Institution: University of Birmingham

Unit of Assessment: UoA 12 - Aeronautical, Mechanical, Chemical and Manufacturing Engineering (Chemical Engineering submission)

A. Context. The Centre for Formulation Engineering comprises research carried out within Chemical Engineering at the University of Birmingham. The Centre incorporates the EngD in Formulation Engineering as a key mechanism for delivery of impact. Unique in UK academia, the success of the Centre was recognised by a **Queen's Anniversary Prize in 2011** awarded for "new technologies and leadership in formulation engineering in support of UK manufacturing". Formulation Engineering is concerned with the manufacturing of materials and products whose structure is complex at a micro- to nano- length scale and highly dependent upon processing history; this sector is worth more than £75bn p.a. to the UK economy. The Centre's impact embraces a portfolio of leading UK and multinational industries manufacturing foods, pharmaceuticals, detergents and personal care products, fuel cells, catalysts, gas turbine components, paints and agrochemicals. The Centre's research is structured into five key industry-focussed research themes which provide a framework through which world-leading economic and societal impact have been generated via creation of novel micro- and nano-structured materials, characterisation of both processes and products and via systems optimisation and modelling, forming the impact matrix shown below.

B. Approach to impact.

The Centre generates economic and societal impact via high-level engagement of staff with leading industries producing formulated products and materials. Examples of impact generating research and main industry beneficiaries are given in the below matrix, with items in **bold** indicating examples incorporated into the four impact case studies.

Impact Generating Research	*Food, health and nutrition*	*Bioengineering*	*Green Processing*	*Speciality Materials*	*Energy*
Novel micro- and nano-structured materials	**Low fat and low salt food formulations** (Unilever, Cargill, Kraft, Nestle, Rich foods)	Bioresponsive ceramics for bone and tissue repair (Smith and Nephew); Probiotic products (Lesaffre)	Novel absorbents for carbon capture (Corus); Functional minerals (IMERYS)	**Turbine blade casting** (Rolls-Royce) **Encapsulated products** (P&G, Encapsys, Philips)	Fuel cell components, PEFC, SOFC (TATA Motors, ElringKlinger, MIBA)
Process character-isation	Energy reduction in food plant (Kraft, Unilever)	Use of novel biofilm catalysts to produce pharmaceutical intermediates (Novacta)	**Catalyst manufacture using PEPT** (Johnson Matthey) **Energy reduction in milling** (IMERYS)	**Fluid and granular flows in opaque systems using PEPT** (washing machines, P&G, extrusion, AstraZeneca)	Electrode and stack design of SOFC fuel cells (Adelan, EADS)
Product character-isation	Texture of meat replacement products (Quorn, Marlow Foods)	Smart paramagnetic particles for bioseparations (Lonza)	Performance structure relationships for catalysts (Johnson Matthey)	**Microcapsule properties** (P&G, Encapsys, Philips)	Life cycle of fuel cell catalysts (SOFCpower, Adelan)
Systems optimisation and modelling	CFD based models of chocolate processing (Mondelez)	Optimised production biomolecules from recombinant cells (Lonza)	Production of high value molecules from variable feedstocks (Boorregard)	DEM modelling of roll compaction & agglomeration (AstraZeneca)	Energy cycle in hydrogen based transportation (Microcab)

The Centre has over £16M in active research contracts with £10M of funding from EP/BBSRC, EU and charities. Industry-facing projects, where the impact agenda is driven by engagement between academics and industrialists, encompass the remainder with £3.1M of direct industry funding with major partners (Cargill, Pepsico, Unilever, Johnson-Matthey, IMERYS, Rolls-Royce, P&G) and £2.7M of TSB/DEFRA projects. We have filed 24 patents in the UK, with 9 further filings in theUSA and 6 in Europe over the REF period. Interaction between industry and academic staff is driven by long-standing industrial collaborations which provide a sustainable platform and environment for generation of future impact. Key approaches and examples are given below:

- *Fostering strategic partnerships and investments.* Relationships have been strengthened over the period via forging of new strategic partnerships with Procter and Gamble (see P&G case study) and growth of existing ones with Unilever and Johnson Matthey. Long standing links with Rolls-Royce have led to a £60M investment for a new High Temperature Research Centre (see Rolls-Royce impact case study).
- *Exploitation of links through EPSRC Industrial Doctoral Training Centre (IDC).* The EngD in Formulation Engineering is our flagship mechanism for impact generation. Over ten years, the IDC has leveraged over £23M of cash and in-kind contribution from over 25 industrial partners. The IDC's Industrial Steering Group, whose membership comprises of our major collaborators, is tasked with ensuring the generation of high impact research and also gives input into the Centre's research strategy. Research Engineers enrolled on the IDC are embedded with industrial partners thus their work and any impact is directly translated. For example, an EngD research engineer (Peter Edmondson) working with Kraft in Bournville was able to identify operational improvements which led to a saving over £1M/year.
- *Engagement with Regional Development Agencies (RDA, Science City).* We were awarded £1.65 million from the ERDF and RDA through Science City to develop an Advanced Materials Laboratory (AML) possessing atomic force and Raman microscopy. The lab has been used by 26 industry partners, e.g. measurements done by Unilever have assisted in the design of new personal care products. Science City has continued beyond the abolition of RDAs in 2012.
- *Exploiting synergy between different process sectors.* Different industries have identical formulation problems. This has led us to create solutions which can be applied cross-sector, for example, work on measuring the strength of adhesion of surface deposits, developed using BBSRC post-doc funding, has been used in a £3.6 million TSB project on minimising the environmental impact of FMCG plant, with EngDs from GSK and Heineken.
- *Leverage of industrial funds for staff exchanges and secondments.* Our impact strategy has enabled industrial secondments supported by the Royal Academy of Engineering (GlaxoSmithKline, Imerys, P&G), the Royal Society (Johnson Matthey) and industry.
- *Appointment of leading industrial researchers and strengthening high impact research areas.* Profs Mike Adams and Ian Norton (see low fat foods case study) have joined the Centre from Unilever, together with election of key industrialists from Johnson Matthey (Stitt) and IMERYS (Skuse) to visiting Chairs. Two new Chairs have been appointed in the energy area to lead the Hydrogen DTC (Steinberger) and lead research into cryogenic energy storage (Ding), the latter involves development of a state of the art demonstrator together with Highview Power Storage. Strong links with Physics (Parker) enable exploitation of positron emission particle tracking in a range of industrial processes (see PEPT case study).
- *Licensing and Intellectual Property.* Research and Commercial Services at the University have been employed for protection of IP via Alta Innovations Ltd; they work with academic staff for filing of patents (24 UK filings over the REF period etc. as described above).
- These approaches have led to an impact-driven research environment with the ability to attract and retain top research staff via career acceleration schemes such as University of Birmingham Fellowships (Oppenheimer). The Centre has promoted industry-facing academic staff based on their growing research profile and impact of their work (e.g. Wood, Simmons, Mendes, Grover and Rowson to Chair).

The matrix-driven group structure enables rapid combination of staff with complementary skills, which ensures the Centre can respond with agility to 21st century challenges with direct impact. For example, the Centre has obtained over £1M since 2006 from BBSRC and TSB to tackle obesity by creation of low fat/salt foods and formulations which increase satiety. We have received over £1.6M from industry (inc Pepsico and Cargill) to create patented formulations.

C. Strategy and plans.

Our future strategic aims for impact generation are twofold, firstly via ***widening participation in the Centre*** both within the University and elsewhere. We seek to build links with companies that have not previously been involved in our research, through encouraging industry to establish research facilities within the Centre as well as involvement with formulation groups via national and international partnerships. We also seek to build links with major academic centres with skills that do not overlap with ours. We have run joint projects with the EngD Centre at Newcastle and share training courses with the EngD Centres at Newcastle, Surrey and UCL.

Our second goal is to ***deepen links to companies*** that are already engaged with the Centre and the EngD programme such as by running challenge events - where business presents current challenges they need solutions to – enabling us to build the programme in response to their business needs. Eight companies already have multiple EngD students. The nature of large companies is such that different parts of the organisation can support research – for example the Centre is funded by Unilever Research Colworth (corporate research), Port Sunlight (personal & home care) and Vlaardingen (food) laboratories, and several divisions of Rolls Royce. We have in the last year started two projects with Kraft at Banbury and one in Bournville following our successful long-term relationship with Mondelez (formerly Cadbury).

All this has been done whilst ***maintaining and enhancing our core academic excellence*** through continued engagement with research council funded projects and publication of results in the best journals. We will continue to develop high-quality research expertise in areas identified of critical importance to our research partners for which we have recruited and continue to recruit new staff. New drivers for generating impact are:

- *Energy and sustainability*: drivers are common across industry sectors. For example; (i) personal products are increasingly using natural feedstocks that are inherently unstable and variable and have to be disposed of without environmental impact; (ii) efficient management of water and waste streams to minimise the impact of formulation processes is critical; (iii) energy usage in formulation processes can be substantial, (iv) removal or substitution of expensive or rare metals (e.g. platinum) in fuel cells and catalysts is essential for sustainability.
- *Health*: designing structures that deliver drugs or nutrients effectively to the body, such as (i) building foods that have high-fat taste but low-fat functionality (TSB/Unilever funded work with Norton and Bakalis; over £3M of industry funding), and (ii) creating delivery systems that enable biotherapeutic agents to be delivered where needed. Here the food and pharmaceutical industries are converging, with both interested in targeted delivery. We will also continue to push forward our research into the development of new technologies for the regeneration of diseased and damaged tissues. The University of Birmingham, with one of the largest university hospitals in Europe on-site, is well equipped to make a translational impact.
- *Scaling up nanotechnologies*: many of these materials could exploit new nano-scale understanding. We are developing routes to scale up of nano- emulsions and encapsulates which can deliver nutritional or biotherapeutic actives when incorporated into formulated products (Zhang). Through a spin-out company, Irresistable Materials Ltd., novel nanomaterials including fullerene based molecular photoresists are being developed (Robinson).

D. Relationship to case studies

Each of our four selected case studies exemplify aspects of our successful approach to impact. Through the case study on *"commercial development of microcapsule based products..."* our impact approaches have enabled a strategic agreement with Procter and Gamble to be signed in spring 2012, together with a regular exchange of staff between P&G and the Centre. Zhang and Bakalis have taken sabbaticals in P&G Innovation Centres in Newcastle and Brussels respectively and P&G personnel (Amador, Quintieri & Broeckx) have spent time with Zhang's group. The Rolls-Royce case study on *"novel materials and processes for more efficient manufacture and operation of gas turbines.."* exemplifies the impact of this work on key policy makers on Rolls-Royce board, leading to £60M strategic investment. Work carried out as part of the *"novel low fat food products...."* case study has led to over 10 patents, with growing markets identified using Birmingham-led formulations. The case study on "*positron emission particle tracking...."* provides evidence of how improved process understanding via our novel PEPT technique can benefit a range of industries from FMCG to large scale minerals comminution.