Institution: University of East Anglia

Unit of Assessment: 8 - Chemistry

a. Overview

The submission to UOA 8 from the University of East Anglia (UEA) comprises faculty from the School of Chemistry. The School celebrates its 50th Anniversary in 2014 and today stands as a mature and dynamic research-intensive department. It is part of the University's Faculty of Science, comprising six Schools that are all located and physically co-joined on the main UEA campus. The University is part of the Norwich Research Park (NRP), a partnership between UEA, four independent research institutes – the John Innes Centre (JIC), the Institute of Food Research, The Genome Analysis Centre (all funded by the BBSRC), and the Sainsbury Laboratory (funded largely by the Gatsby Foundation) - and the Norfolk and Norwich University Hospital. The NRP is a major UK centre for life sciences research and the School plays an integral role in its activities.

Research in the School of Chemistry is conducted within three broad groups, viz., *Synthetic chemistry, Physical & Analytical chemistry,* and *Biophysical & Biological chemistry*. The submission consists of 20 faculty members, carefully selected for their research excellence, spread evenly across the three groups. Several faculty have research interests bridging more than one group.

The Faculty structure of the University promotes close cooperation between Science Schools, and there is a long tradition of highly successful inter-disciplinary, cross-School research. During the REF period, the School has placed great emphasis on developing much closer links with the NRP Institutes, particularly the JIC, as part of a long-term strategy that was strongly endorsed by the RAE 2008 panel. Notably, the School has appointed **O'Connor** (from MIT) to a 'Synergy' position, whereby she is a full member of faculty in the School, with research labs situated at the JIC. In response to the RAE 2008 recommendations, the School has substantially increased doctoral research student numbers by, on average, 30% and contributed to a new and vigorous Faculty of Science Graduate School, which oversees progress reporting and transferrable skills training for graduate students. The University has invested substantially in the School in both infrastructure (>£4.5M) and appointments (a total of 8) over the REF period. Faculty in the School have won >£31M in research grants, supporting at any one time an average of ~30 postdoctoral fellows. The School's science is published in high-impact science journals, including *Nature*, *Science*, and *PNAS USA*, as well as leading chemistry journals such as *Angewandte Chemie* and *J Am Chem Soc*. Indeed, >60% of the School's REF-returned publications are in this group of journals.

b. Research strategy

During the current REF period, the School significantly developed its three core research groups and, as described below and in the following sections, invested (through new appointments and infrastructure) in several emerging interdisciplinary themes that cut across the research groups, including chemical biology, energy materials and theoretical/computational chemistry.

Synthetic chemistry: Strategic goals for synthetic chemistry during the REF period were to develop: ● chemical biology through closer interactions with biologists/biological chemists at the JIC; ● organic chemistry through leadership/new blood recruitment; ● energy materials research; ● catalytic materials capability.

Chemical biology: The School has extended its capability in the area of chemical biology, with an emphasis on exploiting biosynthetic pathways in plants and microbes to generate new-to-nature molecules that are challenging or impossible to make using classical approaches. This has been led by **O'Connor**, who bridges synthetic bioorganic chemistry and plant/microbial studies, with a focus on engineering plant-specialised metabolism to generate complex natural products.

Highlights include: The generation of novel monoterpene indole alkaloid analogues by **O'Connor** through the introduction of bacterial-derived halogenase enzymes into a plant to specifically incorporate chlorine into the products. This demonstrated that complex, plant-based pathways can be manipulated to yield new-to-nature compounds that may have new/improved biological activities and potential as therapeutics. She has also used sophisticated bioinformatic analyses to uncover

novel plant natural product biosynthetic pathways; the discovery of an enzyme that catalyses terpene cyclisation via an unprecedented mechanism is a good example of this.

Organic chemistry: This area was significantly boosted by the leadership appointment of **Page** (Chair) at the beginning of the REF period and more recently of **Muñoz-Herranz** (lecturer). Research in organic chemistry has focused on the synthesis of novel organic materials, including discotic liquid crystals, and of natural products and other bioactive molecules, and the development of asymmetric synthetic strategies using organocatalysis approaches.

Highlights include: The development by **Page** of new electrochemical and organocatalytic processes, including highly enantioselective iminium salt-catalysed systems for asymmetric epoxidation. These made possible the total synthesis of natural products such as (−)-(3′S)-Lomatin and (+)-(3'S,4'R)-trans-Khellactone.

Energy materials: The aim of developing critical mass in the increasingly important area of energy materials led to the creation of the *Energy Materials Laboratory*, headed by **Pickett**, with substantial support from the Royal Society (RS)/Wolfson Foundation. Research here seeks to address major challenges in meeting future energy needs. The major thrusts are: (i) the synthesis of nanomaterial mimics of the active sites of hydrogenase enzymes, which catalyse the reversible uptake/evolution of H_2 (technologically important for clean energy transduction); and (ii) artificial photosynthesis, in which (bio)inorganic catalysts are interfaced with light-harvesting electrodes for solar fuel generation. The appointment of two new lecturers, **Fielden** and **Wright**, has significantly strengthened and expanded capability in this area.

Highlights include: The first evidence that the active site of the 'third hydrogenase' is low-spin Fe(II) was provided by **Pickett** and **Wright**. They followed this with the synthesis of a close structural model of the enzyme's 'ferracyclic' active site. **Pickett** also revealed fundamental aspects of protonation and 'electronation' of the diiron-subsite of FeFe-hydrogenase. These are key steps in natural and artificial systems that electrocatalyse H_2 evolution.

Catalytic materials: The School's research on polymerisation catalysts and catalyst activators is internationally recognised. This, together with multidisciplinary approaches to making molecular and supramolecular assemblies and nanoscale materials with novel catalytic properties, is embodied in the School's *Wolfson Materials and Catalysis Centre*, led by **Bochmann**. The appointment of **Wildgoose** (formerly a RS University Research Fellow) significantly strengthened the area of electrocatalysis and directly complements the work of the *Energy Materials Laboratory*.

Highlights include: The elucidation of the mode of action of metallocene-based olefin polymerisation catalysts by **Bochmann**. His group are also pioneering studies of the largely unexplored chemistry of gold catalysts, recently describing the first examples of gold(III) olefin, hydride and peroxide complexes, key intermediates in catalytic processes. **Wildgoose** showed how to link organometallic catalysts to the surface of carbon nanotubes, with great potential for the development of novel electrocatalysts and sensors. He synthesised a series of highly electrophilic and Lewis acidic perhalogenated aryl borane complexes, which have potential applications in frustrated Lewis pair activation of small molecules such as CO_2, with potential impact for synthetic applications in chemical feedstock lines and energy materials.

Physical & Analytical chemistry: Strategic goals during the REF period were to: ● develop ultrafast laser spectroscopy and photonics; ● develop computational chemistry as an interdisciplinary theme; ● expand capability in the area of nanoscience and catalysis.

Ultrafast laser techniques: Novel ultrafast methods, with world-leading time resolution and outstanding sensitivity, have been developed within the *Ultrafast Laser Laboratory*, led by **Meech**. These have been applied in key areas of ultrafast spectroscopy, including excited state dynamics, molecular dynamics in liquids and solutions and photophysics of photoactive proteins.

Highlights include: The discovery and characterisation of a new H-bonding mode associated with halide solvation in salt solutions by **Meech**. This work on liquid state dynamics was expanded to embrace systems as complex as protein solvation, while studies of transient electronic/vibrational states in photoactive proteins helped to unravel the earliest events in flavoprotein blue light-sensing mechanisms that regulate bacterial photosystem synthesis.

Computational chemistry: Developments in theory, simulation and calculation of optical signals, magnetic resonance spectroscopies and excited state dynamics have enhanced research activity across all three groups. This area was significantly strengthened by the recent appointment of **Jones**, whose research links directly with the *Ultrafast Laser Laboratory*.

Highlights include: Simulation by **Oganesyan** of EPR spectra from molecular dynamics calculations, thus directly correlating spectral features with molecular motion. This has led to new insights into order in discotic liquid crystals and protein dynamics.

Nanoscience and catalysis: The development of nanoparticle-based applications in bioassay and therapeutics at UEA is well-established. The characterisation of nano-catalysts, which links particularly to **Wildgoose** in the *Wolfson Materials and Catalysis Centre*, is also now established.

Highlights include: **Russell**'s use of functionalised metal/metal oxide nanoparticles to develop novel and sensitive bioassay methods, including highly specific and sensitive detection of multiple analytes within a single fingerprint. He established a spin-out company, *Intelligent Fingerprinting Ltd*, to exploit the commercial and societal potential of his discoveries. He also developed lectin-photosensitiser functionalised gold nanoparticles for targeted photodynamic therapy of cancer, and working with Field (JIC), has imaged glycoarrays with surface plasmon resonance to identify novel carbohydrate ligands for sensor development.

Biophysical & Biological chemistry: Strategic goals during the REF period were to: ● extend the research strengths of the *Centre for Molecular and Structural Biochemistry* (CMSB); ● increase connections with NRP strategic priority areas in the life sciences.

Research in this area is undertaken within a single, highly collaborative group under the umbrella of the CMSB, a multidisciplinary, cross-School research centre with an international reputation for the application of biophysical techniques to solve biological problems. Following strategic review in 2008, the Centre broadened its research portfolio, building on its long-time areas of strength in metalloprotein systems but also extending into areas such as protein folding and plant-pathogen interactions. Core metalloprotein research centres on proteins involved in microbial nitrogen, sulfur and iron cycling and this connects directly with the Earth & Life Systems Alliance (ELSA), a strategic research priority of the NRP for which life-sustaining elemental cycles is a central theme.

Highlights include: Pioneering work by **Le Brun** (Director of the CMSB since 2010) on mechanisms by which iron-sulfur cluster-containing global transcriptional regulators 'sense' O_2 and nitric oxide (in part with Buttner at the JIC), which underpins the ability of bacteria to thrive in a wide range of habitats, including the human body. He also elucidated novel mechanisms by which iron oxyhydroxide minerals are deposited within the protein cages of ferritin iron-storage proteins. **Butt** used protein film electrochemistry and optical and magnetic spectroscopies of poised samples to reveal redox and catalytic properties of multi-heme cytochromes. These cytochromes, which occur in a subset of bacteria, are key for electron transfer across the microbial outer-membrane to extra-cellular minerals of Fe(III) and also to electrodes. Her work using artificial membranes provided novel insights into how protein-protein interactions in this unusual respiratory system govern the direction of electron transfer and catalysis.

Research vision for the next five years

The research structure described above provides a framework for the next REF period that aligns well with both NRP and RCUK strategies to meet international need. The School is well placed to continue its success in attracting funding from a range of sources, and will build on recent successes at the European Research Council (ERC) as the EU Horizon 2020 programme begins.

Synthetic chemistry: **O'Connor** has obtained major ERC/RCUK funding (> £2M) to further engineer plant natural product pathways to generate novel compounds. The School will strengthen its bioorganic/chemical biology activity by making an appointment in this area in 2014, complementing existing strength in more traditional synthetic approaches. **Bochmann** was recently awarded an ERC Advanced Grant (£2M) to expand his pioneering work on gold(III) chemistry, while **Wildgoose** recently won major ERC support (>£1M) for his work on frustrated Lewis pairs. They will lead work in catalytic materials over the next REF period. The *Energy Materials Laboratory* recently established a strategic partnership with the *Laboratory of Advanced Materials* and the Department of Chemistry at Fudan University, Shanghai, China, which will lead

to a range of new collaborative projects over the next few years. **Pickett**, together with new appointments **Wright** and **Fielden**, will drive the growth of the energy materials area.

Physical & Analytical chemistry: The *Ultrafast Laser Laboratory* recently won EPSRC support (>£1M) to provide a tuneable ultrafast laser source for multidimensional nonlinear optical spectroscopy. The School will make a new appointment within this area to complement **Meech**, and to capitalise fully on the recent appointment of **Jones** in theoretical and computational excited state dynamics. With Jones, computational chemistry now has a critical mass of theoretical expertise that also includes coupled quantum and classical molecular dynamics (**Oganesyan**), and nanophotonics and radiation-matter interactions (**Andrews**). Together, the theory/computation chemists have recently won substantial external grant support (total £825K) and will increasingly provide important new research dimensions to projects across the School. In nanosciences, **Russell** will lead research in bioassay, imaging and therapeutics over the next REF period.

Biophysical & Biological chemistry: The CMSB is central to future strategy, with a research focus on transition metal, sulfur and nitrogen bioelemental cycles, led by **Le Brun** and **Butt** (>£1M current support from BBSRC). Recent initiatives include developing mass spectrometry methods to study native metal-protein and protein-protein interactions (**Le Brun**). **Butt**'s recent grant from BBSRC to exploit transmembrane cytochrome complexes for solar energy conversion illustrates growth of the increasingly important area of synthetic biology. The School will make a new appointment in protein-based synthetic biology to stimulate further activity in this area across the NRP. This appointment will complement the bioengineering work of the *Synthetic chemistry* group.

In anticipation of future retirements, Chemistry intends to make two additional proleptic appointments to further build research strength in organic and physical chemistry.

The School has benefited greatly from increased interactions across the NRP. The Chemistry-JIC joint 'Synergy' position and a successful NRP-wide BBSRC Doctoral Training Partnership programme are tangible illustrations of this and growing links will remain a key future strategy. Infrastructure investment of £26M by HM Treasury as part of the 2011 budget highlights the strategic national importance of the NRP. Chemistry will directly benefit from this investment.

c. People, including:

i. Staffing strategy and staff development

Staffing strategy, recruitment and fellowships: Over the REF period, the School's staffing strategy has closely reflected its research strategy (above) and infrastructure investment (section d), with recruitment from the UK and internationally. Key appointments have been made in synthetic organic chemistry (**Page** from Loughborough University and **Muñoz-Herranz** from Insituto de Química Orgánica General, Madrid, Spain), energy materials (**Fielden** from Emory University, USA and **Wright** from within the School), theoretical/computational chemistry (**Jones** from Industry) and chemical biology (**O'Connor** from MIT, USA). Also, three fellows were promoted to full faculty positions in theoretical/computational chemistry (**Oganesyan,** Advanced EPSRC Fellow), energy/nano materials (**Chao,** RCUK Fellow), and energy/nano materials and electrocatalysis (**Wildgoose**, RS University Research Fellow). Another RS Fellow (**Banfield** from Newcastle University) brought expertise in protein crystallography to the *Biophysical & Biological* grouping before moving to a group leader position at the JIC (further strengthening links). A total of 16 other research fellowships have been held in the School over the REF period, including RS Industry, Marie-Curie, Daphne Jackson Trust and Leverhulme Trust fellowships, and the School has hosted >55 externally funded visiting scholars.

The above appointments were made possible by a number of retirements and departures. Of the latter, Field moved to the JIC but retains an honorary Chair position (and many collaborations) within the School, Redshaw moved to a professorship at Hull, and Goss to a readership at St. Andrews. Nann and Hoogewerff moved to senior positions at the Universities of South Australia and Otago, respectively.

Career development support: UEA's Centre for Staff and Educational Development provides a broad programme of courses and events, from media training to business skills to ethics. The Careers & Employability Service provides dedicated advisers for research staff. Post-docs are

encouraged to advance to fellowships or faculty positions (within the School and elsewhere), as exemplified most recently by **Wright**. All faculty members may enhance their research by applying for a semester or more of Study Leave (at a frequency of ca. one in seven semesters).

The University, in support of the implementation of the *Concordat to Support the Career Development of Researchers*, has established a Research Staff Working Group, with representatives of academic staff and researchers from all Faculties, which steers the University's strategy for career development and monitors implementation activities. The School also has a research staff coordinator who acts as a point of contact and mentor for research staff. In 2012, UEA was awarded the HR Excellence in Research Award from the European Commission, recognising commitment to personal, professional and career development of research staff, particularly through alignment with the principles of the European Charter for Researchers, Code of Conduct for Recruitment and the UK Concordat.

Progress of research staff at all levels in the School, from post-docs to professors, is considered at individual formal annual appraisal meetings (senior staff can be appraised biennially). A research plan is an integral part of the process and appraisers act as mentors for junior staff to help determine priorities for the coming year. The University's rules for confirmation of appointment and promotion of academic staff involve assessment of performance (as appropriate) across the areas of research, teaching, and enterprise and engagement, as well as related administration, management and leadership. The School and the University are keen to reward staff for outstanding performance. During the current REF period, three fellows were promoted to permanent faculty positions (**Oganesyan** and **Chao** to senior lecturer and **Wildgoose** to reader). Also, several faculty members were promoted by more than one level (e.g., **Le Brun**, from senior lecturer to professor; **O'Connor**, lecturer to professor).

Equality and Diversity: The University, through its *Single Equality Action Plan* and activities such as RESNET (a contact, support and information network for female research staff from across the NRP), works hard to increase *diversity*, eliminate gender bias and develop an inclusive culture that values all staff. In 2012, UEA gained a Bronze Award from *Athena SWAN* in recognition of this. Three of the last six Chemistry faculty appointments and two of the last four professorial appointments in the School were female.

ii. Research students

An important outcome of RAE 2008 was the need for the School to increase its doctoral student numbers. This has been achieved by increasing success with external studentship funding competitions, through attracting overseas students and through institutional investment. The School has won two consecutive EU Inter-regional PhD training grants (~£1.9M) in synthetic organic chemistry. In addition to the School's EPSRC DTA studentships, the NRP holds a BBSRC Doctoral Training Partnership award - in which the School of Chemistry is a core partner. Further, an annual PhD studentships competition, run across the NRP, fosters new collaborative links. Consequently, doctoral student numbers in the School increased from a mean of 52 in the RAE 2008 period to a mean of 67.5 over the REF period (see Table), a rise of ca. 30%, achieved against a backdrop of ever-increasing competition for studentships.

Year	**2008/9**	**2009/10**	**2010/11**	**2011/12**	**2012/13**
Doctoral students	**59.5**	**64.4**	**69.5**	**72.6**	**71.9**

The process of recruiting students is rigorous. PhD projects are screened for their suitability, the strength of their training element, and their fit to research strategy. Potential supervisors must have an excellent track record in four year completion rates, high levels of research activity (judged by publications and grant activity), and be up-to-date in progress reporting requirements for all existing doctoral students. Applications are handled by the Faculty Postgraduate Research (PGR) Office, ensuring that applicants meet University (and sponsor) admissions criteria before progressing to the next stage. All candidates are interviewed by a panel of academics and selection is based on academic record, relevant skills/knowledge and researcher potential.

Another major initiative following RAE 2008 was the creation of a Faculty of Science Graduate School, which ensures that all research students are provided with a rounded research experience that combines the highest quality supervision and training in state-of-the-art methods with a rich

and varied programme of professional and personal development, equipping them for a variety of careers. Each student has a supervisory team comprising at least two academic staff. Mentoring and training are provided to all supervisors. Formal *progress meetings* take place at least quarterly (every six months for part-time), including the annual progress meeting, for which students write a report and benefit from a PhD *viva*-style discussion. The School PGR Director acts to resolve any difficulties highlighted by the review process. The Graduate School's *Personal and Professional Development* programme, which now comprises >120 modules of transferable and technical skills training, is founded on the RCUK Researcher Development Statement and is supported by a dedicated Skills Training Officer. The programme includes presentation skills, ethics, IP/business skills and CV writing. Students are strongly encouraged to participate in public engagement and outreach activities, including the Norwich-based Teacher-Scientist Network. Assistance in finding suitable employment is provided by a range of employability events and two PGR Career Advisers.

d. Income, infrastructure and facilities

The School's infrastructure, comprising a range of core and specialist facilities, has benefited from externally won grants and strategic investment from the University and reflects well a modern, research-intensive chemistry department. Importantly, a formal framework for sharing research facilities across the NRP has been established, providing easy access to a wide range of platform and specialist technologies, including proteomics, atomic force microscopy and imaging. More than 90% of research space has been refurbished to a high standard during the past 10 years, providing state-of-the-art facilities. The remaining areas will be upgraded during the next REF period.

Synthetic chemistry: Core infrastructure in the School includes NMR, small molecule X-ray crystallography and mass spectrometry, each of which is managed by a dedicated technician. Existing NMR facilities (300 and 400 MHz instruments) were greatly enhanced by the purchase in 2012 of a new 500 MHz spectrometer, capable of triple resonance measurements and equipped for high throughput work, and a new solid state 400 MHz instrument. The total investment by UEA over the REF period in small molecule, solid state and biomolecular NMR (see below) was ca. £2.2M. Mass spectrometry facilities now include a new LC-Q-TOF instrument, enabling MS/MS analyses (purchased in 2013; £200K), and a GC-MS instrument, in addition to existing LC-MS and MALDI-TOF. The School has its own transmission electron microscope (TEM) that is extensively used for nanoscience, which will be significantly upgraded early in the new REF period. A second TEM and a scanning electron microscope are available under the NRP sharing framework.

Physical & Analytical chemistry: Research in this group is largely underpinned by specialist facilities. For example, the newly refurbished and upgraded (EPSRC/UEA funding of >£1M) *Ultrafast Laser Laboratory* houses a multi-dimensional multi-frequency ultrafast laser spectroscopy facility. Analytical capabilities were extended through the acquisition of stopped-flow FT-IR, stopped-flow UV-visible and time-resolved spectroelectrochemistry (RS/Wolfson Foundation/UEA, £500K), and through an attenuated total reflectance FT-IR spectrometer and an electrochemistry suite (>£100K). For high resolution confocal fluorescence microscopy, the Henry Wellcome Laboratory for Cell Imaging was upgraded (£550K) to include multi-photon and confocal fluorescence lifetime imaging. **Russell**'s group is the University's largest user of this facility.

Biophysical & Biological chemistry: The CMSB laboratories are equipped with a comprehensive range of facilities from cell culture through to a unique array of advanced spectroscopic techniques. These include a pulsed multi-frequency, time domain EPR, multi-frequency continuous wave EPR, and ENDOR spectroscopies. Displex closed cycle cryostats (£100K) that significantly reduce liquid helium usage were recently installed. The School has excellent facilities for biomolecular NMR, including an 800 MHz spectrometer (also capable of solid-state ^{13}C measurements) and a second 500 MHz instrument recently upgraded with a new triple-resonance probe. Magnetic CD spectroscopy facilities were upgraded through a new superconducting magnet for room temperature studies (BBSRC, >£100K). Extensive facilities for protein film electrochemistry, rapid reaction kinetics, calorimetry and ultracentrifugation are also available. The new LC-Q-TOF MS instrument (see above) with ESI source now provides high accuracy mass data for protein work. Advanced proteomics facilities are available at the JIC/Sainsbury Lab. An NRP-funded upgraded protein X-ray crystallography facility (£220K, £70K from UEA) is also available at the JIC.

The School's high quality research environment is supported by a team of 11 FTE technicians,

providing a wide variety of services, from glass-blowing to protein purification to NMR expertise. Extensive mechanical workshops are located within the Faculty of Science. The University provides some key services centrally, including IT support and an annually upgraded high performance computing cluster, providing a total of 4148 cores and a theoretical peak performance of 65 TFlops, supporting computational chemistry across all three research groups. The UEA Library provides electronic access both on and off campus to all major journals. Refurbishments in the School have sought, where possible, to reduce the environmental impact of research activities. For example, a 30% reduction in water effluent has been achieved since 2011.

Research Income: Over the REF period, the School has held a total of >£31M in grants, including >£20M from Research Councils, >£4.7M from the EU, >£3M from charities, and >£1M from industry, approximately evenly split across the three research groups, demonstrating strength across the School's research portfolio. Current grant holding totals >£12.9M, and in 2012 >£5.7M of new grants were won, including two ERC Starting Grants (**O'Connor**, **Wildgoose,** ~£1M each). The School is on course for similar success in 2013, boosted by **Bochmann**'s recent ERC Advanced Grant (~£2M). This sustained success reflects the School's high quality, vigorous research effort. All applications to Research Councils go through a formal process of internal peer review and this has proved particularly valuable for early career faculty. This is illustrated by success rates of >50% and 71% for all of the School's applications to BBSRC for 2010-12 and 2011-13, respectively (BBSRC data). In addition, faculty are engaged with various industries and have acted as consultants to >20 companies (total consultancy income >£200K).

e. Collaboration or contribution to the discipline or research base

Collaborations: Collaboration with other academics across the University/NRP, elsewhere in the UK and abroad, and with industry, is a key part of the School's research and faculty have been involved in collaborative grants worth in total >£40M during the REF period. Examples include:

- **Pickett**, in the *Energy Materials Laboratory*, leads a Grand Challenge consortium on solar fuels ("*SolarCap*") involving academics at York, Nottingham and Manchester, and is also part of the "*Biofuel Cells Supergen Consortium*" (led by Oxford). Such consortia are key for the technological breakthroughs that will be required for meeting future low carbon energy needs;
- The *Energy Materials Laboratory* (**Pickett**) has developed a formal cooperation with the *Laboratory of Advanced Materials*, Fudan University, China. This has been funded by the British Council and the Fudan-Tyndall Centre, enabling the exchange of PhD students and staff between the two laboratories. Both UEA and Fudan University have recently invested in international PhD studentships to support this venture. Establishing international partnerships of this type is increasingly important as a way to increase research opportunities;
- **Bochmann** is part of an EU network focused on methylaluminoxane, an important activator for olefin polymerisation catalysis and the plastics industry, that includes partners such as DSM, Sabic, Lanxess and Chemtura. This provides an excellent example of how academic expertise can feed into commercial processes;
- **Meech** has collaborated extensively with Tonge, at SUNY Stony Brook, supported by two successive EPSRC/NSF "*International Collaboration in Chemistry*" grants, complemented by two "*Approved Access*" programmes at the ULTRA facility of the Rutherford Appleton Lab. This illustrates well how internationally leading teams can cooperate effectively.

Inter/multi-disciplinary research features prominently in the School. The examples below illustrate how interactions with researchers in different areas (locally, within NRP, nationally and internationally) can lead to world-leading research outcomes:

- **O'Connor**'s recent discovery of a plant-derived iridoid synthase involved a multi-disciplinary and international collaboration with Courdavault and Burlat (Tours, France) for imaging and Cui (Michigan State) for statistics;
- **Russell**'s work on applications of nanoparticles in photodynamic therapy (PDT) and intracellular analyses involves collaborations with Jori (Padova, Italy) a biologist, and Galindo and Luis (Castellon, Spain) organic chemists;
- **Le Brun**'s work on iron-sulfur cluster global regulatory proteins, supported through three BBSRC project grants, involves collaborations with geneticists including Green (Sheffield) and Buttner (JIC), Johnson (Georgia, USA), a resonance Raman spectroscopist, and **Oganesyan**

(Chemistry, UEA), a theoretical chemist. His US links were recently extended through a BBSRC US Partnering award with the West Coast Mössbauer Center at UC Davis, USA;
- **Butt**'s work on electron transfer at the microbe-mineral interface with Richardson, a microbiologist/biochemist, and Clarke, a structural biologist (both Biology, UEA, returned with UOA 5) has involved a US Dept of Energy-supported collaboration with Fredrickson, a microbial ecologist, and Zachara, a biogeochemist (both at Pacific Northwest Nat Lab, USA).

Some of the above projects provide clear examples of where existing collaborations have significantly influenced subsequent research activities, including:
- **Russell**'s work on PDT with Jori led to Cancer Research UK funding a joint programme between the labs and the licensing of patents from UEA;
- **Butt**'s work on microbe-mineral electron transfer has led directly to a large new BBSRC-funded project with Jeuken (Leeds) and Reisner (Cambridge) aiming to explore and exploit the bioenergy potential of multi-heme cytochromes;
- **O'Connor**'s work on plant natural product pathways has led to a programme project grant application to NIH (USA) with Buell and DellaPenna (Michigan State) and Tang (UCLA).

Contribution to the research base: Faculty at all career levels have engaged in a wide range of activities that support and promote the research base in the UK and internationally.

Committee membership: Key examples include: **Russell** served as a member of the RCUK Basic Technology Strategic Advisory team; Service on key grant committees, e.g., **Meech** and **Cammidge** as EPSRC Panel Chairs; **Butt** and **Le Brun** as core members of BBSRC grants committees; **Russell** as a member of MRC's Discipline Hopping panel; **Cammidge** as expert evaluator and chair for CEC Marie Curie programmes; Royal Society panel membership includes **Bochmann** (Industry Fellowships) and **Le Brun** (International Exchanges).
Service as committee members of learned societies includes: **Cammidge** as elected member of RSC Materials Division Council; **Macmillan** as vice-chair and chair-elect of Theme panel III of the Biochemical Society; **Andrews** as a member of the Board of Directors, and the European Advisory Committee of the International Society for Optical Engineering (SPIE).
Service as invited international expert assessors of research facilities, e.g. in Grenoble (**Pickett** for ANR, France) and Saclay (**Oganesyan** for AERAS, France).
Membership of judging panels for international prizes, e.g. Prism prize for photonic innovation (2011-13, **Andrews**); RSC Materials chemistry awards (2013, **Cammidge**); International Society of Electrochemistry prize for contributions to bioelectrochemistry (2012, **Butt**).

Visiting professorships: These include **Bochmann** at the Graduate University of the Chinese Academy of Sciences, Beijing and **Oganesyan** at the University of Queensland, Australia.

Conference organisation and invited lectures: Faculty have given >325 invited lectures over the REF period, including >175 at international conferences covering the full spectrum of the subject. They have also taken leading roles in organising conferences, for example:
Andrews was co-chair of the annual Nanoscience & Engineering Symposium, San Diego US (2007-12), the largest nanotechnology meeting in the US. In 2013, he was overall Chair of OPTO, the Optoelectronics symposium in San Francisco, comprising 40 co-located meetings;
Bochmann organised an ACS Symposium to mark the retirement of Dietmar Seyferth as Editor-in-Chief of *Organometallics*, at the 240th ACS National Meeting in Boston, August 2010;
O'Connor was vice-Chair of the Plant Metabolic Gordon Research Conference 2013.

Editorial postions: Faculty have editorial positions with many journals, senior examples include: **Bochmann**, the only non-US Associate Editor of ACS Organometallics; **O'Connor**, Editorial Board member for ACS Chemical Biology and ACS Synthetic Biology; **Meech**, European Editor, Journal of Photochemistry and Photobiology A Chemistry; **Russell**, Advisory Board member for RSC Analyst; **Andrews**, International Advisory Board member of Journal of Physics B: Atomic, Molecular and Optical Physics; **Page**, Scientific Editor of Annual Reports, Section B, RSC.

Prizes, awards and fellowships: Faculty have won numerous awards, for example:
Pickett, RSC Ludwig Mond Medal 2009; **Page**, RSC Tilden Prize 2009; **O'Connor**, ACS Pfizer Award in Enzyme Chemistry 2011; **Thomson**, OBE in 2008; **Macmillan**, **Nann** and **O'Connor**, RS Wolfson Research Merit Awards; **Wildgoose** and **Banfield**, RS University Research Fellowships.