Institution: University of Reading
Unit of Assessment: 8 Chemistry

a. Overview

The Department of Chemistry at Reading currently comprises 24 permanent academic staff: 7 Lecturers, 6 Associate Professors and 11 Professors (one of whom is currently Dean of Science). The Head of Department (Powell) is supported by a Director of Research (Harwood) and a Director of Teaching and Learning (Mckendrick), and by the heads of the three Research Sections *Molecular Chemistry* (led by Hartl and including Harwood, Brown, Mckendrick, Nutt and Russell), *Materials Chemistry* (led by Colquhoun and including Hayes, Held, Powell, Bennett, Chippindale, Davis, Elliott, Grau-Crespo and Vaqueiro) and *Chemistry for Life and the Environment* (led by Hamley and including Almond, Cardin, Cramer, Marston, Pfrang and Squires). These groups reflect the multi-disciplinary research activities of the UoA more accurately than the traditional divisions of Organic, Inorganic, Physical and Analytical Chemistry, though the latter are retained to some degree for teaching purposes.

The Department is a well-defined unit within the School of Chemistry, Food & Pharmacy. Academic staff, research staff, postgraduate students and undergraduates are organised at Departmental level, while technical, clerical and administrative staff are managed by the School. The University supports central instrument platforms that are particularly important for Chemistry, notably the new (2009) £4.5M Chemical Analysis Facility which also now incorporates a Centre for Advanced Microscopy. These facilities are funded centrally at a level of ca. £400K/a (technician salaries and instrument maintenance) with further funding from grants and industrial contracts. Specialist technicians provide analytical services in NMR, mass spectrometry, X-ray diffraction and electron microscopy, and further technical support for research in Chemistry is provided in the form of glassblowing, electronics and fine mechanics workshops, each with a dedicated technician.

b. Research strategy

Our research strategy is focused on major scientific and technological challenges facing humanity in the 21st Century, specifically (a) developing sustainable technologies for energy production, (b) improving healthcare and quality of life in ageing populations, (c) understanding and limiting anthropogenic climate change, and d) maintaining supplies of clean drinking water to an increasing world population. This strategy, involving world-class research on both applied and fundamental aspects of chemistry, has enabled us to engage successfully with a diverse range of stakeholders through collaborative research with international industries and governments, and to shape international scientific policy (for example, through Harwood's recent breakthrough in nuclear reprocessing chemistry and Mills' success in re-defining the entire basis of the world's system of scientific measurement, the SI). As described below, the UoA has made substantial and significant progress since RAE 2008 in terms of research infrastructure, staff appointments, research funding, industrial collaboration, involvement in the work of national and international facilities, quality of outputs, and international profile.

Sustainable energy: Energy technologies that consume resources without replenishment and result in progressive degradation of the environment must inevitably become obsolete. The development of sustainable approaches to energy generation, conversion and storage is thus now recognised as one the highest priority areas across the sciences. It is one to which the Reading UoA is making a substantial contribution. For example, in the field of sustainable nuclear energy, Harwood is a member of the FP7-funded EU consortia "ACSEPT" and "SACSESS", and also of an EPSRC-funded UK consortium ("MBase"). During the assessment period, he has succeeded in developing a series of very stable and highly selective ligands for separating lathanides from actinides in next-generation nuclear reprocessing cycles (*J. Am. Chem. Soc*., 2011; highlighted in *Chemistry World*). Hartl, working with groups in Amsterdam and Utrecht, has shown the potential of multinuclear transition-metal complexes to promote photochemical splitting of water for hydrogen generation (*P.N.A.S.* 2009). Hayes and Colquhoun, working with Johnson Matthey plc and an EU-funded consortium, "NEXPEL", have developed a successful new approach to low-cost, high-stability proton-transport membranes for use in fuel cells and in electrolysers for hydrogen production (*Fuel Cells*, 2009; *US Patent*, 2010; *Macromolecule*s, 2013). Working with DuPont-Teijin Films, Colquhoun has recently developed a new class of highly crystalline poly(ester-imide) films as flexible, temperature-resistant substrates for large-area solar cells (*five priority patent*

applications, 2011-2013). The new (2013) appointments of Powell and Vaqueiro, working on the chemistry of thermoelectric materials for energy applications (*J. Mater. Chem.*, 2013), represent major University commitments to sustainable-energy research in the UoA.

Healthcare: The worldwide improvement in life expectancy is leading to increased levels of the degenerative conditions associated with old age, notably cancer, cardiovascular disease, eye conditions, and amyloid diseases such as Alzheimer's. Understanding these at the molecular level will lead to improved long-term quality of life, and will reduce the burden on society in terms of healthcare provision. Important advances in our understanding of the formation of amyloid fibrils have been made by Hamley and Castelletto (*Biochemistry*, 2008; *Angew. Chem*., 2009, *Chem. Commun*., 2011, 2012). Hamley was also recently awarded a major collaborative BBSRC grant with Connon (Pharmacy) to develop polymeric templates for growing corneal implants from stem cells (*Langmuir*, 2013). Cramer has developed mass spectrometric techniques both for clinical diagnostics (*Cancer Genomics Proteomics,* 2011) and for more general genetic and proteomic analysis (*Science*, 2010). Cardin has made important strides in our understanding of metal-complex binding to DNA through her crystallographic studies of the interactions of transition-metal complexes (with potential value in photodynamic therapy) with specific DNA sequences (*P.N.A.S.*, 2011; *Nat. Chem*., 2012, *J. Am. Chem. Soc.* 2013). Mckendrick's research with Biointeractions Ltd. on the development of anti-thrombogenic polymers as coatings for arterial stents has led to commercialisation of a new series of related products (*US Pat. Appln.*, 2013). Harwood has developed a new approach to the synthesis of peptidic drug-candidates, allowing efficient construction of previously inaccessible peptide sequences (*J. Peptide Sci*., 2009; *Int. Pat. Appln.* 2012). He has also launched a start-up company (Technopep Ltd.) to develop this technology. In relation to diseases associated mainly with developing countries, Brown's isotope-labelling and NMR studies have identified many of the key steps in the biosynthesis of the key anti-malarial drug artemesinin (*Molecules*, 2010). Most recently, Hayes, working with Greco (Pharmacy), has developed a family of dendrimer molecules with significant potential in controlled drug-release for combination therapy (*Biomacromolecules*, 2013).

Climate change: The potential dangers of climate change are well understood, but the underlying mechanisms – especially those involving the chemistry of the atmosphere – are not. The Reading UoA is strongly committed to improving our understanding of the chemical mechanisms involved in global warming. Thus, for example, Marston's research, in collaboration with the Department of Meteorology and the Walker Institute for Climate System Research at Reading, has established experimental global warming potentials for a wide range of halocarbons and hydrofluoroethers (*J. Geophys Res., Atmos*., 2010; *Rev. Geophys.,* 2013, *C&EN News* 2013). This research was highlighted in the 5th Report (2013) of the Intergovernmental Panel on Climate Change, of which Marston was a co-author. Pfrang, working in collaboration with atmospheric scientists in Mainz and Bielefeld, has successfully developed a new, general model for gas-particle reactions and interactions in aerosols and clouds (*Atmos. Chem. Phys.,* 2012).

Water purification: Population growth and economic development across the planet are leading to increasing demands for clean drinking water. Even in the UK, where water may seem plentiful, reverse osmosis (RO) plants are being installed (most recently in the Thames estuary) to provide drinking water for regions of high population density. Conventional RO membranes, however, require very high driving pressures for effective operation, and the UoA is working to develop alternative approaches, specifically in the design of novel membranes for RO and nanofiltration of recycled water (Colquhoun, *J. Mater. Chem.*, 2009) and in the development of nanostructured gels and microgels for the capture of high-toxicity organic pollutants from water (Hamley, *J. Am. Chem. Soc.,* 2008; Hayes, *Chem Commun*., 2010).

Underpinning research: In addition to the above, applications-directed research, the UoA supports a broad range of underpinning chemistry aimed at developing the foundations of the subject and increasing our understanding of chemical reactivity, molecular and supramolecular structure, analytical methodology and materials' functionality. Thus, for example, fundamental studies on the chemistry and physics of nanostructured polymers are currently supported by a £1.1 M EPSRC Platform grant (Colquhoun, Hayes and Hamley, working with Matsen in Mathematics). The work of Held and Bennett in surface science (*J. Am. Chem. Soc.,* 2012; *Top. Catal.*, 2011) underpins research in heterogeneous catalysis, as do the computational studies of Grau-Crespo. Chippindale's research on the synthesis and structure of polynuclear transition-metal cyano complexes, especially framework-type systems (*J. Am. Chem. Soc.,* 2009; *Phys. Rev. B*, 2012),

builds fundamental understanding of materials properties such as negative thermal expansion and has important implications for the extraction of increasingly-scarce precious metals from their ores. The work of Cramer in developing liquid-matrix MALDI-MS has opened up a new, general approach to biomolecular analysis (A*ngew. Chem.,* 2013). Nutt's research in computational chemistry underpins a wide range of research in the UoA, but in particular his work aims to develop computational methods for understanding the solvation of biomolecules and the significance of hydration – for example in antifreeze proteins (*J. Am. Chem. Soc*., 2008).

Infrastructure strategies: Following strategic planning and wide consultation by Chemistry staff in 2008, the University committed £4.5M to providing an advanced chemical analysis facility (CAF) within the Department of Chemistry. This state-of-the-art facility – completed in 2009 and described in detail in Section **d** – complements the analytical instrumentation located in individual research groups and enables the UoA to work at the forefront of the areas of chemistry noted above,. Most recently (2013) CAF has incorporated a Centre for Advanced Microscopy. The University publications repository "CenTAUR" (http://centaur.reading.ac.uk) is an open-access facility for the archiving and dissemination of research publications. This facility meets RCUK requirements for "green" open-access publication, and the University has also instituted a scheme, with funding from RCUK, to enable staff publications to be made "gold" open-access where appropriate.

Diamond: The construction of the *Diamond* synchrotron at Harwell, very close to Reading, has provided valuable strategic opportunities for the UoA, which has a strong tradition of working with national and international research facilities. The Director of Diamond (2001-2013), Prof. G. Materlik FRS, holds an Honorary Chair in the Department. A joint post in Chemistry – the *Diamond Chair* – was funded by Diamond and the University in the previous assessment period, and Hamley was appointed to this post, moving from Leeds. More recently (2011), a further joint appointment (the *Diamond Fellowship*) was created, and Held took up this post in 2012. The Fellowship includes a 0.4 FTE position at Diamond so that, while retaining his Chair at Reading, Held also now leads the Diamond team designing/building VERSOX – a soft-X-ray beamline for surface science, atmospheric science, heritage science, and catalysis research.

Other National Facilities: Reading Chemistry has a close working relationship with several national facilities on the Harwell site including the ISIS neutron source (Powell, Chippindale and Vaqueiro) and the Central Laser Facility [where an international team led by Cardin (Reading) was recently awarded Programme access over three years for DNA research]. Our close relationships with these national facilities were key to the appointments of Powell, and Vaqueiro, who both moved from Heriot-Watt University in 2013. Further examples of the UoA's research collaborations with national and international facilities are given in Section **e**.

c. People, including:

i.Staffing strategy and staff development

Academic staff appointments: Seven new appointments were made during the assessment period, in specific alignment with the UoA's strategic research plans outlined in Section **b**. Thus, in 2013, Powell joined the UoA as Professor of Solid-State Chemistry and Head of Department. His expertise is in the development of new inorganic materials for sustainable-energy applications. Vaqueiro, working in a similar field, was appointed to a Lectureship in the same year. Grau-Crespo, a specialist in computational solid-state chemistry, again with high relevance to the field of sustainable energy, was appointed to a Lectureship in physical chemistry in 2013. Two RCUK Fellows were appointed to Lectureships in Chemistry in 2012: Pfrang (atmospheric chemistry and climate change – working also with the Department of Meteorology and the Walker Institute for Climate System Research); and Nutt (computational chemistry – underpinning a wide range of topics in the UoA's strategic research plan, from climate research to biomedical chemistry/healthcare). Castelletto, working in the field of protein and peptide chemistry (focused on Healthcare), was appointed to a permanent University Research Fellowship in 2011. In 2008 Hartl was appointed to the Chair of Inorganic Chemistry, moving from the University of Amsterdam. He is a specialist in the spectro-electrochemistry of transition-metal complexes and directs research programmes in the area of sustainable energy, specifically in hydrogen generation by photocatalytic water-splitting, and related processes including the fixation of carbon dioxide.

Since moving to Reading, his innovative designs of spectro-electrochemical cells (the "OTTLE" range) have been commercialised through Specac Ltd, the University of Reading and the University of Amsterdam. The above academic appointments have resulted in a well-balanced age profile for the UoA, as shown in the Table below.

Age range	30-40	40-50	50-60	60-70
Number of academic staff	4	10	7	3

Academic Staff Development: All new academic staff undertake the University Postgraduate Certificate in Academic Practice, which covers aspects of both teaching and research. Designated mentors are provided for all new appointees, and annual or biennial staff-development reviews take place between academic staff and their managers. Such reviews provide formal opportunities for discussion of training, career development and progression, research plans and achievements, collaborations, publications, teaching, and grant/studentship funding, and actions to progress these issues are agreed. The University Centre for Quality Support and Development (CQSD) provides monthly updates of available training courses to all staff. A call for submission of promotion cases is issued annually to staff, who are encouraged to apply when this is timely. Assistance in developing promotion cases is provided at both Departmental and School level. Nine internal staff promotions were recorded during the present assessment period; four to Associate Professor and five to Professor.

Concordat to Support the Career Development of Postdoctoral Researchers: At the outset of each project, the Principal Investigator (PI) agrees a statement of objectives and responsibilities with the researcher. Progress towards targets is reviewed at least monthly, and any changes in the targets recorded. Research Staff are provided with a mentor (in addition to their PI) to aid career development, and expectations of researcher performance are made clear at the outset. Researchers teach and supervise at appropriate levels, including co-supervision of PhD and MSc students. Such teaching and supervision is supported by required attendance at relevant training and development events provided by the CQSD. Research Staff spend a minimum of 5 days each year on professional, personal and career-development – the CQSD provides a course leading to the Certificate in Research Career Management. Research Staff attend Group, Department, School and Faculty meetings, and are encouraged to present their results at national and international research conferences. When further research is proposed beyond a current contract, then Research Staff are actively involved in the preparation and submission of new grant applications where they are clearly identified as Researcher-co-Investigators or equivalent. The University of Reading was one of the first ten UK HEIs to win the EC "HR Excellence in Research" award, demonstrating its commitment to fulfilling the principles of the Concordat for the Career Development of Researchers.

International staff appointments and international recruitment*:* The UoA has made four international appointments to the academic staff during the period of the assessment, specifically (i) Hartl, from the Czech Republic, appointed (2008) to the Chair of Inorganic Chemistry, moving from the University of Amsterdam, (ii) Pfrang, from Germany, appointed (2012) to a Lectureship in Atmospheric Chemistry, having previously been an RCUK Fellow in the Department, (iii) Grau-Crespo, from Cuba, moving (2013) from University College London to a Lectureship in Computational Chemistry, and (iv) Vaqueiro, from Spain, moving (2013) from Heriot-Watt University to a Lectureship in Materials Chemistry. International PDRAs have included Zhu and Zeng (both from China), Paoloni (from France), Burattini (from Italy) and Vaiyapuri (from India). Numerous PDRAs and doctoral students have subsequently moved to international academic positions including, for example, Chen (Nanjing, China), Makama (Kano, Nigeria), Al Khelany (Diyala, Iraq), and Bravo (Castilla La Mancha, Spain). Kopecka, Parras, Paoloni and Manolakis moved to industrial positions in continental Europe. Zhu moved to Northwestern University, Illinois, Shavorskiy to a (now-permanent) post at the ALS, Berkeley, and Hermida-Merino and Newby to the ESRF, Grenoble. In 2008, Hayes was Tewkesbury Visiting Fellow in the University of Melbourne. Staff holding invited Visiting Professorships during the assessment period include Cardin (Guangzhou, 2009-2012), Cramer (Muenster, 2010-2012), Colquhoun (Messina, 2010), Hartl (Grenoble, 2008 and Paris, 2010), Harwood (Urbino, 2010), and Held (Erlangen, 2011).

Equality and diversity: Of Chemistry's 24 academic staff, five (21%) are women, comprising one Lecturer, three Associate Professors, and one Professor (compared with a UK national average of 18% for women academics in physical sciences and engineering). In 2012, the School received an Athena Swan Bronze Award for its work in developing policies and practices for eliminating potential gender bias and promoting an inclusive culture that values female staff. We are now working towards the Silver qualification. Of the doctoral students enrolled in Chemistry since Oct. 2008, 44% were female, and 27% were of ethnic-minority origin. All appointment panels include members of both sexes who must undertake equality and diversity training. The UoA is particularly attentive to gender issues when considering staff rewards including payment of performance lump sums, and submission of cases for increments, regrading or promotion. All relevant members of staff within the UoA are aware of the legal obligations concerning maternity/adoption leave, and all female members of staff are made aware, via the University's HR Department, of what leave is available. The University provides teaching cover for staff members on maternity leave and paid *Keeping in Touch* days during that leave. Staff returning from maternity/adoption leave are provided with a light teaching/administration load during the first term after return, to further support their research.

ii.Research students

Information on PGR recruitment: Some 60 doctoral research students have enrolled in Chemistry during the REF assessment period, and 65 PhDs have graduated. Doctoral studentships for UK/EU students by the UoA are invariably fully funded (including tuition fees, stipend at or above Research Council level, and all research costs), with no financial contribution from the student. In the current assessment period, this has been achieved through new funding from RCUK (EPSRC-DTG, NERC-DTG, EPSRC and NERC grants), the European Union (Marie Curie ITN; Fuel Cells & Hydrogen JU), KTPs (TSB), UK hospital trusts, overseas governments in Asia and Africa, national/international facilities (Diamond, ISIS, ILL), and major industries including AstraZeneca, AWE, BAE Systems, Biointeractions, BP, CEMAS, Enterpris, Cytec Engineered Materials, Domino Printing Sciences, DuPont-Teijin Films, Henkel, Johnson Matthey, LGC., Syngenta and Unilever, plus University funds. External funding for PhD studentships totalled £1.7M in the REF assessment period. The Table below shows the total population of doctoral students enrolled in Chemistry in each academic year.

	2008-09	2009-10	2010-11	2011-12	2012-13
Population of students on doctoral programmes (FTEs)	36.9	32.7	44.2	38.1	31.9

Doctoral students are recruited though a range of mechanisms including (a) direct approaches to potential supervisors, (b) the Department's annual postgraduate recruitment fair, (c) nomination by companies sponsoring new PhD studentships in the Department, (d) advertising of specifically funded PhD opportunities, and (e) applications to the University's scholarship schemes, including Felix Foundation PhD scholarships available to Indian students working at Reading, Oxford or SOAS. The UoA also provides a one-year MSc programme in Chemical Research. This programme maintains steady recruitment, notably through a new (2012) collaboration with the Nanjing University of Information, Science and Technology. We encourage the most able of these graduates to join our PhD programme.

Training and Support for research students: In addition to conventional training in scientific research provided within the Department of Chemistry, the University Graduate School (established in 2011) provides all graduate researchers with generic skills training, in association with their home department, through the Reading Researcher Development Programme. Industrially-funded doctoral students also gain valuable experience from extended placements with their sponsors. Research students funded by international research grants including EPSRC-NSF joint awards (Colquhoun and Hayes) and EU Marie Curie Initial Training Networks (Held) have benefited greatly from extended working visits to project partners in the US and continental Europe. The University and Department provide travel funds to enable graduate students to attend

national and international conferences. All graduate researchers have the opportunity to attend at least one national or international conference during their studentship. Several doctoral students have been awarded prizes for their presentations at such meetings, including Claire Murray, James Hall and Elena Marelli (BCA meeting, Keele, 2011), Dora Sousa (ACS meeting, Maryland, 2009) and Raj Vaiyapuri (UK-India Symposium, RSC, London 2012). Doctoral student Claire Murray was also awarded the Cruikshank Prize "for outstanding contributions to crystallography" at the 2011 BCA meeting.

Monitoring the progress of doctoral students: PhD students take a minimum of 20 credits of taught course material in their first year and submit a first report after 5 months summarising the background to their project and their initial studies. This report is assessed by the student's primary and secondary supervisors, and also by an assessor who monitors and helps support the student during their degree. Feedback is given to the student and the project plan is revised accordingly. A further report at 12 months is assessed in the same way but now also through a structured interview with the supervisors and assessor. A third report at 24 months is in the form of a full paper, produced to international publication standard. A second oral examination is also held at this point as part of the assessment. Detailed, written plans for the third year are agreed between the student, supervisors, and assessor. In June each year, the department holds a Research Day at which 2nd year doctoral students present posters, and 3rd year students each give a lecture on their work to academic and research staff, fellow students, and industrial scientists. Doctoral completion rates in Chemistry (thesis submission within four years and award of the degree of PhD) during the assessment period were > 98%.

d. Income, infrastructure and facilities

Investment in infrastructure: Our research infrastructure was massively enhanced in 2008-2009 by the University providing £4.5M to develop a new instrument platform within the Department of Chemistry, the "Chemical Analysis Facility". This project entailed major refurbishment of laboratories over two floors and the installation of new instrumentation including: Bruker 400, 500 and 700 MHz multinuclear NMR spectrometers, all with multichannel and variable temperature capabilities and fitted with sample autochangers; DSC, TGA, ITC and hot-stage microscopy, for thermal analysis; I.R., Raman, and fluorescence spectrometers; I.R. and Raman microscopes; GC/MS; an "Orbitrap" mass spectrometer with HPLC interface, and an isotope-ratio mass spectrometer for environmental and geochemical research; two wide-angle X-ray powder diffractometers - one for high-throughput studies and the other with thermal and environmental sample stages; and finally a Bruker "Nanostar" SAXS instrument for analysis of materials, especially polymers, at the nanoscale. This new instrumentation, *funded and installed entirely during the current REF assessment period*, complements an existing, EPSRC-funded single-crystal X-ray diffractometer (Agilent "Gemini" dual-wavelength instrument), a triple-detection, size exclusion chromatograph (also EPSRC-funded), a Bruker Ultraflex MALDI-TOF/TOF instrument, HCT ion trap and Q-TOF instruments for biomolecular analaysis, and an EPR instrument. The Facility is supported by three full-time technical staff, specialising in NMR, mass spectrometry and X-ray diffraction. In 2013, the University Centre for Advanced Microscopy (SEM, TEM, AFM, also staffed by specialist techical staff) was incorporated into the Chemical Analysis Facility. Detailed access costs for each relevant instrument are included in all grant applications, and additional income to support the facility is generated from external (e.g. industrial) users. Most recently, the University has committed some £200K for laboratory refurbishment and new instrumentation in support of Powell's research on thermoelectric materials for renewable energy application.

Research funding portfolio: As shown in REF-4b, research income from centrally-managed, external grants, expended to date since the start of the assessment period, was some **£14.7M**. Of this, £5.6M represents RCUK grants, including a £1.1M EPSRC Platform Grant to the Reading Polymer Group (P.I. Colquhoun) for work on nanostructured polymeric materials, and >£0.5M from NERC for work on atmospheric chemistry and climate change (P.I.s Marston and Pfrang). Industrial income for collaborative research is currently shown in REF-4b as £0.24M, but this was in fact supplemented by a further **£0.95M** of direct funding in the form of industrial contracts for collaborative (CASE-type) doctoral programmes. This latter funding is managed at School-level, and does not appear in the REF-4b record. Further external support for PhD studentships, not included in the above figures, was provided by overseas governments, the EU, EPSRC and NERC doctoral training grants, UK hospital trusts, charitable trusts (e.g. the Felix

Foundation), and national and international facilities (Diamond, ISIS, ILL). The sum total for all external income in support of PhD studentships in Chemistry, over the assessment period to date, was **£1.7M**. Beamtime at national and international (EU) facilities, mainly Diamond, ISIS, the NERC MS facility, the ESRF and the ILL, is valued at **£7.3M**. In this assessment period, average annual research income (spend) per member of staff has almost doubled when compared to RAE 2008. Major new grants awarded to the Department in 2013 include BBSRC funding for Cardin (DNA-ruthenium chemistry – £460K), and EPSRC support for (a) Powell and Vaqueiro (thermoelectric materials for energy recovery – £318K), and (b) Cramer (high-sensitivity MALDI mass spectrometry for biomedical applications – £631K).

e. Collaboration or contribution to the discipline or research base

Support for and exemplars of research collaborations: The UoA has successfully developed a very wide range of industrial collaborations based mainly on sponsorship (at either the 50% or 100% funding level) for PhD projects. The value of such industrial sponsorship in the current assessment period is approaching £1M (see Section **d**). Numerous international collaborations have also been funded by the EU, EPSRC and NSF.

Collaborating companies: Companies that have supported doctoral students on collaborative projects during the period of assessment are give here (numbers of studentships in brackets): AstraZeneca (3), AWE (2), BAE Systems (1) Biointeractions (1), BP (1), CEMAS (3), Enterpris (1), Cytec Engineered Materials (3), Diamond Light Source (6), Domino Printing Sciences (1 via EPSRC Industrial CASE), DuPont-Teijin Films (2), GSK (1), Henkel (2), ICI (1), ISIS (1), Johnson Matthey (3), Nuvia (1), Syngenta (1) and Unilever (1). In many cases the studentships were jointly supported by strategic use of RCUK doctoral training grants accruing to the UoA from its grant income, or more recently won from internal University competitions. These collaborative PhD programmes typically involve the doctoral student working at the premises of the industrial sponsor for between 3 and 6 months during the course of the project.

Intellectual property rights: Patents arising from collaborative research are either held directly by the University or, more commonly, assigned to the industrial partner through a royalty agreement. Harwood's patent application on new peptide synthesis methodology is thus assigned to the University, whereas other recent patent filings have been assigned to companies including DuPont-Teijin Films, Cytec Engineered Materials, Domino Printing, Johnson Matthey, and Biointeractions, with royalties to the University and the inventors.

Sustainable energy: Harwood's groundbreaking research on selective ligands for nuclear reprocessing, especially for extractive separation of lanthanide and actinide residues in nuclear waste, originated in the EU project "EUROPART" and continues with the FP7-*Euratom* programmes "ACSEPT" (2008-2012) and "SACSESS" (2012-2014). These EU consortia, each comprising 20-30 research groups and nuclear agencies in up to ten countries, are researching new approaches to the separation, transmutation and recycling of waste radionuclides. The aim is to develop new reprocessing chemistry that will avoid the storage of high-level nuclear waste almost entirely: demonstration facilities are planned for 2015-2020. Related work is pursued by Harwood within the EPSRC programme "MBase" (Molecular Basis of Nuclear Fuel Separations). This series of grants (£1.3M, 2010-2014) funds research at Reading (£212K), Imperial College, Manchester and Lancaster Universities, with partners at the UK National Nuclear Laboratory and the Idaho (US) National Laboratory. The work of Powell and Vaqueiro on thermoelectric materials for solar energy applications is supported by the FP7 programme "INNOVTEG" (2012-2014), a pan-European consortium comprising five industrial partners, two universities and two government research institutes.

Self-healing materials: A major international collaboration was supported by an EPSRC-NSF Materials Grant (£346K, 2006-2010) awarded to Colquhoun and Hayes for work with researchers at Case Western Reserve University (S.J. Rowan) and the University of Delaware (M.E. Mackay) on self-healing supramolecular polymers. This programme was highly successful, with many opportunities for exchange of research staff and doctoral students between the institutions, publication of 8 high-impact primary papers, a book, book chapters, a themed issue of the journal *Polym. Chem.* (guest-edited by Colquhoun), and many invitations to speak at international meetings. The work attracted great industrial interest and has led to new collaborations, for example with Domino Printing Sciences Ltd of Cambridge (EPSRC Industrial CASE award 2011, priority patent filing 2013).

Biomolecular mass spectrometry: Cramer holds an Alexander von Humboldt Fellowship that has enabled innovative development of MALDI-TOF methods with Hillenkamp (Muenster), leading to a patent application and to support from the Waters Corporation and, notably, from EPSRC (£630K in 2013). His collaboration with Imperial College on the proteomic analysis of fungal pathogens is currently funded by BBSRC (£357K at Reading) and has led to several high profile publications (*Science*, 2010). Related collaborations include a Marie Curie ITN for work on plant pathology and an EU-FP6 programme in systems biology (2007-2010).

Surface science: Held, in addition to his funded collaboration with Diamond (see Section **b**, p.3) holds a Marie Curie ITN award (2 PhD studentships, €400K) as part of the EU network "SMALL" (Surfaces for Molecular Recognition at the Atomic Level, 2010-2014). This involves 11 research centres, 15 investigators and 22 doctoral students in universities from the UK, Spain, France, Germany, Sweden and Denmark. Research is focused on exploring directed non-covalent interactions on surfaces, and is supported by high-level analytical equipment both in university laboratories and at synchrotron facilities across Europe. Held also works closely with scientists at the Advanced Light Source, Berkeley; the Elettra Sincrotrone, Trieste; and Sychnrotron Soleil, Paris, at all of which facilities he receives frequent allocations of beamtime for work (mainly) on soft X-ray photoelectron spectroscopy of surfaces.

Materials Chemistry: Hartl was recently awarded EPSRC funding (£330K, 2013-2016) for research with Liverpool and Durham on electronic conduction in molecular wires (also supported at Reading by Corning USA Inc.). In 2012, Hayes was awarded £387K for work with the Materials Department in Oxford (with partners Akzo-Nobel UK and Henkel UK) for research into the synthesis, engineering and processing of novel, supramolecular polyurethanes. Within the University, several new research collaborations have developed between Chemistry and other Departments during the current assessment period. Thus, Hamley's work with Connon (Pharmacy) on the development of synthetic polypeptide templates for directed stem cell growth was recently funded by BBSRC (£654K, 2010-2014). A collaboration between Hamley and Matsen (in Mathematics) on microphase separation of block copolymers at surfaces was similarly funded by EPSRC (£576K, 2008-2011). Finally, a collaborative EPSRC Platform Grant for research in Nanostructured Polymeric Materials (£1.1M, 2009-2013) was awarded to Colquhoun (P.I.), Hayes, Hamley and Matsen (Mathematics).

The basis of scientific measurement: Over the past decade, Emeritus Professor Mills FRS, President of the Consultative Committee for Units at the International Bureau of Weights and Measures, has led an international project to increase the accuracy and self-consistency of the SI. This research has redefined the SI in terms of the invariant constants of nature (e.g. the Planck constant and the Boltzmann constant) rather than by reference to man-made artifacts such as the "standard kilogram". In October 2011, the International Conference on Weights and Measures, representing 78 countries, agreed unanimously to re-define the entire SI in terms of such constants. Recognising this in 2012, the International Union of Pure and Applied Physics awarded Mills their "SUNAMCO" Senior Scientist medal "for his outstanding work in the field of **S**ymbols **U**nits, **N**omenclature, **A**tomic **M**asses and fundamental **CO**nstants".

Awards and contributions to the discipline: Examples of leadership and distinction are provided by Hamley receiving the Royal Society Wolfson Merit Award in 2011 and Page receiving the Royal Society of Chemistry Education Award in 2010. Cardin was a member of the Scientific Council of the ILL from 2009-2012. Colquhoun received the Macro Group UK (RSC/SCI) Medal in 2012 for contributions to polymer science, and an ScD (higher doctorate) from Cambridge in 2008: in 2012 he was elected President of the Materials Chemistry Division of the RSC. International conferences organised at Reading during the assessment period included the *European Colloquium on Heterocyclic Chemistry* (2012, chaired by Harwood), *Polymeric Biomaterials* (2010, chaired by Hamley), the *17th Interdisciplinary Surface Science Conference* (2009, chaired by Held) and *Molecular Nanoscience* (2008, chaired by Colquhoun). Plenary lectures at international conferences, were delivered by Hamley at the *European Colloid and Interface Society* conference (Antalya, 2009) and by Colquhoun at *Thermosets 2011* (Berlin). Chemistry staff are also members of editorial/advisory boards for internationally-recognised journals, including *Soft Matter* (RSC), *Synlett* (Thieme) *Polym. Adv. Technol.* (Wiley), *Polym. Int.* (Wiley), *Macromol. Chem. Phys*. (Wiley)*, and Molecules (MPDI).*