Institution: Imperial College London

Unit of Assessment: 15 (General Engineering)

A. Context

Research in the Department of Bioengineering has three strands. (i) We conduct investigations at the interface of engineering and life sciences in fields ranging from synthetic biology to biomimetics. (ii) We investigate mechanisms underlying trauma and disease. (iii) We develop techniques and devices for diagnosing or assisting with such conditions, from algorithms and software, through hardware, to tissue engineering and regenerative medicine. Our five Research Themes are all actively generating impact, e.g. Biomechanics [Case Study: CS3,4], Cell and Molecular Bioengineering (Synthetic biology policy, Kitney output1), Detection, Devices, Design [CS1,2]; Implants and Regenerative Medicine (spinout Veryan Medical); Neurotechnology (spinout Cortexica).

We have three main types of impact: **health & wellbeing**, **economic**, and **growth and profile of the bioengineering discipline**. Our beneficiaries are:

A.1 Patients. *Impact: health & wellbeing.* For example, for patients with liver cancer [CS1], brain injury or oral cancer [CS2], coronary artery disease [CS3], and blast injuries [CS4]. Other applications include robotic devices for stroke rehabilitation, knee surgical technology and implants derived from mechanical modelling, and helical stents and grafts (spinout Veryan) that maintain blood vessel patency for longer.

A.2 Healthcare Providers. *Impact: health & wellbeing* through time and cost reduction of investigations and interventions. For example, the picture archiving and communications system (PACS) developed by spinout Visbion has been sold to 15 NHS Trusts, the North of England Cardiovascular Network (serving 3.2M people), Alliance Medical (serving 300 hospitals) and others. This has increased speed, data quality and ease of data transfer and sharing. CS3 describes time and cost savings when our Wave Intensity Analysis is used to assess coronary disease.

A.3 Sport. *Impact: health & wellbeing (including society, culture and creativity)*, through sporting success, injury reduction, and standards. Our musculoskeletal dynamics studies have increased GB Rowing success and reduced injury amongst rowers. We developed a mathematical definition of bowling, and a method for measuring it, as well as a method for quantifying cricket bat compliance on behalf of the Marylebone Cricket Club (MCC), which defines the rules of cricket worldwide.

A.4 Military. *Impact: health & wellbeing (including public policy and services)*, through protection from, and treatment for, battlefield injuries. This work has impacted army procurement, vehicle design, testing procedures, Dstl policies and NATO standards [CS4]. Our neurotechnology expertise is used by defence contractor Blue Bear Systems in the design of bio-inspired micro-air vehicles.

A.5 Industry. *Impact: economic.* For example, sales of the resection device licenced to AngioDynamics total $40M [CS1]. Our spinouts have direct economic impact (Visbion has 16 employees and annual turnover of £1M) and offer new products and services. We contribute to the knowledge base of companies such as Allergan (glaucoma), J&J (eczema) and Scientifica (microscopy).

A.6 Public. *Impact: growth and profile of the discipline.* In addition to extensive outreach activities, we have benefitted the subject as a whole by giving advice to academies, government bodies and funders on bioengineering. We authored the discipline-defining RAEng report on Synthetic Biology which was a major factor in Synthetic Biology being one of Government's "8 Great Technologies".

B. Approach to impact

Delivering impact to our beneficiaries is a key part of our research strategy; we support Imperial's overall founding mission to deliver "world-class scholarship, education and research in science, engineering and medicine, with particular regard to their *application* in industry, commerce and healthcare."

The importance that we attach to impact is understood by all staff and is reflected in our processes. Actual or potential impact from research is considered at recruitment, and forms part of the personal development and mentoring plans for Early Career Researchers. Impact is encouraged at annual appraisals, formally considered in promotion and reward procedures, and remunerated and incentivised by a percentage of income from IP. Staff are encouraged and supported to undertake commercial activities for up to one day per week. We actively promote and celebrate leading ex-

amples of high impact research.

Members of our Advisory Board come from industry, commerce, clinical practice and technology transfer. We also establish separate, specialist advisory boards for the inter-disciplinary Centres that we lead. These advisory boards help ensure that impact considerations underpin our work.

The Department employs a wide range of impact and translation mechanisms. Commercialisation is achieved chiefly through *Imperial Innovations plc,* with whom Imperial College has a pipeline agreement. Innovations provides: incubation and venture funding; support in the patent process; and proof-of-concept funding. Innovations has a dedicated member of staff assigned to bioengineering. When commercialisation is not appropriate, we employ a range of mechanisms for impact and knowledge transfer to our beneficiaries, strongly assisted by our collaborative ethos (highlighted in REF5) and by the Institute of Biomedical Engineering's (IBME) Networks and Centres.

B.1 Licensing: We creatively utilise licensing. Successes include our liver resection device [CS1] - the contract stipulates that the device be made available to developing countries in Africa at cost price, increasing reach – and Departmental spin-out *Heliswirl*, which licensed IP concerning its bio-inspired methods for piping industrial fluids to Technip.

B.2 Spin-out companies: Achievements include *Cortexica*, a provider of image search and recognition technology based on research by Bharath. It has been granted BizSpark One status by Microsoft, clients include Waitrose, Tesco, Centrica, Virgin Money and eBay (book value £6M). *Veryan Medical*: formed based on Caro's research into helical grafts and stents (book value £16M). *Visbion*: Kitney's expertise in developing and trialling Electronic Medical Records software based on open standards led to the formation of this developer of PACS. All three spin-outs demonstrate the importance we give to "follow though": Bharath remains CSO of *Cortexica*, Caro is a consultant for *Veryan* and Kitney is chairman of *Visbion*. The importance of our relationship with Innovations is demonstrated by the fact that they now own 31% of *Cortexica* and 47% of *Veryan*.

B.3 Proof-of-Concept: Internal and external funding brings our research to a stage appropriate for commercialisation. We obtained a total of £582k from the following sources in the REF period: *Impact Acceleration Funding* from EPSRC is allocated by the College in competitive calls for proof-of-principle work. The College's *Kick-Start Scheme* targets projects between the Faculties of Engineering and Medicine, with the goal of generating clinical impact. The College and its NHS trust jointly award grants for clinical translation from their NIHR-funded *Biomedical Research Centre*. The Department raised charitable funds for its own *Bagrit Proof-of-Concept scheme* in 2008; all income generated will be re-invested in the scheme. The IBME, managed by the Department, runs a translational *Centre for Medical Engineering Solutions in Osteoarthritis* with proof-of-concept funds derived from EPSRC, the technology translation wing of the Wellcome Trust and Imperial Innovations; an IP management group reviews progress and evaluates effectiveness.

B.4 Technology Strategy Board: We have undertaken knowledge transfer projects through TSB grants totalling >£1M on cell therapy (BioCeramic Therapeutics, Plasticell, Finsbury Orthopaedics) and on point-of-care diagnostics for clinical enzyme biomarkers with Mologic (Departmental component is 50% - Stevens is a joint appointment and returned to REF by the Materials Department).

B.5 Industry-Funded PhDs: In addition to CASE studentships and studentships fully-funded by industry, we have established a departmental industrial PhD scheme, which provides funds to match industrial contributions. To date four studentships have been funded with J&J, JRI Orthopaedics, TMO Renewables and Microsoft.

B.6 Medical Doctorates: We have supervised and co-supervised eight MD(Res) higher degrees to completion in the REF period (five more on-going). This gives broader reach into health and wellbeing as all graduates have returned to clinical practice upon completion.

B.7 Direct collaboration with end users: This mechanism is central to the Department's impact. We utilise our medical school (Europe's largest) and our NHS Hospital Trust for *clinical* interactions. Collaborating UK *military* personnel are assigned to full-time research for between 1 and 2 years each (six individuals to date); the same mechanism has been used to assign visiting professor Colonel Clasper a part-time role at Imperial since 2010. Through their subsequent embedding in the NHS, these have resulted in civilian transfer of our military medical engineering research, changing clinical practice (CS4). Collaboration with *industrial* personnel is exemplified by visiting professor Woodward, Senior Director at the USA pharmaceutical company Allergan, who participates in our research on glaucoma, osteoarthritis and obesity. In all cases, appointment of end us-

ers as visiting or honorary staff allows them to participate in IBME Networks and Centres. This also works in the opposite direction, such as the Royal Society Industry Fellowship held by Schultz with Scientifica; he also holds a BBSRC Industry Partnership Award with them.

B.8 Consulting: Consultancy transfers existing knowledge and also gains insight into emerging problems. ICON, a subsidiary of Imperial, has brokered 53 consulting projects between 16 of the Department's researchers and 56 clients in the UK, USA, Italy and Germany during the REF period.

B.9 Advisory Roles: Staff have carried out extensive advisory work for the British and US Armed Forces and NATO [CS4]. Staff have also advised the EC, NRF (Singapore), BIS, CSIRO (Australia), GenArt, TMO, Bayer, GSK, Syngenta and Agilent-California on synthetic biology. There are, in addition, numerous other roles such as participation on the MCC Laws Committee.

B.10 Public Engagement: We actively raise the profile of the discipline via media, open days, museums, festivals, public lectures and conferences. Our full-time Departmental Outreach Manager facilitates public and governmental body engagement. For example, the Rio Tinto Sports Innovation Challenge has involved over 20 public exhibitions, along with wide media exposure (C4, Sky, BBC, CNN, ABC). Similarly, the Centre for Blast Injury Studies has had wide exposure (C4, BBC, Times, Mirror, Daily Mail, Telegraph, Discovery Channel). We have also raised the academic profile of the discipline by establishing the *Bagrit Lecture Series* and the *Bioengineering Society* detailed in REF 5.

C. Strategy and plans

Our immediate principal focus will be to **increase engagement and collaboration with industry.** We will:

C.1 Develop Industrial Partnerships: *Strategic Partnerships* with specific companies will be formed, particularly to exploit the move of Pharma from drugs to devices. This activity will use Imperial's *Corporate Partnerships service.* Our full-time post of *Industrial Liaison Manager* created in 2012 will increase partnerships. We have established (Oct. 2013) our *MRes in Medical Device Design & Entrepreneurship*, led by Professor Moore (recruited from the USA) and through this anticipate a growth in similar partnerships. We are advertising *part-time professorial posts for industrial researchers*. These are expected to draw in involvement from the appointee's industrial employer.

C.2 Increase industrial representation on our Advisory Board.

C.3 Exploit our leadership in synthetic biology: Kitney will lead an Innovation and Knowledge Centre in synthetic biology with 17 academic institutions and 13 industrial partners including Microsoft, Shell and GSK. Funded by £10M (£2.5M Departmental component) from EPSRC, BBSRC and TSB, it aims to accelerate transition of discoveries from lab to factory. Kitney will also lead a £5M (Department: £1.2M) Frontier Engineering award for industrialisation of synthetic biology.

We will increase our impact through growth in numbers and breadth. For example, we expect our clinical reach to expand as a result of our recent establishment of an IBME Network in Cancer Engineering.

D. Relationship to case studies

All four of our case studies exemplify aspects of the approaches outlined above:

CS1. Bipolar resection devices: Impact arises from a collaboration between our staff and staff in what is now the Imperial NHS Trust (**B.7**). The first device was initially exploited through a spin-out (**B.2**), but later licenced (**B.1**). Subsequent devices are being exploited through the spin-out.

CS2. Rapid-sampling microdialysis: Impact is generated by direct collaboration with clinicians (**B.6**, **B.7**). The impact has benefitted from BBSRC CASE awards with Sharp Europe and with GSK (**B.5**), and two internally-allocated translation grants totalling £135k (**B.3**).

CS3. Wave Intensity Analysis: The initial research was conducted with a collaborating clinician who held a post in the Department as well as at a hospital (**B.7**). There continues to be a strong collaboration with clinicians at the Imperial College Healthcare NHS trust.

CS4. Blast Injury: Military staff are seconded to, and have visiting appointments in, the Department (**B.7**). CASE studentships have been held with Dstl (**B.5**). Clinical impact has arisen from direct collaboration with clinicians. Staff have advisory and consultancy roles in NATO and Dstl (**B.9**), and wide dissemination has achieved significant exposure and impact (**B.10**).