Institution: Cardiff University

Unit of Assessment: 8 Chemistry

a. Context. The School's high quality research translates fundamental chemical understanding into a broad spectrum of applications. These include health (e.g. novel imaging agents), clean chemical manufacture (e.g. exploiting benign oxidising agents), environmental clean-up (e.g. exhaust after-treatment), sustainability (e.g. replacing rare metals in catalysis), security (e.g. sensors for chemical warfare agents) and energy (e.g. processing and reforming biofuels). The end-users are the many industries and national/international organisations with which the School collaborates. This is best exemplified by the Cardiff Catalysis Institute (CCI) which has close interactions with over 30 companies worldwide, attracting over £5M of industrial funding since 2008. The School's network of industrial contacts provides a supply-line of challenges that continually revitalise its research agenda, as illustrated by the development of a train of novel catalyst technologies for the manufacture of chemical products as diverse as Perspex and hydrogen peroxide.

b. Approach to impact.

Interaction with End-users. The School interacts with both traditional and emergent industrial sectors that rely on chemical technology, as well as with the national and international organisations that support these sectors through knowledge transfer. In particular, within the manufacturing sector, it interacts with all parts of the chemistry supply chain – from producers of raw materials and chemical intermediates through to original equipment manufacturers.

These synergies are nurtured through several mechanisms at different stages of technology-readiness. Recent and ongoing examples are:

- Early-stage training - Murphy has trained staff from AstraZeneca in the techniques of electron paramagnetic resonance spectroscopy, helping to establish a research unit to exploit this technique for pharmaceutical development.
- Interdisciplinary research collaborations - The School is part of the Jaguar Land Rover *University Aftertreatment Research Consortium* and the Johnson Matthey *Bauhaus* Programme, both of which provide an interface between several university groups and the sponsoring companies.
- Proof-of-concept studies - McKeown has been funded through the TSB Innovation Voucher scheme to carry out research for Safe Training Systems.
- Provision of technical expertise - Members of the School have held consultancies with the Environmental Protection Agency of Ireland (Attard, 2008); BP America (Bowker, 2008-); Dow Chemicals (Bowker, 2007-9); King Abdullah University of Science and Technology (Bowker, 2011); GE Healthcare (Buurma, 2010); Cambridge Display Technology (Carpenter, 2011-); Dow Corning (Dervisi & P Edwards, 2007-); Asalus Innervision (Fallis, 2011); BG-Tunisia (Golunski, 2012-13); Panasonic UK (Golunski, 2012-13); AstraZeneca (Harris, 2008); Eastman Chemicals (Hutchings, 2008-10); AstraZeneca (Murphy, 2008); Johnson Matthey (Willock, 2008; Murphy, 2009); Oxford Catalysts (Taylor, 2008-9); Sasol (Murphy & Cavell, 2008-2012).
- Technology Transfer - A Knowledge Transfer Partnership (KTP) has been established between the CCI and Selden Research.

Such collaborations are frequently prompted by the high-profile dissemination of our research. The initial interaction often consists of a joint exploratory research project, with specific objectives set by the industrial sponsor, followed by more extensive stage-gated programmes, such as those funded by the Technology Strategy Board (e.g. the collaboration between Golunski and G-Volution on the enhancement of fuel economy of haulage trucks) or the EU (e.g. the collaboration between McKeown and Tecno Project Internationale, Italy, to develop enhanced gas separation membranes). More locally, the Welsh Government's *Academia for Business (A4B)* and related programmes have helped to establish Knowledge Transfer Centres, enabling enterprises in Wales to access the School's expertise and facilitate knowledge transfer and collaborative R&D activities in the areas of catalysis (Taylor) and contrast agents for medical imaging (P Edwards, Pope).

Over the assessment period, industrial beneficiaries have provided a total of over £6.0M to the School in direct research funding (i.e. sole-funded projects, industrial CASE awards, and matched-

funded studentships). This represents a 4-fold increase over the direct industrial funding secured during the RAE2008 assessment period, with a corresponding increase in the number of researchers in the School working on industry-specific projects. Further indirect funding of £2.0M has come from collaborative projects funded by government bodies (such as the Technology Strategy Board), while substantial in-kind industrial support (e.g. staff time and high-value raw materials and precious metals) has been used to leverage research council funding.

The list of partners funding research over this period highlights the breadth of interactions:

- *UK Industry:* AstraZeneca, AWE Hunting BRAE, Aventis Pharma, BP International, Cogent Power, GE Healthcare, GlaxoSmithKline, G-Volution, International Greetings UK, Invista Intermediates, Jaguar Land Rover, Johnson Matthey, Magnox Ltd., Molecular Light Technology Research, Molecular Products, Novartis Pharmaceuticals, Neem Biotech, Optas Ltd, Oxford Catalysts, Panasonic, Polymer Health, Prosidion, Quest International, Safe Training Systems, Selden Research, Syngenta, Unilever.
- *International Industry:* Acta Spa, BG-Tunisia, Dow Chemicals, Eckert & Ziegler, Exxon Mobil, General Motors, Henkel AG, Pierre Fabre, SABIC, Sasol Technology, Scania CV Aktiebolag, Solvay Duphar BV.
- *Non-industrial End-users (facilities and labs):* Diamond Light Source, Defence Science and Technology Laboratory, Defense Threat Reduction Agency (US), ESRF, ISIS, Institut Laue-Langevin, National Physical Laboratories, and the National Nuclear Laboratories.
- *Market Developers:* World Gold Council.

Many of these collaborations began before 2008, with the first project's success leading to repeat funding from the end-user, e.g. Exxon Mobil, Invista Intermediates, Johnson Matthey, SABIC, Sasol Technology, Selden Research and World Gold Council. However, the list has grown over the past 5 years to embrace a wider sphere of industrial users of chemical technology, such as car and engine manufacturers (General Motors, Jaguar Land Rover and Scania).

Evidence of the Identification of Potential Impact. The most tangible evidence is provided by the School's record in protecting its intellectual property (IP). Since January 2008, the University has filed 11 discrete patent applications originating from research carried out within the School. These applications result from a clear-cut route for identifying exploitable IP. Whenever a material, design or chemical process is believed to be novel, the details are submitted in the form of an Invention Disclosure to the Research, Innovation & Enterprise Services (RIES) of the University - 21 disclosures were submitted by the School during the assessment period. If a disclosure results in a positive evaluation of potential IP, the RIES Technology Transfer Group requests funding for a patent application from the University's Commercial Advisory Panel (CAP), made up of local industrialists, entrepreneurs and representatives from Fusion Cardiff (a venture company providing funding and expertise to exploit technology - http://www.fusionip.co.uk). Our industrial partners have filed 8 further patent applications in the REF period. These resulted directly from sponsored research at Cardiff and included our staff among the named inventors.

Evidence of an Agile approach to Opportunities and Institutional Support for Impact. Mechanisms are in place to ensure rapid transition from a fundamental research phase to a development pathway. For example, RIES actively supports grant applications to enhance the commercial potential of IP through EPSRC schemes such as *Follow-on-Funding* and *Collaboration Fund* support. In the REF period, the School made 9 successful applications to fund such projects, including catalyst technology (Hutchings), photovoltaic materials (Pope) and sensors for detecting chemical warfare agents (Fallis). Support for promising IP related to gas separation membranes (McKeown) and electrochemical engineering (Attard) was also accessed through the EPSRC *Impact Acceleration Account* administered by RIES. In addition, RIES facilitated support from the University's *Cardiff Partnership Fund* for postdoctoral resource at the critical proof-of-concept phase in the development of photovoltaic materials (Pope) and enhanced delivery of anaesthetics (Paul), and from the *Early Stage Development Fund* for the scale-up of novel gels for sedation (Paul).

Incentives for Staff to Follow-up on Research Impact Activities. Staff members are actively encouraged to identify inventions and know-how arising from their research prior to dissemination,

so that these elements of IP can be protected. Advice on IP protection is readily available from the School Innovation & Impact Officer (Golunski) and other members of the Research Committee, including the Research Section heads and the School's designated contact in RIES. The University runs a generous income-sharing scheme for licensing royalties to reward staff who exploit their IP.

c. Strategy and plans.

Our strategy is underpinned by the belief that fundamental research - often starting from theory - when targeted at real-world challenges, will lead to IP that can ultimately generate new and improved technologies with maximum potential for application. Therefore, we actively pursue opportunities to patent and license materials, designs and processes through a 3-point plan:

(i) Identification - The School Innovation & Impact Coordinator monitors emerging technologies with support from our dedicated contact in RIES. They are both permanent members of the School Research Committee, which first assesses any new IP.

(ii) Facilitation - The School Research Committee and RIES work closely with the key investigator(s) to define the next steps in developing the technology. These might include the sourcing of follow-on funds from the research councils or, increasingly, selecting an industrial partner to pull the new technology from the laboratory to the market-place.

(iii) Project Management - A team (typically, key investigator, School Innovation & Impact Coordinator and RIES representative) manages the exploitation process as far as the point of technology transfer to an end-user or a product-developer. The School has over 40 staff-years of industrial experience at its disposal (Bowker, Cavell, Golunski and Hutchings having held full-time posts in major companies), which it uses to steer the process.

The effectiveness is demonstrated by recent patent applications relating to colorimetric sensors for detecting chemical warfare agents (Fallis), nano-dispersed gold catalysts (Hutchings), novel amine-based microporous polymers for gas separations (McKeown) and a dispersion anaesthetic device (Paul). These technologies are now at different stages along our 3-point pathway.

Our success has led to a divergent and growing research portfolio, with steps in place to manage the transition to convergent (development focused) activities. In this respect, CCI's industrial interface is a successful template for impact generation that we aim to replicate in other areas. A core group of industrial affiliates provides direction for research and exploitation, and in return has access to CCI's non-proprietary scientific developments. The affiliates represent largely complementary industries (to avoid conflicts that might arise among competitors) from local SMEs (e.g. CatSci) to business units within multinational companies (e.g. Shell Global Solutions).

Our longer term plans include building alliances with other academic centres with complementary expertise (such as the other *GW4* universities), allowing us to create critical mass for impact in new areas, particularly sustainable and green technology. This is best exemplified by the recent successful bid by UK centres active in catalytic chemistry and engineering for a UK Catalysis Hub, in which the School is a principal player and of which Hutchings is Director.

d. Relationship to case studies.

Enabling the cost-effective and environmentally friendly production of Perspex originated from an industrial contract with Ineos Acrylics (now Lucite) to the P Edwards research group for focused research into the cost-efficiency of the preparation of a key palladium-based catalyst.

The generation of impact from *Transforming quantitative prediction of molecular properties through software – Molpro* was aided by RIES through its commercial arm, University College Cardiff Consultants (UC3), which has promoted and distributed Molpro under licence since 2004.

Gold catalysts for vinyl chloride manufacture owes much to the CCI's high profile within the catalysis community and its close interactions with industrial collaborators. The impact can also be traced back to the publication of the seminal gold catalysis research in a high profile journal (*Science*).