Institution: Imperial College London
Unit of Assessment: 13B Metallurgy and Materials
a. Context

Research in the Department of Materials has had a substantial economic, social and environmental impact. The unit's key non-academic user group is industry, with collaborative research and consultancy in the assessment period in the following sectors; oil/gas, ceramics, biomaterials, metallurgy, electronics/communications, aerospace, chemical/pharmaceutical, defence/security and energy. The impact of our research has arisen both within the industrial and professional domains traditionally associated with Materials Science and Engineering (e.g., high performance alloys for aerospace and nuclear, ceramics for extreme environments) and increasingly on new interfaces we have actively developed with adjacent domains such as healthcare, sensing and energy materials. The principal forms of impact include:

- **Economy and commerce**: Industry has benefitted through collaborative research and consultancy addressing key industrial challenges including sustainability, efficiency and competitiveness through the creation of spin out companies offering new products and services and through the patenting and licensing of new IP. During the REF period, we have engaged with over 100 companies and attracted a total of £5M of direct industrial income. (2 Case studies *Jet Engines* (Rolls Royce) and *Solid Oxide Fuel Cells* (Ceres Power))
- **Public policy**: Through influence on the formation of public policy at national and international level particularly in the area of nuclear though formulation of guidance on public policy implementation and appraisal. (Case study *Nuclear*)
- **Environment, Energy and sustainability**: Research in the areas of low solid oxide fuel cells – impact of energy costs, coal fired power stations – impact on environment, nuclear – impact on energy and environment, solar and turbines – impact on reduction in CO_2 emissions and local air pollution. (2 Case studies *Biomass Power Generation* and *Solid Oxide Fuel Cells*)
- **Health and welfare**: Research in the biomaterials and tissue engineering areas has led to the introduction of new products, e.g., by GSK and the development of nanoparticle-based cancer therapy capable of mimicking the transendotheial migration of leukoycytes. (Case study *Bioglass* in Sensodyne™ Toothpaste and in NovaBone® which has to date treated over a million patients).
- **Public engagement**: Our research is actively disseminated through traditional and new media channels (TV, radio, web, social media) – see section b(v) – and through dedicated outreach activities including public lectures, demonstrations and school visits. Our Postgraduate Student Ambassadors have contacted over 200 students and contributed to articles provided to over 400 schools (2013).
- **Security**: The development of novel dielectric resonator based sensors capable of rapid identification of explosive liquids is now being implemented at security checkpoints at European airports with sales by the company Emisens in collaboration with LinkMicrotek.

b. Approach to impact

Since 2008, the Department has made maximising the impact of its research on industry, government, the profession and the wider community, a key priority, in line with Imperial's overall mission: "*To develop our range of academic activities to meet the changing needs of society, industry and healthcare*." During this REF period the Department has expanded significantly with 18 new staff members. This expansion of expertise means that we are now far better placed to exploit our research and create impact. We actively promote and celebrate leading examples of high impact research and senior academics are expected to emphasise the importance of impact within their research groups. In order to ensure that all staff are aware of the College-level mechanisms available to support impact, we work closely with *Imperial Innovations* (a publicly listed company specialising in technology transfer, company incubation and venture funding and providing support in all aspects of patenting and licensing process) and *Imperial College Consultants* (a wholly owned subsidiary of Imperial which handles all aspects of consultancy activity) to arrange briefings on issues such as intellectual property management, start-up formation and consulting practice and to organise drop-in sessions at which staff can discuss tentative ideas for exploitation with nominated contacts. We meet regularly with the College's

Corporate Partnerships team to identify opportunities to apply new research results through the College's existing corporate relationship network (http://www3.imperial.ac.uk/corporatepartnerships/whoweworkwith) and to explore opportunities to develop new corporate relationships based on emerging capabilities. Impact related activities are strongly incentivised by direct payment from consultancy and via a well-developed 'rewards to inventors' scheme for the proceeds from licence agreements and staff setting up spin-outs have a significant shareholding in the business at the outset. Impact and public engagement are also part of annual staff appraisal processes and criterion for academic promotion.

The mechanisms we employ to create and promote impact include:

(i) Industrial Engagement:

- We work with a number of key industrial and public sector partners (e.g. Rolls Royce, BP, Shell, Caparo Steel, Tata, Morgan, Murata, Ericsson, AWE and Baker Hughes), who, as well as partnering with us in individual grant applications to third party funders and directly supporting research of relevance to their business, play an important, wider role in helping us to explore research needs, provide feedback on research visions and advice on pathways to exploitation and commercial impact. Relevant mechanisms include workshops, away days and drop-in clinics with senior industry representatives.
- We also receive support in the form of studentships, discounts and postdoctoral support from companies with whom we co-develop instrumentation and apparatus (Agilent, Kurt Lesker, Mantis, VG Scientia, Rhodes and Schwartz, IonTof) and for whom a London-based activity to showcase their equipment, is advantageous.

(ii) Development and Exploitation of Intellectual Property:

- To aid development of research, we have made use of Impact Acceleration Funding to carry out proof of principle work in order to prepare patent filings, a good example of this was support for the recent discovery of a room temperature MASER and development of a new nanoparticle based cancer therapy.
- Development of IP-to-products is demonstrated by one of our newest companies Emisens, which, in collaboration with Link Microtek, is trialling and selling an instrument based on dielectric resonator sensors developed by members of the Department for very rapid identification of explosive liquids at airport checkpoints (39 units sold to date).
- Successful exploitation of IP, in the area of Solid Oxide Fuel Cells, has allowed us to support fully the BCH Steele Chair in Energy Materials.

(iii)Transfer of Knowledge via Exchange of Personnel

- Interaction with SMEs is a very important route to impact; since these companies tend to be focused on a single topic, the link is usually via an individual academic or research group. Since most SMEs cannot fully fund research work, it is necessary to use other mechanisms such as CASE conversion studentships, Engineering Doctorates and Knowledge Transfer Partnerships (KTPs). *Imperial College Consultants (ICON)* has appointed a manager for the KTP scheme who helps academics in setting up partnerships and also, where appropriate, with their management. The Department has taken advantage of KTPs to facilitate the transfer of individuals and skills between academia and industry.
- The Department also offers support to individual staff members to win industrial fellowships, for example for Dr Shollock in obtaining a Royal Society Industrial Award and Dr Qin in obtaining a Corus (now Tata) funded academic position.
- The majority of our PhD students are directly exposed to industry and in many cases have formal industrial co-supervision arrangements. Over 50% of our PhD projects (2012 intake) involve joint working with industry, as sponsor and/or collaborator. Since 2008, over 40% of our graduating PhD students have gone on to work in industry or industrial research, including at Rolls Royce, Schlumberger and IBM.
- The External Advisory Panel comprises representatives of industrial partners, including IBM, Shell, Rolls Royce, DSTL, Morgan Crucible and the Nuclear Decommissioning Agency, all companies with which we have active research projects. The panel meets once a year to review and advise on the Department's strategy. Advice from the Panel allowed us to obtain College support for a Departmental Research Operations Officer resulting in far better control and indeed expansion of our grant portfolio.

(iv)Transfer of Knowledge via Professional Activities:

- Academic and postdoctoral staff are able to capitalise on their specialised knowledge and expertise by undertaking external consultancy work to benefit society and the economy through *ICON.* The Department carried out consultancy in industries ranging from aerospace, ceramic processing, microwave dielectrics, polymer films and single crystal substrates for LEDs and provided expert advice to International intellectual property disputes. As an example, one IP dispute was successfully resolved in 2012 by our expert knowledge in sapphire with a settlement agreement in favour of our client in Singapore valued at US$7.55M.
- The Department capitalises on its state-of-the-art equipment by charging external bodies for access to its instrumentation and expertise in materials characterisation; such activity is undertaken through *Imperial Innovations.* Examples of organisations that have used our facilities in the REF period are Rolls Royce, Mitsubishi, GSK, Element 6, QinetiQ and US Air Force, the latter choosing to interact with the Department as the instrumentation and knowledge base was "better than anything available in the US."
- Staffs' research output has resulted in them been asked to provide advice to both UK (Nuclear) and to the ESF Materials Science and Engineering Expert Committee (MatSEEC) where Dr Heutz is a member and where Professor Alford was formerly the chair. The Department fully supports such activity, for example agreeing a part-time contract with Professor Robin Grimes to allow him to serve as the Chief Scientific Advisor to the Foreign and Commonwealth Office.

(v) Public Engagement

Since 2008 staff from the Department have increasingly appeared in external media (press/TV/radio/WWW) nationally and internationally to publicise its research to both potential investors and comment on current issues relevant to wider society. Highlights include:

- Professor Ryan received worldwide press, TV and radio coverage for her work on the retrieval and restoration of a WW2 German bomber, the only example of its kind.
- Professor Stevens has continued to maintain a very high profile with press coverage of her work on regenerative medicine. In 2011, Professor Stevens was identified as one of the top 100 women in science by *The Guardian* and was interviewed by Jim al-Khalili for BBC Radio 4 "The Life Scientific".
- The Department's work on the room temperature maser attracted over 200,000 hits on Google within 4 days and a huge amount of external interest from news agencies across the globe including ranking in the IoP world's top 10 Physics breakthroughs of 2012. The Department's work on Graphene was highlighted with interviews on Channel 4, BBC Radio and Sky News and now appears on YouTube.
- Centre for Nuclear Engineering staff based in the Department appeared on national (BBC/Sky News) and international (CBC/Cape talk, South Africa) media to comment on Fukushima.

(vi) Mentoring for Public Engagement

Staff act as mentors to aid junior members of staff in achieving impact for their work and this has helped Drs Wenman and Britton respectively in their winning of industrial support from Rolls Royce, enabled Dr Heutz in her promotion to the MatSEEC committee (an organisation that advises the EU on funding for materials research and development), assisted Dr Wenman to give radio interviews on Fukushima and resulted in Dr Payne giving evidence to the House of Lords Select committee on major facilities. Drs Moram and Giuliani featured in *Materials World* in 'Ones to Watch', which highlighted 35 worldwide materials scientists, under the age of 35 and Professor Stevens was awarded the EU-40 Prize by The European Materials Research Society, 2012.

c. Strategy and plans

In the future, whilst building on the successful strategies outlined in section b., we recognise that the Materials Science and Engineering sector itself is capable of change on remarkably short timescales. The new areas we are developing in the areas of organic electronics, ultra-sensitive disease detection, very low noise amplifiers based on room temperature MASERs and new techniques for detecting liquid explosives. To maintain our success, we must respond rapidly. In brief, the many aspects of the sector's key trends we see are:

- Continuing disruptive technological innovation resulting in the further blurring of traditional disciplinary boundaries, increasing the need for multi-disciplinary collaboration.

- Accelerating globalisation and development of the Biomaterials/Bioengineering industry, creating new technical challenges, new industrial players and new routes to impact.
- Greater emphasis on the efficient and sustainable whole life use of materials including sustainable and non-polluting power generation and storage.
- Greater involvement in policy at government level to shape the future energy research agenda.

To respond to these emerging challenges and opportunities, we intend to:

- Undertake horizon scanning exercises, jointly with our strategic industrial partners and key overseas academic collaborators to identify the main technological and institutional trends.
- Develop a new Departmental communications strategy, placing key emphasis on impact and on positioning ourselves to benefit from the changing global context (Materials Gateway).
- Create a senior Departmental post with responsibility for overseeing translation and impact, reporting to the Departmental Research Committee.
- Extend the very successful industrial club model more generally across the Department. We are currently piloting this approach through the Centre for Advanced Structural Ceramics consortium (CASC) exploring alternative business models for subscription and arrangements for access to students, researchers and facilities.
- Engage closely with the College in developing Imperial West, a 22.75 acre site for translation activities.

d. Relationship to case studies

We have submitted 5 case studies demonstrating how our research has generated impact.

Impact mechanism: Direct work with Government Agencies: Our case study *Nuclear* builds on several years of Government interaction. Professor Grimes was technical advisor (nuclear) to the House of Lords Science and Technology Committee for their report on Nuclear R&D Capabilities and Professor Lee was Deputy Chair of the Government Advisory Committee on Radioactive Waste Management. When the Fukushima Nuclear accident took place, Professor Grimes was appointed to the UK Scientific Advisory Group in Emergencies committee that handled all Government announcements and he is now Chief Scientific Advisor to the Foreign and Commonwealth Office.

Impact mechanism: Spin-out: Within the Ceramics and Glasses theme, research into ionic conductors for *Solid Oxide Fuel Cells* led by Professors Steele, Kilner, Brandon and Atkinson led to the spin-out, Ceres Power listed on the Alternative Investment Market and employing over 140 people. The research is still on-going and has led to the use of surface analysis techniques in the study of new materials for use in solid oxide fuel cells.

Impact mechanism: Direct work with large companies: Our case study *Jet Engines* builds on work that began in the 1990's with Professors McLean and followed through with Professors Lindley, Flower and P.D. Lee and Drs Shollock and Dye supported by Corus and by Rolls Royce. The key output was a far better understanding of the microstructure property relationship in nickel superalloys for turbine blades. Our case study *Biomass Power Generation* describes how research in the Department on *Low NOx* burners have led to reductions in energy consumption and improvements in recycling in power stations. These case studies are illustrative of how research undertaken in collaboration with industry can lead to commercial and environmental benefits.

Impact mechanism: Dissemination of intellectual property: The case study *Bioglass* builds on pioneering work by Professor Hench and Dr Jones that led to the use of biomaterials in Sensodyne^{TM} toothpaste, now one of the fastest selling toothpastes in the UK.

Summary: With the exception of the case study *Nuclear* in which the research that Lee and Grimes carried out was of direct relevance to advice given to Government bodies, the thread that runs through all the case studies is a recognition that fundamental research is a prelude to commercialisation and that this is both nurtured and supported within the Department either through direct technology transfer via research projects, as is the case with the *Jet Engines*, *Bioglass* and *Biomass Power Generation* case studies, or via industrial activity as is the case with *Solid Oxide Fuel Cells* (Ceres Power) and Emisens.