in particular, in addition to the facilities time we have through EPSRC at Grenoble), allowing a significant expansion of this capability, accompanied by high level joint publications. We have specialist skills and facilities for image processing (optical and thermal), both in-process and off-line, and for electromagnetic field evaluation (of relevance to healthcare with respect to electromagnetic-tissue interactions).

The **MPE research area** includes a unique set of world-class automotive power train experimental facilities with associated instrumentation, hardware, and software for Quality, Design, Modelling, Simulation, and Manufacturing. Our laboratory, designated the Hybrid & Powertrain Engineering Research Centre (HyPER-C), has attracted over £800k RKT funding from EPSRC, TSB and industrial partners and over £500k competitive SRIF support. It has state-of-the-art experimental and simulation facilities in a laboratory with two computer controlled regenerative dynamometers, one of which is unique (in the UK) being for large engines up to 500kW. Other equipment includes hardware-in-loop with powertrain modelling, an axle mounted Chassis Dynamometer, brake squeal and friction test rigs, mechanical power transmission (belts) test rigs, and in-vehicle

instrumentation and data logging equipment with GPS for on-road vehicle and driver evaluation.

Both AME and MPE research areas are supported by general and dedicated computational suites with the state of the art facilities and software (Abaqus, Ansys, MATLAB, Autodesk Moldflow, Fluent, gPROMS, ASPEN, CF-X).

e. Collaboration and contribution to the discipline

Our vision is for modern engineering research, pursuing top quality fundamental research with a strong emphasis on application. We have an outstanding long-standing record of collaboration (for example, building on the founding of the EPSRC Polymer Interdisciplinary Research Centre in 1989), which we have expanded on significantly in the REF period. Key drivers are to deliver international and national visibility and leadership, combined with industrial and sector credibility. To this end our team have collaborated with UK - providing leadership at (i) a national level in our discipline e.g. through the Polymer IRC and Science Bridges China platforms, and (ii) international researchers, particularly from China, Europe, North America, Japan and India. This is evidenced by joint research grants, EU projects, joint publications in journals, and funded visits by post-doctoral researchers and research students. Funding from EPSRC, RCUK, MRC, EU, Royal Society, Royal Academy of Engineering, and industrial sources, has supported research collaboration with our other international and industrial partners.

AME: in addition to examples above, the international agenda has been most strongly supported by staff collaborating in the EPSRC Science Bridges China (SBC)/ Global Engagements programme with researchers from 28 leading Chinese institutions, including Sichuan, Tsinghua, Beijing University of Chemical Technology, Chinese Academy of Sciences (ICCAS Beijing, CIACAS Changchun, SIMMCAS Shanghai), and Hong Kong University of Science & Technology. This has led to the establishment in 2010 of a Joint International Laboratory for Polymer Microprocessing with Sichuan University (***Coates***, *Whiteside*) and the founding of the UK-China Advanced Materials Research Institute (Directors: ***Coates***, with Li, Senior Vice President of Sichuan University; board member *Caton-Rose*). We have joint international grants with Sichuan (the prestigious '111' award (~£2m over five years) in Sep. 2012; NSFC and MOST joint grants). We lead the UK teams involved in this area, including them in our research programmes, and we won the only MRC healthcare award (***Twigg***, ***Coates***, ***Grant***, *Whiteside, Caton-Rose*) to develop advanced materials for tissue repair in aging populations, in the RCUK-MOST China joint call with Sichuan, ICCAS and CIACAS 2013, with Sheffield and Durham as partners. We are the only university on the Polymer Society Board of the IoM3, and the Advisory Group for the Materials KTN. We run a biennial international conference (13th due Nov 2013) and have run five Research Workshops under the SBC banner, three in China, two in the UK, with the 6th due in Beijing in May 2014. We are on the International Polymer Processing Society board, and have run symposia in major international conferences in the polymer engineering area, worldwide - including SPE Antec, IUPAC Macro, Int. Coating Society, and are regularly called to give plenary and keynote addresses (***Coates***, ***Benkreira***, ***Kelly***, ***Beggs***, *Caton-Rose, Whiteside*). Our strong industry collaboration is reflected in a unique 'club' the Bradford Industry Group (currently sponsored by Victrex), with over 100 member companies, which meets approximately six monthly, to share technical progress (including industrial presentations) and discuss UK strategic issues for our sector; this group has previously successfully lobbied DTI/BIS for particular investment on behalf of the sector. The two AME Impact Case studies (oriented polymers and Smartpoint root canal) reflect how our fundamental scientific research has been combined with industrial needs to deliver exciting new, high added value products.

We have close links with the Department of Health and have contributed to changes in clinical practice, including • gait analysis (***Buckley***): a new emphasis on the role of correctable vision impairment in the prevention of falls in the elderly (influencing NICE guidelines); • biotribology (***Twigg***): development, design and testing of new implants for hip replacement; • haemodynamics (***Beggs***, *Shepherd*): the development of a new test for diagnosing venous drainage abnormalities in multiple sclerosis (MS) patients; • infection transmission modelling (***Beggs***, *Shepherd*): changes in infection control practice that have resulted in a substantial reduction in hospital acquired

infection rates in the UK.

MPE: Braking research (***Bryant***, ***Hussain***) at Bradford has led collaborations with academics in the UK, Europe and globally for over 25 years (e.g. Dr. Tirovic, Cranfield University; Professor Fieldhouse, formerly Huddersfield University but now Bradford University; Professor Ouyang, Liverpool) and industrial colleagues from Ford and Jaguar Land Rover. The collaborative partnership with Ford, which is based on Quality Engineering but has extended to many aspects of academic collaboration including braking, is the longest-running collaborative partnership in Engineering at Bradford, and one of the longest collaborative partnerships in the University. The recent award of Ford Centenary Scholarships is evidence of this. Work has been presented regularly at SAE Brake Colloquia in addition to SAE Congress, FISITA, EAEC, and IMechE events, and through the annual 'Braking of Road Vehicles' short course which is internationally regarded as the 'industry-standard' short course for the road vehicle and braking industries.

The MPE research group links with industry on a wide range of research and knowledge transfer projects mainly associated with automotive engineering, systems, and manufacturing through the Automotive RKT Centre where efficiency, cost-effectiveness, and optimisation are mainly focused (*Campean*, ***Wood***). The partners over the years have included Ford, Cummins Turbo Technologies, Jaguar Land Rover, Tata Motors European Technical Centre, BAE Systems, Honda R&D (Europe), MCB International, BP, and many more.

The research in particle science (***Rahmanian***) was initially aimed at scale-up of the batch granulation process to find the best scale-up rules (supported by EPSRC and four industrial collaborators: P&G, Pfizer, Hosokawa Micron, Borax Europe Ltd). Due to interest from the industrial collaborators, the work was extended to the continuous granulation process to explore the possibility of "seeded granulation" (sponsored by GEA Pharma and Hosokawa Micron, UK and the Netherlands). The outcomes of the research have benefited the industrial sponsors of the project as well as the other companies and manufactures in the field of food, pharmaceutical and chemical industries.

Research in green fuel (hydrotreating), water desalination, and separation processes were carried out through PhD sponsorships (Libyan Petroleum Institute, Royal Golden Jubilee PhD Program under Thailand Research Fund, Ministry of Energy Iraq) (***Mujtaba***, ***Wood***). Recent work on hydrotreating of whole crude oil attracted much attention from various companies in the UK and abroad (Saudi Aramco, Invensys, Johnson Matthey, DuPont, Sasol, Haldor Topsoe). Future collaboration with some of these companies is currently being discussed.

In systems engineering approaches to dynamic simulation, model-based analysis and experimental verification, modelling and optimization of large-scale systems, there are on-going interdisciplinary activities with the Berlin Institute of Technology (Germany) within the framework of a Collaborative Research Centre in which advanced methods are being developed for integrated chemical processes in liquid multiphase systems (***Arellano-Garcia***).

Overall we are contributing a variety of unique capabilities to our discipline sectors, in advanced materials engineering and automotive engineering, providing a lead in the UK to our communities, which is also expressed in leading collaborative ventures or being integral to others at a national level, and leading international activities in our field - all of which has helped to attract leading industry worldwide. We intend to continue to build on this success, pushing our discipline boundaries, developing further fruitful interdisciplinary co-operations across engineering and life sciences, promoting resource efficiency, and wellbeing, and genuine international co-operation to mutual benefit.