Institution: WestCHEM
Unit of Assessment: UoA 8 (Chemistry)

a. Overview

WestCHEM is the joint research school of chemistry for the West of Scotland comprising researchers from the Universities of Strathclyde (**SU**) and Glasgow (**GU**) and is now in its 8th year of continuous growth with respect to research income and researchers. PGR student numbers and research income have increased significantly since RAE 2008, which demonstrates that WestCHEM is a thriving research school. Research is organised into five strategically selected research groupings highlighting our internationally leading chemistry research.

Research groupings with current academic leads	Core staff
Catalysis and Synthesis: Murphy and Lennon	19
Chemical Biology, Molecular Medicine, & Synthetic Biology: Liskamp & Tomkinson	8
Complex Chemical Systems: Ulijn and Cronin	6
Dynamics & Structure: Wynne and Cussen	15
Nanoscience and Materials Chemistry: Skabara and Cooke	18.2

The governance of WestCHEM is through a Management Committee, which consists of a Director, (rotating biennially between GU and SU), Deputy Director who becomes Director, the Heads of departments from both institutions, and two senior researchers from each partner institution. A Science Committee supports the Management Committee.

b. Research Strategy

Significant achievements and improvements since RAE 2008

WestCHEM was ranked 15th in RAE2008, which laid a strong foundation to significantly advance our research quality through continued growth of our internationally excellent research. Since 2008, we have achieved an upward trajectory in terms of research performance as demonstrated by the increased volume and quality of our research supported by our continually evolving infrastructure and environment. Since 2008, academic appointments have been made at both junior (19) and professorial (4) level; all new staff are submitted in REF and constitute 35% of the number submitted. These new appointments reflect a strengthening of key areas and result in 66.2 FTE now being submitted compared to 51.4 FTE in RAE2008. The WestCHEM staff profile includes 16 individuals who have been supported during the assessment period by prestigious personal fellowships from the Royal Society (6), Royal Society of Edinburgh (4), European Research Council (2), EPSRC (3), and Ramsay Memorial Trust (1). The number of PGRs (PhD + MPhil) has increased from 167 in 2007 to 251 in 2013, while research spend during the assessment period averages £9.1M *per annum* (double that of the £4.4M average from RAE2008) with WestCHEM positioned in the top ten in terms of EPSRC support with our total RCUK spend doubling from £17.5M to £36.3M. This growth has been mirrored by substantial increases in international academic and industrial collaborations. Major infrastructural investments were made in the Continuous Manufacturing and Crystallisation Centre (CMAC, £28M), the Technology and Innovation Centre (TIC, £100M, ~£12M benefit to WestCHEM), and in research lab refurbishment (£12M). Collectively, these have supported a significant increase in the number of research outputs (285 *per annum* compared to 210 in RAE2008 period) and the quality of these outputs, with papers appearing regularly in Science, Nature, and other journals from the Nature stable (18 over the REF period compared to 4 in RAE2008) as well as Angewandte Chemie (67), JACS (42), and PNAS (5).

Strategic Vision

The WestCHEM vision is to become recognised as an internationally leading centre of excellence in each of our strategically selected areas of research. Research themes were identified on the basis of our unique strengths, critical mass, sustainability, and vitality, and then five research groupings were established. The research groupings provide a collaborative research environment in which academic staff and students can move freely across the two constituent departments. The groupings also facilitate the hosting of collaborators and the placing of researchers at external collaborators thus facilitating ground-breaking research in a flexible and effective manner. Each

research grouping has two leaders with one based at each institution. Strategic appointments have been made to strengthen priority areas and create critical mass. Senior established research leaders and less experienced staff members with complementary expertise have been appointed since 2008, *e.g.*, in chemical biology through the appointment of Profs Liskamp and Tomkinson and Drs Burley and Jamieson. Each of our research groupings is at a different stage of evolution. Some groupings have specific research programmes where critical mass has been achieved and in these cases strategic effort has been focussed on the creation of centres of excellence, optimisation of responsiveness to funding opportunities, recruitment of staff and students, and interdisciplinary collaborations. Key examples are the Centre for Molecular Nanometrology and the Glasgow Centre for Physical Organic Chemistry. The creation of centres of excellence in Chemical Biology and Synergic Bimetallic Chemistry is now being vigorously pursued.

The WestCHEM strategy is to maximise research potential and deliver internationally leading research programmes by focussing on enhanced collaboration, internationalisation, and training:

- **Collaboration** – We place a heavy emphasis on collaboration within WestCHEM and with partners outside the research school, particularly from different disciplines. The Glasgow Centre for Physical Organic Chemistry (established with a grant of £4.8M) is a prime example of internal collaboration and emerging activities in Chemical Biology provide a strong linkage to researchers in the life sciences in the host institutions and beyond.
- **Internationalisation** – A major pillar of our strategic vision is global visibility for our researchers and their work. We have prioritised activities such as dedicated exchange schemes (*e.g.,* the EPSRC Global Engagement scheme) and joint international funding (*e.g.*, EPSRC-NSF funding) to maximise our international profile. These endeavours are facilitated by a supportive management approach in both partner departments, allowing flexibility in teaching and administration to allow researchers time to engage in international activities. We have also developed a strategy for our research training that involves an international interaction with world-leading research partners such as Tsinghua and Nankai in China, IIT Bombay and IISER Pune in India, Stanford in the USA, and Osaka University in Japan.
- **Training** – Training and mentoring of the next generation of researchers is a priority and have been at the heart of our research strategy since the creation of WestCHEM eight years ago. Our PGR numbers have increased significantly since the last assessment period and research students continue to be central to our collaboration and internationalisation strategies.

Our strategy to strengthen these priorities has involved focussing resources on people, training, and infrastructure in support of the five research groupings. Income generation is vital to support growth of all of the groups. Consequently, we have developed an income generation strategy that relies on targeting large initiatives appropriate to the research strengths of WestCHEM, supporting staff in large multidisciplinary grant applications, and diversifying the sources of income. Each of these aspects is presented in more detail in the separate sections within this document.

Our overall research strategy is implemented by the Management Team and is devolved to our research groupings. Continuous review of progress and the setting of future targets mean that our trajectory is maintained, we are adaptive to changes in the research landscape, and we are responsive to new funding opportunities as they arise.

WestCHEM research groupings and key areas

Catalysis and synthesis. The grouping specialises in homogeneous catalysis, heterogeneous catalysis, target-driven synthesis, computational chemistry, and emerging new developments in digital synthesis and reactionware. The grouping performs research into asymmetric catalysis for the synthesis of chiral compounds and in particular bioactive targets; solid-supported catalysts for industrial applications such as petrochemicals, fine chemicals and fuels; total synthesis of natural products, pharmaceuticals, agrochemicals, and biological probes; and computer simulation studies of catalytic reactions. Notable breakthroughs span a broad range, from the design of new reactions and mechanistic studies to the synthesis of complex natural products, and from metal-free reagents to important metal-based transformations and the emerging area of synergistic bimetallic chemistry. The grouping has strong international links and collaborates with more than 25 companies, *e.g.*, GSK, Merck, and Huntsman.

Chemical biology, molecular medicine, and synthetic biology. All of the molecular and biological sciences are present within the City of Glasgow and this has led to an exceptionally

strong biomedical research environment that is unique in the UK. Molecular and biological sciences are fully integrated with the medical and veterinary sciences across several institutions including SU, GU, and the Beatson Institute for Cancer Research. Given the enormous potential for multidisciplinary collaboration offered by this biological and biomedical grouping, we have been building capacity in chemical biology over the past few years with major investments in both infrastructure and staff. This capacity has been recognised through an EPSRC-BBSRC-MRC funded Chemical Biology Network grant which has accelerated growth and facilitated collaboration.

Complex chemical systems. This grouping addresses the major challenge of the self-assembly of non-biological chemical components into complex structures that have unique properties, such as adaptability, molecular recognition, and programmability. The interplay between chemical systems and hybrid devices that have the potential to deliver revolutionary new technologies based on inorganic biology and synthetic systems is also being addressed. Applications range from the development of adaptive materials for biomedical applications, strategies for solar fuel devices, clean water, to the production of potential drug and drug delivery candidates.

Dynamics and structure. Research in this grouping addresses the physical aspects of chemistry and focuses on ultrafast chemical physics, the use of chiral photonic and meta-materials for biosensing, investigation of biomolecular structure and dynamics, synthesis and evaluation of organic electronics, solid-state chemistry, polymer chemistry, and computational chemistry. The group is growing its activities in soft condensed matter theory and experiment; the interface between biology and chemical physics studied through spectroscopy and imaging; and solid-state physical chemistry. This strategy has been supported with investment in infrastructure and staff to enhance the group's vitality and international standing.

Nanoscience and materials chemistry. The Centre for Molecular Nanometrology is pioneering the fundamental understanding of plasmonic materials for enhanced optical spectroscopies and the creation of new approaches to bioanalysis, based predominantly on functionalised nanoparticles and surface enhanced Raman scattering. The grouping's materials research is internationally leading in renewable energy applications (fuel cells, hydrogen storage, solar cells), low power optoelectronic devices, chiral plasmonic metamaterials, and magnetic materials. It has wide-ranging capability in inorganic, organic and polymer synthesis, and combines this expertise with device work conducted in-house and through external academic collaborations and industry.

Future research strategy

Our future research strategy for delivering world-class science and setting research agendas builds on our established strengths whilst developing embryonic research areas that lie at the frontiers of research. We expect WestCHEM's five research groupings to significantly advance their research profiles and metrics. Clearly, some groupings will evolve more rapidly than others; for example, the chemical biology grouping is relatively new and the appointments made during the current assessment period are just starting to have an impact and to establish this grouping. We will continue to nurture and mentor our ECRs and we are vigorously seeking to appoint additional new young academics through the personal fellowship route. Our goals are for WestCHEM to become a consistent top ten earner for Chemistry in the UK, to maintain a large and dynamic graduate school of >250 PGRs, and to expand state-of-the-art facilities. This will be achieved by extension of our well proven and successful policies of targeted strategic investment, enhancement of facilities, and the recruitment of high calibre staff. In particular, we are undertaking the following:

- Major expansion of facilities through the Technology and Innovation Centre (TIC, building work started in 2013 on SU campus) with £100M investment. This will enhance our ability to work collaboratively with industry with ~£12M of investment directly benefiting WestCHEM.
- Major expansion of WestCHEM by direct investment of £8.5M in refurbishment of the Joseph Black building (GU School of Chemistry) and subsequent investment of up to £750M over 15 years by GU to develop the former Western General Hospital site and the current campus.
- Leading Centres for Doctoral Training: WestCHEM is the focus for the GSK CDT in medicinal chemistry (provision for 70 PhD students). In addition, we are integrated with the CDTs in proteomic technologies, medical devices (renewed in 2013), and the CMAC CDT.
- The strengthening and enhancement of our research groupings through new jointly coordinated appointments. We are currently recruiting and have open fellowship schemes that are being used to identify high quality international joint appointments.

- Annual review of WestCHEM membership to maintain focus on quality through setting and reviewing individual targets by the WestCHEM Management Group.
- Release of staff time for research development by use of fellowships and study leave.
- Closer working relationships with industrial partners to build sustainable collaborations and diversify our sources of income. This will be aided by our involvement in TIC and CMAC.

c. People

I. Staffing strategy and staff development

The WestCHEM staffing strategy is to recruit established world-leading stars, identify and recruit future research leaders, and to retain and support our own talent through staff development.

Recruitment and staffing strategy

Recruitment of high quality staff has been facilitated by WestCHEM's established international reputation and the attraction of our research strategy with its emphasis on collaboration, internationalisation, and training, resulting in a healthy developing staff profile. The strategy for staffing and staff support has been a coordinated approach between the two institutions. In order to strengthen our research groupings, we have made strategic appointments at all levels of seniority, have invested heavily and optimised the usage of our physical research infrastructure. More specifically, WestCHEM's strategy for people has focused on:

- Recruitment of research leaders at professorial level to create critical mass in areas of strategic importance, *e.g.,* Tomkinson and Liskamp now lead our growing research grouping of chemical biology and Wynne has taken on leadership of the dynamics and structure grouping.
- Recruitment of potential research leaders and the provision of the necessary research environment and infrastructure for them to succeed, *e.g.,* Magennis strengthened the Dynamics and Structure grouping while Ulijn was an appointment early in the assessment period and now leads a substantial (22 researchers) and well-funded research group.
- Recruitment of ECRs to all five research groupings to support our interdisciplinary research vision, *e.g.*, Forgan, France, Ganin, Hill, Jamieson, Lau, and Sproules.
- Mentoring and support of our ECRs with support for fellowship applications where appropriate.
- Release of academic staff time for research and leadership through the appointment of 8 University Teachers.
- Rewarding staff successful in research and impact through adjustment of workloads to increase research time and allocation of resource.

We have recruited 23 new high calibre members of academic staff in the assessment period (all are submitted), representing 35% of staff returned in this assessment. This includes 16 ECRs, 2 Senior Lecturers, 1 Reader, and 4 Professors.

Early career researchers

All ECRs on permanent contracts have been recruited into areas that are either identified for capacity building (13 FTE) or provide complementary expertise to a research leadership appointment in a new area (3 FTE). We have supported ECRs through specific training as detailed in the staff development section below. Part of this support has consisted of earmarked support from EPSRC equipment grants (£946k). Evidence of the success of our strategy for recruitment and support of ECR's is provided by their performance. Since 2008, ECRs from the previous assessment period have been promoted to Senior Lecturer (Cussen, Nordon, O'Hara, Tuttle), Reader (Faulds, Marquez), and Professor (Hevia). One indicator that reflects well on our support of ECRs and our research environment is that retention has been excellent (90%) in the period since RAE2008. We attribute this to the clear ambition that WestCHEM holds for achieving research excellence coupled with the mapping of individual research expertise onto our areas of strength, which contributes to our significant international profile. This is all part of our overall strategy and is evidence of the high value we place on ECRs and their role in continuing to improve research performance and the establishment of WestCHEM as a world class research school.

Fellowships

WestCHEM has been highly successful in research-fellowship competitions and this has contributed greatly to the expansion of our talent base. Over the period of assessment, 16 prestigious personal fellowships have been awarded to academic staff (Table 1). These fellowships

have all been secured through open peer-reviewed competition and are clear indicators of the high quality of the fellows and the research environment in which these fellows are being hosted.

Fellowships held by established staff have contributed strongly to our philosophy of supporting staff and providing them with the opportunities and time to devote to research. Several established staff have been successful in securing personal fellowships to release their time for research, which in turn has allowed the appointment of temporary staff to build the staff base. These temporary staff have been encouraged to seek independent funds and are eligible for appointment to permanent positions. An exemplar of this is O'Hara, who was appointed as temporary cover for RS URF Hevia, moved to a permanent contract, and now has his own EPSRC fellowship.

The WestCHEM research school is highly attractive to both ECRs and established researchers, and we have been successful in shortlisting and appointing many international applicants. Prospective internal applicants for fellowships are identified and encouraged to apply for fellowships appropriate to their status and ambitions. Successful staff in fellowship schemes act as mentors to new applicants and mock interviews are held using experienced staff from WestCHEM to prepare the candidates. Both universities offer open internal fellowship schemes to attract new staff and WestCHEM has used these successfully to recruit high calibre young staff.

Table 1. *Personal fellowships won in open competition.*

Funder:	Scheme:	Fellows:
European Research Council	Consolidator fellowships	Hevia, Ulijn
EPSRC	Advanced Research Fellowship	Magennis
EPSRC	Career Acceleration Fellowship	O'Hara
EPSRC	Leadership Fellowship	Marquez
Royal Society	University Research Fellowship	Forgan
Royal Society	Wolfson Research Merit Awards	Cronin, Graham, Mulvey, Skabara, Ulijn
Royal Society of Edinburgh	Research Fellowship	Hill, Miras, Robertson
Royal Society of Edinburgh	BBSRC Enterprise Research Fellowships	Irvine
Ramsay Memorial Trust	Ramsay Memorial Fellowship	Boyer

Internationalisation aspects of staffing

Internationalisation is a key strategic priority for WestCHEM and we have recruited extensively from the global pool of talent. WestCHEM has enhanced its international research profile through recent staff appointments, global research engagements of staff (*e.g.,* with Tsinghua, Nankai, Stanford), and knowledge-exchange activities. As befits our status as a leading international research school, since 2008, we have attracted academic staff from positions at institutions in North America (Forgan and Lau: Northwestern; Hill: Washington State; Symes: Harvard; Watson: Princeton; Boyer: Toronto; Miras: Puerto Rico), and Europe (Liskamp: Utrecht; Prunet: Ecole Polytechnique Palaiseau; Senn: Bochum). In WestCHEM, 30% of academic staff members originate from outside the UK. We have increased our global research profile by interacting with world-class institutions through exchanges of established academic staff, junior researchers, and students. This has been aided by an EPSRC Global Engagements Award, which has facilitated 16 such exchanges in the past year and has allowed us to target high quality international collaborations for our staff (see below). Furthermore, several staff hold visiting professorships in international universities (*e.g.,* Beijing University of Chemical Technology, Charles University Prague, Ecole Normale Supérieure Paris, Kyoto, Nagoya, Northeast Normal, Otago, Rennes, Stockholm University, UCSB, University of Paris, and Zejiang University of Technology).

Staff development

Staff development at all levels contributes strongly to and underpins all of WestCHEM's strategic priorities. WestCHEM reviews are coordinated by the management group and are performed to assess the development of staff and the research groupings. WestCHEM staff members are employed by one of the partner institutions and formally undergo annual performance review through the corresponding host's policies and procedures. This includes directing staff to

development courses that are offered by the host institutions. For example, WestCHEM has identified potential research leaders and has placed these individuals on leadership courses using internal funds. Following attendance, these developing leaders are challenged to use their newly acquired skills to form a research cluster within their research landscape with an allocated budget.

In 2009, the partner institutions launched the **Concordat for Career Development of Researchers** implemented through a Researcher Development Framework (including piloting the *Vitae* online planner tool) to develop and support its researcher community. GU was one of the first universities to be awarded the 'HR Excellence in Research' award in 2010 from the European Commission, in recognition of its commitment to support researchers' careers, personal and professional development, and management. In 2011, SU also received the HR Excellence in Research award and was shortlisted in 2011 and 2012 for a Times Higher Education Award for 'outstanding support for ECRs'.

We place particular emphasis on the mentoring of ECRs who have been recently appointed to academic posts. Each is given an experienced and successful member of staff as their research mentor who is responsible for providing direction and assistance in personal strategy planning. An official performance review is undertaken each academic year to assess the performance of the ECR against agreed criteria and guide them through the probation period. Peer support is made available for grant writing and the acquisition of new skills, such as achieving impact from research. Successful examples of this are grant-writing workshops run at both institutions that encourage ECRs to work in teams to prepare and critically appraise grant applications. These innovations have resulted in an increasing number of successful WestCHEM submissions and have had a direct impact on the success of grant applications (~£1M) to which ECR WestCHEM staff have contributed. WestCHEM also promotes interdisciplinarity and imaginative thinking, and encourages staff to participate in the Scottish Crucible (a leadership and development programme) every year via a local crucible event held for ECRs. WestCHEM also provides mentoring, online resources, training workshops, and mock interviews for research staff applying for fellowships.

Equality and diversity

WestCHEM has been proactive in developing a culture in which equality and diversity is fully recognised and appreciated. Both Institutions have online equality and diversity training courses that are compulsory for all staff. Equality and Diversity Essentials outlines the key legislation in relation to the Equality Act 2010, protected characteristics, and various types of discrimination and harassment. WestCHEM has embedded equality training into all management structures and courses are provided by both of the universities. This has led to robust performance and development review processes that are supportive of staff requiring parental or adoption leave. Athena SWAN is a key driver to achieve a higher proportion of women in senior academic posts, not only in STEMM subjects but across all academic disciplines. In response to this, WestCHEM operates under the Athena Swan Charter and is committed to advancing women in the STEMM disciplines. Both SU and GU hold an Athena SWAN institutional Bronze Award and the School of Chemistry at GU is preparing an application for a Bronze Award in early 2014. An application for silver status will be submitted by SU in 2014. We also encourage applications from those returning from a career break as part of our recruitment policy. Professorial zoning is a mechanism being implemented to remove gender-based inequalities in promotion and remuneration at this level.

c. II. Research students

Recruitment and training of PGRs

Researcher training is central to our priorities and we have implemented a successful strategy to increase student numbers, improve the quality of training (via a unified approach across WestCHEM for generic and discipline-specific credit-bearing courses in line with the recommendations in the Roberts report), increase industrial connectivity, and expand the diversity of support. The result of this is that our PGR numbers have increased substantially since RAE2008 and there has been a significant improvement in our training environment. WestCHEM has a thriving postgraduate community with 251 (PhD + MPhil) students originating from around the world (37 outside the EU) with the WestCHEM Graduate School being responsible for the delivery of coordinated research training. Table 2 shows the yearly FTE of doctoral research students. There has been significant growth (29% for PhD) since 2007 when our graduate school numbered

167. Our target is to increase our graduate numbers substantially in order to further strengthen our competitiveness in the training of PGRs.

Students graduate from one of the partner institutions, with the host being responsible for the management of the studentship training. The WestCHEM Graduate School remit is to provide a stimulating and challenging environment that ensures the consistency and quality of research training, to provide WestCHEM-wide PGR courses, and to facilitate cross-WestCHEM supervision of students. It also provides a forum for students to meet and network at various events, including lectures by international research leaders (*e.g.,* Prof David Macmillan, Princeton, Prof Doug Stephan, University of Toronto, and Prof Philip Power, UC Davis). Regular social events are held so that PGR students can develop their skills in networking, which in turn helps them to prepare for their future careers. PGRs present their research at the research groupings' seminar series, providing an opportunity to have their research peer-assessed in a supportive environment. The entire Graduate School meets at the annual WestCHEM Research Day where the best final year PGRs present their work to the whole of WestCHEM and a distinguished external speaker headlines the event. This very successful event has been in operation throughout the assessment period and brings all of our staff and students together at a single research-focused event.

One of our strategic aims following RAE2008 was to increase our PGR numbers whilst maintaining the recruitment of top quality students. To achieve this objective, we devised an approach that utilises multiple sources of funding and, in particular, we sought to increase the number of industrial collaborations that support studentships. This resulted in a change in the nature of funding and support for PGRs with a higher proportion (~25%) co-funded by industrial partners through doctoral training centre involvement and through direct institutional funding. WestCHEM is currently involved in three RCUK doctoral training centres including the DTC in Continuous Manufacturing and Crystallisation (CMAC), the DTC in Proteomic Technologies, and the DTC in medical devices. The successful renewal of the CDT in medical devices with CIs from WestCHEM ensures our continued access to this centre for PhD students. PGRs graduating during the REF period are employed in a wide variety of roles in academia, industry, government, and charities. The quality of our research students is evidenced by their success in gaining external recognition with over 35 awards and prizes given during the REF assessment period. Highlights include a Lindemann Trust Fellowship and awards of best student talk at international conferences such as the European Materials Research Symposium and EuroCPAT.

Table 2. *FTE of postgraduate research students (PhD) enrolled on WestCHEM graduate school.*

	2008/09	2009/10	2010/11	2011/12	2012/13
Total	187.52	205.47	209.22	200.8	214.84

Industrial co-supervision

The first steps towards more extensive collaborative partnerships for studentship training started in 2008 with the co-funding of studentships by the Scottish Funding Agency and WestCHEM along with industrial partners based in Scotland such as Schering Plough and Fujifilm. The Strategic Priority Investment in Research and Innovation Translation (SPIRIT) grant scheme was initiated and piloted by ScotCHEM (the umbrella organisation of Scottish research schools in chemistry). A total of 31 studentships were funded and 13 of these were awarded to WestCHEM. The success of the pilot scheme resulted in a larger SPIRIT call from SFC (£8M); in subsequent years the scheme was aimed at research rather than researcher training. Once again, WestCHEM featured heavily in this initiative through the award of £700k for continuous crystallisation, which was the catalyst for the CMAC activity. There is a commitment from WestCHEM to continue to support PGRs that bring together new partners and to develop the relationships that have been formed through the above schemes. This includes making available part-funding for studentships when external income can be used to create a full studentship with a particular emphasis on establishing new partnerships.

Significant amounts of industrial funding have come through the **GSK Postgraduate Doctoral Training Centre**. The scheme is a bespoke collaborative programme, involving GSK-based drug discovery and development functions, within which GSK employees and other hosted researchers work towards a higher research degree through work-based projects. The GSK DTC works on several different levels: (i) GSK employees with work programmes aligned with academic

progression to gain a PhD with direct co-supervision from WestCHEM academics; (ii) WestCHEM registered new PhD students who are based within GSK labs engaged on projects covering a wider range of themes aligned with overall GSK priorities and co-supervised by WestCHEM academics; and (iii) GSK-supported students who are based within WestCHEM working on academic supervisor driven projects with GSK co-supervision. The uniqueness of this partnership was recognised by the Life Sciences Cross Party Group of the Scottish Parliament and has been endorsed by a Scottish Parliamentary motion (S3M-05519). The programme was highlighted as an exemplar in Sir Tim Wilson's Review of University Business Collaboration (commissioned by the UK Government) and also highlighted in his presentation at the Department of Business Innovation and Skills Innovation and Research Strategy for Growth meeting held at the Royal Society on 1st February 2012. Direct investment from GSK has totalled more than £2M to date and has resulted in 56 students being registered for higher degrees at SU. This programme is being extended to countries beyond the UK, most notably Brazil where the UK government, Brazilian government, GSK, and SU have entered an agreement to provide PhD training (30 four-year studentships in 2013-2015) with students based at SU and GSK. Our forward strategy is to replicate the GSK model into other chemistry disciplines and promising preliminary discussions are underway with potential partners.

International PGRs

Our non-UK intake has increased by 100% since 2008 with self-funding students being attracted to the WestCHEM graduate school through our increased international profile, strategically marketed research strengths, and the positive experiences of previous graduates. Besides self-funding we have used the Scottish Overseas Research Student Awards Scheme **(**SORSAS, 3**)**, partial or full institutional fee waivers agreed with partner countries such as China, and the UK-Iraqi postgraduate scheme. One highlight was the award of one-of-25 Chinese Scholars Awards to WestCHEM for excellence in achievement, which added WestCHEM to the list of research schools for top quality scholars from China. We are also embarking on a new PGR programme with Brazil and GSK as mentioned above, and this will feature heavily in our future internationalisation activities. In Europe, we are involved in three Marie Curie Initial Training Network (ITN) schemes, which have provided opportunities for the training of European researchers.

As part of our internationalisation, collaboration, and training strategies, we have laid the foundations for an **international graduate school** linking WestCHEM to institutions such as Stanford, MIT, Tsinghua University, Osaka University, Indian Institute of Technology (IIT) Bombay, and the Indian Institutes of Science Education and Research (IISER) Pune, where movement of PhD students is facilitated by a network of academics in these institutions. A total of 9 students have participated in the exchange programme in its first year of operation. The aspiration is to provide all PGRs with the opportunity of an international exchange within the next five years. This is a highly ambitious target that will involve PGRs spending periods of up to several months in internationally leading research laboratories or industrial settings to enhance their research training. WestCHEM is setting up this programme by exploiting existing international relationships and collaborations. The mechanism used to support this programme will involve targeted investment from the partner institutions with competitive funding available for the best students. Internal resources and targeted schemes such as those operated by the British Council will be used to ensure that our graduate students are able to engage fully in the internationalisation agenda. This initiative has been catalysed by the EPSRC global engagements award, which was used for staff and student exchanges.

d. Income, infrastructure and facilities

Income

Income is the lifeblood of a successful research school and underpins all of its strategic priorities. WestCHEM currently generates income from a wide variety of sources. As part of its general upward trajectory, WestCHEM has experienced an increase in overall research spend with a doubling of our average spend per annum from £4.4M for RAE2008 to £9.1M for REF2014. This significant increase has been achieved by strategic targeting of large funding opportunities appropriate to the research strengths of WestCHEM, as well as the diversification of funding sources.

UK research councils are the main source of funding and WestCHEM is in the top 10 for EPSRC income for chemistry. When comparing the previous assessment period with the current, we have more than doubled our RCUK spend from £17.5M to £36.3M. Overall, spend from all sources has increased from £28.5M to £45.7M over the assessment period. Most notably, several large grants have been awarded to WestCHEM members:

- Cronin received a Programme Grant of £3.5M and a Platform Grant of £1.4M from EPSRC.
- Tomkinson received £1.2M to work with GSK on a joint research programme.
- Clark received a ~£934k grant from EPSRC.
- Cooke was successful in two NSF-EPSRC proposals totalling £1.4M (one with Kadodwala).
- Marquez (~£1M) and O'Hara (~£1M) won funding associated with EPSRC fellowships.
- Graham received a £900k EPSRC grant with the TSB and a £3M EPSRC grant for healthcare.
- Hevia (**€**1.5M) and Ulijn (**€**1.5M) won ERC Consolidator Fellowships.
- Skabara and Ulijn (£1.3M) received industry-coupled funding from the Korea Institute for Advancement of Technology (KIAT).
- Cronin, Littlejohn, and Nordon were key players from WestCHEM in the >£28M funding for the EPSRC Centre for Continuous Manufacturing and Crystallisation (CMAC).

EPSRC has supported CMAC with funding of £10M and more than £14M of additional funding has been provided by SFC and leading pharmaceutical companies, including GSK, Novartis, and AstraZeneca. Recent further funding of £11.4M from HEFCE under the UK Research Partnership Investment Fund (UKRPIF) plus funding totalling £22.8M from industry and charity has enabled CMAC to become a formidable UK research hub with significant benefits to WestCHEM. Part of the EPSRC sponsorship is an associated CDT that provides funding for 45 PhD students in this area. We have been very successful in obtaining funding from the EU, which includes involvement in several FP7 programmes (9) and the hosting of several Marie Curie Fellows (3) by WestCHEM. In addition to research council and industry funding, we have also received grants from major charitable trusts and government bodies such as the Leverhulme Trust, Carnegie Foundation, Nuffield Foundation, Royal Society, Royal Society of Edinburgh, Cunningham Trust, Scottish Enterprise, DSTL, and the Home Office. These successes indicate the diversity of funding sources that were utilised in order to create a substantial, extensive, and sustainable research landscape.

Plans for future research funding

Our plans for the future are focussed on growing our research income and further diversifying our funding sources to enhance the vitality of research. WestCHEM has an excellent track record of securing collaborative funding for research and researcher training from a wide variety of sources. We will continue to adopt an innovative approach to fundraising over the next five years and use this increased resource to propel us to a higher level in terms of the quality and quantity of research. Our key targets for income generation are:

1. To secure high value funding from the research councils by building on the recent successes of Cronin, O'Hara, and CMAC. This will include programme, platform, critical mass, and fellowship funding schemes. We will focus on our research groupings and select appropriate funding strategies based on the degree to which each grouping has evolved (*e.g.*, the network grant in chemical biology with the aim of transitioning to programme and critical mass grants).
2. To increase the proportion of funding from EU sources and in particular from schemes available through Horizon 2020. This includes ERC-funded excellence in science fellowships (advanced, consolidator, and starting grants) and Marie Curie network grants. Our successful ERC fellowship holders (Ulijn, Hevia) will hold surgeries and master classes for colleagues and will be intimately involved in the process of bringing new external fellows into WestCHEM.
3. To build long-term collaborative research programmes with industry in similar ways to the existing programme with GSK. An expansion of the GSK graduate school model to other industries and sectors such as chemical and life science companies.
4. To create centres for doctoral training focussed on our research strengths (*e.g.*, life sciences-chemical interface) using multiple sources of funding while exploiting unique Scotland-wide pooling initiatives. EPSRC have made significant funding available to pump-prime this process and we intend to use this model of research training to attract new funders including other funding councils and industry. The renewed CDT in medical devices is a key starting point.

5. To increase our overseas income through the recruitment of self-funded PGR students and through overseas national funding bodies such as NSF or NIH. Current success with the NSF (Cooke, Cronin, and Kadodwala) gives us confidence in succeeding with this approach. We will also diversify funding streams and source funding from BRIC countries.

Infrastructure and facilities

Research environment

WestCHEM is housed in state-of-the-art accommodation at both institutions. Major facilities are shared between the two sites (*e.g.,* NMR, x-ray crystallography, mass spectrometry) and are available to all members of WestCHEM on the same terms. Internal investments in infrastructure during the assessment period of over £12M (£8M GU, £4M SU) have helped create an environment that inspires innovative research and is attractive to new recruits.

Facilities and Support Staff

WestCHEM was created to deliver world-leading chemistry research and our infrastructure is organised to achieve that goal. In line with our overarching strategy, collaborative and multi-disciplinary research continues to grow in importance and links with other disciplines are evolving rapidly. We now have capacity within WestCHEM to perform device manufacturing linking us to research in physics, engineering, and materials science. We also have biological handling facilities for cell culture and phage display and are pioneering 3D printing for chemical applications. Our infrastructure allows us to participate in collaborative research activities and to assume a leadership role in these activities. Examples of infrastructure-enabled WestCHEM leadership include the **Centre for Molecular Nanometrology**, the **Glasgow Centre for Physical Organic Chemistry,** the **Chemical Biology Cluster**, and the national **Centre for Innovative Manufacturing in Continuous Manufacturing and Crystallisation** (CMAC). A central feature of WestCHEM's research strategy is capitalisation on our areas of strength and we have unique, world leading facilities that will allow us to accomplish this. These facilities include (1) the largest multi-line Raman facility in the UK and one of the largest globally as part of the Centre for Molecular Nanometrology; (2) a leading multidisciplinary activity in the area of biomolecular gels, with capability spanning from fundamental discovery, characterisation and application in biomedicine; and (3) the Ultrafast Chemical Physics grouping providing state-of-the-art femtosecond laser facilities. In addition to our unique core facilities, members of WestCHEM regularly use other world-leading facilities at both institutions such as the **Kelvin Nanocharacterisation Centre** and the **James Watt Nanofabrication Facility** at GU, which houses more than £20M of nanofabrication equipment in a 750 m^2 clean room. WestCHEM staff have been particularly successful securing funding for access to central RCUK facilities amounting to **£1.5M *per annum*** over the assessment period. This involves neutron scattering experiments at ISIS but in particular beam time at the Diamond Light Source for x-ray crystallography.

A key feature of WestCHEM that enables research to be performed efficiently is the quality of the technical staff. Major facilities are operated by skilled technical staff and researchers in WestCHEM are able to access the facilities and resources offered by each partner. This includes technician support to perform x-ray crystallography, spectroscopy (NMR, ESR, UV/VIS, IR, Raman, ROA, CD), microscopy (Raman, fluorescence, FLIM, SEM), microanalysis, and MS.

Future plans for infrastructure improvement

An exciting development for WestCHEM is the formation of the £100M **Technology and Innovation Centre** (estimated completion date Autumn 2014), which will be focused on multidisciplinary research themes and will have a strong emphasis on PGR training. Graham is leading the bionanotechnology theme and accommodation for up to 130 researchers (including 6 academic staff from WestCHEM) will be provided in this multidisciplinary area. One of the stated strategic aims of the TIC is to increase research collaborations across disciplines and to translate that research into the commercial sector by working in partnership with industrial sponsors. This opportunity will be available to all researchers in WestCHEM and the mechanisms being deployed in the TIC will be used to increase the industrial translation of research across WestCHEM. Investment related to chemistry is estimated at ~£12M.

Over the next 15 years, GU will be investing up to £750M on the redevelopment of its existing campus and a recently acquired 14-acre site immediately adjacent to the campus. The redeveloped campus will provide a state-of-the-art research environment along with inspiring new

buildings for teaching and research. The new campus is being planned to maximise opportunities for interdisciplinary collaboration while retaining the diversity and core strengths of a broad-based university. These developments will further enhance WestCHEM's infrastructure and facilities.

Consultancies and Professional Services

Members of WestCHEM take leading roles in consultancy activities such as acting as expert witnesses in patent and other court cases, and providing advice to companies, ranging from SMEs to global multi-national entities. In addition, significant income has been generated from IP licensing opportunities generated from research performed in WestCHEM. Over the assessment period over £1.6M has been generated as income via these mechanisms, which has been reinvested in the WestCHEM research programme and in support of PGRs.

e. Collaboration and contribution to the discipline or research base

Examples of Innovative and Sustainable Research Collaborations

A key priority of WestCHEM's strategy is collaboration with internal, external, national, and international partners from both academia and industry. WestCHEM has been a leading partner in many high profile collaborations at the school level, *e.g.,* Glasgow Centre for Physical Organic Chemistry (funded by EPSRC, SFC, and industry), SFC's SPIRIT scheme, and also with other disciplines, *e.g.,* CMAC. Multidisciplinary research is actively supported within WestCHEM through our involvement in multi-partner research collaborations that make use of our unique infrastructure and research strengths, which in turn contributes to our strategy for income generation from a range of sources. International collaborations are often cemented through researcher exchanges, which is consistent with our overall strategy of combining collaboration with internationalisation and training. Over the review period, 307 international collaborations have been active in producing co-authored publications or generating substantial income.

Interdisciplinary Collaborations

WestCHEM has been involved in a wide range of interdisciplinary research projects that have been enabled either through collaborative funding or the supportive environment provided by WestCHEM. For example, several Cancer Research UK grants (> £3M) have been awarded to Suckling with colleagues from the life and medical sciences at GU, SU, and Dundee. The resulting research has led to RCUK collaborative funding of >£500k to investigate a potential new class of drug. Additional externally awarded funding where WestCHEM members are active as contributors includes a £1M Wellcome Trust award to McCarron at Strathclyde's Institute for Pharmaceutical and Biomedical Sciences (SIPBS), with Hartley as a key member of the team, and a £6.4M Programme Grant to the University of Cambridge in the area of intelligent lighting, with Skabara as a key member. Interdisciplinary research involving WestCHEM members is a key component of our strategy for continued growth, expansion, and sustainability as a world-leading centre of excellence that is able to interact on a larger scale and across a wider diversity of research projects. Further interdisciplinary research projects have been encouraged and promoted by the partner universities through strategic internal investment. For example, the Bridging the Gap Award was set up to support cross-faculty and interdisciplinary research collaborations through either short project funding or themed workshops. Twenty-five pump-prime projects have been funded in WestCHEM (total value £140k) to catalyse new interdisciplinary research collaborations. An ever-increasing number of PhD students (25 in 2012/13 compared with 7 in 2008/9) are involved in projects in which supervision is spread across more than one department or discipline. Future plans for doctoral training centres involve partners from outside WestCHEM (*e.g.*, life scientists and clinicians at the SU, GU, and Edinburgh) in order to broaden the training experience for these scholars.

Industrial and Non-Academic Collaborations

Applied research has always been an important component of our portfolio and this has resulted in the development of strong links with industry. WestCHEM members have published more than 500 papers with non-academic (*e.g.*, government agencies, hospitals, *etc*.) or industrial co-authors during the review period. Further details are given in the impact narrative regarding the strategy we have adopted to maximise impact. In short, over 50 different companies and agencies ranging in size from SMEs to large multinationals based in the UK and abroad have supported our research.

International academic collaborations

WestCHEM is an ambitious internationally leading school of chemistry research. Our aspirations to develop our international reach and impact are fully supported by the internationalisation strategies of both the partner institutions. WestCHEM members have been active in establishing formal MoUs with leading research institutions across the world, partly supported by EPSRC's Global Engagement Award and stimulated by our commitment to provide international experience for our PGRs. The award allowed academics to forge international networks with the aim of creating sustainable research relationships. More than 16 exchanges and several fact-finding visits have taken place within WestCHEM (including Stanford, Tsinghua, Nanyang Technical University, Osaka University, IIT Bombay) and these significantly enhanced our internationalisation collaboration agenda. International research collaboration is further supported in part by external funds such as UKIERI, JSPS Fellowships (Prunet, 2010, Marquez, 2011), NSF–EPSRC awards (Cooke, 2010, Kadodwala, 2013), NSF-EPSRC and NSF-BBSRC (Cronin, 2011 and 2010).

Evidence of contributions to the discipline

Conference presentations and organisation

WestCHEM members have been very active in delivering invited international (457) and national (280) lectures during the research assessment period. These have included **plenaries** at EuChemMS, European Science Foundation COST High Level Research Conferences, Gordon Research Conferences, Pacific Symposium on Radical Chemistry, Polymer International, Symposium on the Frontiers of Chemistry; **keynotes** at IUPAC, MRS, Pittcon, SciX, SPEC, Pacifichem, and many other conference series including ACS national meetings.

WestCHEM members have also been very active in leadership of **conference organisation** both internationally (>60) and nationally (>45) and have served on local organising committees and advisory board. Examples of major conferences for which WestCHEM members have taken leading roles include: Bionanotechnology III, Dynamics of Molecules and Materials-II, EuropaCat X, Europact, Faraday Discussions 151, 167 and 174, International Conference on Advances in Energy Research 2009, 23rd International Congress on Heterocyclic Chemistry, International Conference on Clean Energy, International Congress on Catalysis, International Symposium on Advances in Electrochemical Science and Technology 9, IUPAC Theme leads, Materials Chemistry 9, MRS symposia (2007, 2010, 2013), OMCOS15, SPIE Photonics West (BIOS), SYMPOC, and Time-Resolved Vibrational Spectroscopy.

Journal editorship and panel membership

WestCHEM staff fulfil prominent leadership roles in international journals with members having roles on the editorial boards of 25 journals and acted as **guest editors for special themed editions** of over 15 journals. WestCHEM members have been **chairs of several EPSRC panels** including those for chemistry, materials, and fellowships and have **provided members of funding panels** for BBSRC, EPSC, EPSRC, EU COST Actions, ISIS, MRC, The Royal Society, as well as Finnish, French, Irish, Romanian, Spanish, and US research councils. Staff have also played key roles on several professional bodies such as the RSC, STFC, ISIS, *etc*. These examples show the clear high regard with which WestCHEM members are held in the chemistry community both nationally and internationally from a publishing and an advisory perspective.

Awards, Prizes and Elected Fellowships

Cronin, RSC Corday-Morgan Prize (2012); **Faulds,** Nexxus Young Life Scientist of the Year Award (2009); RSC Joseph Black Award (2013); **Graham,** RSC Corday-Morgan Prize (2009), Craver Award from the Coblentz Society (2012), Fellows Award Society for Applied Spectroscopy (2012); **Gregory**, RSC Sustainable Energy Award (2009); **Hevia,** RSC Harrison-Meldola Memorial Prize and Medal (2009), Sigma-Aldrich Emerging Investigator Award (Spanish Royal Society of Chemistry) (2011); **Kočovský**, Axel Wenner-Gren Foundation Award (2012); **Miras**, Scottish Crucible 2013 award; SET for BRITAIN 2012; **Mulvey**, Arfvedson Schlenk Prize from the Gesellschaft Deutscher Chemiker (2013); **Murphy,** RSC Bader Award (2012); **Suckling,** RSC Adrien Albert Lecture & Prize (2009), Nexxus Lifetime Achievement Award (2011); **Ulijn**, RSC Norman Heatley Award (2013); RSC Emerging Technologies Award (2013).

Many members of WestCHEM were elected to fellowships of learned societies over the assessment period with our most prestigious being the Royal Society of Edinburgh (Clark, Cronin, and Kočovský) and the RSE's new Young Academy of Scotland (Faulds, Forgan, and Hevia).