Institution: University of Birmingham
Unit of Assessment: Metallurgy and Materials (UOA 13b)
a. Context: Our materials' research produces major economic benefits and impacts for UK industry, with particular emphasis on the aerospace and nuclear power sectors. The impacts of our studies extend not only to improvements in products and processes, but also to improvements in risk assessment for both safety critical applications and the reduction of environmentally damaging emissions. Metallurgy is the discipline at the core of our research activity (with 77% of staff engaged primarily on metallurgical research), and in terms of wealth creation it has close affinity with 'High Value Manufacturing'. We operate with four research groups: (i) alloy processing and process simulation; (ii) functional materials; (iii) materials characterisation, alloy development and materials modelling; (iv) engineering properties and degradation. Our metallurgical research is now much more focused on translation into commercial products (components). In the past the development of new alloys contributed markedly to scientific understanding and the knowledge base, but routes to commercial exploitation comprised only the gradual diffusion of this newly created understanding into industry. The 'cradle to grave' approach for 'design driven materials' adopted by our Interdisciplinary Research Centre (IRC) in Materials for High Performance Applications in the 1990s emphasised the importance of a target component (with required performance properties that had to be achieved) and this approach now features strongly in our current research. This approach also recognised the importance of multi-university and interdisciplinary research in exploiting materials developments. Our current approach to impact not only incorporates these features, but also crucially emphasises commercial exploitation as a priority. This has led to the Manufacturing Technology Centre (MTC) in 2010, and to the High Temperature Research Centre (HTRC) - due to open in 2015. MTC is a not-for-profit company limited by guarantee, in which the University is one of four partners with TWI and the Universities of Loughborough and Nottingham. Our activities in collaboration with MTC have already impacted on the rapid introduction of new products and processes within the aerospace sector; for example inertia welded components incorporated in the latest Trent 1000 aeroengines of the Boeing 'Dreamliner' 787.
b. Approach to impact: Our mechanisms are based around: (i) **long-term relationships with industry usually supported by securing major grants/funding in collaboration.** For example, the Rolls-Royce/EPSRC Strategic Partnership (2009-2019) integrates long-term major materials' research programmes with core areas driven by postdoctoral research associates (PDRAs), together with cohorts of doctoral researchers (PhD/EngD) networked to ten universities and eight companies. The School's success in seizing opportunities for impact is exemplified by the growth of its relationship with Rolls-Royce, from a relatively small-scale University Technology Centre on titanium alloys to its present day interactions across a wide spectrum of research, with over 70 individual research programmes annually. Such relationships are critical in ensuring that Rolls-Royce, with its global opportunities for research, remains anchored in the UK for its core research programmes on materials. More generally, we have long-term research programmes with over twenty companies (predominantly within the UK) and with over one-hundred companies involved in some form of collaboration. (ii) **the development of MTC (and later HTRC) to allow the rapid introduction of new products and processes into industries.** One example - the development of titanium aluminides features in one of our impact case studies. However, the expected entry into service of the first component (2015) from our research studies in the 1990s serves to illustrate the step-change required to introduce new alloys more quickly. The challenge can be expressed using Technology Readiness Levels (TRLs) and Manufacturing Capability Readiness Levels (MCRLs) adapted from NASA – where the scale ranges from fundamental scientific studies (1-3) through to full, validated use in service (9). Universities are adept at fundamental studies (TRL 1-3) and process innovation and simulation studies (MCRL1-3), while companies are proficient at exploiting validated technology (TRL7-9) and mature processes (MCRL7-9). Gaps at TRL/ MCRL4-6 require scaled-up facilities and validation in a production-simulated environment such that 'right first-time' introduction of materials/processes into service applications can be achieved. While not neglecting our activities on scientific understanding (TRL/MCRL 1-3), through MTC we seek to bridge these gaps, while HTRC will have the potential (2015) to integrate fully TRL/ MCRL1-9. The University recognising the potential for MTC, invested significant resource (both manpower and financial underwriting of £1.5M) to support the School of Metallurgy and Materials and the development of

research themes during the start up phase of MTC. We provide scientific underpinning for all major research themes within MTC. As an example, we have worked closely with Rolls-Royce to support the rapid introduction of linear friction welding technology (for titanium blade-to-disc combinations) and inertia welding technology (for advanced nickel based superalloy disc-to-disc combinations and by utilising facilities at MTC) within the current assessment period. Thus, underpinning research of a fundamental nature has been carried out on full-size facilities to achieve an accelerated maturation of these new technologies;

iii) **the use of doctoral researchers (PhD/EngD) to establish, to cement and to grow our relationships with industry.** These researchers provide a potent knowledge transfer mechanism by developing patents and by often pursuing careers with their sponsoring companies. The School has won a series of EPSRC major awards/programmes to support its home/EU postgraduate researchers. Our large body of postgraduate research students plays a critical role in creating impact. The School secures part-sponsorship of such students by industry, together with support from Research Council and Central Government. Typically 80% of all doctoral researchers collaborate with industry during the course of their research programme. Over 70% of EngD research engineers join their sponsoring company on completion of their studies, and since 2008 EngD students alone have filed approximately forty-five patents with company support;

iv) **academic research staff.** Here acknowledgement is made of the individual contributions of our PDRAs. Six have been in post continuously for more than fourteen years and we support progression by the use of open-term contracts and/or senior research positions. These staff members provide specialist expertise across our research groups. Next we note the continuing presence in the School of (part-time) visitors from external organisations is extremely helpful in facilitating impact – for example, currently, Dr M. Lunt (DSTL), Prof. P. Withey (Rolls-Royce) and Dr Z. Zhang (Doncasters). Academic staff are also encouraged to hold individual positions on advisory committees at national level. An example is our involvement in the Graphite Technical Advisory Committee (GTAC), focused primarily on aspects of nuclear safety. It provides input to industry and to the Office of Nuclear Regulation (ONR) and under the Chairmanship of Bowen, it has considered aspects of safety cases that have proved critical to the life extension of Magnox and AGR nuclear power stations. Founded in 2004 (with Bowen, Knott), GTAC has produced over 46 reports to date and has contributed to eight safety cases. Formal GTAC reports are available from ONR under Freedom of Information requests. A further eight staff hold positions on advisory committees at national/international levels. Although he is now retired, Knott's part-time presence provides contacts with wider aspects of nuclear safety (and with Rolls-Royce).

c. Strategy and plans: Our future plans and strategies for impact over the next five years rely principally on our existing large-scale initiatives and their future development. We also highlight examples of expansion in three key areas. All research programmes will be supported both by: comprehensive characterisation studies, with an increasing emphasis on 3D imaging across a wide size range (components to atoms); and, the numerical modelling of materials' microstructures/properties and of manufacturing processes. Both characterisation and modelling are regarded as critical enabling capabilities for our planned programmes. To deliver these plans will require that we, at least, maintain our numbers of doctoral researchers and PDRAs at current levels.

Existing large scale initiatives.

i) <u>EPSRC/Rolls-Royce Strategic Partnership.</u> Central to our strategy for future materials impact within aerospace is the Strategic Partnership which is due for renewal in 2014 for a further five years. This integrated training (doctoral researchers) and research (PDRAs) programme also supports doctoral researchers at Birmingham with Tata Steel, Timet and AEC in addition to core support from Rolls-Royce. It is a vehicle for creating impact through the introduction and use of new/improved alloys over 5, 10 and 20 year horizons.

ii) <u>MTC.</u> This provides an ideal focus for much of our scientific research in support of 'High Value Manufacturing'. We have the opportunity to exploit our fundamental understanding of materials processing, simulation, characterisation and behaviour across a range of TRL/ MCRLs by linking our University based research through MTC to end users. This will promote the rapid entry into service of new components and technologies. In addition, we will continue to provide distinctive materials scientific expertise to underpin major manufacturing research themes (especially net-shape manufacturing and high integrity welding and fabrication) at MTC as it continues to expand on the Ansty Park site. There are many exciting opportunities for us in partnership with MTC:

within the UK, across Europe and globally. These opportunities encompass education and training in the (£36M) MTC Elite Training Centre (announced recently) through to support for doctoral researchers and experienced PDRAs. One scientific focus for the next five years will be modelling and simulation - here continued growth will generate an integrated team of at least 60 such researchers shared equally across the University and MTC locations. This will also enable MTC to lead a major initiative to drive the increased use of modelling/simulation into UK industry.

iii) <u>HTRC</u>. This presents a major challenge over the next decade: the establishment of a unique world-class research and development facility to enable a step change to be made in the research capability in the UK in the areas of materials, investment casting, design for manufacture and systems simulation. The facility will place the UK at the forefront of casting technology world-wide - linking fundamental understanding with fast design-and-make capability. In 2011, Rolls-Royce invested £908M on research and development, two thirds of which had the objective of further improving the environmental performance of its products, in particular reducing emissions. A key driver of engine efficiency is the high temperature turbine performance. To enable higher turbine temperatures to be achieved requires the development of new improved alloys, but net efficiency gains also require new design concepts to reduce 'parasitic' cooling losses. To realise these advanced designs, new and improved manufacturing technologies are required in the investment casting process. To accelerate the development of design and manufacturing technologies for high temperature turbine components, a dedicated research facility is required where existing research can be executed more effectively and new research capacity can be created. This is a primary goal and it is envisaged that an integrated team of 80 researchers will be located at HTRC.

Key areas for expansion.

i) <u>Critical materials and their reclamation</u>. Our intention is to pioneer at proof-of-concept stages and beyond, commercial scale recycling processes for rare earth magnets that will provide a long-term stable supply of materials which are crucial both for existing uses, such as magnets, and emerging clean energy technologies (wind turbines and electric vehicles).

ii) <u>Additive layer manufacturing</u>. In extending our work on aerospace structures (blades and guide vanes), we will address complex functional structures that can achieve a specific mechanical performance or physical advantage (auxetic structures, sonic crystals, and mesh catalytic structures). It is expected that this technology applied to difficult-to-process aeroengine materials will enable significant increases in 'turbine inlet temperature', increased compactness (due to mass flow reductions) and a ten-fold reduction in lead times. A targeted area is within materials and components for missiles - building on current work with the UK MoD and French DGA.

iii) <u>Nuclear power generation.</u> Here we will remain heavily involved in life extension and safety issues of AGR stations. We will also continue to develop expertise in niche areas of relevance to new-build (PWR) opportunities and to prosecute fundamental irradiation studies using ion bombardment (cyclotron experiments). These latter studies will support both new build of LWR plant and also efforts to solve materials challenges in Generation IV reactors and Fusion reactors.

d. Relationship to case studies: Case studies chosen, illustrate impacts across the full-range of our research groups. Our studies of advanced melting and casting of high temperature alloys for aeroengine gas turbines, highlighting single crystal (SX) investment casting of nickel blade alloys and the development of titanium aluminides, demonstrate co-operation between our research groups to deliver major technologies and investment within the UK. The second case study is on the use of hydrogen processing to reclaim rare earth metals. This is a powerful illustration of how detailed scientific studies over an extended period to optimise magnetic properties through understanding processing-microstructure relationships, can be utilised in a previously unforeseen manner to stimulate recycling opportunities on 'the grand scale' for metals of strategic importance. The third case study involving advanced processing and simulation demonstrates the success of our approach to impact, including interactions with the current MTC, where new advanced processes can be researched on an industrial scale, validated and simulated to shorten exploitation timescales and promote 'right-first-time' manufacturing. Finally, opportunities for the extremely large economic benefits that can accrue if engineering properties (and their degradation) in service can be predicted through-life are illustrated in our fourth case study. Detailed understanding of failure mechanisms and predictive models of behaviour have contributed critically to life extension in the major industrial sectors of aerospace and nuclear power generation.