Institution: University of Nottingham

Unit of Assessment: UoA 8 (Chemistry)

a. Overview: The School is returning 42 category A researchers (100% of eligible staff), including 25 Professors (two FRSs[$]), 8 Associate Professors, 4 Lecturers and 5 fixed-term Research Fellows (denoted*). Our research, impact and industry engagement has attracted international recognition in the following overlapping thematic areas:

• **Theoretical and Computational Chemistry**: *Besley, Bichoutskaia, Hirst, Robinson*, Teale*, Wheatley*.

• **Molecular Structure and Spectroscopy:** *George, Jones, Powis, Reid, Sarre, Stace[$], Wright*.

• **Chemical and Structural Biology:** *Dowden, Oldham, Searle, Soultanas, Thomas*.

• **Sustainable Synthesis and Catalysis:** *Denton, Hayes, Kays, Lam, Licence, Liddle, Lygo, McMaster, Moody, Moses, Poliakoff [$], Stockman, Woodward*.

• **Functional Materials and Nanosciences:** *Blake, Champness, Gibson*, Gimenez-Lopez*, Howdle, Khlobystov, Mokaya, Schröder, Titman, Walsh, Yang*.*

b. Research strategy

b1: Achievement of strategic aims stated in RAE2008:

1. Achieving a Sustainable Research Environment. Our aims since 2008 have been to strengthen our research at the interfaces between Chemistry and other physical sciences, the life sciences and engineering. We have built upon our strong research base and have ensured the sustainability and vitality of our environment by the strategic allocation of resources, major investments in instrumentation and infrastructure to provide world-class facilities (see **d**), and by nurturing Early Career Researchers (ECRs, see **c1**). The School has exploited new research opportunities and driven national research priorities by engagement in EPSRC Portfolio Shaping, membership of SATs and boards of UK facilities (see **e3**). We have strengthened our knowledge exchange activities with industry (see **e2**) and the public to increase research impact, and have built critical mass in research and training (see **e1**). Our successes have been underpinned by:

• Support for a strong research base by commitment of >£700k pa of School resources alongside RCUK/Charities/Industry awards to fund *ca.* 55 PhD students pa (>1 pa per member of staff, **c2**).

• Committed investments of >£35M in new infrastructure and refurbishments (including a new research building), and in new instrumentation (£8.43M) through EPSRC, ERC and CIF awards.

• The School has nurtured the career development of future research leaders. ECRs have won 15 prestigious EPSRC, EU, RS and Charity-funded Fellowships, leading to four ERC Starter Grants (>£0.8M) (*Bichoutskaia, Khlobystov, Lam* and *Liddle*). Three of these colleagues are amongst the 8 Chair promotions/appointments since 2008 (see **c1**). Vitality across the thematic research areas has been further strengthened through the recruitment of fixed-term ECRs: *Gibson* (photovoltaics), *Gimenez-Lopez* (carbon nanotubes), *Robinson* (theoretical biophysics), *Teale* (quantum chemistry), *Yang* (functional materials) and 11 EU Marie Curie Fellows (see **c1**).

• The School's embedded Business Partnership Unit (BPU) and team of *Industry and Business Science Fellows* (14 since 2008) have enhanced the development of a knowledge exchange research culture (see **e2**) which has included new collaborations with SMEs through an ERDF funded *Chemistry Innovation Laboratory* project (£0.8M), expansion of our extensive network of contacts with the *Chemistry-Using Industries* and establishment of a high-profile, industry-led, Strategic Advisory Board to inform our business engagement strategy (see **e2**).

2. Achievement of Strategic Aims.

• ***Research awards and esteem.*** The School has a wide portfolio of UK and international research collaborations and has established major academic and industrial partnerships that have generated research spend of >£32M since 2008 (ca. £170K per FTE pa) with a current portfolio of active grants of > £25M (see **d3**). The School has graduated 232 PhD students (ca. 6 per staff FTE) virtually all of whom have contributed to the strong research base as co-authors of publications in leading journals, including *Science* and *Nature* (4 papers) and *Nature* family journals (19 papers). Staff have received >50 major internationally recognised honours, awards, and fellowships, including election of *Poliakoff* (2011) as Foreign Secretary of the RS, 3 RS Wolfson Merit Awards (*Schröder, George, Champness*) and 12 RS/RSC Prizes (see **e3**).

• ***Driving Innovation between Chemistry and Engineering (DICE)***: A £3.5M EPSRC/HEFCE Science and Innovation Award for DICE (2005-10) funded six appointments at the Chemistry-

Engineering interface (*Licence, Liddle* and *Walsh* returned for Chemistry) and has shaped a strong strategic alliance in sustainable technologies with the energy industries (see **e2**). New technologies developed through DICE have been commercialised via two UoN spin-out companies, Promethean Particles (*Poliakoff*) and Critical Pharmaceuticals (*Howdle*) (**CS1** and **CS2**), and have led to significant impacts in sustainable process chemistry (*Poliakoff* with Invista and Lucite, see **CS3**). Activities in Green Chemistry are connected internationally through EU COST Actions and collaborative projects (*e.g.* €10M SYNFLOW in sustainable processing) with strengthening of critical mass in research and training networks (see **e1**). We have contributed to advisory boards of other major Green Chemistry Centres (Kansas, USA; Aachen, Germany) and have MoUs with Moscow State and Aarhus Universities and the National Chemical Laboratory (Pune, India). The School has led the way in promoting sustainable technology initiatives and chemistry education in Ethiopia (see **CS4**) by working with policy makers in the UK (RSC and the British Council) and Africa (*Licence, Poliakoff*). We have expanded the sustainability agenda into new areas of functional energy materials and organic synthesis through major funding initiatives, co-investments in infrastructure and training networks (see **e2**).

• ***Strategic Partnerships with Industry.*** Building directly upon our EPSRC *DICE* initiative, our strategic approach has been endorsed and our research strengthened by a major partnership with GSK to build a unique Carbon Neutral Laboratory (CNL) to be opened in 2015 as part of a *Centre for Sustainable Chemistry* (**see e2**). The CNL is co-funded by GSK (£12M) as part of a £30M project supported by the HEFCE Research Partnership Investment Fund with support from a range of industrial stakeholders and co-investors across the chemistry-using sector, the pharmaceutical and energy technology industries (Rio Tinto, Invista, EoN, Lucite, AstraZeneca (AZ) and Syngenta). Two GSK/EPSRC co-funded Chairs in Sustainable Chemistry, with *Lam* (2013) the first of these appointments, have enabled us to grow in this area. The CNL will not only expand our capacity to do research in Sustainable Chemistry: this unique infrastructure seeks to redefine how the science is conducted within a designed carbon-neutral research environment (see **e2**).

• ***Chemistry links to Interdisciplinary Centres:*** Chemistry research has benefited considerably from integration within the £40M flagship interdisciplinary Centre for Biomolecular Sciences (CBS) (accommodating *Searle, Soultanas* and *Thomas*). The School has built new, and strengthened existing, cross-disciplinary collaborations using expertise in synthesis, biochemistry, structural analysis, and theory and simulation to develop programmes in drug discovery, bacterial biology, epigenetics, structural biology, biophysics and in developing chemical probes for biological applications. Chemistry has led in establishing facilities for Biomolecular Mass Spectrometry (*Oldham*) and a new £1.8M CIF-funded Centre for NMR Structural Biology within the CBS (*Searle*). A £1.5M CIF-funded robotic managed compound collection, which is unique in UK Universities, has strengthened interdisciplinary links in drug discovery with Pharmacy and Biomedical Sciences by enhancing the impact of our expertise in synthetic chemistry.

The Nottingham Nanosciences and Nanotechnology Centre (NNNC) provides a hub for nanoscience research, training and outreach and has grown significantly since its founding in 2007. The NNNC provides access to SEM/TEM, ultra-high vacuum AFM/STMs and confocal microscopy and new XPS facilities (£700k, led by *Licence*) to underpin advanced structural characterisation of novel materials and surfaces. Chemistry, through the NNNC, has strong links with Physics in the areas of nanofabrication and novel nanostructures and materials (*Champness*, *Khlobystov*, *Bichoutskaia, Besley, Gimenez-Lopez)*. EPSRC Open Access grants have allowed UK academics to benefit from NNNC facilities.

• ***Strategic alignment in postgraduate programmes.*** The School has developed a strong strategic alliance of postgraduate training and research with Loughborough and Birmingham Universities in functional energy materials through the Midlands Energy Consortium (MEC) and the Midlands Energy Graduate School (MEGS). This academic-industry partnership involves >200 staff and >900 PGR students. As hosts of the Energy Technologies Institute (ETI), the MEC supports major research activities, including two EPSRC DTCs in *'Hydrogen and Fuel Cells'* and '*Efficient Fossil Energy Technologies*'. In Nottingham, the Energy Technologies Research Institute (ETRI), the Energy Priority Group, and the Energy Research Building (£10M, 2012) oversee the provision of a breadth of science and engineering interfaced with business and knowledge exchange. EPSRC Programme and ERC Advanced grants and SUPERGEN funding via the UK Sustainable Hydrogen Energy Consortium (UKSHEC) have underpinned major interdisciplinary collaborations in this area (*Schröder, Champness, Mokaya*) (see **e1**).

b2: Future strategic aims and goals:

• ***Building collaborations and strengthening interdisciplinary interactions***

The School has developed strong interdisciplinary links across faculties and interfaces through University Centres (including CBS and NNNC), and by taking a lead in major University initiatives in collaborative supercomputing, by driving a virtual centre for analytical science (UNICAS), and in developing green and sustainable technologies with Engineering. We have particular strengths in instrument development with strong links into UK and international facilities, and have developed in partnership with industry and other UK institutions critical mass in energy research. These areas of activity cut across all five research themes (see **a**) and will be developed and strengthened in the coming period with strategic growth of research capacity with new staff appointments and investments in new infrastructure, as now outlined.

• ***Sustainable Chemistry at Nottingham:*** Building upon DICE, the new CNL infrastructure and our present and developing Impact Case Studies, we will meet the challenges of developing new processes, technologies and materials that are more sustainable in the use of energy and natural resources. With external investment of £23.5M already secured for the CNL infrastructure, and two GSK/EPSRC-funded Chairs, we have an outstanding opportunity to establish a new and innovative *Centre for Sustainable Chemistry* as a research and training centre to develop knowledge exchange and business engagement activities. This has recently been underpinned by the **EPSRC announcement to co-fund a new Centre for Doctoral Training in Sustainable Chemistry in Nottingham in 2014** (led by *Moody* and *Licence*). This vision, track record of multidisciplinary research and close relationship with industrial partners (*e.g.* AkzoNobel, AZ, BP, Bruker, Croda, e2v, GSK, Invista, Lucite, SI Group, Synthomer) has already attracted strong support, including PhD funding (15 FTEs) as part of the CDT. The longer term financial stability of the Centre will be secured by recruiting further partners through the outward-facing UoN *Priority Group* in *Sustainable Chemical and Biological Processing* (led by *Howdle*) and by strengthening our links with Nottingham's BBSRC-funded Sustainable Bioenergy Centres. Also, we will address the EPSRC priorities in *Catalysis*, *Novel and Efficient Chemical Synthesis* and *Functional Energy Materials*, capitalising on our strong links with industry, Nottingham Engineers and our partners in the MEC. For example, in the area of functional energy materials, the MEC Universities (led by *Schröder*) have commitments from 30 companies and over 50 international Universities to support the training of PhD students over the coming 5 years.

• ***Developing new instrumentation and theory:*** The School has considerable expertise in fundamental and applied spectroscopy in studying molecular clusters (*Stace*), bonding (*Wright*), energy transfer and dynamic processes (*Reid*), and has strong links to UK and international facilities, *e.g.* STFC at Harwell (*George*), SOLEIL (*Powis*) and with ISIS and DIAMOND for X-ray and neutron diffraction and scattering (*Blake, Schröder, Yang*) (see **d2**). We are well advanced in using this platform to develop new interdisciplinary technologies and capabilities. Initiatives are in place to secure funding for, and access to, centres of excellence in free electron lasers (*Reid*), time-resolved X-ray and electron diffraction (*George*), 2D-IR (*George, Hirst*), EPR (*McMaster*) and mass spectrometry (*Oldham*). These initiatives are linked to current strengths in fundamental theory, method development and simulation (*Hirst, Wheatley, Besley, Bichoutskaia, Teale and Robinson*) which will be used to further strengthen collaborations with Mathematics, Physics and Computer Science, all underpinned by recent investments in HPC (see **d2**).

• ***International partnerships:*** Our future strategy has an international dimension through collaborations with activities on our overseas campuses, which include the *Centre of Excellence in Green Technologies in Malaysia*, the new *Shanghai-Nottingham Advanced Academy* (a joint venture with the East China University of Science and Technology and Shanghai-based chemical industries focusing on green chemistry and healthcare), and the new £25M *International Academy for the Marine Economy and Technologies* (IAMET) in Ningbo. These are complemented by our links with the *Centres for Sustainable Chemistry* in Kansas and Aachen and a new GSK-Brazil-Nottingham strategic alliance with the São Paulo Research Foundation (FAPESP).

• ***Building research capacity:*** The School has begun a period of growth that will be delivered through a University commitment to further investment in world-class facilities for Chemistry. The first phase started in 2012 with the conception of the GSK *Centre for Sustainable Chemistry*. This will be followed over the next 3-5 years with additional major refurbishments/new build that will permit the expansion of our research capacity by 20% (8 posts) thus enabling us to strengthen our research portfolio and interdisciplinary collaborations across our five thematic areas. The new

posts comprise the two GSK/EPSRC-funded Chair appointments in Sustainable Chemistry (see **c1**) and six further appointments. In 2014, a full-time 'Alumni Development Officer' will be recruited to engage alumni contacts world-wide with the School's research and its impact.

c. People, including:

c1. Staffing strategy and staff development

The School is pro-active in supporting the success and career development of colleagues at all levels through the University's promotions process.

• ***Appointment of new staff and promotions:*** Since RAE2008 Pattenden (FRS) and Garner (FRS) have retired, and Anderson and van Slageren have moved to Chairs at UCL and Stuttgart. The success of staff in delivering high impact publications and achieving international visibility has resulted in 8 Chair promotions since 2008 in Chemical Biology (*Soultanas, Thomas*), Molecular Structure and Spectroscopy (*Wright*), Synthesis and Catalysis (*Hayes, Licence, Liddle*), Functional Materials and Nanosciences (*Mokaya, Khlobystov*). *Lam* (Sept. 2013) will lead key aspects of our strategy around sustainable synthesis; he has expertise in catalyst-based organic synthesis, an EPSRC Leadership Fellowship (2010-15), an ERC Starter Grant (2011-15) and a track record of securing significant funding from the EPSRC and UK Pharma. An appointment to the second GSK/EPSRC co-funded Chair in *Sustainable Chemistry* is imminent in late 2013.

• ***Theoretical and Computational Chemistry:*** *Bichoutskaia* (EPSRC CAF, 2008-13) was appointed to a Lectureship in 2011, bringing an innovative theoretical framework to interdisciplinary collaborations in functional materials and nanoscience, leading to an ERC Starter Grant in 2012. *Teale*, following postdoctoral experience in Norway with Helgaker, moved to Nottingham with a RS URF (2012) in applications of fundamental DFT in molecular magnetism, while *Robinson* was awarded a Leverhulme Trust Fellowship (2011) for theoretical studies of fluorescent probes in biological systems. *Besley* has strengthened interdisciplinary collaboration in quantum chemical applications to spectroscopic studies of protein structure and dynamics and in nanomaterials; he was promoted from Lecturer to Associate Professor (2011).

• ***Sustainable Synthesis and Catalysis / Chemical Biology:*** In addition to appointing *Lam*, we have recruited *Denton* from Cambridge as a new Lecturer (2009) and have promoted *Moses* and *Stockman* (EPSRC ARF, 2007-13) to Associate Professor with all four contributing to current strengths in synthetic methodology and target synthesis. *Soultanas* (2008) and *Thomas* (2008), based within the Centre for Biomolecular Sciences, and *Hayes* (2011) were promoted to chairs and have strengthened the chemical biology interface through strong links to Pharmacy and Biosciences. *Licence* was promoted to a chair in 2013 and has established an international reputation in sustainable chemistry in a new discipline within the field of liquid surface science; he will take the lead in developing the School's strategy as the new Director of the CNL (2014).

• ***Functional Materials and Nanosciences:*** Our strategic approach of nurturing young scientists to be research leaders has been especially successful in this area. *Khlobystov* (RS URF, 2005-13), recipient of a prestigious young EU researcher (EURYI) award (2006), has established an international reputation in carbon nanotubes, nanofabrication and nanodevices. He has developed strong interdisciplinary links with the Nottingham NanoCentre (*Khlobystov* appointed Director 2013) supported by an ERC Starter Grant (2011-16). *Liddle* (RS URF, 2007-15) has an international profile in *f*-block organometallics and new functional nuclear materials for energy with high impact publications leading to EPSRC awards, ERC Starter Grant (2010-15) and €2.1M ERC Consolidator Grant funding (from 2014). We have strengthened this area by recruiting *Gibson* (2010) and *Gimenez-Lopez* (2011) with RS Dorothy Hodgkin Fellowships to develop new materials for solar cell technology and magnetic nanomaterials, respectively, and *Yang* (Leverhulme EC Fellow, 2011) who is designing metal-organic frameworks as functional energy storage materials.

• ***Career Development:*** The annual Professional Development and Performance Review (PDPR) process benchmarks and rewards achievements against key indicators, sets medium and long term goals, identifies career development opportunities and manages workload. An embedded research leave culture (2-4 staff pa) is a mechanism for catalysing research innovation. The School makes effective use of University Leadership programmes in developing level 6 and 7 staff, regularly refreshes membership of all of its Committees to provide opportunities for all staff to engage with School governance, and has annual staff Away Days for inclusive discussion in developing School strategy. New staff are given a reduced teaching load for the first 3 years and career development and independent research activity is supported with pump-priming funds for PhD studentships, equipment/consumables and with mentoring. Since 2008, >40 ECRs from

Nottingham have taken up academic posts world-wide.

• ***Postdoctoral Researchers:*** The School pro-actively supports the career development of its 60-70 PDRAs and has embraced the principles of the Researchers Concordat by: (i) establishing a PDRA Forum (2010) with members represented on other School committees; (ii) encouraging 5 days pa of external career development opportunities; (iii) developing a bespoke PDPR process with both supervisor-led project feedback and an independent mentoring and personal development review; (iv) the appointment of a Director of PDRA Development to champion the interests of all researchers; (v) establishing an annual RSC-sponsored research showcase (the Dan Eley Postdoctoral Symposium); (vi) engagement in the commercialisation of research through our *Business Science Fellowship* (BSF) scheme within the School's BPU, and (vii) supporting an effective mentoring scheme to assist with proposal writing and fellowship applications.

• ***Technical support and workshops:*** Research is supported by dedicated laboratory (5) and workshop (9) technicians, many recruited from industry, who provide technical support services in electrical and mechanical engineering, IT and glassblowing. We have invested over £100K in four state-of-the-art computerised machine tools to enhance these capabilities. Expertise in the design and construction of bespoke instrumentation has underpinned RCUK and industry-funded collaborative projects with Engineering (*Howdle, Poliakoff*). The School provides a University-wide custom glassblowing service. The IT Workshop supports IT infrastructure and develops software and hardware for research and teaching. As part of our succession planning strategy, we have embraced government apprenticeship schemes and currently we have two workshop trainees who have the opportunity for full-time employment within the School. The School's Analytical Services, with an industry-trained Manager and support team of 7 staff, underpin chemistry research. A dedicated NMR Centre Manager is located with 600 and 800 MHz facilities in the CBS building.

• ***Staff with fellowships:*** The School injects vitality and dynamism into its research environment by attracting gifted young scientists to Nottingham and by mentoring them in applying for nationally competitive Fellowships. Category A staff: EPSRC Leadership Fellowship, *Lam* (2010-15); EPSRC ARFs, *Licence* (2006-11), *Stockman* (2007-12); RS URFs, *Liddle* (2008-15), *Khlobystov* (2005-13); EPSRC CAF, *Bichoutskaia* (2008-14); EU Young Research Investigator (EUYRI) *Khlobystov* (2006-11). Fixed-term researchers: RS URF, *Teale* (2011-16), RS Dorothy Hodgkin Fellowships, *Gibson* (2010-13), *Gimenez-Lopez* (2011-14); British Centenary Ramsay Fellow/1851 Research Fellowship, *Thurecht* (2007-08); Leverhulme Trust Fellowships, *Robinson, Yang* (both 2011-14); Nationally-competitive University of Nottingham Research Fellowship (NRF), *Yang* (2013-16), and Anne McLaren Fellowships, *Turyanka* (2009-2011) and *Gibson* (2010-12). Also, in 2010 *Champness* secured a RS Leverhulme Trust Senior Research Fellowship and *Hirst* was awarded a Leverhulme Trust Fellowship.

• ***International appointments and visiting scholars:*** The School attracts many international PDRAs, some with personal research fellowships, and since 2008 we have welcomed 11 EU Marie-Curie Fellows. 23% of our PDRAs (from a total of 210) were recruited from outside of the EU, 29% from the EU and 48% from the UK, of which 30% (across all categories) were women. 12 members of staff hold distinguished academic appointments at Universities in Asia, North and South America, the Middle East, Africa, Australia and Europe. International visitors constituted 30% of the School's extensive seminar programme of >60 invited lectures pa, including recipients of RS/RSC prestigious awards, Nobel Prize winners and attendees at international meetings in Nottingham (*e.g. Negishi, Schrock, Nicolaou, Trost, Kitagawa, Waldmann, Meier*), and visiting scholars from leading Green Chemistry Centres (*e.g. Subramaniam*, Kansas; *Adshiri*, Tohoku; *Anastas*, Yale).

• ***Equality and Diversity:*** The membership of the School's Equality and Diversity Committee embraces all groups and job families, including PhD students. We have fully engaged with the Athena Swan Charter (Bronze Award, 2013, alongside a UoN Silver Award) and have developed a framework to: (i) support staff during and after returning from maternity leave; (ii) address issues of unconscious bias and workplace behaviour (*Drama for Training* events), and provide clear support mechanisms for all staff; (iii) provide a robust and transparent promotion mechanism. As a positive indicator, the number of women joining the School on prestigious Fellowships (two RS Dorothy Hodgkin, and one EPSRC CAF) has increased since 2008. For services to science in developing the Juno Project to promote diversity, Research Officer *McCombie* was awarded an MBE in 2013.

c2. Research students

• ***PG Recruitment and funding:*** The funding of PhDs has remained a strategic imperative and

has grown 20% from the high levels of investment in 2008. 70% of the School's REF publications have at least one PhD student as a key author, clearly demonstrating their significant contribution to the quality and vitality of the research environment. The School has recruited an average of 55 PhD students pa since 2008 giving an average total registered cohort equivalent to 157 FTEs pa (see Table), representing 4 PhD students per staff member.

	2008-09	2009-10	2010-11	2011-12	2012-13
Registered PGR students (FTEs)	147	158	165	160	157

Since 2008, 232 PhDs have been awarded in Chemistry (203 FTEs). Studentships have been funded from School resources (>£700K pa since 2008); EPSRC DTA and DTG (£0.5-0.8M pa); BBSRC DTGs within the Centre for Biomolecular Sciences (£1.11M since 2008); Chemistry involvement in the £5.4M Nottingham BBSRC DTP (2012-18); funding from the MRC, STFC, Charities (RCUK, AICR, Leverhulme *etc*.), University and International Research Scholarships; CASE awards and co-funding from industry; the Midlands Energy Consortium (EPSRC £5.5M DTC in Hydrogen and Fuel Cells); and Marie Curie training sites (INDAC-CHEM 2006-2010 in catalysis; FUMASSEC 2006-10 in functional materials). We have a number of effective recruitment tools which include highlighting our activities to Undergraduates through an annual open-lab '*Research Showcase*' event in April, through the '*Journal of Nottingham Chemistry*' our quarterly in-house collection of published research, our '*Chemistry Annual Report*', and through summer vacation projects (>30 pa) funded by industry, RCUK, Charities, Alumni and School resources.

• ***Training and support:*** Our PGR programme of training offers a diverse range of subject-focused lectures on research skills, ethics and safety, augmented with a school-wide programme of colloquia. Participation at international conferences around the globe is high. The generic and transferable skills-base and careers events are run through the Graduate School hub within the new (2011) £10M *Engineering and Science Teaching and Learning Centre* adjacent to Chemistry. Our BPU and the Business School (NUBS) deliver key transferable business skills modules in entrepreneurship, business awareness, research management and IPR. The PGR module *'From the Bench to the Bank'*, supported by the *Society of the Chemical Industry*, features monthly speakers from industry and commerce to show-case commercial exploitation of ideas.

• ***Progress and monitoring:*** Our training provision and rigorous safety induction meets the strict standards recommended by current RCUK, QAA and HEFCE guidelines and is quality assured by a demanding system of internal peer review. Student evaluation is performed on all taught courses, and training and research activities are monitored through a formal 'Research Student Annual Review' process involving written reports and viva examination with supervisors and independent assessors, culminating in a presentation at the 3rd year School PG Symposium.

d. Income, infrastructure and facilities

d1: Refurbishment of laboratory infrastructure:

Although the Chemistry building dates from the 60s, it has undergone extensive refurbishment and modernisation of research labs, instrument suites and office areas from CIF, EPSRC, University, ERDF and Wolfson infrastructure funds totalling £2.64M: for example, a new 18-person 200 m^2 synthetic materials chemistry facility was created in 2012 in a £0.54M project which also relocated our central chemical stores; new laser facilities have facilitated advances in research in photochemistry and catalysis (£0.48M, 2013); a number of synthetic chemistry and instrument laboratories have been upgraded in smaller projects (£1.06M). The completely new £22.35M CNL is work-in-progress (started Sept. 2013) and will add substantially to the extent and quality of the School's infrastructure.

d2: Investments in instrumentation and access to facilities:

• High-resolution X-ray structural analysis (led by *Blake*) has been substantially upgraded since 2008. A CIF award of £0.9M (2009) provided two new single crystal and one powder diffractometer plus a significant upgrade of the existing facilities. The suite of 6 instruments has increased capacity and throughput by 30%, and enabled the handling of more challenging and novel materials under extreme temperatures (80-1200K), with specialist facilities for innovative high pressure studies (*Blake*). A £1.26M award from the *EPSRC Chemistry Core Capability* initiative (2013) enabled Nottingham to acquire the first high intensity Agilent GV1000 systems in the World.

• Interdisciplinary research in high-field NMR spectroscopy has been enhanced through £1.8M CIF-funding (2012) of a Bruker 800 MHz instrument for structural biology (*Searle*), along with

upgraded 600 MHz facilities for solid-state (bio)materials science (*Titman*). The instrumentation is housed in dedicated facilities within the CBS and has catalysed BBSRC and Charities-funded collaborations across the life sciences within the CBS, Biosciences and Pharmacy (£1.05M), and with Food Sciences and Engineering. *Titman* was a co-I in securing the £3.5M EPSRC-funded UK national 900 MHz solid-state NMR facility at Warwick, and chairs the User Allocation Panel.

• EPSRC-funded XPS Facilities (£0.76M, led by *Licence*), with unique capabilities for ionic liquid-based solution studies at surface interfaces led by Chemistry (*Licence, Jones*), has expanded surface analysis instrumentation housed within the NNNC. New collaborations with Physics in functional carbon-based materials have been enhanced by a Molecular Beam Epitaxy system for graphene synthesis (£1.3M EPSRC, *Khlobystov*).

• The School is a primary user of the University's HPC facilities which were upgraded in 2013 with £1.2M of institutional investment. A further £3.5M as part of the *EPSRC MidPlus supercomputing Centre of Excellence for Computational Science, Engineering and Mathematics*, with Nottingham (led by *Hirst*) as one of four key UK MidPlus partners, has built capacity and promoted interactions with SMEs and businesses with demands for modelling, simulation and analysis.

• Many staff are major users of UK and international central facilities (LSF, DIAMOND, ISIS), and consistently secure competitive access with an equivalent value of £1.8M to UK STFC facilities (*Schröder, Yang*). Staff play significant roles on UK advisory boards (*Jones*) (see **e3**) and in the development of synchrotron, laser and spectroscopic facilities, including: ULTRA as a UK and European STFC facility at the Rutherford Appleton Laboratory (*George*); the DESIRS beamline at SOLEIL in Paris (*Powis*); the UK high-field Solid State NMR facility at Warwick (*Titman*); and international telescopes (*Sarre*) (South African Large Telescope (SALT), Airborne far-IR telescope, SOFIA and Herschel far-IR observatory).

d3: Research Funding Portfolio:

• ***Current funding:*** In addition to capital investment funding and philanthropic donations (£35M), staff have successfully competed for external research funds from a wide variety of sources, realising a portfolio of awards since 2008 with a total value of >£40M with a corresponding research spend >£32M (ca. £170K pa/FTE). These awards represent single investigator and major programme grants and Fellowship awards. RCUK grants (EPSRC and BBSRC) provide the majority of the spend (73%), alongside EU Research Council awards (12%), Industry (8%) and UK-based charities (4%). The currently held portfolio of active awards is >£25M (July 2013). The School has expanded its EU portfolio with four ERC Starter Grants, an ERC Advanced Grant, FP7 Consortium Grants (SYNFLOW and IMI Awards), with a current EU portfolio of £7.57M, augmented by £3.12M of active awards from industry.

• ***Future funding strategy:*** The School's Research Committee (SRC) monitors grant applications, success rates and provides a framework for internal peer review and mentoring. The SRC has been pro-active in the identification and recruitment of ECRs and provides a robust selection, mentoring and mock interview process and commitment of resources (PhD funding and consumables) to successful Fellowship applicants. The SRC co-ordinates chemistry-led strategic equipment bids towards final proposals via the Faculty Research Committee. The University 'Facilities' Priority Group (led by *George*) has established an Interdisciplinary Centre for Analytical Sciences (UNICAS) to promote cross-faculty collaboration, facilitated by a Nottingham and Midlands-5 (M5) 'Kit Catalogue' inventory and strategic equipment 'road map'. Workshops and pump-priming funding have created a culture for interdisciplinary collaborations through access to specialist instrumentation and expertise.

• ***Consultancies and professional services:*** Since 2008, 25% of staff have engaged with companies through consultancy (*e.g.* Unilever, Solvay, Pfizer, GSK and AZ), facilitating product development and process innovation in the pharmaceutical and agrochemical industries.

e. Collaboration or contribution to the discipline or research base

e1: Collaborations and interdisciplinary activities:

• ***EU Innovative Medicines Initiative (IMI):*** Nottingham's expertise in synthesis (*Stockman, Moody*) is part of the largest IMI funded thus far, representing Europe's biggest public-private venture aimed at accelerating the development of new medicines. This innovative "European Lead Factory" (€196M), representing an EU-wide inter-disciplinary collaborative network with major pharmaceutical companies (*e.g.* Johnson & Johnson, Sanofi and Bayer), will boost drug discovery innovation in Europe and cement key strategic partnerships. Collaboration with Sygnature Discovery will see €6.2M from this EU project come to Nottingham (€1.6M to Chemistry).

• ***EU critical research mass and training:*** The School has taken a strong lead in establishing a critical mass in sustainable synthesis and catalysis through Marie Curie student training sites (INDAC-CHEM Catalysis, 2006-10 and Functional Materials FUMASSEC, 2006-10); in COST initiatives in 'Innovative Catalysis' (COST-D40 Action, 23 countries, 2007-11) and in 'Sustainable Chemical Resources' (COST Action CM0903, 26 countries, 2009-13), both grants held by *Woodward*; in the highly interdisciplinary 'Alternative Energy Sources' (FP7 Future Emerging Technology H2ESOT, 5 countries, 2013-16, *Woodward*); and is a key player in the €10M SYNFLOW, connecting 14 University and Industrial Centres across the EU (*Poliakoff*). *Liddle* chairs 'EUFEN: European *f*-element Network' (COST Action CM1006, 21 countries, 2011-15). New initiatives have strengthened our EU-wide collaboration and training opportunities through an Erasmus Mundus joint Doctoral Programme in 'Sustainable Industrial Chemistry - SINCHEM' (2013), and through the Marie Curie ITN 'REFINE' in renewable polymers (*Howdle*, 2013). Notably, COST-D40 was rated in the top 2 for the quality and extent of research exchange training.

• ***Interdisciplinary and international collaboration:*** The School has a strong profile in the application of functional micro- and meso-porous materials, based upon metal-organic frameworks (MOFs) for gas storage and capture (*Schröder, Champness, Yang*) and as solid state catalysts and molecular sieves (*Mokaya*). Activity is underpinned by strong UK and international (Kyoto) interdisciplinary collaborations, extensive use of UK facilities (ISIS and Diamond) and industrial partnerships (General Motors, Johnson Matthey). Research collaboration with engineers, materials scientists and theoreticians has attracted significant ERC Advanced Grant (€2.5M, COORDSPACE) and EPRSC programme grant funding (£4.13M, ChemEnSus). Linked to this, the Midlands Energy Consortium (Nottingham, B'ham and L'borough) through a £5.5M EPSRC DTC in 'Hydrogen and Fuel Cells' underpins PhD student training in low-carbon energy research (see **b1**). Strong links with Physics through the NNNC have led to pioneering research in molecular self-assembly and nanofabrication on surfaces (*Champness*, *Science 2008*), and novel carbon nano-structures and materials (*Khlobystov*, *Nature Chem. 2011*; *Gimenez-Lopez, Nature Comm., 2011*).

Our theoreticians have made major contributions to the development of quantum chemistry codes (Q-Chem and DALTON, *Besley* and *Teale*), collaborated with industry in developing a theoretical framework for high-energy-density electrostatic storage devices (*Bichoutskaia* with EnergiaQ, Texas) and in quantum chemical modelling of nanomaterials (*Bichoutskaia*, *Besley*, *Nature Chem. 2010*). Technical advances at SOLEIL have led to pioneering developments in photoelectron circular dichroism (*Powis, Nature Commun. 2013*). Advances in lanthanide single molecule magnets have benefited from an integrated experimental and theoretical approach (*Liddle*, *McMaster* with the UK EPR Facility and *van Slageren* (Stuttgart), *Nature Chem. 2011*).

Trans-Atlantic collaborations have led to the elucidation of bacterial replication mechanisms (*Soultanas* with MIT geneticists, *Nature 2011*) and synthesis-led cancer drug discovery (*Moody* with *Ross* in Denver and leading to the spin-out QGenta, *Nature Chem. 2013*). Strategic investment in a Chemistry-led CIF-funded £1.5M Centre for Biomolecular Mass Spectrometry (appointment of *Oldham*, 2007) has catalysed pioneering applications of mass spectrometry in chemical biology and biosynthesis (*Oldham*, *Science 2013*). Strong links with Pharmacy, the Life Sciences and Physics have generated a breadth of interdisciplinary collaborations in chemical biology and structural biology (*Searle*), led to quadruplex-targeted drug discovery (*Moses, Moody*), use of nucleic acids and chemical tools as epigenetic probes (*Hayes, Dowden*), and development of quantum-dots for *in vivo* tissue imaging (*Thomas*).

e2: Industrial and user input into the research strategy:

The School has strong links with a broad range of Chemistry Using Industries (CUI) and has developed major partnerships since 2008 that have significantly influenced our research strategy:

• ***Business Partnership Unit (BPU) and School Strategic Advisory Board (SAB):*** Opportunities for industry and business engagement with our research have been greatly enhanced through the School's BPU aided by our '*Industry and Business Science Fellows'* scheme which, through £750k of funding from a range of knowledge transfer initiatives, *e.g.* the Gatsby Trust, HEIF, EPSRC, TSB and industry, has supported 14 BSFs since 2008, typically on 1-year projects. The BPU brokers new relationships with external partners, secures investment in knowledge transfer projects leading to technology licenses, spin-out company formation and industry workshops (see **REF3a**). In 2009, the School established a strategic advisory board (SAB) which meets bi-annually chaired by *Stickings* (former Chairman BASF) involving industry leaders (*Allen*, VP GSK; *O'Shea*, Alliance Boots; *Layden*, Croda), local SMEs (*Crocker*, CEO BioCity) academic (*Richards*, Oxford, Chair of

the IP Group), government advisors (*Gibson*, Whitehall and Industry Group) and representatives of professional bodies (*Brown*, IChemE; *Elliot*, CIA) to inform our business engagement strategy.

• ***Chemistry Innovation Laboratory (CIL):*** Recognising the importance of SMEs within the CUI sector, the School secured £0.8M of ERDF support in establishing a "Chemistry Innovation Laboratory (CIL)" (2010-15), subsequently extended as part of the £755k University-wide 'Ingenuity Plus' project, which has allowed >30 Chemistry-using SMEs to interact with 50% of our staff in short-term feasibility studies to develop innovative ideas and knowledge transfer activities through access to expertise, facilities and through SME placement of >10 PhD students. Pump-primed industry collaboration through CIL with, for example, European Thermodynamics has realised significant EU funding (£1.27M) towards new product development through a consortium of industry and academia (*Woodward*). The School maintains strong links with its spin-out companies (Critical Pharmaceuticals, **CS1** and Promethean Particles, **CS2**) through consultancy, board directorships (*Howdle & Farren*), contracted access to analytical services and co-funded projects.

• ***The Carbon Neutral Laboratory (CNL):*** Our CNL project represents a rare opportunity to redefine how future scientific research is conducted at the level of the supporting infrastructure through a unique partnership catalysed by GSK's environmental strategy for carbon neutral global operations by 2050. The construction and operation of the CNL will be totally sustainable with all energy requirements being met by on-site generation from renewable resources (solar power and biomass). Carbon credits from the exporting of energy over the building's 25-year lifetime will pay back the embodied carbon used in construction. Performance criteria will be monitored as part of an on-going £0.5M project funded by GSK to inform future designs. The CNL will accommodate ~120 researchers and support staff plus a 40-person advanced teaching laboratory for undergraduate GSK 'drug discovery projects' and outreach activities. Collaboration with GSK's 'Green Chemistry Performance Unit' at Stevenage will be further strengthened through the secondment of a senior scientist to Nottingham (*Macdonald*, 2013) as a 'GSK Industrial Visiting Professor' to promote excellence in medicinal chemistry and advance translational research.

• ***Industry Collaboration:*** Since 2008, we have collaborated with 36 companies on 106 projects that have involved 28 academic staff in £3.66M of industry funded awards, with PhD students benefiting from industry secondments. The School has recruited experienced staff from AZ and Pfizer to work in developing collaborative research and teaching programmes in medicinal chemistry with GSK, and within the BPU as a BSF. The School's strength in the development of new synthetic methodology and catalysis has resulted in EPSRC/industry co-funded collaborations in 'Chemical Arrays' (GSK, *Moses, Moody, Stockman*), 'Flow Chemistry' (Pfizer, *Moody, Hayes*) and 'Asymmetric Catalysts' (AZ and Syngenta, *Lygo*). Since 2008, project-based collaborations with GSK involving 6 research groups have realised £1.8M in funding and 12 joint publications.

New synergistic research collaborations at the Chemistry/Engineering interface in synthesis and processing of new materials have opened up new areas in: synthetic building blocks from renewable feedstocks (*Poliakoff* with Lucite); porous MOF materials for selective storage (*Schröder* with General Motors USA, Johnson Matthey); novel thermochromic ceramics (*Licence, Champness* - Rolls Royce); lightweight high-density storage devices (*Walsh, Licence* - DSTL); studies of phase behaviour in carbon capture and storage (*George, Poliakoff, Drage* - Rolls-Royce, National Grid and EoN); development of novel analytical tools and processes (*George* with Sasol, Sanofi, Unilever); alternative more benign solvents for materials processing (*Howdle, Licence* - Unilever); and strategic investment in greener process chemistry (*Poliakoff*, Invista, **CS3**). A recent institutional framework agreement with Unilever (£0.6M, supporting PhD studentships) places us as a key partner in developing sustainable process chemistry.

e3: Leadership in the academic community:

• ***Outstanding achievements.*** Foreign Secretary and Vice-President, Royal Society (*Poliakoff*, 2011-16); CBE in 2008 New Year's Honours List (*Poliakoff*) for services to science; MBE in 2012 New Year's Honours List (*McCombie*) for services to public engagement in science; Thomson Reuters 'Top 100' most cited Chemists in the last decade (*Champness*, 2011); Honorary Doctor of Science, UEA (*Poliakoff*, 2008); Foreign Member, Russian Academy of Sciences (*Poliakoff*, 2012).

• ***Awards and Prizes.*** 3 RS Wolfson Merit Awards (*Schröder*, 2005; *George*, 2008; *Champness*, 2011); RSC/SCI Macro Group UK medal (*Howdle*, 2008); RSC Noble Metals Award (*Schröder*, 2008); International Association of Scientists in the Interdisciplinary Areas Award for Computational Chemistry (*Hirst*, 2008); RSC Pedlar Lectureship (*Moody*, 2008); Silver Jubilee Medal, Molecular Graphics and Modelling Society (*Besley*, 2008); RSC Harrison-Meldola Prize (*Lam*, 2008); IChemE

Hanson Medal (*Howdle*, 2009); RS Leverhulme Medal (*Poliakoff*, 2010); Novartis International Lectureship (*Moody*, 2010); Eli Lilly Early Career Award (*Moses*, 2010); RSC Supramolecular Chemistry Award (*Champness*, 2010); Thieme Journal Award (*Lam*, 2010; *Moses*, 2012); Janssen Lectureship (*Moody,* 2011); RSC Sir Edward Frankland Fellowship (*Liddle*, 2011); Craver International Spectroscopy Award, Coblentz Society (*George*, 2011); RSC Nyholm Prize (*Poliakoff*, 2011); Newton Award, RSC Radiochemistry Group (*Liddle*, 2011); RSC Hickinbottom Award, AZ Chemistry Award (*Lam*, 2011); RSC Charles Rees Award (*Moody*, 2012), RSC Inorganic Mechanisms Award (*George*, 2013); Aston Medal, British Mass Spec. Society (*Stace*, 2013); Diamond Young Investigator Award and IoP Willis Prize for Young Scientists (*Yang*, 2012, 2013).

• ***National or International advisory board members.*** Staff within the School have contributed to scientific governance in the management, development and resource allocation of RCUK and international facilities as members of Science Advisory Councils, *e.g*., EPSRC Physical Sciences SAT (*Howdle*, since 2008); EPSRC Infrastructure Strategic Advisory Team (*Jones*, 2009-2011); Chair, RS Paul Instrument Fund (*Poliakoff*, 2006-2011); Chair, CRUK Studentship Committee (*Moody*, 2007-09); EPSRC college members (currently 17 staff out of 37); Member, RS Dorothy Hodgkin Fellowship Panel (*Howdle*, 2008-2011); Co-Chair, RS Newton Fellowship Panel (*Poliakoff*, since 2012); EPSRC International Review of Chemistry Steering Committee (*Powis*, 2009); Chair UK Southern African Large Telescope (SALT) Consortium (*Sarre*); Chair EPSRC National High-field Solid-state NMR Facility Time allocation Panel (*Titman*, 2010-13), Senior Advisor British Council Science and Engineering Advisor Group (*Champness*, since 2009); Foreign Councillor, Institute for Molecular Sciences in Okazaki, Japan (*Stace*, 2009); Panel (Senior), Institut Universitaire de France (*Schröder*, 2011-12).

• ***Leadership roles in industry and commerce.*** Company Directors/Board Members. SusChem UK – Strategic Advisory Board of the CIKTN on European policy development (*Howdle*, 2011-14); Innovation Strategy Board (ISB) member advising UK industry on sustainability (*Howdle*, 2011-14).

• **Learned societies.** RSC President (*Garner*, 2008-10); Advisory Board, UK Green Chemistry Network (*Licence*, since 2008); Pan African Chemistry Network of the RSC/Syngenta (*Mokaya*, since 2008; *Licence*, since 2010); Chair, RSC Spectroscopy and Dynamics Group (*Reid*, 2009-12); Member of RSC Dalton Council (*Champness*, 2005-13); Chair of SCI/RSC MACRO Group (*Howdle*, 2010-13); RS Equality and Diversity Network (*Howdle*, since 2009); RS DFID Africa Capacity Building Committee (*Mokaya*, 2013-15). Chair, Chemical Sciences and Society Summit (*Howdle*, 2011). Chair, Management Board of EPSRC National EPR Service (*Schröder*, 2011-13). Vice President, European Rare Earth and Actinide Society (*Liddle*, 2012).

• ***Invited/Keynote lectures and conference organisation.*** Staff have delivered >375 invited conference lectures (>150 keynote or plenaries), 60% of these were at international conferences outside of the UK. Plenary lectures, *e.g.* Seaborg Memorial Lecture, Berkeley (*George*, 2009); 2nd EUCheMS Chemistry Congress, Turin (*Poliakoff*, 2008); Modern Trends in Inorganic Chemistry, MTIC-XV, Roorkee, India (*Schröder*, 2013); 25th European Colloquium on Heterocyclic Chemistry (*Moody*, 2012); 3rd International Conference on Metal-Organic Frameworks (MOF-2012) (*Champness*). Staff have chaired international meetings, *e.g.* Gordon conferences on 'Heterocyclic Compounds' (*Moody*, 2009), 'Green Chemistry' (*Licence*, 2010 and *Howdle*, 2012), Federation of Analytical Chemistry and Spectroscopy Societies (FACSS)-SciX conference (*George*, 2013). Nottingham has hosted major international conferences: 'New Horizons in Natural Products' (annually since 2009); '6th International Green & Sustainable Chemistry' Conference (2013).

• ***Journal editorships.*** Chair, Editorial Board of 'Green Chemistry' (*Poliakoff*, 2007-2010); Chair, Editorial Board of 'CrystEngComm' (*Champness*, 2007-10); Editor-in-Chief, RSC Theoretical and Computational Chemistry Series (*Hirst*, 2008-13); Editor, European Journal of Physics (*Stace*, 2010-present); Ass. Editor, Journal of Flow Chemistry (*Licence*, 2011-13). Editor-in-Chief, Philosophical Transactions A, Royal Society (*Garner*, 2011-present); Ass. Editor ACS Sustainable Chemistry and Engineering (*Licence*, 2013).

• ***Outreach and Science Communication.*** Four Royal Society Summer Exhibition Events (Exhibitions: 'Wonder in Carbon Land' (*Khlobystov*, 2008), 'Solar Energy' (*George*, 2011), 'Functional Energy Materials' (*Schröder*, 2010); Demonstration Lectures, 'Wonder of Chemistry' (*Liddle*, 2012). The YouTube channel *"The Periodic Table of Videos"* (www.periodicvideos.com) has been recognised by the IChemE Petronas Award (*Kays, Licence, Liddle, Poliakoff, Tang*, 2008), the SPORE award (*Science*, **2011**, *332*, 1046) and a prestigious *US Webby Award* in 2012.