Institution: Cardiff University

Unit of Assessment: 8 (Chemistry)

a. Overview

Research activity in the School of Chemistry has developed and advanced substantially throughout the REF period, reflected by several indicators including a 290% increase in the average annual research income compared to the RAE2008 assessment period. In a recent development, the School completed a significant process of restructuring and realignment in spring/summer 2013, associated with the appointment (in 2012) of a new Vice-Chancellor and reorganization of the University into a College structure, within which Chemistry is one of seven schools in the College of Physical Sciences and Engineering. As a result of this process, Allemann will lead the School of Chemistry forward during the next five years as Head of School. Research strategy and operations in the School are developed, promoted and managed by the Research Committee, chaired by the Director of Research (Murphy). Each research-active member of academic staff has a primary association with one of three Research Sections (section leader in bold):

Biological and Organic Chemistry (**Wirth**, Allemann, Buurma, Carpenter, Elliott, Knight, Loveridge, McKeown, Miller, Platts, Redman, Richter, Tippmann);
Inorganic Chemistry (**Pope**, Amoroso, Cavell, P Edwards, Fallis, Leoni, Newman, Ward);
Physical Chemistry (**Harris**, Attard, Bartley, Bowker, Carley, Davies, J Edwards, Golunski, Hutchings, Kariuki, Knowles, Murphy, Paul, Taylor, Willock).

A further cross-cutting structure, fully embedded within the School of Chemistry, is the *Cardiff Catalysis Institute* (CCI), led by **Hutchings** and established in 2008 as a focus for research across catalytic sciences (heterogeneous, homogeneous and biological catalysis). Members of the CCI are drawn from all three Research Sections.

Each section fosters research by coordinating collaboration and exploiting funding opportunities, mentoring each independent researcher by the section leader, and providing an environment for junior researchers to interact and develop. Most members of the School collaborate more widely than their primary section and are involved in the activities of one or more of the other sections.

b. Research Strategy

The research mission of the School is to generate and to disseminate world-class research knowledge across all branches of Chemistry and its interfaces with other scientific disciplines, with focus on research that significantly informs academic scholarship but also impacts on policy-making and economic output. Following RAE2008, the School set out the following objectives with external advice from a panel of academic and industrial advisors:

(1) to establish a strong Research Committee to meet monthly, led by the Director of Research (Allemann, 2008-13; Murphy, 2013-) and including selected key researchers in the School (Allemann, Golunski, Harris, McKeown, Pope, Wirth) and the School Manager (Akhtar), with the remit of formulating and implementing a forward-looking Research Strategy;
(2) to reorganize the research structure of the School according to the three canonical sections (Biological and Organic; Inorganic; Physical) defined in Section a, driven by the aim of ensuring that each section has critical mass to support strategic and operational objectives and to facilitate quick reaction to emerging scientific challenges and funding opportunities;
(3) to further promote interdisciplinary research by establishing a research institute in catalysis and cross-cutting themes, exploiting synergistic strengths in the three research sections;
(4) to target funding from research councils, industry, the EU and charities, and to significantly increase the number of large and collaborative research grants;
(5) to continue to invest in the equipment base and in training of research support staff;
(6) to increase the quality and quantity of research space through refurbishment and expansion;
(7) to continue to recruit and develop high-quality academic staff, particularly in the areas of Biological Chemistry, Catalysis, Synthetic Chemistry, Energy and Materials.

The research strategy further set out to establish seven research themes, which intermesh the structure of the three research sections indicated above. In this regard, the three research sections primarily serve an organizational function within the School, whereas the seven research themes define focused groups of researchers working in closely related fields, promoting targeted activity

in key areas that are closely aligned with research council priorities. The seven research themes have served as descriptors of research activity in the School since 2008, and are as follows:

Biological Chemistry: This theme aims to probe and engineer the reactions and interactions of biological molecules, focusing on proteins and nucleic acids. This research impacts across diverse areas from enhanced health and well-being for efficient, sustainable manufacture of chemicals.

Catalysis: Research covers a wide range of complementary disciplines, including surface science, electrochemistry, organometallic, organic and biological chemistry. Activities in heterogeneous catalysis are strongly driven by industrial applications in environmental control and chemical synthesis. A major emphasis is to exploit the emergent understanding of properties of supported gold and bi-metallic nanoparticles. Research in homogeneous catalysis is developing novel ligands to exploit first-row transition and main-group metals, particularly in asymmetric catalysis.

Energy: This theme is developing materials for use in energy applications including membranes for natural gas purification and carbon capture, the design and synthesis of materials for hydrogen storage, fuel cells and catalysts for the enhanced production of biofuels.

Imaging: This theme targets imaging probes for cellular microscopy developed from functionalized luminescent transition metal complexes, underpinned by photophysical characterization. Fundamental aspects of magnetic resonance imaging agent design are being addressed through field-cycling relaxometric studies, including responsive (sensors) and bimodal agents. The chemistry of applicable radioisotopes is being developed in collaboration with the Wales Research and Diagnostic Positron Emission Tomography Imaging Centre, which is located in the University.

Materials: Research is focused on understanding structure and dynamics of crystalline materials and soft matter, gaining fundamental insights on crystallization processes, developing applications of materials (including polymer-drug conjugates) and advancing new aspects of experimental techniques for studying materials (particularly EPR/ENDOR, powder XRD and X-ray birefringence).

Physical Organic Chemistry: Research is focused on developing a quantitative understanding of structures, mechanisms and interactions in organic chemistry, with applications in a range of areas such as catalysis, chemical biology, energy and healthcare.

Synthetic Chemistry: This theme is developing novel methods and elucidating mechanisms to target the synthesis of natural products or bioactive compounds with pharmaceutical or agrochemical significance. Synthesis of heterocycles is a major activity, yielding new insights into novel electrophiles, cascade cyclizations and enantioselective functionalizations. Another focus is ligand design for novel s-, d- and f-block metal complexes for fundamental investigations and applications in catalysis, imaging, sensors and solar cell materials.

Central to the Catalysis theme, but also linking to the Biological Chemistry, Energy, Physical Organic Chemistry and Synthetic Chemistry themes, the Cardiff Catalysis Institute (CCI) was established in 2008 under the directorship of Hutchings with support of over £2.3M from the University. Integrating researchers from across the School and focused both on the fundamental understanding and the strategic application of catalysis, the CCI has contributed to making many processes (both in the academic research lab and in industrial large-scale reactors) faster, cleaner, economically more viable and more sustainable. The University committed further investment (£3.3M) over the period 2013-18 and upgraded the CCI as a University Research Institute from 2013. The strategic plan of the CCI includes close synergy with other academic centres in the south-west region and with the new UK Catalysis Hub, with the aim of broadening its research base to impact upon photocatalysis, sustainable fuel-to-energy transformations and biomimetic catalysis. Through this activity, the CCI has nurtured an alliance with Bristol (Chemistry) and Bath (Chemistry, Chemical Engineering) for the past 2 years. Outputs to date include a suite of short "pathfinder" research projects, which have initiated new collaborations between these centres. This alliance has been strengthened by the recently announced EPSRC CDT in Catalysis.

Other significant University investment in Chemistry has included £1.1M for Energy and Materials in 2011 and £0.8M for Biological Chemistry in 2012. Future strategic investments (from 2014) in new facilities and infrastructure will benefit from Cardiff University's £250M Innovation Fund.

Since 2008, the School has increased the level of funding from research councils and industrial sources compared with the RAE2008 period, accompanied by significant growth in large inter-disciplinary and collaborative research (see Section d). Details of major research awards and high-quality outputs relating to the seven research themes are provided in Sections d and e.

The School has also continued to recruit and support high-quality staff. Since 2008, the following posts have been created: Professor in Catalysis (Golunski), Reader in Energy (Leoni), Lecturer in Biological Chemistry (Loveridge). In addition, 8 University-funded research fellows (Bartley, J Edwards & Dimitratos in Catalysis; Faraldos & Mart in Biological Chemistry; Newman in Imaging and Catalysis; Bezzu & Carta in Energy and Materials) have been appointed. The School is pro-active in nominating candidates for internal promotions in recognition of their achievements in research, resulting during the REF period in promotions to Professor (Murphy, Taylor) and Reader (Fallis, Platts). The School actively encourages researchers to apply for prestigious external fellowships, and during the REF period the following fellowships have been awarded: Platts (Leverhulme Research Fellowship, 2009-11); Leoni (Heisenberg Fellowship, 2013-16). The research environment is further enhanced by appointment of distinguished scientists to honorary professorships (including Masatake Haruta, Ekkehardt Hahn and Sir John Meurig Thomas).

Four new taught MSc programmes have been initiated (Catalysis; Chemical Biology; Sustainable Chemistry; Physical Organic Chemistry) with University investment to provide scholarships to attract outstanding students. The content of these MSc programmes is strongly research oriented; the lecture courses are focused at the current frontiers of knowledge in these subjects and all MSc students carry out a substantial research project. These MSc degrees have served successfully as a "pipeline" of well-trained, highly-qualified students into the School's PhD programmes.

Significant investments have been made in research infrastructure since 2008, including new X-ray diffraction instrumentation, the development of a high-performance computer facility across the university (ARCCA), and the establishment of facilities for high-field liquid NMR and transmission electron microscopy (TEM). For further details, see Section d. In response to growth in research activities, there has been extensive acquisition and refurbishment of research space.

The overall objectives for the 5-year period following this submission are to consolidate the School within the top 10 chemistry departments in the UK and to raise the profile of the School within the international arena, by achieving the following targets:

(1) to recruit further high-quality academic staff to expand critical mass in Biological Chemistry and Synthetic Chemistry (both organic and inorganic) through a currently-active recruitment exercise for 6 new academic positions, with further positions planned;
(2) to attract high-calibre researchers supported by externally funded fellowships;
(3) to respond to the needs of modern Chemistry research to relocate the School in a new purpose-designed building with investment from Cardiff University's Innovation Fund (£250M);
(4) to increase recruitment of high-calibre students to PhD, MSc (taught) and MChem degree programmes, including specific new initiatives targeted to increase international recruitment;
(5) to extend our equipment base and facilities in line with our research aspirations.

c. People

i. Staffing Strategy and Staff Development

Current staffing strategy is driven by a comprehensive forward-looking review that took place in 2012 with the aim of establishing a coherent plan to sustain the success of the School, focusing on staffing, student recruitment, research funding, estates and equipment, international engagement and staff development. This review resulted in a strategy to recruit new academic staff in research areas complementary to existing strengths, with the aim of introducing new research expertise and opportunities, and a complete restructuring of technical and administrative staff, which has increased the total number of support staff. The School has also implemented a pro-active strategy to support applications of high-quality researchers for independent externally-funded fellowships.

The policy of the School is to facilitate all staff to reach their full potential by achieving the highest standards in research, teaching and administrative functions, *via* the following mechanisms:
(1) Considerable support is provided to newly appointed academics, including generous start-up funds and PhD studentship support, allowing their independent research to be initiated rapidly.
(2) The School operates a mentoring system in which the leader of each research section has responsibility for advising and assisting members of the section (academic staff and postdoctoral researchers) to maximize their research potential, both through informal discussions and through the formal process of annual appraisal (which involves a critical review of research achievements and setting agreed targets for the following year).

(3) Additional mentoring is provided for early-career academics through participation in the University probation system, including a postgraduate educational qualification (PCUTL).
(4) The School has a Staff Opportunities Committee (SOC) with the remit of promoting opportunities for personal development of researchers and other staff at all levels in the School.
(5) All research grant applications are subjected to internal peer review prior to submission. This process, managed by the Director of Research, serves important roles in (i) training early-career researchers and (ii) optimizing the quality of grant applications prepared by researchers at all levels, hence maximizing competitiveness and increasing the potential for success.
(6) The School aims to achieve optimal teaching and administrative workloads for all individuals, allowing maximal staff time to be devoted to research. Early-career academics are initially assigned light teaching and administrative loads to facilitate rapid development of their research. Researchers with large research programmes are also given reduced teaching and administrative loads. Two members of academic staff have full-time roles in teaching, thus helping to lighten the teaching loads of the research-active majority of staff.

The School is fully committed to advancing the career development of researchers, promoting equal opportunities and supporting diversity. The SOC is tasked with monitoring, action-planning and promoting all equality and diversity matters, and all staff have recently undertaken equality and diversity training to ensure that individuals are fully aware of their legal and ethical responsibilities in this regard. The School was awarded an Athena Swan Bronze Award in 2011, and is implementing the associated action plan through the SOC.

ii. Research Students

During academic years 2008/9 to 2011/12, an average of 35 full-time postgraduate research (PGR) students were recruited per year, virtually all for PhD degrees. The number of PGR students registered in each academic year during the REF period is indicated in the Table below. Most significantly, the average FTE number of PGR students per academic member of staff (excluding those staff whose contracts do not include research supervision) increased substantially in 2012/13, reaching its highest value throughout the entire REF period.

The Director of PGR Studies (Wirth) has overall responsibility for PGR matters, assisted by colleagues overseeing recruitment (Ward) and progression (Davies) of PGR students. Recruitment initiatives include identifying promising researchers among our final-year MChem students and making provisional offers of PhD studentships to them early in the recruitment cycle, and strategies to recruit high-quality PGR students from abroad. The University organizes an annual PGR Open Day, at which Chemistry is strongly represented. During the REF period, the proportions of PGR students recruited from different regions have been: UK, 68%; EU, 11%; Overseas (Non-EU), 21%.

PGR students are fully integrated in the research environment in the School. Research colloquia by external speakers from the UK and abroad are organized weekly (during term-time), with PGR students expected to attend all research colloquia (irrespective of subject area). Every year since 2002, the School has organized the annual Cardiff Chemistry Conference. This two-day event features lectures by eminent scientists invited from across the world (including several Nobel Laureates in Chemistry) to describe frontier research in Chemistry and its interfaces with other scientific disciplines. Significantly, the conference also includes lectures given by selected final-year PhD students from the School and poster presentations by all final-year PhD students. The unique format of this event allows young scientists at the early stages of their research careers to share the same platform as internationally leading senior scientists, and to describe their research to an audience that includes international experts in their field.

In addition to activities organized by individual research groups (e.g. weekly group meetings) and research sections (e.g. presentations by PGR students to research sections), the School organizes an extensive training programme for PGR students (lecture courses, training sessions on safety, training in specialized research techniques and instrumentation). Thus, all PGR students follow a programme of training, development, research awareness and education appropriate to their needs. As a result, the School provides effective support for the development of research skills. A PGR student-staff liaison committee meets regularly to discuss the needs of the PGR community and to inform future developments in PGR training courses and mentoring activities. In addition, there is strong engagement with courses and opportunities provided by the University Graduate College for PG Development and the Careers service. PGR students are also encouraged to pursue opportunities for career development, via attendance at conferences and training courses.

A mentoring/reviewing process provides support to PGR students and ensures that progress in their research is maintained. Each PGR student is assigned a mentor (a member of academic staff not associated with their research project) to provide support complementary to the day-to-day interaction with their supervisor. The mentoring/reviewing process involves an initial meeting at 3 months followed by reports submitted at regular intervals. Each report is scrutinized at a viva conducted by the mentor and another member of academic staff; at each viva, progress in the student's personal development plans is also monitored. During the REF period, PhD submission rates have been: for 2005/6 (start year of PhD), 79% (RCUK), 79% (all students); 2006/7, 94%, 81%; 2007/8, 75%, 76%; 2008/9, 76%, 74%.

Table: Total numbers of PGR students registered at the end of each academic year

FT = full time; PT = part time	**2007/8**	**2008/9**	**2009/10**	**2010/11**	**2011/12**	**2012/13**
Total FTE / (number of academic staff)	**3.06**	**3.27**	**3.16**	**2.93**	**2.67**	**3.42**
Total FTE	**112.5**	**120.5**	**124.5**	**115.5**	**100**	**95**
Total (FT + PT)	**116**	**123**	**126**	**116**	**100**	**95**
Total (FT)	**109**	**118**	**123**	**115**	**100**	**95**
PhD (FT)	108	116	121	114	100	94
MPhil (FT)	1	2	2	1	–	1
Total (PT)	**7**	**5**	**3**	**1**	**–**	**–**
PhD (PT)	6	5	3	1	–	–
MPhil (PT)	1	–	–	–	–	–

d. Income, Infrastructure and Facilities

Infrastructure and Facilities

The School has outstanding research facilities and a strong equipment base, which supports research in all research themes in Chemistry and interdisciplinary collaborations. State-of-the-art facilities are available in all the standard instrumental techniques that underpin a modern chemistry laboratory, including: NMR (liquid-state and solid-state), X-ray diffraction (single-crystal and powder), mass spectrometry, EPR/ENDOR, UV/visible, time-resolved luminescence, field cycling relaxometry, thermal analysis, electrochemical, surface science techniques (including AES/STM-AFM, LEED, XPS, SEM, surface-Raman) and instrumentation underpinning research in Biological Chemistry. The XPS facilities were enhanced by high-quality support for data analysis and interpretation as part of the EPSRC funded Access to Materials Research Equipment, 2007-12.

Single-crystal XRD, liquid NMR and mass spectrometry are operated as part of a Central Services facility, which is supported by two specialist members of academic staff (Kariuki, single-crystal XRD; Loveridge, liquid NMR), an experimental officer (Jenkins, mass spectrometry) and a further 2 FTE of technical support. This facility operates under the overall direction of the Research Committee and is managed by the Technical Services Manager (Jenkins).

Specialist research facilities established as a direct result of University investment include:

Cardiff Catalysis Institute (CCI): As highlighted in Section b, the CCI has received substantial investment from the University for custom refurbishment of labs (600 m^2), recruitment of new staff (academic and technical), and purchase of equipment (including the creation of an equipment base for a unique facility for *in situ* studies of heterogeneous catalysts). Future investment of £10M from Cardiff University's Innovation Fund will provide new facilities for the CCI as part of a new building.

Cardiff High-Field NMR Facility: Established in 2012 with funding from the University's Large Research Equipment Fund (LREF), this facility is equipped with state-of-the-art liquid NMR spectrometers including a new Bruker 600 MHz system with cryoprobe, which provides a highly sensitive, fast and efficient platform for modern NMR protocols in the physical and life/medical sciences. This instrument is the most advanced high-resolution NMR spectrometer in Wales and the south-west of the UK and is ideally set up for biological samples as well as small molecule analysis. This facility is accessible to, and exploited by, researchers from across the University.

The School has access to a shared high-resolution transmission electron microscopy facility, with EDX analysis, dark-field imaging and a cryogenic stage for biological samples. Established in 2012, this facility was funded by the University *via* the LREF scheme (£387K), with contributions

from all participating Schools (Chemistry, Engineering, Optometry, Biosciences and Medicine).

The University provides excellent facilities for high-performance computing (HPC) and graphics/visualization, which are available to researchers in Chemistry, and are enhanced through major on-going University initiatives including the establishment of a division for advanced research computing based on £2M SRIF3 investment in hardware and dedicated software support personnel, with a further £1M investment in hardware renewal in 2012. The School is also actively involved in the HPC Wales project which provides HPC to academia and industry across Wales.

Members of the School are extensive users of national and international research facilities through competitive applications for facility time, including: (1) synchrotron radiation facilities (Diamond Light Source, Elettra, ESRF); (2) neutron facilities (ISIS, ILL); (3) high-field liquid NMR (Mill Hill, Birmingham); (4) high-field solid-state NMR (Warwick); (5) supercomputing (HECToR); (6) central laser facility (RAL); (7) EPSRC National Services in scanning transmission electron microscopy, mass spectrometry, computational chemistry and crystallography; (8) the Wales Research and Diagnostic Positron Emission Tomography Imaging Centre.

The School is also well served by library and information services. The Science Library is located in the same building as the School, and the University has undergone major developments in recent years in the provision of electronic information resources and the delivery of other key services (e.g. online collaboration and data sharing).

Research Income Portfolio

Since August 2008, the School has secured research awards totalling £29.8M from 152 grants, equivalent to £5.74M per year, representing an increase of 290% compared to the average annual income for the RAE2008 period. The breakdown of income sources is: RCUK (£18.2M, 61% of overall income), European Commission (£3.8M, 13%), UK Government, charities, industry and other sources (£7.8M, 26%). These awards can also be expressed in terms of the number of research grants received from different funding sources (since 2008): EPSRC (52 grants), BBSRC (7), ESRC (1), NERC (1), MRC (1), CCLRC/STFC (3), European Commission (8), UK Government (17), industry (45), charities (9) and other sources (8). Some representative examples of research grants received are the following: (a) *UK Catalysis Hub*, EPSRC, £2.5M, 2013-18 (Hutchings, Allemann, Bowker, Golunski); (b) *AFTERTHEGOLDRUSH: addressing global sustainability challenges by changing perceptions in catalyst design*, European Research Council, £1.9M, 2012-17 (Hutchings); (c) *PCATDES: photocatalytic materials for the destruction of recalcitrant organic industrial waste*, European Commission (FP7), £644K, 2013-17 (Davies); (d) *Greywater*, TSB, £510K, 2009-13 (Hutchings); (e) *Spins under pressure: a mechanistic understanding of homogeneous catalysis by HP-EPR*, EPSRC, £498K, 2013-17 (Murphy); (f) *The significance of the oxidation state of gold in heterogeneous catalysis*, EPSRC, £464K, 2012-15 (Davies); (g) *Protein-ligand coupled motions in DHFR catalysis*, BBSRC, £429K, 2012-15 (Allemann).

As an attractive financial incentive to researchers, the School allocates 45% of recovered indirect costs from research grants to the grant holder, who has discretion to use these funds for any academic purpose but with encouragement to use them to part-fund PGR studentships. For early-career researchers, funds are allocated for conferences and consumables, and research capacity is nurtured *via* a competitive seed-corn research fund focused on providing PGR studentships.

The School provides strong support to academic staff in preparing research grant applications and operates an internal peer review system (see Section c.i). By maintaining a high-quality and vibrant intellectual environment, researchers are encouraged to generate the innovative ideas required for successful RCUK applications. The Director of Research, the School Manager together with associated support staff, and the University's Research, Innovation and Enterprise Services (RIES) provide advice and support to staff in developing grant applications. The School has a link member in RIES who provides information about research grant opportunities and application procedures.

Members of the School have held consultancies with industrial companies and other agencies, including: Environmental Protection Agency of Ireland (Attard, 2008); BP America (Bowker, 2008-); Dow Chemicals (Bowker, 2007-9); KAUST, Saudi Arabia (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; Murphy, 2008); Eastman Chemicals (Hutchings, 2008-10); Johnson Matthey (Willock, 2008; Murphy, 2009); Oxford Catalysts (Taylor, 2008-9).

e. Collaboration or Contribution to the Discipline or Research Base

Collaboration

Researchers in the School are engaged in a wide range of research collaborations with academia and industry, many of which are highly interdisciplinary. During the REF period, collaborations with industry included 39 funded projects (total £3.2M) with EU (including UK) industry and 12 funded projects (total £2.6M) with overseas industries and agencies. A prime example is the Dow Methane Challenge awarded to Hutchings with the aim of utilizing hydrocarbon feedstocks in new ways to form intermediates and products for use in the chemical, pharmaceutical and agricultural business sectors. Another major collaborative development is the establishment of the UK Catalysis Hub, in which several members of the School (Hutchings, Bowker, Golunski, Allemann) are strongly involved, together with researchers from 29 other UK institutions (including UCL, Bath, Belfast).

Interdisciplinary research features collaborations across the spectrum of biological, medical, physical and engineering sciences, and with a range of industrial sectors, including:

Agrochemical Interface: Synthetic Biology approach for structural prediction of odorant molecules (semiochemicals) for pest control and new medicines (Allemann, with Rothamsted Research).

Biomedical Sciences Interface: Cancer specific multimodal image contrast agents (P Edwards, with Biosciences & Medicine); silver sensing luminescent probes for anti-microbial drug development (Fallis & Dervisi, with Medicine); a novel strategy to stratify pancreatic cancer patients *via* new ^{18}F-labelled nucleosidic drug tracers (Fallis, with Biosciences & Medicine); new medicines to treat auto-immune disease (Allemann, with Medicine); functional bio-nanomaterials and novel processing for targeted catalytic applications (Attard, with Biosciences & Engineering in Birmingham & Manchester); a novel device for anaesthesia delivery (Paul, with Medicine) and new topical anaesthetic gels (Paul, with Medicine & Pharmacy).

Biophysical Sciences Interface: Intracellular biophotonic nanoswitches for programmed control of molecular pathways by light (Allemann, with Medicine & Pharmacy); Mechanical control of stem cell fate through non-invasive imaging technologies (Tippmann, with Dentistry, Medicine, Biosciences, Physics & Social Sciences); Understanding magnetic behaviour of metallic bio-nanoparticles by muon spin rotation (Attard, with Biosciences & Physics in Birmingham).

Engineering Interface: Enhanced electrochemical DNA biosensing with active sensitizers (Buurma & Pope, with Electrical & Electronic Engineering in Bath); Design of clean low-carbon vehicles (Golunski, with Combustion Engineering in Birmingham & Brunel); New polymers for delivery of sustainable hydrogen and nano-structured polymeric membranes for gas separation (McKeown, interdisciplinary consortia); Innovative gas separations for carbon capture (McKeown, with Chemical Engineering in Edinburgh); Smart burglar alarm systems (Smith, with Engineering).

Environmental Sciences Interface: Molecular sensors and dosimeters to detect chemical warfare agents (Fallis, with DSTL); Speciation and detection of spent nuclear fuel radionuclides in environmental samples (Pope & Fallis, with Magnox Ltd & NDA).

Geosciences Interface: Hydrogen generation in the deep hot biosphere (Bowker & Davies, with Earth Sciences; NERC funded); Structural elucidation of nanoparticulate sulfide materials (Harris, with Earth Sciences).

Physics Interface: New materials for astronomical X-ray polarimetry (Harris, with Space Research in Leicester); New materials for improved photovoltaic device efficiencies (Pope, with Physics).

Contribution to the Discipline or Research Base

Research achievements of members of the School have been recognized by the award of prizes, honours, distinctions and other indicators of esteem, and by appointments to leadership roles in the research community (nationally and internationally), learned societies and professional bodies.

Members of the School **elected to national academies and learned societies** are as follows:

- Fellow of the Royal Society (Hutchings, 2009).
- Member of Academia Europaea (Hutchings, 2010; Harris, 2013).
- Fellow of the Royal Society of Edinburgh (Harris, 2008).
- Fellow of the Learned Society of Wales (LSW) (Hutchings, Founding Fellow, 2010; Bowker, Carpenter, Cavell, Harris, Knight, Knowles, Smith, 2011; P Edwards, 2012; Allemann, 2013) [the School has more Fellows of the LSW than any academic department in any university].

Among **awards and prizes**, Hutchings received the Davy Medal of the Royal Society (2013), and members of the School received the following prizes from the Royal Society of Chemistry (RSC): Tilden Medal and Lectureship (Harris, 2007-8); Sir Christopher Ingold Lectureship (Carpenter, 2008); Beilby Medal (McKeown, 2008); Award for Surfaces and Interfaces (Hutchings, 2009).

Other **awards and distinctions** received by Hutchings have been: France-Great Britain Chemistry Prize (2011); Henry J Albert Award, International Precious Metals Institute (2011); Dechema Alvin Mittasch Award (2012); Heinz Heinemann Award, International Association of Catalysis Societies (2012); Thompson Reuters Citation Laureate (2012); Distinguished Visiting Lecturer, Catalysis Society of South Africa (2013). Other awards to members of the School have been: Innovation and Excellence Award in Sustainable Technology, Institute of Chemical Engineers (Hutchings & J Edwards, 2009); Carol Tyler Award, International Precious Metals Institute (J Edwards, 2011); Clara Immerwahr Award, UniCat Germany (J Edwards, 2013).

Visiting professorship appointments held by members of the School at foreign universities include: University of Witwatersrand, South Africa (Hutchings, 2002-9); Tohoku University, Japan (Harris, 2008); Osaka Prefecture University, Japan (Wirth, 2008); University of Bordeaux, France (Harris, 2008-9); Hokkaido University, Japan (Bowker, 2010); Tokyo Metropolitan University, Japan (Hutchings, 2010-); Kyoto University, Japan (Harris, 2011). Other appointments include: Wilsmore Fellow at University of Melbourne, Australia (Knight, 2008); Adjunct Professor at University of Louisiana, USA (Hutchings, 2011-).

Appointments on international advisory boards include: Consultant to Commission on Aperiodic Crystals, International Union of Crystallography (Harris, 2008-11); International Assessor on Materials Prioritization Panel, Finnish Academy of Science (McKeown, 2009); Assessor, Excellence Initiative, German Research Foundation (DFG) (Allemann, 2012); International Assessor for *Membrain* (membranes for CO_2 capture) Helmholtz Programme, Aachen, Germany (McKeown, 2010); Member of Evaluation Panel, Academy of Finland (Wirth, 2011); Chair of International Review of Dutch Catalysis (Hutchings, 2011); Member of Advisory Board, EXSELENT project, Stockholm University, Sweden (Hutchings, 2012-).

Leadership roles in industry held by members of the School include: Winner of the Dow Methane Challenge (Hutchings, 2007-11); Senior Consultant in Organic Chemistry, Eli Lilly Research Centre (Knight, 2008-11); Managing Director, CatCelt Ltd. (Smith, 2006-).

Leadership roles in research councils held by members of the School include: Chair of PE5 Panel of the European Research Council (ERC) (Carpenter, 2012); Member of PE4 Panel of ERC (P Edwards, 2008-14); Core Member of BBSRC Committee D: Molecules, Cells and Industrial Biotechnology (Allemann, 2009-12); Member of EPSRC Strategic Advisory Teams (SATs) (Chemistry SAT: Knowles, 2006-8; Physical Sciences SAT: Knowles, 2008-; Research Infrastructure and International SAT: Knowles, 2009-12, Hutchings, 2013-).

Leadership roles in learned societies, professional bodies and government committees include: President, Faraday Division, RSC (Hutchings, 2012-15); Chair of Science Community Representing Education (SCORE) (Hutchings, 2010-13); Chair, RSC Bioorganic Group (Allemann, 2005-2009); Chair, RSC Heterocyclic Chemistry Group (Knight, 2012-14); Chair, RSC Theoretical Chemistry Group (Knowles, 2009-12); Member of Council, RSC (Smith, 2009-13; Knowles, 2013-17); Member of Council, Learned Society of Wales (Smith, 2012-); Member of Cross-Party Group on Science and Technology, National Assembly of Wales (Smith); Member of Wolfson Research Merit Award Committee, Royal Society (Hutchings).

Among **other distinctions**, Pope (2008) and Buurma (2013) were invited to the RSC/ACS/GDCh meeting *Trans-Atlantic Frontiers of Chemistry for 100 Exceptional Young Scientists*. In 2012, the career of Smith (who retired in 2013) was marked by a special issue of ARKIVOC and a one-day symposium *A Celebration of Organic Chemistry* attended by two Nobel Laureates (organized by RSC and the Learned Society of Wales). JSPS short-term fellowships were awarded to J Edwards (2010) and Wirth (2012). Wirth also received a JSPS London Furusato Award (2013). During the REF period, members of the School gave 141 plenary and keynote lectures at international conferences, served as chairs of 15 international conferences, held senior editorial positions (Hutchings, Editor, *Journal of Catalysis*; Wirth, Co-chair of Editorial Board, *ChemistryOpen*; Knight, Senior Consulting Editor, *Tetrahedron Letters*), held 25 appointments on journal editorial boards, and served as guest editors of 5 books and 8 special issues of journals.