Institution: University of Cambridge

Unit of Assessment: UoA 12

a. Context The Department of Chemical Engineering and Biotechnology (CEB) is a fertile ground for advancing chemical engineering and biotechnology, bringing scientific innovation to collaborative and entrepreneurial advances. Research, aligned under the strategic umbrella of sustainability, includes **processes, healthcare and materials** with impact focussed on business value drivers. The beneficiaries emerge across the full value chain through industrial collaboration, clinical relationship and spin-offs/start-ups, supported by engagement and media activities to achieve scientific, health and engineering advancements.

b. Approach to impact A guiding principle for CEB research outcome has been to recognise impact that may arise from innovative fundamental science in **processes, healthcare and materials**, but *not all with the same culture*. Research may impact new or existing **processes** or result in new **products**, so that impact has been driven through: 1) **entrepreneurship**, leading to spin-outs, where CEB has also extended this to embrace the movement in **social entrepreneurship;** 2) **industrial collaboration** which recognises that by *improving processes*, existing companies may become more competitive, so innovative scientific solutions to critical problems are value-adding; 3) **Clinical relationships** resulting from both entrepreneurial and collaborative activities (see Psynova and Agamatrix impact case studies). In the latter case since RAE 2008, **collaborations** have started with Cambridge University Health Partners (incl. Wellcome Trust ISSF clinical internship) as well as other UK, overseas and developing world clinical connections in Asia and South Africa, and reinforced by attention to the clinical interface, by appointment of a clinically-facing Chair in Healthcare Biotechnology (Bahn).

While CEB has an exceptional record of industrial impact, it has also made progress in driving impact through ***policy and public engagement and media based communication***. For example, CEB members are engaged in science and policy committees (Home Office Science Advisory Committee, Gates Biological Sciences Panel, Royal Society Council, EPSRC Council, Innovation Strategy Board, Board of the Royal Commission for the Exhibition of 1851, BIS, MOD Strategic Research and Technology Committee) and work via the Centre for Science and Policy (CSaP, 23 engagements since 2011) and Office for External Communications to interface with senior opinion leaders in industry, government, banking, finance and law, through the CSaP Policy Fellowship programme. CEB also leads interaction with stakeholders and users through the University's **Cambridge-Sens** strategic network and **Energy@Cambridge** strategic initiative and links with the 1400 companies that form part of the Cambridge cluster. CEB also recognises that attention must be given to the role of media (exhibitions, festivals, social media) in translational impact of research and it has embraced dissemination *by international press engagement, YouTube videos, University news features* etc. Protection against enterotoxigenic E.coli and typhoid, for example, was promoted for a bacteria-based oral vaccine with these media, with phase I clinical trials beginning later in 2013, with the technology licensed by Prokarium, through Cambridge Enterprise (CE).

Industrial Collaboration has been an historical strength in CEB, recognised in promotion, with on-going relationships and funding (eg Schlumberger Gould Research, ExxonMobil, BP, BorgWarner, CEPSA, ENI, INEOS, SINTEF, LE/LINDE, Topsoe, Nestec, Pharrnas) indicators of successful partnerships. Some highlights are: MEL Chemicals who are marketing CO_2 adsorbents that emerged in collaboration; elucidation of colloid stabilisation mechanisms in engine oils, enabling improved product manufacturing, being patented and developed by Infineum; die-flow characterisation methods for tungsten carbide pastes reducing testing times to one day for Ceratizit Austria GmbH, and supporting die design *in silico*. This collaboration has been extended with Ceratizit and their major competitor, Sandvik Hard Metals, the leading manufacturers of hardmetal tools worldwide. We have also used advanced computational modelling for synthesis of nanoparticles and nanocomposites (Huntsmann, Kronos) as well as hydrocarbon fuels and commodity chemicals with a lower carbon footprint (CMCL) and we are impacting development of low-emission Tier IV final compliant non-road machines (Caterpillar, BorgWarner) with sophisticated numerical modelling algorithms to solve complex problems in the areas of friction, turbocharging and combustion. A closed-loop optimisation of large-scale industrial polymerisation processes (BASF) is currently being considered for demonstration on a working 60m^3 plant, whereas with Bayer and AstraZeneca we are developing a pilot-scale demonstrator of a novel

pharmaceutical manufacturing process. In some cases collaboration is coordinated through a third party: we are working with PCI (Guildford), a consultancy undertaking technical and economic work for the polyesters industry, to look at environmental impact of sourcing ethylene from Brazilian ethanol, rather than from petrochemicals. This is important in the context of "green" PET bottles. **Fora** to generate new opportunities for industrial impact have also been organised in collaboration with CE and, as seen with the MedImmune Forum (2012), impact has resulted in 2 projects, both driven by recent lecturers (Zeitler, Christie). The first, on formulation stability led to a follow-on TSB project to translate the research into MedImmune via a local SME, TeraView. The latter supports development of a spore-based therapeutic antibody storage/delivery system. Imaginative partnerships in equipment are also being used to catalyse further research collaboration. Eg, Schlumberger have embedded an MRI instrument within CEB and Psynova have supported a mass spectrometer for 7 yrs from 2010.

Enterprise: CEB benefits from the wider University, supporting exploitation through top class advisory, legal and financial support services within the University's Research, Technology Transfer and Corporate Liaison offices. Incentives are encouraged by generous IP returns for staff. 44 patents have been filed through CE since 2008. There are around 15 companies from CEB in the 2013 CE Equity Portfolio, with several others outside this, eg CMCL, Metrica.Bio, Agamatrix, Smart PM. Collectively, they have raised substantial City, Angel and VC funding and employ >600 people. With the exception of Prometic (market capitalisation ~$400M) they remain privately owned and through these enterprises CEB continues to make on-going impact. Smart Holograms, for example, was third in Telegraph's 2010 top 50 University spin-outs. Psynova won the Medical Futures Innovation Award and was named top bioscience spin-out, Europe (2011). Enval was voted one of Europe's up and coming cleantech companies, shortlisted for the Environment and Energy Awards (2011), also winning Best New Technology prize at the National Recycling Awards and European ACES prize (Chase) in the Materials/Chemistry category 2011. There is strong mentoring of new lecturers by role models in CEB (eg Lowe guided Bahn to establish Psynova) and the **entrepreneurial culture,** which was recognised by the Queen's Anniversary Prize, during RAE 2008, has been followed by the BBSRC Commercial Innovator of the Year award to Lowe, as well as OBE in the 2010 New Year Honours List. **Social Entrepreneurship** aligns well with the CEB sustainability agenda and has motivated direction for research, with a number of emerging but immature case studies. Eg a novel manufacturing process for vaccine formulation and drug production based on natural product extraction in the Third World. The US Agency for International Development has nominated a grant through its Saving Lives at Birth programme, to develop an innovative nipple guard for nursing mothers in HIV endemic regions and a novel heart valve design is being developed with consultant heart valve surgeon at Papworth Hospital. Mental health has also been targeted and its incumbent social problems, leading to foundation of Psynova, the 'youngest' addition to CEB's diagnostics legacy, with a test for Schizophrenia. Similar examples exist focussing on energy and environment: eg Microwave Induced Pyrolysis, to process 2,000 tonnes of waste p.a. is driving up recycling rates through separation and recovery of high-value chemicals present in wastes (Enval), whereas Biobullets, using a zebra mussels' natural filtering to deliver a control ingredient, is preventing fouling of water. The motivation (EU Water Framework Dir., 2000/60/EC) is both water quality and socio-economic activities reliant on water ecosystems. The economic drive comes from $1-5Bp.a. lost revenue and also affirms that targets set through social entrepreneurship require economic market drivers to enable take up.

Underpinning activity: Understanding the diverse drivers and working effectively with industry, is endemic in CEB. Some key training components informed by CEB's research are the seminal work on "Chemical Product Design" (Moggridge), the first dedicated Master's course in Bioscience Enterprise now in its 12th year and an Advanced Chemical Engineering Masters, which won EPSRC Entrepreneurship Training Funds. Partnerships with major multinationals such as BP and GSK coexist with enterprise activities, some inspired by participation in business competitions and awards in each year of the census (eg Medibeta, CamStent, AutoTB, Desktop Genetics; >80% of graduate and doctoral members of CEB participate) as well as the Social Enterprise award for "Khadija's Business Park". Outcomes are also demonstrated in the 2013 CE Equity Portfolio, associated with CEB alumni (who act as Enterprise champions) including Cambfix, Expedeon Protein Solutions and Horizon Discovery. These activities have gone on to raise in excess of £10Million from technology investors.

c. Strategy and plans The department takes a long-term view, in preparation for occupation of a

new £60M building on the West Cambridge campus in 2014/15. It will continue to develop impact through the strategy outlined in (b) and respond to trends due to changes in business drivers, a strengthening of CEB outreach initiatives will be pursued with new multinational industrial partners and serial entrepreneurs, focussing on **(i) industrial secondment** (eg Johnson Matthey and Schlumberger research embedded within CEB) and on independent **entrepreneurs** (eg Bains). **(ii) international reach and influence** (a) *through CREATE* by combing our expertise in Energy related research with that in Singapore to provide a unique approach to energy utilisation on Jurong island. This capacity-adding platform will become a living lab, where we can do reaction-engineering research *that can be translated in an environment where new technology is being implemented*. This and other burgeoning far and middle east activities will mature through the next decade (environment template). (b) *through training activities***,** targeting major international industry, rolled out to deliver to mid/senior level staff, playing to the culture of the MBE flagship. For example, a Chinese industrial programme in Biomanufacturing was delivered in Tianjin in 2013 and our Biopharmaceutical Pricing and Market Access Strategy Programme will be delivered in China in Spring 2014. **(iii) interface with industry**, further strengthened through industry Fora, begun in 2012 as discussed above and via the 3 early career lecturers appointed with industrial experience, where new links are emerging with Jacobs Engineering Group, Timmins CCS (in energy and processes) as well as with Dow Chemical Company, Cadbury's, Kraft Foods, Mondelez International (in materials and food). This will be enhanced by the University's EPSRC Impact Acceleration Award, which will fund flexible secondments between industry and academia. **(iv) major University-wide partnerships:** members of the department will actively contribute to multifaceted partnerships brokered University-wide, for example Nokia, Unilever, BP, Schlumberger, TATA; the former 4 companies have already undertaken collaborative research with CEB during the census period. Similarly, Dennis' involvement with the Foreseer project with BP, provides an online tool for visualising future demand scenarios on requirements for energy, water and land resources. This tool will impact industry, policy- makers and researchers in developing technologies for usage of energy, water and land. **(v) maturing translation in the pipeline** Other sustainable process solutions further exemplifying CEB's core skills are in the pipeline and effort will be invested in their maturation: eg, a software tool (SmartPM), optimally scheduling cleaning of heat exchangers in crude oil preheat trains, permits fouling mitigation. The code was developed with EPSRC funding after analysing the preheat train performance for a refinery *in situ*, and then commercialised by IHS-ESDU; it is now under test by oil companies. CMCL, a business spin-out from CEB in 2008, is also now beginning to provide a conduit for impact with engineering software and technical solutions to automotive, materials, chemical and energy industries. Software has been exported to USA, Germany, Austria, Japan, Turkey and India and future development is indicated by its profile in the UK Trade & Investment's official low carbon automotive directory and the uptake of its recommendations for biomass fuelled chemical looping and carbonate looping carbon capture technologies by the Energy Technologies Institute, with stakeholders including the UK government (DECC, Defra, etc.) to build a pilot demonstration plant in the UK. CEB also expects to see an increasingly important strand of impact in food-related technology eg MCF, bendy chocolate. Furthermore, the University's awards to pump-prime translational projects such as the EPSRC IAA follow-on fund and the MRC Confidence in Concept award (renewal under consideration) will be made use of, as well as the newly established Cambridge Investment Capital, a technology investment company with the University as a major investor, with funds of £50M. This will provide follow-on investments in new ventures in the Cambridge area and will complement the healthy Angel and seed funding already present in the Cambridge environment.

d. Relationship to case studies As stated in (a), impact is driven through 1) **entrepreneurship**, 2) **industrial collaboration**, 3) **clinical relationships.** Together the case studies selected, cover a primary research period from 1998 – 2011 and provide examples of impact across CEB's core research areas. AgaMatrix started as an entrepreneurial venture in metrology in healthcare that has matured beyond an SME to have a multinational operation; Psynova is another example of entrepreneurship at the clinical interface and has been acquired by a multinational (now Myriad RBM). Biobullets and Enval are examples emerging from core research in materials and processes and are now SMEs in production. Other collaborations with industry cited in (b) and (c), which have had outcomes and impact across the value chain, are not available for case study.