Institution: University of Liverpool

Unit of Assessment: 8 Chemistry

a. Context

The Department of Chemistry has an outward-facing philosophy and engages with research activities across a wide range of scientific communities, from industry to public events. Our research aims to address fundamental science challenges, as well as contribute to societal and economic needs. This is reflected in our interdisciplinary research clusters (**Materials Chemistry, Medicinal and Bio-nano Chemistry, Energy and Catalysis, Functional Interfaces, Theoretical and Computational Chemistry**).

Principal beneficiaries of our research impacts are: multinational companies and SMEs; healthcare clinicians; charities and related bodies [such as Medicines for Malaria Venture (MMV)]; and local schools and colleges which benefit from our outreach activities. Our achieved impacts include: economic and environmental benefits resulting from improved chemical manufacturing processes; healthcare benefits relating to improved diagnosis and treatment of diseases; and changes in policy relating to drug development and economic benefits from new products brought to market. Impact is facilitated by collaborations with researchers in the Faculties of Science and Engineering and Health and Life Sciences, particularly in areas allied to medicine and healthcare. Our interactions with a wide range of industrial partners are assisted through research facilities such as the Centre for Materials Discovery (CMD), the Knowledge Centre for Materials Chemistry (KCMC), and the Ultra Mixing and Processing Facility (UMPF), which provide industry with ready access to our skills, expertise, and specialist equipment.

Non-commercial impact on society and culture is generated by our schools' outreach activities for Years 7–13, which are delivered in state-of-the-art laboratories.

b. Approach to impact

Research activity is developed through our Research Committee (chaired by **Rosseinsky**), which has established interdisciplinary research clusters that map onto the UK Innovation landscape with the identification of Advanced Materials and Energy Storage, as two of the Eight Great Technologies that will propel UK Growth (Business Innovation and Skills, 2013).

The Research Committee also provides an early review of new grant applications aimed at connecting applicants with potential beneficiaries (established through CMD and KCMC partners) so that impact is identified at project onset. Successive Heads of the Department of Chemistry have encouraged Knowledge Exchange (KE) and outreach by prioritising pump-priming funds. The Department supports impact through targeted provision of DTA studentships to collaborate with industry and allocation of teaching/administration duties and sabbatical support to facilitate these opportunities. All of the staff leading our case studies have benefitted from DTA studentships during the REF period.

To promote interdisciplinary collaborations and ensure a strong connection to research areas that address societal needs (e.g. energy, medicinal chemistry and nanomedicine), the Department has pursued joint appointments with other departments within our University e.g. **Hofer** (Physics), **Levy** (Biological Sciences), and **McDonald** (Q3 2013) and **O'Neill** (both Molecular and Clinical Pharmacology).

Interdisciplinary collaborations resulting in significant impact include; a major antimalarial project involving **O'Neill** with Ward (Liverpool School of Tropical Medicine) and Park (Institute of Translational Medicine)] together with GSK and Medicines for Malaria venture (MMV, a public-private partnership that internationally coordinates the development of antimalarial medicines). This project developed and trialed a novel 4-aminoquinoline drug candidate, Isoquine, in a Phase 1 clinical trial in humans in 2008. Data derived from the clinic resulted in MMV changing its drug development policy and drug safety guidelines with respect to the 4-aminoquinoline class of antimalarial. **Aspinall's** collaboration with Chalker (Engineering), developed from a Liverpool spin-out company, has led to an impact case study resulting in a collection of new and improved precursors for chemical vapour deposition.

Industry has been attracted to collaborative projects through the Department's state-of-the-art research facilities and internationally leading expertise. For example, the CMD is an open access facility for high-throughput materials discovery (led by **Al Cooper**), that hosts industrial scientists for short to long-term projects. During the REF period, an average of 12 Unilever staff were co-located in the CMD and a further eight companies used CMD facilities; in total 264 staff from external organisations received training and accessed experimental facilities in the CMD laboratories. Other research facilities that have attracted industrial collaborations include the KCMC (led by **Rosseinsky**), and the UMPF mixing centre (led by **Brust** initially, then **Shchukin)**. The KCMC has engaged with more than 120 companies and set up Knowledge Exchange partnerships enabling a total of £9M revenue, including £1.5M industrial funding, during the REF period.

These research facilities foster long-standing relationships with non-academic partners and have also allowed us to develop impact at both a regional and national level. Regionally, we are a member of the Liverpool City Region Local Enterprise Partnership (LEP) and contribute to the Knowledge Economy priority, specifically the Advanced Manufacturing theme (via both the CMD and UMPF). The KCMC, initially a regional project, now has a national remit having secured funding from the TSB to continue and expand its activities on materials chemistry innovation with industry. As a founding member of the KCMC, our research outputs are disseminated to the relevant industry sectors through the KCMC networks, with resulting collaborative R&D projects managed by a dedicated Knowledge Transfer Team. Our future strategy and plans centre on the development of a Materials Innovation Factory (MIF) with Unilever, which will advance the CMD model of industrial collaboration to a significantly enhanced level.

Collaborative projects with potential commercial impact are exemplified by Technology Strategy Board (TSB) funded projects and include: (i) Improved Processes and Materials for Energy Saving Glazing (**Rosseinsky**, Pilkington); (ii) Functional, Renewable and Sustainable Hybrid-Materials (**Al Cooper**, Unilever); (iii) Manufacturing Innovation for Resource Efficient Structured Liquids (**Brust**, UMPF with Unilever and Maelstrom APT). Through TSB funding, five new projects have started in the REF period with a total income of >£1.6M. New materials for oil-recovery are being developed (**Al Cooper**, **Satherley**) through a major BP project (£1M value). The Department currently has active research links with >30 companies, including AstraZeneca, BP, Johnson Matthey and Unilever, and SMEs such as ACAL Energy Ltd. 10 staff are inventors on a total of 59 unique WO, European, US or GB patents (published since 2008). Of these 25 were published in collaboration with Unilever; Bayer; Johnson Matthey; and Thermo Electron.

Non-commercial impact is largely derived from our School's extensive outreach programme which is led by **Aspinall** and delivered by academic staff, dedicated outreach staff, and postgraduate research students in our new, state-of-the-art, undergraduate Central Teaching Laboratories (CTL). We deliver 45–50 practical workshop sessions per year for schools/colleges, each catering for around 20 students (>3000 students in total since the start of the 2007/8 academic year). The workshops are based around research interests in the Department: e.g., 'Porous polymers' have been developed by summer students funded by EPSRC (Complex Materials Discovery Portfolio Partnership) and popular workshops based on gold nanoparticles, have been developed by undergraduate students. Students benefit from conducting research-based practical work in a state-of the-art laboratory with hands-on use of equipment unavailable to them at school.

Impact through public engagement is exemplified by an EPSRC public partnership grant (**Raval**) 'Giants of the Infinitesimal' (http://giantsoftheinfinitesimal.com), which created an interactive exhibition on nanoscience and nanotechnology for school children. With over 300,000 visitors, the exhibition has attracted profiles in Times Magazine and BBC Radio 4's You and Yours programme. Additionally, the British Society for Nanomedicine (Vice Chair **Rannard**, www.britishsocietynanomedicine.org), is a registered charity, which promotes UK nanomedicine through the creation of a portal to enhance public engagement with leading-edge nanoscience through provision of lay-summaries of research outputs.

c. Strategy and plans

We believe our research strengths in materials, energy, catalysis, bio-nanotechnology, and medicinal chemistry provide the foundation for a wide range of industrial collaborations, and are

underpinned by our emphasis on fundamental areas such as structure; synthesis; spectroscopy; mechanisms; computational techniques; and thermodynamics. This approach complements our aims to address fundamental science challenges, in tandem with societal needs and economic challenges. To achieve this vision and maximise opportunities to exploit impact, we have developed the following core objectives:

1) Exploiting MIF for a new level of academic-industrial collaboration. The MIF is a £68M project (funded by UK Research Partnership Infrastructure Fund, HEFCE, the University, and Unilever), which will take our CMD model to a higher level, allowing the collocation of >100 industrial scientists in an advanced facility for functional materials discovery. The chosen research themes (sustainability; nanomedicine; high throughput formulation; and biotechnology) address societal challenges in energy, healthcare and sustainability, and have been identified for their likely future scientific and industrial impact and alignment with both National and European Innovation Strategies.

2) To address future societal needs in energy through the Stephenson Institute for Renewable Energy (SIRE). This Institute brings together energy-related research activities from across the Faculty and has benefited our department through the appointment of seven new researchers. In particular, the appointment of **Shchukin** (chair) expands our research expertise into more applied themes such as encapsulation technology. The Department's success in generating impact through interdisciplinary research centres is exemplified by the case study on ethyl acetate production, involving **Kozhevnikov** (Leverhulme Centre for Innovative Catalysis within the Liverpool Chemistry Department) and BP.

3) With support from our University, the Department plans to establish a Centre for Medicinal Chemistry that will build on strengths in Chemistry, the Liverpool School of Tropical Medicine, and the MRC Centre for Drug Safety Science. To provide critical mass and expand our research programme into new areas, this centre is also being supported by two new chemistry appointments, nanomedicine (**McDonald,** Q3 2013) and in medicinal chemistry (planned Q2 2014). Our research in nanomedicine will also benefit from a new research lab (£0.6M, part funded by Unilever) which will integrate radiolabelling into our existing facilities.

4) Actively marketing our skills and expertise to industry. **Raval** is developing scoping workshops where leaders from multinationals, SMEs and academia outline challenges and forge interdisciplinary teams to address them. A key example is the launch of the Open Innovation Hub for Antimicrobial Surfaces set up to combat microbial attack on surfaces. The Hub will create rapid innovation pipelines by developing connections and forging partnerships between academia and the supply chains that connect innovative SMEs with market leaders. Close links with Knowledge Transfer Networks and the NHS will enable the Hub to direct industrial and academic innovation to societal needs. Starting in Q4 2013, funding from EU, TSB and the European Research Development Fund, has enabled £3.7M worth of projects to be launched, involving 20 companies.

5) The Department plans to exploit IP more proactively in the future and this is facilitated by the Institution's new IP exploitation model (ClearView IP), which uses an operations team (**Rannard** is an IP champion and member of the team) to evaluate and develop the model.

6) Strengthening outreach through the CTL, which provides a world-class facility for teaching chemistry, and the allied subjects of physics and environmental science. The capacity and exceptional range of equipment at the CTL will significantly expand our school's outreach activities and grow impact by enhancing chemistry education in schools and monitoring its effect.

d. Relationship to case studies

Our impact case studies demonstrate that our impacts have been achieved through long-standing industrial collaborations [*e.g.*: methylmethacrylate production (**Iggo**); chemical vapour deposition (**Aspinall**) and ethyl acetate production (**Kozhevnikov**)] and through delivering high quality outputs that attract companies to our research [for example: gene sequencing (**Cosstick**)]. Our strategy and plans are designed to: promote our facilities and expertise to beneficiaries; make researchers in the Department more aware of the potential applications of their work and put them in contact with beneficiaries at a much earlier stage of project development.