

<b>Institution:</b> University of Hull			
<b>Unit of Assessment:</b> 8 Chemistry			
<b>1. Unit context and structure, research and impact strategy</b>			
<b>Overview</b>			
<p>During this REF period the University of Hull (UoH) underwent a significant transformation to deliver impactful and excellent research focused on key themes including Health &amp; Wellbeing, and Environmental Sustainability. The Department of Chemistry (UoA) has followed this lead and structured its research into: (i) <b>Chemistry for Health</b>, (ii) <b>Chemistry for Sustainability</b>, and (iii) <b>Chemistry for Smart Materials</b>.</p> <p>A strength of Chemistry is our close working relationship with other areas of UoH. The transformation of the UoH structure has enhanced cross-disciplinary research by embedding chemists within other Departments and Institutes, including the Departments of Physics, Biomedical Sciences, Biology and Chemical Engineering. These individuals are closely linked with Chemistry, including via research space within the Chemistry building. This distribution of chemists throughout the institution benefitted UoA8 by linking us to University investments in health- and environmental-focused research and allowing the UoA to be particularly successful in securing internal funding to support cross-centre interactions and our vitality, e.g. PhD clusters, HEIF support (Lab-on-a-Chip) and investment (PET Research Centre, Plastics Collaboratory).</p> <p>The reorganization resulted in a reduction in FTEs within UoA8 to 14.5 FTE. Yet staff previously contributing to UoA8 are now contributing to Chemical Engineering (UoA12) and a new REF return for Physics (UoA9). Despite the smaller cohort, research productivity and impact have remained strong (see table). Publication quality, numbers and citations have improved considerably. Research income per FTE is broadly similar, with our knowledge exchange funding improving significantly. This reflects strategic decisions to conduct more applied research aligning with the needs of the extensive regional chemical industry, local health authorities and environmental agendas. The result of this realignment of our research strategy is reflected in our impact case studies (PET Research Centre and Magnetic Ink).</p>			
	<b>UoA 8 - Chemistry</b>	<b>REF2014</b>	<b>REF2021</b>
	Staff Returned	<b>24</b>	<b>14.5</b>
	Research spent per staff returned	£396k	£397k
	Funding through KTPs	£741k	£1.2M
	Individual publications of staff submitted (no double counting of papers)	483	619
	Citations of those papers during the REF periods	3437	7916
	Visiting Professorships	8	9
		<b>July 2013</b>	<b>July 2020</b>
	PDRAs	9	11
	PG student body	72	44
<p><b>Research response to COVID</b> – following lockdown in March 2020 the majority of the University's laboratories were closed for approximately 4 months. Laboratory reopening was prioritised on research need and relevance to the COVID crisis, e.g. <b>Redshaw</b> was prioritised to complete a large multi-centre grant and <b>Pamme</b> shifted research to coronavirus RNA diagnostics. All UoH laboratories reopened in August 2020. Estate planning enabled us to maintain physical distancing without major restrictions on research activities. All third year PGR students received a 4-month extension and can apply for additional funded extensions. Staff and students were provided with home IT equipment and office furniture. Furloughed research and technical staff salaries were</p>			

topped up to 100%. Research communications moved online, facilitated by IT investment. The University implemented its own test and trace system and from 07/2020 supported an NHS PCR testing site on campus (with lateral flow testing for staff since 12/2020). Consequently, the department had no COVID transmission between staff/students.

## Achievement of strategic aims and impact during assessment period

Our mission is to be a centre of excellence in research that is particularly relevant to the region's extensive chemical industry, healthcare sector and environmental challenges. This ethos permeates the University and is reflected in its vision of a fairer, brighter and carbon-neutral future and its drive to address challenges of '*living with water*', '*eradicating health inequalities*' and '*accelerating net zero carbon*'. We have aligned ourselves with this vision by focusing our research on three core themes (Health, Sustainability and Smart Materials).

We aim to achieve research excellence in these areas through four objectives that underpin our UoA strategy: (1) driving an increase in quality and volume of our research output; (2) diversifying our research income (3) providing effective, transparent management and a stimulating, supportive environment for our researchers to thrive, (4) excelling in science communication so that science and research engages with citizens across society. This strategy will secure our vitality and sustainability for the future.

### (1) Enable our researchers to excel in key thematic areas

Our three strategic themes: Chemistry for (i) Health, (ii) Sustainability and (iii) Smart Materials map onto UoH focus areas and tap into application-driven research partners (facilitated by the Aura Innovation Centre, see REF5a).

The **Chemistry for Health** theme (led by **Archibald**) encompasses *clinical diagnostics, imaging/theranostic agents, drug/agent delivery systems, antimicrobials and anti-cancer agents*. The UoH **PET Research Centre** (Director **Archibald**) is central to this theme. Its on-campus facility houses a research-dedicated cyclotron, and multimodal imaging units for preclinical research. The Centre, and the sister facility at Castle Hill Hospital, were co-established to support translational clinical studies. Underpinning this is research focussed on creating and characterising new diagnostic compounds. Outputs from the Centre resulted in a change of practice for NHS radiopharmacy in Hull (**impact case study**). Researchers have attracted > £8M in funding from UKRI, EU and charities.

- The PET Research Centre enables us to build significant strengths in development of new medical imaging and theranostic agents. We pioneered the use of copper isotopes in chemokine receptor targeting (*J. Nucl. Med.* 2018, **59**, 10927; patents filed) and developed tetrapyrrolic macrocycles for combined PET/photodynamic therapies and multimodal (PET/MR) imaging (*Chem. Commun.* 2018, **54**, 7952). Research on designing lab-on-a-chip devices for integrated synthesis and quality control of radiopharmaceuticals led to e.g. (*Chem. Eur. J.*, 2018, **24**, 13749) and 5 patents.
- Our researchers developed systems for delivering diagnostic and therapeutic agents, including matrix metalloproteinase activated multimodal theranostic drug delivery imaging agents for thrombosis (MRC). In collaboration with Sporomex, a UoH spin-out, we exploit sporopollenins for encapsulation of compounds aiding oral delivery (*Chem. Sci.* 2019, **10**, 7549) and enhanced shelf life (highlighted in interviews with *Times*, *BBC Radio*, and *The Biologist*, 2019, **66**, 8).
- A growth area is the synthesis of antimicrobials and anti-cancer agents, including metal-based chemotherapeutics for the treatment of cancer and antibiotic-resistant bacteria (*Nat.*

*Commun.*, 2017, #1575), bio-imprinting technology to target and remove blood cancer cells (CRUK Pioneer Award), antibiotic nanocarriers and cationically functionalised nanogels with enhanced antibacterial and antifungal action (industry funded).

- We have continued to excel in developing lab-on-a-chip devices. A successful strand has been point-of-care diagnostics in resource-limited settings, taking advantage of funder priorities to achieve the UN sustainable development goals in Southern and Eastern Africa, with several Newton Fund supported projects on pathogen analysis (including Newton Prize 2020). Our integrated on-chip workflows for analysis of lung cancer from liquid biopsies (EU-LungCARD) and tissue/organ-on-chip systems contribute to the development of personalised medicine.

**Chemistry for Sustainability** (led by **Redshaw**) maps onto the core UoH commitment to be carbon neutral by 2027 and the UoH Energy and Environment institute (EEI) research. The EEI, established in 2016, supports 80+ interdisciplinary researchers tackling environmental challenges and low carbon, sustainable energy solutions. This provided opportunities for our UoA through the EPSRC-DTC (Aura), with its focus on renewable energy technologies. Chemistry contributes especially through research on *developing plastics designed to fit within a circular economy*, as well as *environmental monitoring and sustainable energy sources*.

- UoH has a long history of sustainable plastics research from the creation of the first fully biodegradable bioplastics, polyhydroxyalkonate, in the 1980s, which led to commercialisation of Biopol by ICI. This longstanding interest in sustainable plastics now informs the **Plastics Collaboratory** (led by **Redshaw**) and draws on expertise from different disciplines across the UoH. We have attracted £17M in research grants to explore structure-activity relationships of metal-based catalysts to access next generation polymeric biodegradable materials (£1.1M RCUK with manufacturers/supermarkets who may utilise the biodegradable plastics we develop. New catalysts are being developed in collaboration with international polymer companies, e.g. Mitsui Chemical Corp. (*Chem. Eur. J.* 2015, **21**, 5199) and Borealis Polymers (*Dalton Trans.* 2015, **44**, 12292). Catalysts have been developed that exhibit novel 'turn-on' activity (*Chem. Commun.* 2019, **55**, 11279) or can operate efficiently in air (*Cat. Sci. & Tech.* 2020, **10**, 1619). UoH polymer catalysis research was highlighted in case studies with *EPSRC National Services* for MS and X-ray crystallography.
- Analytical science underpins environmental monitoring. We developed a point-of-need method for analysis of bacterial contamination in drinking water (Newton Fund, South Africa) (*Chem Eur. J.* 2017, **23**, 1). As part of the North Sea Regional Development Fund Sullied Sediments Project (€4M), we analyse EU watch-list chemicals in sediments and have developed paper-based nutrient analysis devices now used by citizen scientist across the North Sea region. UoH became a member of the Community of Analytical Measurement Sciences to develop on-site environmental monitoring systems. This theme also provides PGR training for six students through a University-funded PhD cluster on Sensing and Safeguarding the Water Environment (Chemistry led).
- Activities in sustainable energy sources include production of biohydrogen from algae (*J. Mat. Chem.* 2015, **3**, 20698), a hydrogel templating technology for fabrication of sustainable lightweight hierarchically structured, porous materials (*J. Mater. Chem. A*, 2019, **7**, 8030), and materials for improved sound absorption properties (*Mater. Chem. Front.* 2017, **1**, 2627).

The **Chemistry for Smart Materials** theme sits under the umbrella of the **GW Gray Centre for Advanced Materials** (Director **Mehi**). This was founded in 2016 to provide critical mass for researchers across Chemistry, Physics and Engineering, and was named after UoH Professor George Gray for his development of LCD technology. The Centre builds on this reputation in *liquid crystal (LC)* research, and an outstanding record in *colloidal science* and a growing area of *nanomaterials*; resulting in £3M from RCUK, EU, Innovate UK, charity and industry sources. The theme provides doctoral training through two strategically funded University PhD clusters on *3D*

*printing* (led by **Chin**) and *Directed Self-Assembly* (led by **Mehl**). Applications of research arising from the GW Gray Centre form the basis of our **Magnetic Ink impact case study**.

- Our research on *liquid crystal* and *photonic/electronic materials* led to several high-quality outputs on nanostructured materials and metal nanocomposites (*J. Am. Chem. Soc.* 2015, **137**, 12736; *J. Am. Chem. Soc.* 2016, **138**, 5757; *Mater. Horiz.* 2020, **7**, 3021); fundamentals of LCs with a focus on novel LC phases (*Nano Lett.* 2017, **17**, 7515, *Mater. Horiz.* 2019, **6**, 1905) and in advanced flexoelectric materials for spatial light modulators (*Adv. Mater. Technol.* 2020, **5**, 2000589).
- We continued pioneering research on *colloidal materials* with focus on the behaviour of colloidal particles and the discovery of new materials emanating from their collective assembly. This includes particles at fluid interfaces, powdered emulsions, oil foams and multiple particle-stabilised emulsions. This research has successfully attracted direct funding from industry (cumulative >£900k) as well as EU (£170k) and resulted in high impact outputs (*Angew. Chem. Int. Ed.* x9, *Nature Commun.* and *J. Amer. Chem. Soc.* x4) and 5 patents.
- *Nanomaterials* research included the development of cellulose-stabilized nanoparticles to develop magnetic inks with widespread applications in the ticketing industry (see impact case). We developed and employed nanoparticles as contrast agents for imaging (see PET), and synthesised molybdenum clusters for oxygen sensing (EPSRC, *Chem. Eur. J.* 2018, **24**, 17915). Other strands include the development of platform systems for controlled delivery of bio-actives, and the design of several classes of inorganic nanoparticles with self-grafting surface functionalities that exhibit antimicrobial properties (*Adv. Colloid Interf. Sci.*, 2017, **249**, 134; *ACS Appl. Mater. Interf.*, 2019, **11**, 12232 and 38519). In collaboration with Unilever we developed *stimuli responsive smart materials* based on a capillary structured suspension (WO 2018/065264 A1, *ACS Appl. Mater. Interf.*, 2017, **9**, 44152). Further avenues include research into clusters at the biology interface (*Angew. Chem. Int. Ed.* 2016, **55**, 1690) linking organic/inorganic chemistry and exploring the electrical response and self-assembly properties of fluidic MOFs (*J. Amer. Chem. Soc.* 2019, **141**, 12989).

Our three strategic themes **provide a focus for impactful research**. Staff can contribute across all themes, thus disseminating expertise in techniques. Examples include:

- Prior** has contributed expertise in **powder and single-crystal diffraction to structural science** across a wide range (as demonstrated by 72 outputs). He carried out structure determination for Chemistry, across UoH and externally on pharmaceutical chemistry, geochemistry and nuclear materials with collaborators (Salford, UCL, Texas, Southwestern Oklahoma and Chiang Mai).
- Pamme** leads UoH research in **lab-on-a-chip devices**. This includes development of microfluidic systems for point-of-care testing (Newton Fund, EU-ITN), tissue-on-chip systems, as well as dose-on-demand radiopharmaceutical production (MRC). She develops portable and deployable systems for environmental analysis of water and soil (EU, GCRF and CAMS-funded) and also leads a cross-Faculty PhD cluster on *Sensing and Safeguarding the Water Environment* (with six postgraduates). With synthetic chemists, microfluidics is employed for assembly of drug delivery vesicles and self-healing materials.

UoA alignment with the University's core values has resulted in an institutional commitment to supporting research within Chemistry. Staff have been awarded lead roles in **six UoH strategically funded cross-disciplinary PhD clusters**. Two in Chemistry of Health, (i) *Adaptive Radiotherapy* (**Archibald**), (ii) *Pharmacology of Natural Products* (**Jones**), two in Chemistry for Sustainability, (iii) *Sensing and Safeguarding the Water Environment* (**Pamme**), (iv) *Circular Plastics Economy* (**Redshaw**) and a further two in Chemistry for Smart Materials: (v) *3D printing* (**Chin**) and (vi) *Directed Self-Assembly* (**Mehl**). Moreover, Chemistry staff contribute to clusters focussed on *Advanced Wound Care* and *Early Biomarker Detection*. Clusters consist of up to 6

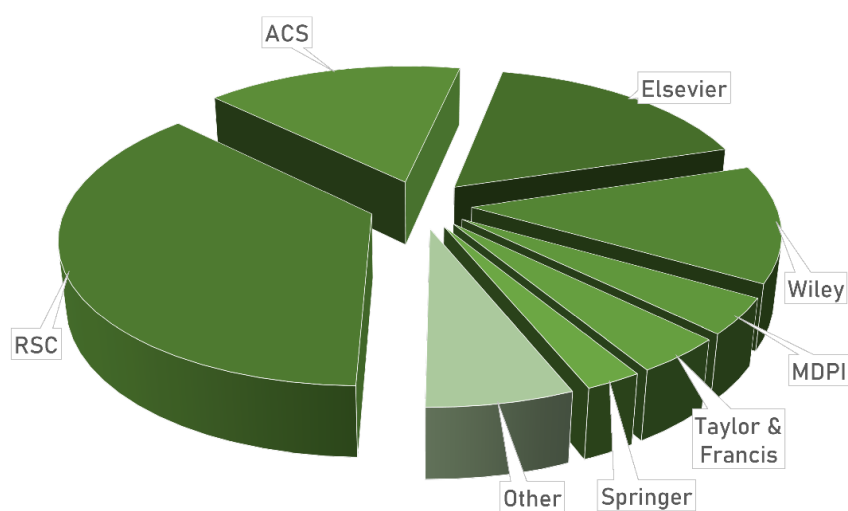


PhD students and act as 'pump-primers' for further grant applications. They also provide an **excellent cross-disciplinary training environment** for ECRs and PGRs.

## **(2) Increase the quality and volume of our research output**

This focus on defined areas produces a high number of quality outputs: **Redshaw** 153, **Binks** 98, **Prior** 72, **Mehl** 62, **Archibald** 54, **Paunov** 32, **Pamme** 38, **Boyle** 34, **Kelly** (0.5FTE) 21, **Horozov** 18, **Francesconi** 10, **Murray** 10, **Iles** 10, **Lorch** 8, **Young** 8. Altogether the UoA has been highly active producing >713 papers from chemistry staff over the REF period, with the majority published in RSC, ACS, Elsevier or Wiley journals (Figure 1).

Many involve collaborations with the UK, Europe, the Americas and Asia (29% of publications are with international partners, figure 3, section 4). UoH is compliant with the **Concordat on Open Research Data**. As part of this process, >99% of our outputs are deposited on the 'Worktribe' (since 2016) and 'Hydra' (since 2014) repositories.



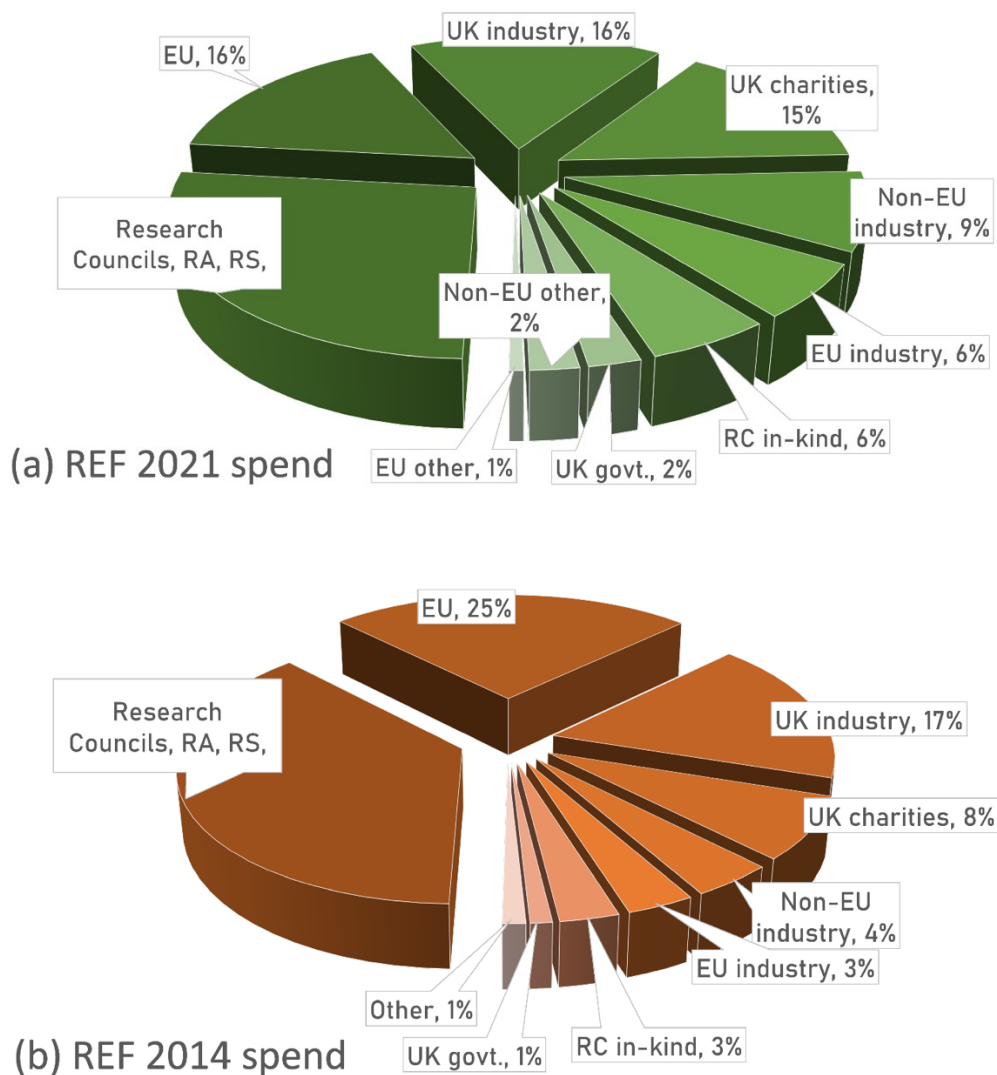
**Figure 1. – UoA publications by publisher**

## **(3) Diversification of research income and collaborations**

Within this REF period we developed **new income streams** (figure 2 for spend versus 2014), using opportunities with EU-H2020, GCRF and Middle East links through PGR recruitment. UKRI funding constitutes 45%. We have increased engagement with regional industry resulting in increased KTP funding to £1.2M in this REF period (section 3). EU funding continues to be significant (25%). Direct **industrial funding** has remained strong (25%) derived from corporations including locally-headquartered companies (Reckitt Benckiser, Smith & Nephew) as well as Akzo Nobel, bioMérieux, GSK, Lonza, Shiseido and Unilever. Through working with local health authorities, we increased the portion of **UK government (non UKRI) funding** (10%), and from **UK charities** (15%).

We broadened our **international collaborations**. New partnerships emerged through FET (**Binks, Horozov**) and ITN (**Pamme**) schemes. Our connections with Asia have grown, including projects with China (**Binks, Mehl, Redshaw**), Japan (**Redshaw**), Singapore (**Murray**), and Russia (**Pamme, Redshaw**). We are active in the Americas, working with researchers in the USA (**Archibald, Mehl, Paunov, Redshaw**), Canada (**Boyle, Redshaw**) and Brazil (**Boyle**). We established new collaborations in lower- and middle-income countries including India (**Binks,**

**Pamme, Redshaw**), Pakistan, South Africa, Kenya and Nigeria (**Pamme**); many enabled through the Newton Fund and GCRF.



**Figure 2.** Contrast in UoA spend for (a) REF 2021 and (b) REF 2014.

**(4) Provide effective, transparent management and a stimulating, supportive environment**

During the REF period the institution has introduced a new appraisal system, an academic career framework initiative and clear promotion guidelines (section 2). Success in research funding applications has been fostered by a supportive environment, comprehensive internal peer review and mentoring. The administration pathway for proposals has been streamlined and is supported by our central **Research and Innovation Funding Office**. The more collaborative atmosphere enabled interdisciplinary grants to be developed, such as the successful Plastics Collaboratory. To free time for core activities, the administrative burden on academic staff was reduced by centralizing administration within a faculty hub and by new appointments including two teaching fellows.

In this REF period, we held 65 departmental **seminars** with mandatory PGR attendance. Time is dedicated for speaker/student interactions. When RSC award winners visit, seminars become mini-workshops with PDRA/PhD students also presenting. We also benefit from seminars offered across campus, e.g. in Biomedical Sciences and the EEI. The Hull York Medical School organises an annual Allam Lecture, which is accompanied by student oral/ poster presentations with many contributions from Chemistry. Hull hosted a number of conferences including UK PET Chemistry (2017) and RSC Northern Dalton (2018).

Staff have been acknowledged through annual intramural awards: **Binks** (2018, Outstanding published output); **Archibald** (2018, Outstanding impact); **Pamme** (2019, Outstanding research collaboration); **Redshaw** (2018 Outstanding published output; 2019 Outstanding grant capture); **Lorch** (2018 Outstanding public engagement), **Prior/Young** (teaching awards).

**Visiting scholars** contribute to a vibrant research environment. We have hosted, e.g. Prof Kai Chen (NUIST, Nanjing University of Information Science & Technology, China; Jiangsu Government scholarship) for 12 months, Prof Xin Wang (NPU, Xi'an, China) for 12 months (CSC sponsorship), Prof B Zhang (NPU, China) in 2018 (Royal Society), as well as Prof Mahesh Varia (CU Shah U., India) for six months and Prof Alahmadi (U. Jeddah, Saudi Arabia). Our research environment was enhanced further by **visiting PhD students**, including Commonwealth Split-site studentships from Pakistan and India, Newton Bhabha Fund students (India), several CSC funded students and a Thai Royal Golden Jubilee Scholarship. The Department hosted **visiting summer research students**, >100 over the REF period, mostly from France, Spain and Holland. Staff hosted 16 RSC- and ACTF-funded summer studentships.

#### **(5) Lead on science communication and public engagement**

Our public engagement activities are designed to ensure our research has an impact on citizens well beyond the academic and chemical industry sectors. These activities go to the University's key challenges of *promoting fairness* by supporting wider access to Higher Education and breaking down the misunderstandings walls that hinder access to research. Engagement also *supports creative industries* by embedding STEM-themed activities within cultural events like Hull UK City of Culture 2017, popular culture/science themed publications and work with creative industries, e.g. Lorch consulting for Microsoft to embed Chemistry within their extremely popular Minecraft game.

UoH leads on science communication with **Lorch** the first UK chemistry Professor of Science Communication. Chemistry is now at the forefront of UoH Public Engagement activities, leading on securing the British Science Festival for Hull in 2018, and Directing the Hull Science Festival in other years (**Lorch**). Our science communication strategy aims to break down cultural barriers to science engagement, and to chemistry in particular. We do this by presenting science as an enjoyable cultural activity similar to music, art and theatre. For example, Chemistry participated actively in Hull's Annual Freedom Festival and City of Culture, reaching audiences that would never actively seek science-based activities.

Other examples of embedding science within the region's cultural life include **Lorch's** mentoring of other science communicators via the Graduate Enterprise project; establishing 'Lab Rascals' (a company delivering chemistry-themed children's parties); and establishing an 'element of the week' slot on BBC regional radio during 2019; **Lorch** and **Pamme** utilised Minecraft to visualise Lab-on-a-Chip devices and molecules. "Molcraft – molecules in Minecraft" featured in the world-wide press and resulted in consulting for Microsoft that resulted in embedding chemistry themes

within Minecraft. **Lorch** provided advice to a major film company (Potboiler Productions), and has written/edited three popular science books, one shortlisted as “book of the year” by the IoP.

Another ambition is to democratise access to science through establishing regional science cafés, “Pint-of-science” events, plus hundreds of school lectures, radio presentations and contributions to “*The Conversation*”.

### Future strategic aims and goals of research and impact

Our research objectives will continue to align with the University’s role as an anchor institution for our region and its drive to deliver wide-reaching, impactful research that addresses key challenges relating to health and environmental sustainability. The imaginative ways we communicate our research will address UoH targets of promoting fairness across society and enhancing creative industries.

We deliver on these objectives by focusing on the three core themes of health, sustainability and smart materials. These are areas of our long-standing expertise that address the particular needs of the region’s industries, while also addressing the global challenges of growing and aging populations and of environmental emergencies.

Our strategy includes a stronger focus on application-driven research through collaboration with commercial and health sectors. This will be facilitated by the University’s Aura Innovation Centre (funded by £12m ERDF funding to link research capacity to commercial users), and by increased emphasis on securing contract and Innovate UK funding. Chemistry will develop overlapping research strategies and operations with the University’s new Chemical Engineering Department, which will broaden our research capability. This realignment to focus on more application-based outputs will increase the wider impact of our research and our broader vitality and sustainability.

Operational plans are already in place to implement these strategies and tactics; Chemistry and Chemical Engineering now have a single, joint head of department (**Lorch**), a joint Director of Research and a joint Post-graduate Research Director. The departments are developing MSc by Research programmes with industrial placements, and enterprise-based KPIs have been established across both units. The University is supporting these activities through implementation of the academic career framework which puts knowledge exchange and enterprise activities on an equal standing with research and education; it has appointed business engagement managers to facilitate collaboration, and has established a wholly owned spin-out company (**Lampada**) to commercialise ventures.

## 2. People

### Staffing strategy

During this REF period, high-quality ECRs were recruited (three male, three female) which established a more balanced staff profile (age, gender and ethnicity) and strengthened research themes. Research Mentors helped develop these ECRs as independently funded researchers:

**Gupta** (bioanalysis with optical waveguide sensors; EPSRC Healthcare Challenge, £1M), **Efremova** (photoluminescent materials, EPSRC 1<sup>st</sup> grant scheme) and **Kyriakou** (inorganic nanomaterials; EPSRC 1<sup>st</sup> grant scheme), **Stasiuk** (multimodal imaging agents; MRC £800k), **Chin** (metal organic frameworks and 3D printing; KTP, Green Port Hull), **Reithofer** (peptide-based



materials for drug delivery). **Iles** was appointed Research Officer for the Lab-on-a-Chip Fabrication Facility that underpins £1.8M in grants. ECRs have been closely coached/encouraged to produce high impact outputs, which led to publications such as *J. Am. Chem. Soc.* (**Chin, Reithofer**), *Chem. Sci.* (**Murray**), *Nat. Commun.* (**Murray**), *Chem. Eur. J.* (**Efremova, Stasiuk, Chin, Bonet**), *Angew. Chemie Int. Ed.* (**Murray**), *Nanoscale* (**Stasiuk**) and *Chem. Commun.* (**Chin, Reithofer, Stasiuk**).

## Staff Development for all stages

UoH was awarded the **European Commission's HR Excellence in Research Award** recognizing universities implementing the Concordat to Support the Career Development of Researchers. We are aligned with the principles of the European Charter for Researchers and Code of Conduct for their Recruitment.

UoH is a **member of Vitae**, part of The Careers Research and Advisory Centre. Vitae supports the professional development of researchers at all career stages. Our **Organisational Development Team** provides career development opportunities, open to staff at all levels. This includes management as well as leadership skills.

Annual appraisals recognise achievement, provide constructive feedback, coaching, and assist with career development, encouraging staff to self-assess progress. Staff are assessed for readiness to promotion irrespective of whether they apply. Examples of promotion in the REF cycle include **Archibald, Lorch** and **Pamme** (to Professor), **Horozov** (to SL).

Our **Academic Career Framework** features three strands - research, teaching, and knowledge exchange. Staff are encouraged to engage in a wide range of professional activities (section 4), including knowledge exchange, consultancy, entrepreneurship, outreach and science communication. All staff are encouraged to seek mentors, internal as well as external via, e.g. the Yorkshire Accord coaching scheme, or Women in Higher Education Network.

### Early Career Researchers (ECRs)

**ECRs** have reduced teaching loads (50% for 2 years) and teaching mentors, support packages and receive preferential treatment on competitive bids to the *Faculty Research Support Fund* (which supports conferences, travel, collaboration and other activities) PhD clusters (**Chin, Jones, Reithofer**) and PhD studentships (**Murray, Efremova**) have been awarded to ECRs to help develop their research profiles.

### Leadership Development

Staff have been supported through leadership courses: **Lorch** (Clare Leadership course, Advance HE Leading Departments), **Pamme / Young** (University Developing Leadership Programme), and **Francesconi / Efremova** (Aurora). Our successful approach to staff and leadership development is illustrated through staff who have **moved onwards**. These include **Evans**, returning to Norwich as Director of NRP Biosciences DTP and Chair NBI Graduate School. **Georgiou** moved to Imperial College (now a Reader), **Reithofer** and **Chin** to the University of Vienna as Associate and Assistant Professors, respectively, whilst **Gupta** and **Kyriakou** built upon successes at Hull and left for promotions to Birmingham and Aston, respectively.

### PDRAs

PDRAs are afforded the same career development opportunities as academic staff through biannual appraisals and access to Vitae (see above). To foster career development, our *Research*

*Support Fund Scheme* enables PDRAs to develop independent researcher profiles, beyond the grant they work on. PDRAs are encouraged to apply for Associate Fellow at the HEA.

PDRA who have benefitted from development at Hull include: Ben Burke (Senior Imaging Scientist, Invicro, London), Johanna Seemann (Manufacturing and Control Manager, Life Molecular Imaging, Germany), Nasr Esfahani (Senior Microfluidics Engineer, Francis Crick Institute, London) and Chuanhe Shen (Lecturer, Nanjing University).

#### Professional support staff

Administrative and technical support staff are now managed at faculty level and provide a streamlined support to students and staff.

### Support mechanisms, training and supervision for PGR students

The UoA has a vibrant and diverse PGR student cohort. In the REF period, **115 PGR students have graduated**, two thirds of them were non-UK nationals. Many of these PGRs were supported by external scholarships (Saudi-Arabia, Iraq, Oman, China, and Commonwealth). Other funding included EU-ITN, University PhD scholarships, Allam Scholarships (a local philanthropist) and industry. Of our graduating PhD students, 26% are female. The percentage is higher (34%) for our home/UK PhDs and close to those identified by the RSC.

At the beginning of the REF period we benefited from international PGR students sponsored by institutions in the Middle East. As these studentships dropped off, we maintained PGR student numbers through the University's strategic investment into University PhD clusters. Recently, the department has refocused PGR provision, developing Masters by Research programmes, utilizing the government's offer of loans for research students. During the REF period, 12 MSc by Research students have graduated.

We currently have 44 PGR students and the PGR student-staff ratio is 3:1. Many of our current PG students contribute to strategic multi-disciplinary PhD clusters (section 1.4) that generate greater capacity via teams of PGR working on connected projects. These constitute particularly **excellent training environments**, often with industry engagement (e.g. Smith & Nephew) or NHS involvement. We also attract Postgraduate students and projects from UKRI centres for doctoral training, i.e. NERC Panorama DTC (lead by Leeds, with Hull and York) that addresses the environmental sciences and changing environments, and the Hull-led EPSRC/Aura CDT (with Sheffield, Durham and Newcastle), that focusses on the offshore wind energy and the environment – of direct relevance to the emerging wind sectors in the Humber and the North Sea.

Our PGR students are **actively engaged in the running of the Department**. PGR students are included in formal structures, e.g. staff-student, recruitment and Athena Swan committees. They are encouraged and supported to lead in ventures, such as International Women's Day activities and public engagement activities, particularly science festivals and organisation of the city's annual contribution to "Pint-of-science". PGRs contribute to the organisation of Departmental Seminars (section 1.6).

The success of our PGR students is externally acknowledged. Six PhD students were shortlisted for 'STEM for Britain awards' at the Houses of Parliament. A Hull PGR student presented at the ACS National conference (San Diego, 2019) which included the ACS press conference/promotional video. Undergraduate project students have appeared as co-authors on publications (e.g. H. Sample: *Chem. Commun.* 2020, **56**, 11090; H. Joy: *PCCP*, 2016, **18**, 9419; C.A. Burnett *J. Mater. Chem. B*, 2018, **6**, 3665).

Our Global Engagement Office supports student visa applications. All PGRs undergo a central and departmental **induction programme**. This includes welcomes from VC, Student Union, HoD, PG support tutor and supervisory team. PG students are familiarised with health and safety aspects, facilities, student support and mental wellbeing and a range of social activities are organised.

All students have a **supervisory team** of at least two supervisors. Projects led by new academic staff are supported by a more senior co-supervisor. All academic staff take and periodically refresh courses on PG supervision. Compulsory training includes topics such as research integrity and ethics, health and safety, diversity and unconscious bias training. Joint supervision of PhD students with supervisors in the NHS was introduced (three students) to increase their experience of Healthcare agendas and practices, including specific training for special positions (e.g. radiochemistry for Thai PET centre).

**Progress and engagement monitoring** are delivered by monthly formal meetings and more substantial 6, 12-month review meetings, the latter with an independent chair and *viva voce*. This ensures good support and development for students as they develop to PhD calibre candidates. At our annual PG symposium, final year PGRs present a talk, earlier PGRs present posters.

Our Doctoral College manages our well-established and pioneering accredited **Postgraduate Training Scheme** that develops academic and professional skills and enhances employability. MRes students' study for 20 credits, PhD students for 60 credits alongside their research project.

Our **Careers and Employability Team** offers tailored support to PGR students. Their **trajectories** are global: many taking up PDRA positions or returning to their home countries and taking up academic and industrial roles e.g.

- Alorabi, Assistant Professor and HoD (Albaha University, Saudi-Arabia)
- Al-Zahrani, Alsamrani, Alqathani, Lecturers (Saudi-Arabia)
- Al-Khafaji Professor (University of Babylon, Iraq)
- Al-Habsi, Lecturer (ICEM, Oman)
- Tyowua, Olusanya and Olusegun, academic posts in Nigeria
- Johnson, Thompson, Masinchi and Darragh (all GSK)
- Marinopoulos (Boots)
- Bignell (Pharma research, Covance)
- Kownacka (clinical trials director, UK)
- Hargreaves (NHS radiopharmacy, UK)
- Jones (Associate Manager R&B)

## Support and promotion of equality and diversity

UoH is committed to promoting equality of opportunity for all, giving every individual the chance to achieve their potential, free from prejudice and discrimination. This is embedded into our Diversity and Inclusivity Policy and permeates the ethos of Chemistry. The success of the policy was recognised with UoH named 'most diverse' University in a 2018 study (HEPI).

Chemistry is fully committed to the **Athena Swan (AS) charter**. A self-assessment team, active since October 2013, chaired by **Binks**, promotes AS and equality of opportunity. Chemistry attained a Bronze Award in November 2015. The resulting action plan, implemented in Chemistry, is regularly updated. It covers all areas of relating to protected groups and equal opportunity. The next application will be faculty wider for further recognition.

Resulting from the University AS Bronze application, our faculty implemented a pilot scheme for women returners from maternity leave, to whom tailored support was provided. Based on the

individual profile and needs of staff, support is designed to provide effective cover and to facilitate effective return, e.g. **Pamme** took 24 weeks maternity leave in 2014. A PDRA contract was extended (six months) to deliver her lectures and supported her research students. During her maternity leave **Pamme** successfully applied for an externally-advertised professorial appointment within UoH. Other staff have taken family leave including **Murray, Armstrong, Prior** and **Jones**.

During the REF period, several female ECR appointments were made (**Efremova, Chin, Gupta**), and female staff took on leadership roles (**Greenway** HoD, **Pamme** DoR and Deputy HoD, **Francesconi** DoR). Female staff have been supported through leadership training (see above) and encouraged to join networks, e.g. WHEN (Women in Higher Education Network).

### 3. Income, infrastructure and facilities

#### Income

We have significantly diversified our research income streams. Research spend during the REF period has been £5.8M, thus broadly similar (per FTE) to the last REF period.

Due to the multi-disciplinarity of our research we have been able to obtain **UKRI** funding from both EPSRC (>£1.7M) and MRC (>£2M). Notable successes during the REF period include an institutional award on evolving the circular plastics economy (EPSRC, £940k, PI **Redshaw**) aligned to our *Chemistry for Sustainability* theme. Significant grant income for the *Chemistry for Health* theme: On-chip clinical radiopharmaceutical production (MRC, £520k, PI **Archibald, Co-I Pamme**), Theranostic systems for combined radio-imaging and photodynamic therapy (EPSRC, £355k, PI **Boyle**); Matrix metalloproteinase activated multimodal theranostic drug delivery imaging agents for thrombosis (£680k, PI **Stasiuk**), Antibody-photosensitiser conjugates for treatment of head and neck cancer (MRC £347k, PI **Boyle**). Examples from our *Chemistry for Smart Materials* theme include funding for high speed multi-level phase devices for active spatial control (EPSRC, £322k, PI **Mehi**). Our 'income in-kind' (£320k) includes access to Diamond, CLF, ESRF, the National EPR and Crystallographic Services.

Through working with local health authorities, we have increased the portion of **UK government (non-UKRI)** funding. Strong links have been formed with co-investigators from the NHS. The portion of income from **UK charities** has increased. Notable examples include a CRUK Pioneer Award on size and shape recognition for separation of blood cancer cells (£142k, PI **Paunov**), Leverhulme Trust 'Photo-activated surface coating to combat bacterial contamination' (£249k, PI **Boyle**), and funding for imaging equipment from the Cardiac Trust (£278k, PI **Archibald**). Further income was generated from the Daisy Charity, Help4Health, Whitelaw Frater Cancer Trust, Analytical Chemistry Trust Fund (ACTF) and Royal Society.

**EU funding successes** include a H2020 FET Open project (ONE-FLOW) on end-to-end green process design for pharmaceuticals (£270k to UoH, **Binks**), an FP7 ITN ('iTERM) on imaging for tissue engineering (£235k to UoH, **Archibald**) and a H2020-ITN (ViBrANT) on studying viral and bacterial adhesins (£220k to UoH, **Pamme, Iles**). UoA staff (**Lorch, Pamme, Boa, Welham**) have been instrumental in delivery of the €4M Hull-led Interreg North Sea Region Programme of the ERDF project 'Sullied Sediments' (£280k to UoH). UoH is leading a H2020-MSCA-RISE project, ATMOS, on understanding gas-gas and gas-solid interactions towards a cleaner atmosphere (£113k, Co-I **Francesconi**).

Direct **industrial funding** remained strong with funding from a diverse range of corporations including Akzo Nobel, Astatech, bioMérieux, Janssen Pharma, Lonza, Lubrizol, Nestle and Rich

Products, rb and Unilever, with grants from Foamix Pharmaceuticals (£360k), GSK (£630k), Nalco Champion (£108k), and Shiseido (£110k) mostly through our soft and colloidal materials researchers (**Binks, Horozov, Paunov**). This supported >10 PhD studentships during the REF period. We have increased our engagement with industry through KTP-funded projects, from five KTPs (£741k) in the previous REF to eight KTPs to 2021 (£1.2M) with AAK, Ansell, Bemrose Booth Paragon (now ParagonID), Centrica, Photocentric and Singleton Birch all KTP collaborators

In recent years, **collaborations outside Europe** have increased significantly. The Newton Fund and GCRF opened up collaborative possibilities with researchers in lower- and middle-income countries. **Pamme** has been particularly successful, securing Newton Fund projects (South Africa £100k; Kenya £100k) on developing point-of-need analysis of pathogens, and receiving follow-on funding through a Newton Prize 2020 (£200k). The UoH QR-GCRF allocation provided pump-priming funding for Chemistry staff, examples are projects with Kenya on on-site monitoring of water and soil quality. The Newton Fund, as well as Commonwealth, ACTF and Commonwealth Scholarships supported several visiting students and scholars from India, Pakistan and Nigeria and China. Furthermore, we have built links with Russia and China through four British Council and Royal Society grants (**Redshaw, Pamme, Mehl**).

## Infrastructure and Facilities

Chemistry shares an estate of 6653 m<sup>2</sup> with Chemical Engineering. This includes synthesis laboratories, laboratories for physical and measurement sciences, Analytical Measurement Instrumentation and Lab-on-a-Chip Fabrication suites as well as teaching laboratories, lecture rooms, the Faculty Stores, office spaces and a library. Chemistry staff also access laboratory space in Biomedical Sciences (biosafety level 2) and the PET Research Centre.

Since 2014, we have improved our research infrastructure with refurbished laboratories housing mass spectrometer provision and ICP systems. Equipment for Lab-on-a-Chip Fabrication has been amalgamated into a dedicated Facility supported by HEIF investment (£270k) and institutional investment. Our physical and analytical chemistry teaching laboratory spaces have been refurbished; they are heavily used by researchers to access various spectroscopy, electroanalytical and separation systems.

Strategic regional investment of £8.25M (including £1.8M from UoH) established a pioneering PET Research Centre on campus and a linked Molecular Imaging Research Centre at Castle Hill NHS Hospital (Director **Archibald**). The Centre on campus features a mini-cyclotron (ABT) for [<sup>18</sup>F], [<sup>68</sup>Ga] generators, bespoke hot-cells, synthesisers, radio-HPLC, radio-TLC, autoradiography and small animal scanners (PET/SPECT), making it the only research dedicated PET Centre in the UK. This provides a unique avenue for bench-to-bedside projects with chemists developing novel imaging probes, and microfluidic synthesis routes to dose-on-demand production (impact case study).

The **Lab-on-a-Chip Fabrication Facility** features rapid manufacturing equipment for quick turnaround of glass, polymer, and paper microfluidic devices, supported by an experimental officer (**Iles**). The Facility underpins £1.8M in current grants and 20+ PhD projects across Science and Engineering and Health Sciences; it also provides service to external partners.

UoA staff use the newly-created Digital Manufacturing Fab Lab in Engineering (**Chin**). The University has invested (£2M) into a supercomputer (VIPER); enabling researchers to perform high-level calculations.



Chemistry has a range of core and specialist facilities; including three NMR spectrometers (two 400 MHz and one 500 MHz systems). Single crystal, powder X-ray, and soft-matter analysis diffraction systems are within the building, as is mass spectrometry provision with Nano-LC MS/MS, LC/MS/MS ion trap, MALDI ToF MSMS and GC-MS. Our ICP suite includes ICP-AES, ICP-MS and a laser ablation (LA-ICPMS) system. We have a wide range of smaller measurement instrumentation such as DSC, TGA, GPC, elemental analysis, zeta sizers and a nano-particle analyser (Nanosight), in addition to a suite of AES, UV-vis-NIR, ATR-FTIR, fluorescence and fibre-based Raman spectrometers, potentiostats and ion selective electrodes. In the Physics Department, we have access to Fluorescence Lifetime Imaging Microscopy (FLIM), VSM, Raman mapping capabilities, a profilometer, white light interferometry, as well as nanoimprint lithography and metal sputtering. The Faculty Microscopy Suite provides SEM, TEM, AFM/STM and confocal fluorescence.

#### 4. Collaboration and contribution to the research base, economy and society

##### Research Collaborations

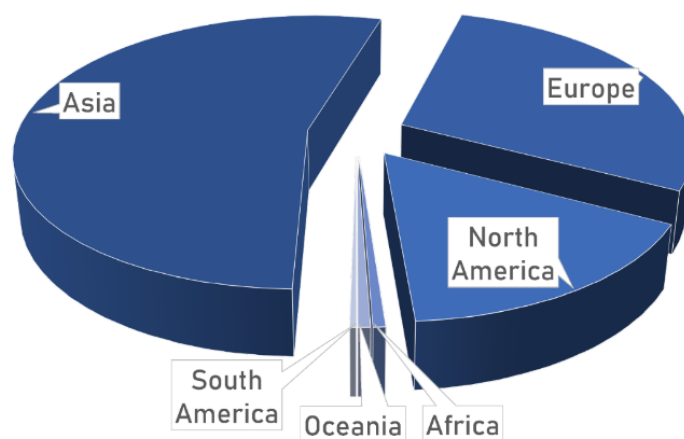
**On-campus and regional:** Chemistry at Hull has extensive, sustained collaborations with universities, professional societies, business organisations and non-governmental institutions across the UK and worldwide.

Collaboration is integral to the culture and strategy of Chemistry (section 1). We are contributing core discipline strength to collaborations with multiple disciplines across campus. Many grants are collaborative and interdisciplinary and outputs are increasingly interdepartmental. Chemistry registered PhD students are also co-supervised by non-chemists including some in the NHS.

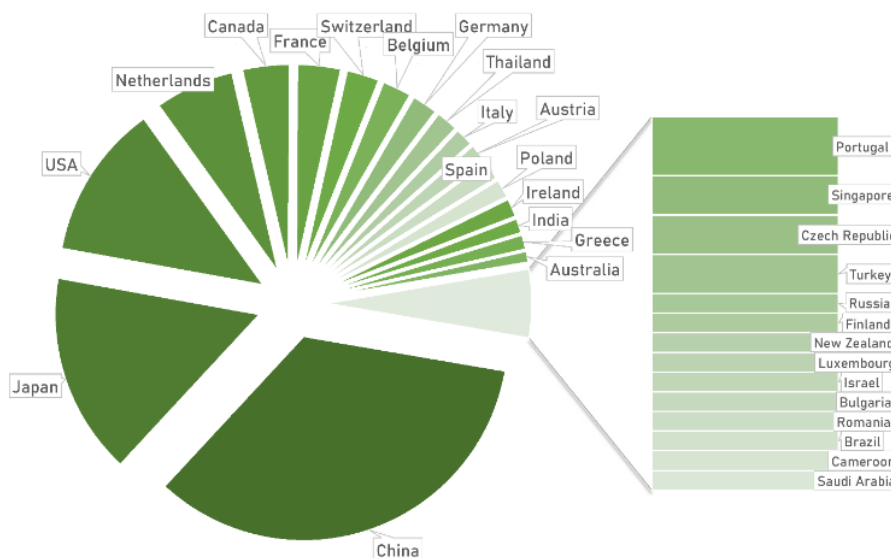
**Nationally**, the Chemistry for Health theme collaborates with Imperial College on antimicrobial surface coatings (Leverhulme Trust, **Boyle**), and UCL on antibody drug conjugates (MRC, **Boyle**).

**Internationally, European Union** projects such as FET (ONEFLOW) (**Binks**)/ViBrANT ITN (**Pamme**)/ATMOS (RISE) (**Francesconi**) and the North Sea Regional Development Fund (Sullied Sediments) work closely with dozens of institutions across Europe. British Council, Newton Fund and GCRF funding has enabled projects with lower- and middle-income countries (section 3). Around 33% of our publications are with international partners (figure 3).

Colleagues have forged collaborations through **visiting and guest professorships**. **Mehl** at Xi'an Jiatong University (China) and **Binks** at Shanxi University (China), both under the 1000 talents programme, **Horozov** at the University of Vienna (Austria), **Prior** at the University of Chang Mai (Thailand) and **Boa** at Universite d'Artois (France). **Redshaw** is a visiting professor at Northwest University, Xi'an (China), the National Institute of Technology, Akashi (Japan), and guest Professor at Sichuan Normal University, Chengdu (China), the Chinese Academy of Sciences, Beijing and Visiting Lecturer Osaka University (Japan).



(a) Publication co-authors by region



(b) Publication co-authors by country

**Figure 3.** UoA publications (a) by region and (b) by country.

Our **collaboration with industry** is highlighted in section 1 (strategic aims) and section 3 (income). We are fostering particularly close links with *local industry* e.g. Smith & Nephew and RB (Reckitt Benckiser). The Plastics Collaboratory is engaging with Tri-pak, Morrison Supermarkets, Chartered Institutes of Wastes Management, William Jackson Food Group and McCains Foods. **Redshaw** is working with companies such as Borealis Polymers (Finland), Mitsui Chemicals Corp (Japan), and Astatech (China). Our UoA also supports the educational and training needs of the industrial sector through the provision of flexible learning pathways (via part-time chemistry degrees and apprenticeships) and a well-established NEBOSH accredited Occupational Health and Safety programmes (ranging from Diploma to Masters level) that also serves the region's industry.

## Research Networks and Partnerships (relationships with key research users, beneficiaries or audiences)

We have set ourselves up to be the focal point for chemical expertise in the region for the local commercial and industrial sector. This is evidenced by our increased recent KTP uptake.

Chemistry colleagues are closely linked within key networks/centres across campus:

- **PET Research Centre** and **GW Gray Centre** as outlined in section 1.
- **Energy and Environment Institute**: a Research Institute focussed on environmental resilience and energy sustainability.
- **The AURA Innovation Centre**: a £12m ERDF-funded centre to connect research expertise with commercial users through Innovation Managers and research labs.
- **Hull Global Health network**, an inter-faculty group of researchers addressing challenges in global health: featuring seminars, peer review, and critical mass for proposal writing.

At **regional level**, staff are active in the **RSC Hull & East Yorkshire local section** and the department frequently hosts section events, providing networking opportunities with members from local industry. We are part of the **Middle England Regional Chemistry Interactive Alliance** of nine universities in the Mercia region that organises workshops, conferences and summer schools to enable networking for staff, ECRs and PGRs.

At **national level**, Hull is a member of the **Community for Analytical Measurement Sciences** set up through RSC Analytical Division and Analytical Chemistry Trust Fund, to foster collaboration between industry (LGC, GSK, Syngenta, Waters, and more) and academia (in-person, on-line events, jointly funded PGR studentships).

## Wider activities and contributions to the research base

### Awards:

- RSC 2014 Surfaces and Interfaces award (**Binks**)
- 2016 ACS Langmuir Lecturer Award (**Binks**)
- Best Masters Supervisor, Sichuan Province, China (**Redshaw**)
- Shaanxi province 100 talents award 2016 (**Redshaw**)
- International Liquid Crystal Society: LG Displays mid-career research excellence award, 2016 (**Mehl**)
- Shaanxi Province 1000 Talents Innovation award 2018 (**Mehl**)
- 2020 Newton award (**Pamme**)

### Editorial roles:

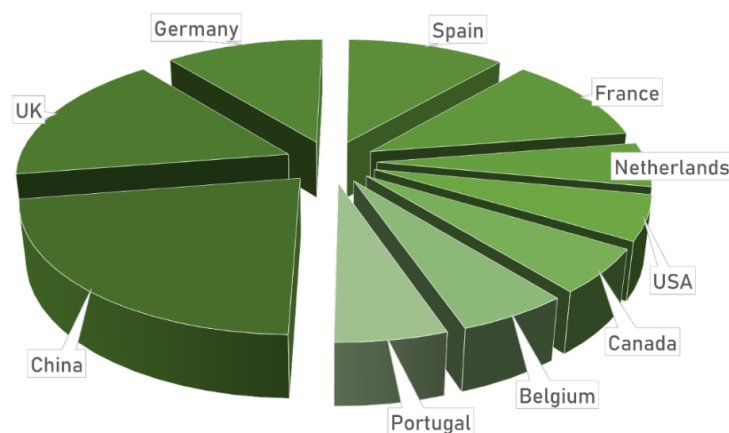
- **Binks** Senior Editor *Langmuir*
- **Pamme** Associate Editor *Analyst*; Editorial Advisory Boards *Analytical Chemistry*, *Lab on a Chip* and *Analytica Chimica Acta*
- **Mehl** Editorial Board *Materials* and *PhysChem*
- **Boyle** Associate Editor *Photodiagnosis and Photodynamic Therapy*
- **Redshaw** Advisory Boards *Catalysts (mpdi)* and *Frontiers in Catalysis*
- **Prior** Editorial Board *Solids*; co-editor *Acta Crystallographica Section E*
- Special issues. **Francesconi** (*Crystals*), **Redshaw** (*Molecules*, *Catalysts*); **Archibald** (*Dalton Transactions*).

### Conference chairs/organisers

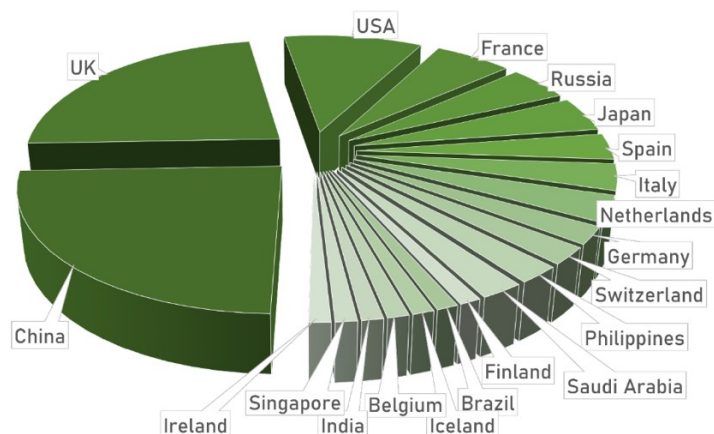
- **Pamme** conference chair, microTAS 2016 (1100 attendees, €1 million turnover)

- **Redshaw** chaired Newton fund international workshops (Japan, China and Russia).
- **Young** organising committee Chemistry and Physics at Low Temperature Jyväskylä (2013) and Biarritz (2016). International Steering Committee Matrix Isolation Community (2009-2017). Coordinator UK inorganic chemistry and X-ray absorption spectroscopy JISCmail (>20 years).
- **International Conference Advisory Committees** include **Binks** (5), **Mehl** (5), **Pamme** (microTAS), **Redshaw** (4).
- We have hosted on campus four British Liquid Crystal Society workshops, two MERCIA workshops, and one Biochemistry Society event.

Staff have given 19 **plenary/keynote** (figure 4(a)) and 93 **invited lectures** (figure 4(b)) at prestigious international conferences. Highlights for leading learned societies in long established conferences series are: **Binks** (ACS, RSC; 2015, 2016, 2017), **Boyle**, (Canadian Chem Soc. 2016); **Paunov**, **Horozov** (European Colloid Interface Soc. 2015, 2016), **Mehl** (Gordon Conf. on LCs, 2019, Int. LC Conf. 2014/16/18), **Pamme / Redshaw** (Pacifichem 2015).



(a) Plenary and Keynote lectures by country



(b) Invited Lectures by country

**Figure 4.** Lectures by UoA members (a) plenary and keynotes, (b) invited lectures.

#### National and international prioritization panels:

- **Archibald; Greenway; Francesconi:** EPSRC panel
- **Pamme:** panel member, Academy of Finland (2018); Swedish Research Council (NT5) (2017-2020, co-chair 2020)
- **Prior:** chair of EPSRC National Crystallography Service Management Panel 2017-2020

- **Mehl:** Diamond Prioritisation panel for soft matter beamlines (2020 - 2023)

**External advisors for academic promotion panels.** **Pamme** Purdue University (USA), KTH (Sweden), Twente (Netherlands), VUB (Belgium) and JUST (Jordan); **Mehl** Huddersfield, Kent State University, CeNS (India) and IASST (India).

Staff are actively engaged in the **organization of subject specific learned societies**. Six members of staff are Fellows of the RSC (FRSC). **Pamme** served as board member and is currently President of the Chemical and Biological Microsystems Society (CBMS) and served on the RSC Analytical Division Awards panel (2020). **Mehl** served as Chair and Vice Chair for the British Liquid Crystal Society (BLCS) and on the Management Board of the International Liquid Crystal Society (ILCS). **Binks** was on the ACS Nomination Awards Committee (3x), and RSC Faraday Division Awards Committee (4x). **Young** was on the International Steering Committee of the Matrix Isolation Community (2009-2017) and **Redshaw** on the International Advisory board of High Technology Polymers (China).

## Wider activities and contributions to economy and society

**Science communication:** We aim to lead in *science communication*. We have reached the wider public through **TV and radio interviews**. **Lorch**, **Young**, **Armstrong**, and **PhD students** contributed to **BBC Radio Humberside** a weekly science slot. **Lorch** has spoken on **BBC Radio 4** 'Four Thought' and 'You and Yours' programmes as well as **BBC Radio 5's** Naked Scientist and Drive Time. Our UoA has submitted 50+ articles in '**The Conversation**' by **Lorch**, **Prior**, **Burke** (PDRA), **Richardson** (PGR), **Roggatz** (PGR) and **Darragh** (PGR) with over 10 million reads.

Staff contributed to the **British Science Festival (2018)**, including **Pamme/Lorch** (Sullied Sediments project), **Archibald** (public lecture), **Kelly** (panel session on LCDs). Our Lab-on-a-chip Team have developed hands-on activities for the annual Hull Science Festival (attracts 3000+ visitors). **Pamme** and **Greenway** contributed to Soapbox Science in Hull City Centre. **Pamme** and **Lorch** have presented research at "Pint-of-Science" in Hull. **Lorch** established a Beverley "Café Scientifique" series with contributing chemists (**Archibald**, **Lorch**, **Pamme**). Our Citizen Science phosphate analysis device, developed as part of the Sullied Sediments EU project, has been used by hundreds of volunteers in the UK, Belgium, the Netherlands and Germany. **Pamme** has delivered hands-on workshops to school children in Kenya (Newton Fund project), **Lorch** has delivered workshops and 'science shows' in Sweden, Bulgaria, Malaysia, Oman, India and Bahrain.

**Impact through creating business:** We contribute to the economy and society through the impact of our research; evidenced by two research impact case studies, "PET" and "Magnetic Ink":

- [1] "**PET**" relates to the establishment of a positron emission tomography/molecular imaging centre for clinical use of 'radio-labelled drugs' on a hospital site. The impact is targeted diagnostic imaging/therapy, lower doses and reduced side effects for patients. The integrated approach allows for administration of custom-made onsite radiopharmaceuticals in response to clinical need. Risks for environmental spillages/exposures to radiation that could occur during distribution are reduced. It incorporates outreach activities to the hospital site for school children showcasing ongoing innovation. Patents for this case study involve 'administering chemicals' to humans either in the form of cosmetics or as imaging and/or diagnostic agents, and for these particular 'chemicals' will guide new practice.
- [2] "**Magnetic Ink**" re-invented printing processes that made a "dying industry" into a world-leading innovator, winning several prizes for innovation on printing processes. The resulting technology is now used globally on tickets (including transport systems and events). The impacts on commerce and technology are palpable, as improved mass production of the



technology has impacted internationally on multiple industries ranging from transport to health and safety. The co-production of knowledge and resulting innovation made the company economically viable again and increased their workforce (83 to 162) bringing desperately needed jobs to a region with social economic deprivation.

Additional impact includes two **start-up companies**. Research on micro-reactors at UoH was instrumental in establishing **Chemtrix BV's** core technology. The company's mainly operates in the Netherlands but CEO, Dr Charlotte Wiles (Hull Chemistry PhD graduate), retains laboratory/office space in Chemistry. Chemtrix BV develops scalable flow chemistry platforms with applications in fine, specialty and pharmaceutical industries. Their customer base encompasses the UK, Europe, North America, Asia and Australasia.

**Sporomex** uses sporopollenins as encapsulation technologies (Technical Director **Mackenzie**) with applications for crop protection (reducing amounts of pesticides) and the food sector, e.g. efficient vitamin bioavailability, leading to less waste and effective pest control. A product is on the worldwide market licenced with Sporomex. A current collaboration with a major meat producing company (USA) exploits inherent antioxidant properties of these pollen microcapsules to stabilise food products and extend shelf life.