

Institution: University College London
Unit of Assessment: 12 - Aeronautical, Mechanical, Chemical and Manufacturing Engineering
<p>a. Context</p> <p>This submission comprises 55 staff (54.16 FTE) from UCL's departments of Biochemical (BE), Chemical (CE) and Mechanical (ME) Engineering. Our research impacts upon the pharmaceutical, chemical, defence, energy, and marine sectors, all of which are vital to the UK and its position in the global economy. It also helps guide policy in UK and overseas government departments and industry bodies. We deliver a wide range of benefits to groups and organisations within these areas. Our research on Ultra Scale-Down (USD) technologies provides new approaches and tools to speed the development of new medicines and ensure their cost-effective manufacture by the UK's world-leading pharmaceutical and biopharmaceutical companies. This brings financial benefits to those companies (and thereby to the UK as a whole) and enhances healthcare provision and patient health and well-being by bringing new medicines to market faster and more cost effectively. Our research in the fields of advanced manufacturing and biocatalysis has benefitted companies in the chemicals sector, yielding specific benefit through its incorporation in next generation ultra-efficient manufacturing technologies and integrated process development and design. This research has also delivered wider impacts via the use of chemical products (made using UCL patented technologies) in related sectors such as the construction and automotive industries. Research identifying more efficient chemical processes, such as that on molten salts and in process systems engineering, allows us to advise chemicals companies on how best to reduce their carbon footprint. Further environmental benefits are effected by our work with the energy and transport sector, where our research has pioneered the development of new fuels, combustion technology, solar energy and fuel cell technology, all of which have a major role to play in reducing emissions in the UK's transportation and domestic sectors. Our research provides guidelines for the safe transportation of CO₂ and on technologies that help the UK meet its targets in reducing emissions through carbon capture and storage or direct CO₂ utilisation in manufacturing. It has likewise delivered environmental benefits within the marine sector, where it has influenced the adoption of approaches to reduce the environmental signature of shipping, as well as informing new wave and tidal stream technologies and novel ship designs.</p>
<p>b. Approach to impact</p> <p>Staff across all three departments within the UoA take a consistent approach to delivering impact. They are encouraged (via appraisal) and rewarded (via promotion) to participate in impact-generating activities including:</p> <p>(i) Provision of expert advice and specialist knowledge to policy-making bodies. Senior staff actively influence UK strategic research goals and help establish impact objectives and funding across the sectors identified above through their provision of expert advice to government and other policy-making bodies: e.g. our Dean, Prof. A. Finkelstein, sits on EPSRC Council, and BE are represented on their strategic advisory network (Titchener-Hooker). BE staff have contributed to government Innovation and Growth Team reports on Bioscience (Hoare, 2009) and Industrial Biotechnology (Lye, 2009), and two House of Lords Science and Technology Committee inquiries into Bioengineering and Regenerative Medicine (Mason, 2009, 2013). Others have contributed to Technology Strategy Board (TSB) road mapping exercises informing policy relating to High Value Manufacturing (Bracewell, Farid), Synthetic Biology (Ward) and Biotechnology (Dalby). They also sit on key industry committees such as the BioIndustry Association Manufacturing Advisory Group (Farid) and the BioProcess UK KTN Steering Group (Titchener-Hooker). CE staff have influenced the UKERC Policy White Paper (Brett, 2009) and been involved in the BIS National Measurement System Programme Working Group (Brett, 2009-13), Global Carbon Capture and Storage Institute (Simons), the UK Carbon Capture and Storage Research Centre (Fraga, Mahgerefteh) and the European Academies Science Advisory Council on CO₂ transportation (Mahgerefteh). They provided expert advice on Systems Biology to the Ministerial Industry Scientific Advisory Group of the Medicine and Healthcare Products Regulatory Agency (Bogle, 2010), and on guidelines for Sustainable Development on Risk (Bogle, 2009, 2010) via the UK Engineering Council Board. ME, staff produce science that influences policy for the marine and off-shore environmental sector (Greig), and are members of the Institute of Marine Engineering, Science and Technology Council, Lloyd's Register Rules Committees and British Standards</p>

Committee for Marine Electrical Installations (Bucknall), NATO AVT Panels (Andrews, 2011-13), US Navy ONR/NAVSEA panels (Andrews, 2008-10), and the UK MoD ViSAG (Andrews, 2008-13).

(ii) Development and operation of industrial consortia. Development of industrial consortia has proven a vital component in the Unit's approach to forging and maintaining links with industry, and of maximising the industrial benefits of its research. The Research Groups described in REF5b operate several **large consortia or Industrial Advisory Groups (IAGs)**, which meet every 6-12 months to help define sector-specific drivers, research goals and pathways to impact. In setting these up we have capitalised on support from our technology transfer office **UCLB** to establish agreements and protect underpinning IP. **BE** operates two such consortia involving leading companies like Eli Lilly, GSK and Pfizer. The first (established 2005) involves 13 companies and supports the Industrial Biotechnology Research Group; the second (established 2011) involves 25 companies and advises the EPSRC Centre for Innovative Manufacturing. As well as building our industry relationships, these consortia enhance our capacity for research impact by providing additional industry funds for impact-generating activities. Since 2008 these funds have totalled £1.1M and have been used to support people-based knowledge exchange (KE) and uptake of UCL technologies (see case studies UCL12-HOA and UCL12-WAR). In **CE**, the Centre for CO₂ Technology (established 1998) has continued to support productive staff-industry relationships throughout the REF assessment period, as has participation in the Imperial/UCL Centre for Process Systems Engineering IAG (established 1989), which includes multinational companies such as BP, Procter & Gamble and Petrobras. The UCL Electrochemical Innovation Lab (EIL, established 2010) is advised by Sharp, ITM Power, Johnson Matthey and a broader network of 5 further companies. Likewise in **ME** a consortium of automotive and fuel companies, including Ford, Jaguar, BP, and Shell, direct and support research in the Energy and Environment group. A further consortium of shipping companies advises on impacts related to low carbon shipping and ship design in major research programmes such as FP7 FIREPROOF, FAROS and MARINELIVE.

(iii) Maximising the impacts of industry collaborative grants and studentships. Since 2008, Unit staff have been instrumental in winning 18 UK Technology Strategy Board (TSB) grants to progress basic research findings to TRL 4-6. In **BE** these grants are used to develop small, technology-focused consortia and establish the supply chains required to take novel therapies to market more quickly. These link SMEs (e.g. ImmunoBio, Plasticell, Syntaxin) with both Government organisations (e.g. HPA, LGC, NIBSC) and companies higher up the value-chain (e.g. AstraZeneca, Lonza and MedImmune). In **CE**, grants related to hydrogen generation, low energy chemical processes and fuel cells have supported productive collaborations with companies ranging from SMEs to large multinationals including Tata Steel, Carbon Trust, NPL, and Nexxon. An ETI grant on gasification (Lettieri) established collaborations with APP, Rolls Royce, BOC and Linde in the development of waste to energy technology. In **ME**, industry-linked grants have supported commercialisation of research on turbomachinery design (Zangeneh), biofuel production (Balabani), combustion (Aleiferis, Ladommatos, Balachandran) and hybrid drive systems (Aleiferis, Ladommatos), including novel hybrid buses developed in collaboration with Transport for London (Bucknall). UoA staff have also secured direct industrial funding for impact-related studies on next generation antibody manufacture via the creation of Bioprocess Centres of Excellence with GSK (£0.9M in 2009) and MedImmune (£0.7M in 2012); a £0.3M National Grid project related to CO₂ transport in pipelines in 2010; and £1.25M from Lloyds Register to support deep water marine engineering in 2012. Across the Unit 124 industry collaborative contracts have been signed since 2008. UCL was the major recipient of EPSRC Industrial Doctoral Training Centres (IDTC) in 2008, and Unit staff have made use of EngD resources, as well as CASE awards and UCL IMPACT Award studentships (requiring 50% industry co-funding), to establish one-to-one relationships with companies. To date, the IDTC in Bioprocess Engineering (Director: Lye) has developed collaborations, supervised by staff across UoA12, with 60 different companies. The DTC in Emergent Macromolecular Therapies (Director: Dalby) plays a specific role in co-ordinating rapid industrial exploitation of life science research across the UK. The Unit's doctoral programmes support important collaborations with companies including AFC Energy, BNP Paribas, Chevron, Dow Corning, Eli Lilly, Ford, GSK, Jaguar, Lonza, Lucite, MAHLE Powertrain, MedImmune, Pfizer, Praxair and Tata Steel. Again, **UCLB** provides support on agreements and IP protection.

(iv) Patents and spin-out companies. Since 2008, the Unit has developed patents in the areas of nanofibre fabrication (Bracewell), protein engineering and analysis (Dalby); microfluidic reactor

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design (Szita); selective separations (Titchener-Hooker); fuel cells (Brett); photocatalysis for CO₂ reduction (Tang); pump construction (Zangeneh) and fuel selection (Ladommatos). In line with **UCL Enterprise Strategy**, staff have also established spin-out companies from their research including Advanced Design Technology (Zangeneh), Amalyst (Brett), Carbon8Systems (Simons), Phonix (Mahgerefteh), Puridify (Bracewell) and Synthace (Ward). Technology commercialisation is supported by UCLB provision of dedicated **Faculty Business Managers**. Each department also has a dedicated **Enterprise Co-ordinator** and staff are encouraged to undertake IP and entrepreneurial training provided through **UCL Advances** and the **London Business School**.

(v) Knowledge exchange and consultancy. 50% of UoA staff are engaged in TSB-funded Knowledge Transfer Partnerships (KTP) or direct consultancy services. UCL Advances provides dedicated KTP support, while **UCL Consultants** promote consultancy activities and deal with contracts. In **BE**, KE focused on exploitation of USD technologies in the healthcare sector has been effected through KTPs with BioPharm Services (Hoare, 2011), GSK (Bracewell, 2011; Hoare, 2012), Pfizer (Bracewell, 2012), Sparq (Szita, 2013) and UCB Celltech (Titchener-Hooker, 2011). A new EPSRC Impact Accelerator award with Camtech Innovations started in 2013 (Szita). In **CE**, Gavriilidis has worked in a KTP with GSK on continuous flow reactors (2012), while **ME** staff have run KTPs with EU VISIONS (Greig/Bucknall/Andrews 2008), BMT DSL (Andrews 2012-13), US Navy ONR (Bucknall/Andrews 2008-2015) and the Australian Department of Defence (Andrews 2009). Consultancy and advisory services span all the industry sectors covered by the Unit's research. Since 2008 these have included transfer of specialist knowledge to: ALMAC (Lye), Baeyer (Farid), BMT MARS (Andrews), BP (Fraga), GSK (Bracewell), Johnson Matthey (Coppens), Microvisk (Dalby), National Grid (Mahgerefteh), NNL Sellafield (Lettieri), NPL (Brett), Office of Naval Research (Bucknall), Pall Life Sciences (Hoare), PassivSystems (Fraga, Papageorgiou), Petrobas (Mahgerefteh) and Qinetiq (Eames). Two **consultancy companies** have been established to advise industry on energy matters (IonIQ Ltd, Brett) and cell therapy bioprocessing (RMBC Ltd, Wall), and to promote the exploitation of UoA12 research outputs.

(vi) Continuous professional development (CPD). At a strategic level, senior staff help define UK training needs and delivery mechanisms by working with sector skills councils such as SEMTA (Keshavarz-Moore) and the Industrial Biotechnology Leadership Forum (Dalby, Lye). CPD delivery is managed at departmental level: in **BE**, a Director of Bioprocess Leadership (Smith) ensures the Department's status as the leading training provider to the international bioindustries. Its **VISION programme** (established in 2010) delivers training and networking opportunities for senior executives alongside the **MBI[®] Training Programme** (www.ucl.ac.uk/biochemeng/industry/mbi), which comprises 12 modules for industrial researchers. Over 350 individuals from more than 185 companies have attended VISION and MBI[®] modules since 2008. **CE** staff contribute to the New Engineering Institute Alternative Energy course (Brett, Shearing) to promote energy efficiency and optimisation, and **ME** runs established CPD courses on ship design through the Marine Technology Education Consortium (Bucknall) and submarine design (Wrobel) as part of the MoD programme. UoA staff also contribute to internal CPD training schemes in various companies.

(vii) Public engagement (PE) activities. UCL was one of six **Beacons for Public Engagement** (2008-2011) and provides dedicated support and funding for public engagement activity. All UoA staff participate in such activity, which includes schools visits, taster courses, public lectures and participation at science festivals such as Cheltenham, the Big Bang, and Green Man Festival. Staff also regularly contribute to television programmes on topics such as cell therapy (Mason), vaccine manufacture (Mukhopadhyay) and medical device design (Micheletti).

c. Strategy and plans

The strategies for delivering impact outlined above will be maintained, with key mechanisms expanded and enhanced. We will encourage the involvement of new staff in impact-generating activity; increase the international reach of our impact activities; and ensure that our KE activities are responsive to changes in sector policy and funding. Specific 3-5 year plans include:

(i) Staff. All three departments have approval to recruit new academic staff (10 FTE by 2018) to enhance their impact activities and CPD course provision. We will use the preferential award of EngD and IMPACT studentships to encourage and support new staff to build industry links, and all staff will be encouraged to take impact related sabbaticals (e.g. Industry Fellowships).

(ii) New industrial consortia and centres. We will build upon our previous successes to establish new consortia to support emerging Research Groups, including the Cell Therapy Bioprocessing

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group (**BE**), which will be closely aligned with the new Cell Therapy Catapult (see below), and will focus on the delivery of patient benefits, especially for age-related diseases. **CE** will establish and co-ordinate two new cross-Unit centres: a £5M Centre for Nature Inspired Engineering (EP/K038656 awarded May 2013), and the UCL Energy Technologies Domain, which will extend Centre for CO₂ Technology activity into a 'translational' College-wide hub to promote business development activities from the engineering and technological research in energy and CO₂. Each will draw upon new IAGs composed of major national and international companies from the chemical and energy sectors. In **ME**, new industry consortia will be developed for Green Shipping and fuel technologies through a Jaguar Centre delivering direct financial benefits to the companies involved, as well as wider environmental impacts.

(iii) Catapult centre interactions. The recent formation of the TSB Catapult Centres provides important opportunities for industry collaboration and KE in both biological and chemical processes. Our existing Industrial Biotechnology links with the £50M High Value Manufacturing (HVM) Catapult will be extended into the Biopharmaceutical sector by 2014. This builds on the 2013 announcement of a further £38M government investment in a National Biopharmaceutical Industrial Innovation Centre, of which **BE** is a key academic partner. We will also establish similar links with the new £70M Cell Therapy Catapult by 2014. In both cases, UCL USD technologies will be used to bridge the discovery activities of SMEs and the demonstration scale of the Catapults. These links are supported by a new £3M HEFCE Catalyst Fund grant (awarded July 2013 to Lye) to support a series of Bioprocess Enterprise Fellows, which will lead to further industry collaborative TSB R&D and KTP grants (~3 p.a.) each with specific impact objectives.

(iv) Spin-out company formation. In line with the UCL Enterprise Strategy (2011-2015) each department will encourage growth in their existing spin-out companies, and support the creation of at least three new companies by 2018. These will be focused in the energy technologies and cell therapy bioprocessing areas, in line with our existing and emerging research strengths.

(v) CPD course provision. We will refine our CPD offerings in areas of emerging interest and establish activities with increasing international reach. The new HEFCE grant will help **BE** establish three new modules in: Single-Use Bioprocessing (building on our £1.5M Responsive Bioprocessing Facility investment); Human Cell Therapy Manufacture (in collaboration with the Cell Therapy Catapult) and Vaccine Bioprocessing (delivered in Europe, with support from ESACT, and in India, with support from EPSRC, EP/K004506, Mukhopadhyay). Our previous MBI[®] experience suggests that we can expect these to benefit some 180 individuals in over 50 companies by 2018.

(vi) Public engagement. Each department will expand its PE activities to inform public debate on key topics (e.g. UCL/IMarESR, The Sea Changes, lecture series) and promote wider involvement in its research. We will seek support for these activities from the **UCL Public Engagement Unit**. Our PE activity has also been boosted by a £2M Faculty of Engineering Sciences investment (2012-13) in a new **Institute of Making** (www.instituteofmaking.org.uk) which provides a 'shop-window' onto all such activities and has won £1.5M additional EPSRC support (EP/K503459/1).

d. Relationship to case studies

The case studies submitted here describe impacts arising from various aspects of the pro-active approach outlined above, and have helped us identify its most effective strands. These have included the creation of industry consortia alongside major RC grants, which has led to the formation of two spin-out companies and broad impact across the chemical and pharmaceutical sectors through **USD Technologies** (UCL12-HOA) and the **BiCE programme** (UCL12-WAR). Strategic collaborations instigated by UoA Research Groups have also helped deliver impact in specific sectors: research on carbon capture and storage led to the spin-out of **Carbon8 Systems** (UCL12-SIM) and work on **3D inverse design software** (UCL12-ZAN) to the spin-out of Advanced Design Technology. Our research on novel ship designs underpinned the construction of **Trimaran Hullform** ships (UCL12-BUC) by the UK MoD and US Navy. In each case, the reach of our research impact has been increased via follow-on TSB grants, KTP schemes and EngD/CASE studentships which have themselves delivered further impact such as the creation of software tools to support biopharmaceutical capacity planning strategies, as illustrated in the **Decisional Tools** study (UCL12-FAR). Our use of CPD to increase the industrial reach of our impact, and of PE activities to inform public debate and acceptance of our new technologies, is demonstrated across the portfolio of our case studies.