Institution: University of Leicester

Unit of Assessment: UoA8 Chemistry

1. Unit context and structure, research and impact strategy

Unit context and structure

The School of Chemistry is internationally recognised for its vibrancy in a range of fundamental and applied fields in chemical science. Our research activity is organised functionally into four research groups, representing our main areas of strength: Chemical Biology (**CB**), Materials & Interfaces (**MI**), Spectroscopy & Atmospheric Chemistry (**SAC**), and Sustainable Synthesis & Catalysis (**SSC**). These research groups operate as nuclei for research staff and students and provide the critical mass needed to generate high-quality research and impact.

Highlights and other achievements in the past 7 years include:

- Patented a green (water-based) method (**Abbott**) for recycling lithium ion batteries.
- Developed novel deep eutectic electrolytes for rechargeable aluminium ion battery technology (**Ryder**/**Abbott**) as an alternative to lithium ion batteries.
- Led national and international policy relating to air quality through the Chairmanship of DEFRA Air Quality Expert Group (**Monks**, 2012-2019).
- Developed NMR imaging (**Ryder**) for the in-situ monitoring and study of electrochemical dissolution and deposition. This research underpins work on battery development (ERA, SAlBaGE, AMAPOLA) and recycling (Faraday Institution, ReLiB).
- Led (Raven) the creation of a new research institute, the Leicester Institute for Structural and Chemical Biology. This has led to new academic appointments and new research programmes, including a key role (**Hudson**) in a £5.5M BBSRC programme grant focusing on how RNA binding proteins control splice site selection.
- Patented a novel approach (**Piletsky**) for a robust biosensor in which fragile antibodies are replaced with molecularly imprinted polymers leading to the growth of, and investment in, a spin-out company, MIP Diagnostics Ltd.
- A leading role (**Monks**) in Space Park Leicester, a world-class research and innovation hub under construction that will position the city of Leicester at the cutting edge of UK space technology (Institutional Environment Statement [IES], sections 2.4, 4.4).

Over the REF2021 period the number of doctoral completions has increased by 110%, income per FTE has increased by 28%, and our outputs have a combined Field-Weighted Citation Impact of 1.77 (SciVal). Our research activity thrives through a team of outstanding research staff and students, a diverse funding portfolio, and a collaborative approach to seeking solutions to major industrial, social, and economic challenges. Additionally, we have appointed seven high-calibre early-career researchers to ensure the continuing vitality and sustainability of our research environment, representing more than one third of the REF-returnable academic cohort.

Research and Impact Strategy

Our goal is to develop vitality and financial sustainability by enhancing existing research

strengths where we are well-placed to make a contribution to society, and providing a vibrant, cohesive, and supportive research environment. The strategy is actioned by our Research Committee, chaired by a Director of Research (**Hillman**) and comprising leaders of the four research groups. Oversight is provided by the School Leadership Team, which is chaired by the Head of School (**Ellis**).

Key elements. Our strategy has proceeded via six distinct elements:

1. Focusing our research by reducing from five groups in REF2014 to four in REF2021. Division into four research groups provides critical mass in our core research strengths while providing flexibility to adapt to new research opportunities.

2. Refreshment and enhancement of research activity via the appointment of a substantial cohort of high-quality early-career academic staff. These have generated new research collaborations, both within the School and externally. The focus of recent appointments was to strengthen two research groups, **CB** and **SSC**.

3. Acquiring additional support for research groups by engaging with UoL interdisciplinary institutes and centres. As well as yielding institutional funding, these have enabled and enhanced interdisciplinary research, particularly with the life sciences (via **CB**), engineering (via **MI**) and environment (via **SAC**). Examples, detailed later, include the work by **Hudson** at the life sciences interface and **Abbott**/**Ryder** in new battery technology.

4. Supporting staff to produce research outputs and grant applications of the highest quality. This has been implemented through formal peer review of grant applications and publications, supplemented by mock interview panels for fellowship and other applications. There is support, training and benchmarking provided at School and institutional level and reinforced through annual research interviews with all academic staff (conducted by the HoS and the Director of Research).

5. Rebuilding expertise in synthetic chemistry. Six of the ECRs appointed since 2016 work in synthetic chemistry, enhancing our research activities here since REF2014.

6. Maximising the reach and significance of impact. We have a rolling programme aimed at delivering impact. Existing impact includes medical diagnostics via molecularly imprinted polymers (**Piletsky**; see ICS2), air quality analysis and policy (**Monks**; see ICS1), novel fingerprint identification techniques in forensic analysis (**Hillman**), and the exploitation of deep eutectic solvents for clean materials production (**Abbott**/**Ryder**). Longer term impact is anticipated in new cancer treatments (**Suntharalingam**) and in battery technology (**Abbott**/**Ryder**).

Impact is now embedded within our activities through the following:

- Early identification of impact in annual research interviews and Research Committee reviews.
- Financial support by our Research and Enterprise Division (RED) for strengthening collaborations with external partners, providing staff for short-term investigations, generating publicity materials, and protecting IP.

- Engagement with the University's Innovation Hub (IES, 2.5), which hosts monthly events blending themed activities and networking opportunities with external (commercial, governmental, entrepreneurial) stakeholders. This has led to collaborations with a variety of businesses including Pepsico, Qualitek and Rolls Royce.

Achievements and Impact of Research Groups. The following are brief descriptions of the four research groups and selected research and impact highlights within the REF period.

Chemical Biology (**Ash**, **Doveston**, **Hodgkinson**, **Hopkinson**, **Hudson**, **Piletska**, **Piletsky**, **Suntharalingam**, Raven, and Jamieson) has a long history of excellence in Leicester. The group comprises two Chairs (**Hudson**, **Piletsky**), two Associate Professors (**Piletska** and **Suntharalingam**) and four ECRs (**Ash**, **Doveston**, **Hodgkinson** and **Hopkinson**).

The Leicester Institute for Structural and Chemical Biology (LISCB) was created in 2016 in response to long-standing collaborations between chemical and structural biologists in Leicester. The Institute comprises 22 internationally recognised research teams, bringing them together under one research umbrella to deliver synergies and critical mass. A large part of our **CB** research falls within the Institute and Chemistry provides roughly one-third of its overall portfolio. LISCB has attracted strong University financial support for new academic staff, postdoctoral research fellows, and equipment, including high-field NMR (up to 800 MHz; ca. £1M upgrade award) and X-ray crystallography. LISCB hosts the Midlands cryo-Electron Microscopy Facility (IES, 4.3), part-funded by a £3.7M MRC grant (2018). The strategic investment in LISCB has been enhanced by five Chemistry appointments within the REF period (**Ash**, **Doveston**, **Hodgkinson**, **Hopkinson** and **Suntharalingam**). It has also led to substantial grant capture, such as a UoL £3.2M share in a £5.5M BBSRC programme grant, of which Chemistry has won £0.8M (**Hudson**; BBSRC Strategic Longer and Larger (sLoLa) grant, 2019). In additional to new academic staff, LISCB has a full-time institute manager, industry liaison staff, and funds for project pump-priming. LISCB reports to a strong Advisory Board with high quality external representation, including a Nobel Laureate.

Hudson is exploiting single molecule optical techniques in chemical biology, e.g. in the first observation of the adaptation of a single bacterium in an aerosol droplet, which is revolutionary for understanding the infectivity of airborne pathogens (*J. Roy. Soc. Interface*; doi.org/10.1098/rsif.2018.0779). **Piletsky** and **Piletska** develop novel molecularly-imprinted polymer (MIP) tools: successes include nanoMIPs targeting the quorum sensing system in Gram-positive and Gram-negative bacteria, showing that MIP nanoparticles can prevent streptococcus-induced pneumonia (*Angew. Chemie Int. Ed*.; 10.1002/anie.201709313). Patents have been registered for (1) a sensor where fragile antibodies are replaced with MIPs (no. GB1809276.7) and (2) development of novel protocols for the study of molecular interactions in proteins (no. PCT/GB2018/050707, US20200033356 A1). The MIP research has led to the creation of MIP Diagnostics, a spin-out company (ICS 1).

Hodgkinson is developing Proteolysis Targeting Chimeras to disable specific proteins, including large gene-regulatory complexes. His team has synthesised the first protein degrader molecules of class I histone deacetylase enzymes, which are important in cancer and other diseases (*Chem. Commun*.; http://doi.org/10.1039/d0cc01485k). Another ECR,

Doveston, is exploring new approaches to the design of small molecule modulators of protein-protein interactions for the treatment of diseases, and has recently discovered novel allosteric inverse agonists of the nuclear receptor ROR□ (*J. Med. Chem.*; doi.org/10.1021/acs.jmedchem.9b01372), with potential in the treatment of autoimmune diseases. **Hopkinson** is investigating the biological role of formaldehyde: his work has identified the so-called folate pathway, which regulates formaldehyde detoxification and may be essential for healthy human cell function (*Sci. Rep.*; doi.org/10.1038/s41598-019-54610-3). The two newest academic appointments are **Ash** and **Suntharalingam**, who arrived in 2019. **Ash** is developing methods for controlling oxidation state and reactivity of proteins and combines this with infrared microscopy and synchrotron techniques in order to monitor single protein crystals. **Suntharalingam** focuses on the synthesis of new metal complexes and metallopeptides to selectively kill cancer cells.

Materials and Interfaces (**Abbott**, **Hillman**, **Ryder**, and Bond) research is carried out in a dedicated Materials Centre (2015). The Centre is supported by institutional funding and facilitates collaborations with the School of Engineering and the School of Geography, Geology & Environment. The group is a partner in the EPSRC-funded IMPaCT CDT in Innovative Metal Processing. As part of a strong enterprise thrust, a full-time dedicated Innovation Fellow is employed to facilitate knowledge transfer. This is reflected in the diversity of funding sources: Rolls Royce, Innovate UK, KTPs and commercial contract income, alongside conventional UKRI and EU funding.

Abbott focuses on green strategies for extracting and recycling natural resources and developing sustainable materials (*Green Chem.*; doi.org/10.1039/C4GC02246G). A water-based method for recycling lithium ion batteries has been developed (patent JA104260P; filed January 2020) which is 100 times faster than using strong acids: a small-scale demonstration unit has been built in Leicester to showcase this new technology. **Abbott** is known for pioneering work on deep eutectic solvents (DESs). A major achievement has been the creation of a Cr(III)-based DES, which eliminates the need for chromic acid in the production of steel. This technology has been licensed by the world's second largest steel producer, Arcelor Mittal, and forms the basis of a €5M pilot plant in Zelzate (Belgium). The group has also patented a process with British Sugar to make MDF boards using waste sugar (WO2015150750A1; Polysaccharide-based materials). **Ryder** and **Abbott** have developed novel electrolytes for a rechargeable battery based on aluminium; this work has progressed to cell fabrication and testing (Horizon 2020, SAIBaGE, €3M total, €569k UoL also in collaboration with the Midlands Energy Research Accelerator). Funding (H2020, AMAPOLA, €2M total, €279k UoL) has also been won for development of a commercially viable prototype of the Al battery. There is strong involvement with the Faraday Institution (FI), founded in 2017 to exploit UK expertise in electrochemistry for developing new battery technology. **Abbott** and **Ryder** are investigators on the FI ReLib project, addressing the recycling of lithium ion batteries, while **Hillman** is a member of the FI Expert Panel.

Ryder has developed NMR imaging for in-situ monitoring of electrochemical dissolution and deposition (*Angew. Chemie Int. Ed.*; doi.org/10.1002/anie.201604310). This is being applied in fundamental science and in the development of new battery technology and metals finishing processes. **Ryder** and **Hillman** have, in collaboration with the STFC Rutherford Laboratory, developed compositional imaging of metal multilayer and alloy structures during electrodeposition and dissolution (*Faraday Disc.*; doi.org/10.1039/C8FD00084K).

For the first part of the REF period, Bond (formerly of Northamptonshire Police) was a member of the **MI** group. In a collaboration with the Schools of Genetics, Criminology, Psychology, and Pathology, and externally with institutions throughout Europe (notably the University of Lausanne), he led the major EU-funded INTREPID forensic science project. Subsequently, **Hillman** has shown that electroactive materials (metals, polymers) can reveal latent fingerprints on surfaces (*Electrochim. Acta.*; doi.org/10.1016/j.electacta.2014.11.061). These processes are now incorporated in the UK government Fingerprint Visualisation Manual, which has been rolled out to all UK police forces. An extension of this is the re-formulation of the Physical Developer process for latent fingermarks on paper, which has resulted in independent recommendation of the method to UK police forces (*Science & Justice*; doi.org/10.1016/j.scijus.2018.10.005).

Research in **Spectroscopy and Atmospheric Chemistry** (**Ball**, **Ellis**, **Monks**, and **Yang**) spans gas-phase chemistry and the spectroscopic detection of molecules in multiple environments. In atmospheric chemistry the primary focus is on reactive trace gases that impact upon air quality and climate change. The team has extensive laboratory-based and field-based measurement capability, including a portable air quality laboratory. **Monks** and **Ball** participate in multi-institution field campaigns, such as the NERC-funded Air Pollution and Human Health in a Developing Megacity project (**Monks**, APHH-Beijing). **Ball** has identified the important role played by iodine emissions from sea water (*Environmental Science and Technology*; doi/10.1021/acs.est.0c02736). **Monks** has been a leading player in the establishment of Space Park Leicester (SPL), a £100M+ investment (IES 2.4, 4.4) leveraging on the University's internationally renowned work in space science, atmospheric chemistry, and earth observation (the UoL hosts the UK's National Centre for Earth Observation). A spin-off from the trace gas technology has been its application to biological processes and in medical diagnostics (**Monks**). An example is investigation of the folate-driven one-carbon (1C) cycle in mammalian cells (*Nature*; doi.org/10.1038/nature23481; 97 citations).

Ellis and **Yang** explore molecules and clusters in low temperature environments, notably superfluid helium nanodroplets, in two broad strands: (1) characterisation of molecules and their interactions, and (2) the synthesis of novel nanostructures. Achievements include the first IR spectrum of protonated acetic acid (*J. Phys. Chem. Lett.;* doi.org/10.1021/acs.jpclett.9b00767), the laser-induced alignment of helium-molecule complexes (*Phys. Rev. Lett.*; doi.org/10.1103/PhysRevLett.113.043004), and the production of novel types of nanowires (*Nano Lett.*; doi.org/10.1021/nl500946u). **Ellis** has a long-standing collaboration with the University of Innsbruck which has led to new findings, including a new form of anionic condensed hydrogen (*Phys. Rev. Lett.*; doi.org/10.1103/PhysRevLett.117.273001), the discovery of dianions in liquid helium (*Angew. Chemie Int. Ed.*; doi.org/10.1002/anie.201408172), and highly charged helium droplets (*Phys. Rev. Lett.*; doi.org/10.1103/PhysRevLett.123.165301).

The **Sustainable Synthesis and Catalysis** (**Ortu**, **Pulis**, **Solan**, and **Stuart**) group has undergone restructuring after the retirement of senior staff (Davies and Hope) in 2019. Two new academics (**Ortu** and **Pulis**) have been appointed and a third appointment, made after the REF census date, has continued this process.

The research activities of this group span organic and inorganic chemistry. **Stuart** sustains the School's longstanding reputation in fluorine chemistry through new synthetic

methodology for building carbon-fluorine bonds. An example is the development of a new fluorinating reagent offering access to novel fluorinated heterocycles that are building blocks for new drug candidates (*Angew. Chemie Int. Ed.*; doi/10.1002/anie.201507790; 58 citations). This discovery has led to commercial availability from companies such as Sigma-Aldrich, TCI and Fluorochem. **Solan** has shown how strategic ligand design can access highly active and sustainable catalysts made from earth-abundant metals. Key achievements include the conversion of carbon dioxide to methyl esters (*Chem. Sci.*; doi.org/10.1039/D0SC02942D) and ethylene into thermoplastic polyolefin elastomers (*Polymer Chem.*; doi.org/10.1039/C7PY00434F). The arrival of **Ortu** in 2019 brings expertise in the organometallic chemistry of s-block and f-block metals, complementing **Solan**'s expertise in transition metal complexes. **Pulis** (appointment 2018) uses catalysts constructed from main group elements in organic synthesis, complementing **Stuart**'s work in organofluorine chemistry.

Forward look

Our goals are to:

- Continue developing a high-quality research environment that is both diverse and maintains a good work-life balance, in line with our strong EDI principles.
- Grow our role in major internal and external research units, such as the Leicester Institute for Structural and Chemical Biology, the Faraday Institute, and Space Park Leicester. This will be achieved through (1) nurturing of our ECRs and (2) a pipeline of further academic appointments, including three that are imminent.
- Nurture research impact likely to mature during the coming 5 years, including work in air quality monitoring, sustainable materials, cancer therapeutics, and latent fingerprint visualisation technologies.
- Support and mentor talented postdocs and ECRs (particularly from underrepresented groups) in fellowship applications.
- Expand the School's international presence, particularly in China. Our school was one of two initial participants in the Leicester International Institute (LII) at the Dalian University of Technology (DUT). Established in 2016, the LII delivers UoL undergraduate degrees in China and, ultimately, long-term research interactions facilitated by fee waivers for DUT graduates to study for a PhD at UoL (2021 onwards), and opportunities for postdoctoral support and extended academic research visits.

2. People

Staffing strategy

Our staffing strategy has been fourfold:

1. To appoint new academic staff of the highest possible quality.
2. To make new appointments that fit with the research aims of the School.
3. To support established academic staff in the development of their careers.
4. A commitment to equality, diversity, and inclusion by developing positive actions to address the underrepresented groups in our current staff complement.

We have a total academic staff complement of 25.1 FTE, of which 18.8 FTE are T&R posts. We have made 7 new T&R appointments since 2016. Six of these were ECR appointments,

made on the strength of the individuals' previous research, their research ideas, and the fit to the School research groups. All are on open-ended lectureship contracts. A strategic decision was made to appoint in the broad area of chemical synthesis. Two of the appointments (**Doveston**, **Hopkinson**) were linked to the establishment of LISCB and a further three (**Ash**, **Hodgkinson**, **Suntharalingam**) align with LISCB; their effect has been to dramatically enhance the School's **CB** research. The remaining two appointments (**Ortu** and **Pulis**) strengthen the **SSC** group. The end result is that the School now has strength in all four research groups and a good demographic balance (6 ECR, 6 mid-career and 7 senior T&R staff).

Staff Development

Our commitment to career development is evidenced in that five of the seven research-active professorial staff in post at the REF census date (**Abbott**, **Ellis**, **Hudson**, **Monks**, and **Ryder**) were initially appointed to junior lecturer positions at UoL. This encourages professional security for recent appointees and is a major productivity and retention tool for the School.

Mentoring is offered to all staff at all stages of their career in order to provide independent career advice. Participation is a requirement for new academic staff, who undergo three years on probation. Mentors may be internal to the School but there be value in having an external mentor, e.g. for staff associated with LISCB, where the mentor may be a biologist. Feedback from mentors is a formal requirement for annual probation reviews of new academic staff. Mentors are also offered for more senior staff where developmental advice, particularly at key promotion borderlines, merits it. For research staff (PDRAs) an informal, school-initiated scheme was introduced in 2015 to ensure access to support and advice, including future careers, that is independent from their research supervisor.

New academic staff receive a series of one-to-one induction sessions where they meet key academic, technical and administrative colleagues. New academic T&R staff have light teaching loads of less than 50% of those for established T&R staff while on probation. The School employs an online workload modelling tool and tasks are reallocated on an annual basis to balance workloads.

All staff, including postdocs, and graduate teaching assistants, are required to participate in an annual appraisal process known as personal development discussion (PDD). As part of PDD there are a range of CPD activities, including EDI training and Unconscious Bias, that the School has augmented to deliver its ambitions to make EDI central to its culture. PDD is an ongoing development activity, rather than a single appraisal-style interview, and involves frequent appraisee-appraiser engagement. For ECRs there is discussion on tasks and responsibilities, both internally and externally (e.g. funding agencies and learned societies), that contribute to their professional skills, networking and leadership experience. The University's Research and Enterprise Division runs mentoring and support activities specifically for ECRs, such as writing research grant applications.

Training is offered to staff to facilitate the step up to leadership roles. A comprehensive in-house course, the Future Leaders Programme, is provided by the University and is available to all established academic and administrative staff with leadership potential. This course, established during the current REF cycle, lasts 10 days spread over several months and has been taken by a number of academic staff in Chemistry, including **Ellis** (now HoS) and **Ryder** (Head of the Centre for Materials Research).

The University has established pathways for academic promotions based on outstanding contributions to research and/or teaching. Promotion decisions within the School are made by a Promotions Committee comprising the Head of School, Director of Research, and Director of Learning and Teaching, along with a representative from HR. Based on written evidence provided by applicants, this group decides whether to forward applications to the University Promotions Committee or defer them (pending further strengthening/mentoring). Decisions are made with reference to the Leicester Academic Career Map, which describes promotion routes and requirements at all grades. The Career Map recognises a variety of types of academic contribution, ensuring that excellence in all its forms is suitably rewarded. Within the REF period, there have been promotions to Reader (**Yang**), to Associate Professor (**Piletska**) and to full Professor (**Hudson**).

All supervisors strongly encourage their PDRAs to use a day per month for CPD, whether internal training or external. The School has established a PDRA forum to address the needs of fixed-term contract researchers and to provide them with a sense of community.

PGR student support, completion & destination

Attracting postgraduate students is essential to the quality of the School's research environment. In pursuit of fairness and transparency, the School policy is to make all PGR positions available to open competition. All viable applicants are interviewed in person or online to demonstrate their knowledge and skills. Since REF2014, we have increased PhD completions by 110% (from 51 to 107)—a consequence of enhanced recruitment, mentoring and supervisory practices.

PhD students receive extensive support and training of specialist and generic nature. All are allocated a first and second supervisor upon arrival and a training plan is established that is responsive to both the project needs and the student's background. The students receive specialised technical training directly related to their research, e.g. spectroscopic characterisation techniques (**CB**, **SSC**), surface imaging and analysis (**MI**) and laser-based techniques (**SAC**). Reflecting the strong School commitment to EDI, interactive sessions on Athena Swan and unconscious bias are delivered alongside the specialist research training. The students participate in School and University research festivals and attend weekly research seminars delivered by external speakers. Funding for student travel and conferences is provided at the minimum level of £1k per annum but can be enhanced by grant funding from supervisors. During the REF period 8 PGR students presented their work to government at STEM for Britain events on topics as diverse as latent fingerprint development and mineral processing using deep eutectic solvents. The School has encouraged other early career researchers to engage with STEM for Britain, e.g. Dr Adrian Boatwright (PDRA) was awarded the RSC Silver Medal Award for work on nanoscale magnets.

Professional skills are primarily taught at College and University level. An example is a publication workshop covering the concept of peer review, the mechanics of publishing, academic integrity, and research metrics. Our School has 10 Graduate Teaching Assistants (GTAs) who, in addition to the above, receive specific training in learning and teaching, with the requirement for achieving Associate Fellowship status of the HEA. PhD students within DTPs and CDTs (NERC CENTA; EPSRC IMPaCT) receive intense training packages that cover specific technical skills and fundamental knowledge in masterclasses plus a

programme of 'soft' skills in areas such as project management, managing budgets, and careers in industry.

The effectiveness of the training and the skills level achieved is formally evaluated in a probation meeting at the end of the first year of PGR study and in subsequent annual reviews. The probation meeting is conducted by two academics who are not supervisors of the student.

To enhance communication with the PGR cohort, the School holds a quarterly discussion forum to which all PGR students are invited. The style is informal and includes the PGR Tutor, the Head of School and a representative from the Doctoral College (IES, 3.2). These meetings provide an opportunity to discuss concerns and requirements and to find solutions to problems. All new PGR students are also allocated a 'buddy' from the more senior PGR cohort on arrival to help make a smooth transition into the PGR community.

The increase in quality (as well as quantity) of completing PGR students in the current REF period (cf. REF 2014) is evidenced by their accomplishments and subsequent career destinations. These include: 25 permanent academic appointments at institutions in the UK and internationally; 16 postdoctoral fellowships and other temporary academic positions; 15 permanent technical positions in industry and governmental organisations.

Equality, diversity and inclusion (EDI)

The School has a strong commitment to EDI and we adhere to Leicester's institutional EDI strategy and policies (IES, 3.1), acknowledging that we cannot reach our potential unless we can benefit from the talents of all. We continue to advocate and advance EDI and address issues of underrepresentation in our School. Our Athena Swan (AS) Bronze award in 2013 was upgraded to Silver in 2016—one of only 13 UK schools/departments of chemistry with a Silver or Gold award at the time of writing.

The promotion to AS Silver reflects the core principles embedded within our School operations in recent years. The AS feedback highlighted changes in culture and processes since our Bronze award, including the option of flexible working patterns, revised induction programmes, and in-School EDI training. Also commended was the opening of Staff Meetings to all staff (academic, administrative, technical and PDRA, plus PGR and UG student representatives) and the appointment of a Working Lives (WL) Coordinator. The WL Coordinator (**Ryder**) leads initiatives in work-life balance, staff feedback, and general school well-being and collegiality.

In addition, we have an academic Diversity Champion (DC) who leads the EDI portfolio within the School, including data collection, policy direction, and new initiatives. The DC is part of the School Leadership Team and EDI is a standing item on the agenda of the monthly School Leadership meetings and at Staff Meetings. The DC also chairs the Athena Swan self-assessment team, which is composed of academic and support staff, including the Head of School, and has postdoctoral, PGR and UG student representation. We survey staff and PhD students, at least biennially, to take the pulse of the School in areas like working culture and job satisfaction.

The BAME representation among our academic staff is 12% and females are 8% of staff. However, we are encouraged by the increasing diversity of our PhD community and what we hope indicates a snapshot of the profile of our School in the future. The male/female

gender split for graduating PGR students during this REF cycle was 55/45, while the BAME/white split was 51/42 (7% not declared). High levels (>90%) of PGR satisfaction reported in internal survey data were more predominant for female and (particularly) BAME students in terms of supervision, the School research culture and professional development.

During the REF period, two PDRAs were appointed under the Daphne Jackson Trust scheme, which brings talented individuals back into science after a substantial career break. Dr Li Liu (appointed 2013, completed 2015) joined the School as a PDRA after a five-year career break following postdoctoral work in the US. Dr Chris Tate (appointed 2020, current) joined as PDRA in 2020, also after a significant career break.

3. Income, infrastructure and facilities

Income

During the REF period our research income was ca. £13.5M, with a total spend per FTE of £717k, a 28% increase on REF2014 (£558k/FTE). Our principal sources of external research funding were EU governmental bodies (£3.6M), UK governmental bodies (£2.5M), UK-based charities (£1.8M), and research councils including EPSRC (£1.5M), NERC (£1.2M), and BBSRC (£1M). We have had particular success in securing funding from UK industry and commerce, with a 100% success rate (15/15). The School has also received £1.9M of in-kind UKRI research income through its extensive use of national and international synchrotron and neutron research facilities.

Strategy for generating research income

Since REF2014 we have targeted new funding sources and made notable gains in a number of areas, including a 152% increase in UK-based charity funding, a 365% increase from UK government bodies, and a 433% increase from industry, commerce, and public corporations. Diversifying our funding portfolio has not only sustained a healthy income, but also facilitated new partnerships with external stakeholders to enhance the impact of our research. KTPs have been an important part of this, such as with FreshPak and Food Attractions (£337k), where a protocol was developed which decreased food waste and increased product quality: this is worth > £1M p.a. to the company.

College- and institutional-level support is provided for the preparation and costing of research grant applications, particularly those targeted at EPSRC, NERC, and BBSRC. The University has created Funder Groups for each research council whose job is to raise awareness of funding opportunities, run workshops to ensure a good understanding of funder requirements, and to provide internal peer review of early-stage to fully-developed research proposals.

The Leicester Institute for Advanced Studies (IES, 2.2) provides funding for proof-of-concept research and exploration of viable interdisciplinary activities. ‘Tiger Teams’ seed short-term innovative projects (examples: **Doveston** in collaboration with Molecular and Cell Biology to explore protein-protein interactions in cancer inhibition; **Hudson** exploring imaging for biomedical applications), while interdisciplinary Networks support longer-term work and allow relationships among researchers to mature (example: **Hillman** leading forensic ‘Identification’ Network with colleagues in Archaeology, Engineering, Genetics, Law and Maths). Successful Networks can graduate to Research Centres with more substantial

support, as has been the case for our Materials Centre. All these schemes are quality-controlled by internal and external peer review.

Our ECRs, who represent a third of our REF return (a notable increase compared to the 9% (2 FTE) returned in REF2014) is part of ensuring the School has a healthy and sustainable income stream. A key part of our long-term income strategy is to mentor, train, and provide robust support for our ECRs in grant capture. To date all have submitted, or are in the process of preparing, UKRI New Investigator funding applications.

Major grants

Our focus has shifted from predominantly lone-investigator to consortium-led research bids. For example, **Ryder** and **Abbott** received £806k (Faraday Institution, total value £9.4M) in 2018 as part of a major consortium—8 academic institutions, led by the University of Birmingham, and 14 industrial partners—for research into the recycling of lithium ion batteries. **Ryder** and **Abbott** are developing significant impact in this field (*Nature*; doi.org/10.1038/s41586-019-1682-5; 138 citations) and directly contribute to regional strategic objectives to put the Midlands at the heart of energy innovation (Energy Research Accelerator, Midlands Innovation project).

Several other substantial grants were awarded during the REF period. Funding of £673k (UK Space Agency, 2015) was awarded to **Monks** for the development of a Compact Air Quality Spectrometer (CompAQS). This device represents the latest in compact differential optical absorption spectroscopy for airborne and satellite equipment (*Atmos. Meas. Tech.*; doi:10.5194/amt-8-4735-2015). **Monks** also secured £780k from the Energy Research Accelerator for developing innovative methods for measuring volatile organic compound (VOC)s. **Hudson** was awarded £788k as part of a £5.5M BBSRC programme grant to apply single molecule optical techniques to the study of splice site selection in RNA binding proteins. Bond co-led the €2.9M Interdisciplinary Training and Research Programme for Innovative Doctorates in Forensic Science (INTREPID Explorer, EU 2014-18), which provided funding for 10 PGRs to develop skills in areas such as ethics in the forensic sciences, forensic science theory and practice, laws of evidence and forensic science in the criminal courts and working with industry to commercialise forensic science innovation. This award, exemplifying the collaborative ethos of the School, supported PGRs co-supervised by academics in a wide range of disciplines including Genetics, Criminology, Chemistry, Psychology, and Pathology.

Future income strategy

Our aim is to grow the size of our research School (25% increase in T&R staff) and our research income (at least 50% per fte) in the next decade via a strategy that includes:

1. Support for and concentration on larger grant applications as part of consortia, both internal to UoL and external (e.g. Faraday Institute).
2. Leveraging our areas of major strength, most notably at the chemistry/biology interface (via the Leicester Institute of Structural and Chemical Biology), clean and sustainable technology (battery technology and clean industrial processes), and earth observation (via Space Park Leicester).
3. Strong support for ECRs: reduced teaching loads and targeted PhD studentships, providing momentum to make them self-sustaining.

Infrastructure & Facilities

The University has a Research Equipment Infrastructure Fund (REIF) which, as well as providing matched funding for equipment purchased from grants, holds an annual internal funding round to support stand-alone equipment purchases costing up to £1M. During the REF period, the School received £950k from this fund, ranging from relatively low cost items (e.g. glove box; gas analyser) through to major instrumentation (Bruker Aspire 400 MHz NMR (£240k); Xevo G2 XS QTOF LC-MS/MS (£196k)).

Physical infrastructure

The School occupies three buildings: the George Porter Building, the Henry Wellcome (HW) Building and the Materials Centre. George Porter hosts the majority of our research teams. The Materials Centre is next door and provides space for both wet chemistry and instruments alongside offices and meeting rooms. Chemistry also has significant space, comprising offices and laboratories, in the nearby HW Building, where the Leicester Institute for Structural and Chemical Biology is headquartered. Several members of the **CB** group (**Hudson**, **Doveston**, **Hopkinson**) have their main research laboratories located there, enabling close contact with structural biologists and the sharing of specialist bio-facilities, such as cell culture units. A specific laboratory has recently been repurposed and refitted to enable synthetic chemistry research in the HW building at a cost of £63k.

Specialist facilities and equipment

The School is well equipped with the major instrumental techniques. It has three NMR machines in George Porter: 1 × 500 MHz and 2 × 400 MHz, and has access to higher field instruments (up to 800 MHz) in the HW Building. Our mass spectrometry service consists of six systems: an open-access LC-MS, an open-access GC/MS, 2 × Q-TOF/UPLC systems, a MALDI-TOF, and an orbitrap MS. These mass spectrometry facilities range from simple open-access systems to more complex instruments with mass resolution up to 100,000 and mass ranges up to 100,000. The University is investing £272k of EPSRC equipment funding into a new state-of-the-art X-ray crystallography facility (Bruker D8 QUEST), which will replace the existing and relatively old instrument. The new instrument will permit both greater throughput and more precise structural determinations. This aligns with the arrival of **Ortu**, who brings specialist crystallography knowledge.

Dedicated NMR, MS and X-ray technicians support instrument operation, data collection, and data interpretation. These facilities have enabled, for example, work by Davies on C-H activation mechanisms (*J. Am. Chem. Soc*.; doi.org/10.1021/jacs.9b02073), the synthesis of a new class of fluorinated lactones by **Stuart** (*Angew. Chemie Int. Ed*.; doi.org/10.1002/anie.201507790), and the development of novel protein-targeting therapeutics (*Chem. Commun*.; doi.org/10.1039/D0CC01485K). Specialist research instrumentation includes a trace gas analysis suite (comprising multiple GC-MS and PTR-MS instruments), a laser spectroscopy laboratory with many fixed frequency and tunable laser systems, an EPR spectroscopy laboratory, optical facilities for single-molecule research and optical tweezing, and a materials characterisation suite comprising atomic force and holographic microscopy, IR surface mapping, and a range of mechanical, thermal and optical profiling equipment.

Chemistry plays a key role in the **Advanced Microscopy Facility (AMF)**, which supports research activities across Chemistry, Engineering, Physics, and Geology (IES, 4.2). The value of the AMF's equipment is ~£4M and includes AFM, FEGSEM w/EDX and TEM w/EDX. Examples exploiting the AMF are; a study of the microstructure of the cathodes in lithium ion batteries by **Ryder** (*J. Phys. Chem. C*; doi.org/10.1021/acs.jpcc.0c02713); the

characterisation of nanowires formed in liquid helium droplets by **Ellis** and **Yang** (*Nanolett*; doi.org/10.1021/nl500946u).

Chemistry researchers have access to Leicester's nationally significant **High Performance Computing (HPC)** facilities (IES, 4.3). The university hosts the STFC-funded DiRAC HPC facility and is one of only three UK universities involved in the Catalyst UK HPC project. These allow access to outstanding computing power and have been used, for example, by **Monks** to analyse satellite observations of the Earth's atmosphere (*Atmos. Meas. Tech*.; doi.org/10.5194/amt-13-1735-2020), and by **Ellis** for high quality quantum mechanical predictions of molecular properties (*J. Phys. Chem. A*; doi.org/10.1021/acs.jpca.0c05224).

Use of major national and international research facilities

A number of academic staff are regular users of synchrotron and neutron facilities, notably Diamond (X-ray), and the Rutherford Appleton Laboratory (RAL) and Institut Laue Langevin (ILL) (neutron). Neutron reflectivity experiments have resolved the long-unexplained effect of electrochemical control function on the internal structure and composition of electrodeposited conducting polymer films (**Hillman**, **Ryder**; *Electrochim. Acta*; doi.org/10.1016/j.electacta.2018.10.064) and permitted real-time dynamic sub-surface imaging of electrodeposited metal films (**Hillman**, **Ryder**; *Faraday Disc*.; doi.org/10.1039/c8fd00084k). One of the newly appointed ECRs (**Ash**) is a member of the STFC Life Sciences and Soft Materials Advisory Panel and is also a member of a working group for a new Diamond Light Source beamline (BERRIES: Bright Environment for X-ray Raman, Resonant Inelastic and Emission Spectroscopies).

Translational support

The culture of translation of fundamental research to the wider economy is encouraged by the **Leicester Innovation Hub** (IES, 2.5). Members of the School routinely attend its monthly 'open house' sessions, which comprise a blend of formal presentations by external stakeholders and informal networking opportunities. The Innovation Hub has facilitated and supported 15 proof of concept and product development projects with companies such as Pepsico, Lam Research Corporation, and Imperial International. It has also supported translational research in Chemistry through financial support for 3 Innovation Fellows (Alex Goddard, Shannon Stodd, and Jack Allen) over a four-year period.

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

Collaboration with and contribution to the research base

The School has a collaborative ethos, with interdisciplinary reach across the University and outwards into numerous UK HEIs, institutions across Europe (Austria, France, Netherlands, Poland, Portugal, Spain), the Americas (US, Brazil) and Australasia (Australia, China, Japan). The significance of these collaborations is evidenced by high-quality outputs across all four research groups (e.g. in Chemical Biology (**Hopkinson**, *Nature Comm.,* 2016; doi.org/10.1038/ncomms11974); Materials & Interfaces (**Ryder**, *Angew. Chem. Int. Ed*., 2016; doi.org/10.1002/anie.201604310); Spectroscopy & Atmospheric Chemistry (**Monks**, *Nature*, 2017; doi.org/10.1038/nature23481); Sustainable Synthesis & Catalysis (**Ortu**, *Nature Comm*., 2018; doi.org/10.1038/s41467-018-05587-6). Overall, 57% of published outputs involve an international co-author and 57% involve a UK co-author outside the School.

A major shift in research strategy over the REF period is away from predominantly single-researcher to multi-institution research. This is exemplified by the **MI** group's engagement with the Faraday Institution (FI) (https://faraday.ac.uk/). **Abbott**, and **Ryder** are involved in the ReLiB battery recycling project, one of the four founding projects of the FI and involving 8 HEIs and 12 industrial partners (£279k to UoL). **Hillman** is a member of the Faraday Institution Expert Panel that oversees the full portfolio of projects. This engagement involves a major collaborative research base and, through industrial partners, makes contributions beyond the academy. Over-the-horizon societal benefits are achievement of climate change goals associated with zero emission vehicles.

Impact & engagement: collaboration and contribution beyond the academy
The School's research involves extensive engagement with partners, external stakeholders, and end users from aerospace, law enforcement, pharmaceuticals/healthcare and security. Since 2014, the School's reach has encompassed organisations as diverse as Rolls Royce (**Ryder**), UK Home Office (**Hillman**), DSTL (**Piletsky**), the medical charity LifeArc (**Doveston**), and Qinetic (**Yang**). These engagements have made significant contributions to the economy and society through improved air transport reliability, enhanced criminal investigation techniques, improved prognosis and quality of life for cancer patients, and protection of the nation's health through drug development and air quality policy. These are represented in the submitted and developing Impact Case Studies, as well as the 9.6% of outputs co-authored with corporate partners (UK average 5.5%, SciVal).

Impact achievement has been incentivised by regular internal funding schemes (£5k-£25k level). The Prospects Fund encourages entrepreneurial vision and research exploitation for the public good. The Proof of Concept fund assists projects with commercial potential in achieving key milestones. The Impact Development fund supports impact evidence collection. These all engage stakeholders beyond the academy, including business, governmental agencies or society. At the life sciences interface, pump-priming funds supporting translational research are available from **Leicester Drug Discovery and Diagnostics** (LD3). Awards for Chemistry include £80k for 'Developing Proteolysis Targeting Chimeras' (**Hodgkinson**), £58k for 'A near patient device measuring Paracetamol' (**Piletska**), and £14k for 'Development of SARS-CoV-2 main protease inhibitor prodrugs' (**Hopkinson**).

Molecular imprinted polymers (MIPs): With the aid of computational design, nanoparticles of biomimetic molecularly imprinted polymers are synthesised with characteristics optimised for analytical, diagnostic and therapeutic applications. Underpinning research in this field (**Piletsky**, *Nature Protocols*, 2016, 11, 443; patents US 20080214405 A1, US 20080311072 A1, US 20120270964 A1) has led to a spin out company (MIP Diagnostics: https://www.mip-dx.com/) with over £7M of investment from Mercia Asset Management, Downing Ventures, BGF and Calculus Capital. New applications for MIPs developed by the Leicester team include antitumor activity, in vivo recognition of human vascular endothelial growth factor, modulation of quorum sensing in a gram positive pathogen, and antiviral agents (**Piletsky**: *Nano Letters*; doi.org/230710.1021/acs.nanolett.6b05052; *Angew. Chemie Int. Ed*.; doi.org/10.1002/anie.201709313; PCT/FR2020/000173). A collaboration (**Piletsky**) with DSTL is yielding materials to counter the effects of acetylcholinesterase inhibitors, in response to the Novichok (Salisbury, 2018) and related poisonings, and to provide treatments for victims of chemical weapon attacks typified by the Khan Shaykhun (2017) and Douma (2018) sarin gas attacks.

Air quality: Societal impact of the scientific accomplishments of the atmospheric chemistry team derive from the use of satellite, aerial and ground monitoring data to improve regional business competitiveness. Governmental policy has been impacted nationally through Chairmanship of DEFRA's Air Quality Expert Group (**Monks**, 2012-2019) and the appointment as Chief Scientific Advisor to the Government's Department of Business, Energy and Industrial Strategy (BEIS) (**Monks**, 2020). Internationally, this is manifested via European representation on the Environmental Pollution and Atmospheric Chemistry Scientific Steering Committee (EPAC SSC) of the World Meteorological Organisation and ICACGP (International Commission on Atmospheric Chemistry and Global Pollution) (**Monks**).

Materials recovery, finishing & recycling: The School continues to be engaged with a spin-out company established prior to REF2014 (Scionix; **Abbott** & **Ryder**). The underlying technology, based on deep eutectic solvents, has been extended to encompass environmentally benign metal finishing (Rolls-Royce; OCAS (Belgium)) and has provided licensing income of ca. €500k. In addition to electroplating and surface finishing technologies, this technology is generating new impact in clean mineral processing (ARGO), novel soldering technologies for the electronics industry and natural product extraction (Naturex). Discussions are at an advanced stage regarding two spin-out companies (with ARGO; **Abbott**, **Ryder**) and with British Sugar (**Abbott**)).

Criminal investigation: Prevention/investigation of criminal activity is a major societal good. Engagement with governmental agencies (Home Office, dstl, Police) in latent fingerprint technologies (**Hillman**) continues to develop societally relevant impact in forensic applications (violent and acquisitive crime). Identification of individuals—whether suspects or victims of crime—is frequently accomplished via fingerprints, whose recovery continually presents challenges. The work by **Hillman** on the interfacial chemistry underlying visualisation of latent fingerprints is affording new routes to fingerprints on various surfaces ranging from documents to weapons. Following environmental outlawing of the established reagent system, a key outcome is a new reagent system for paper (documents, currency, correspondence, blackmail/ransom notes), now incorporated in the Fingerprint Visualisation Manual and the Home Office Fingerprint Source Book (https://www.gov.uk/government/publications/fingerprint-source-book-v2 (2018); **Hillman** acknowledged). This is mandated to all UK police forces and used by overseas law enforcement agencies.

Influence & esteem

Leadership in Professional Bodies and Governmental Agencies: Members of the School have served in leadership roles for a variety of (inter)national professional bodies: President of the RSC Dalton Division (Raven, 2016-2018, while in Leicester); Chair of the RSC Spectroscopy and Dynamics Group (**Ellis**, 2012-2014); Chair of the Institute of Physics Molecular Physics Group (**Ellis**, 2017-2021); Chair of the RSC Fluorine Subject Group (**Stuart**, since 2016); Chair of the RSC Molten Salt Discussion Group (**Abbott**, 2012-15); President of the Institute of Materials Finishing (**Ryder**, since 2019; Vice-President since 2017); member of the RSC Environmental Chemistry Group (**Ball**); member of the Electrochemical Society Sensor Division Committee (**Hillman**); member of the Electrochemical Society Education Committee (**Hillman**).

The expertise and status of **Monks** in the field of atmospheric chemistry has been recognised via membership of NERC Council, Deputy Chair of DEFRA Scientific Advisory Council, Chair of DEFRA Air Quality Expert Group and Member of the World Meteorological Organisation Environmental Pollution and Atmospheric Chemistry Steering Group. Evidence has been provided (**Abbott**) to the Governmental Commission on Critical Metals.

Journal Editorship/Advisory Boards: Members of the School contribute to the dissemination of research via roles on the editorial boards of international journals, e.g. *Journal of Molecular Spectroscopy* (**Ellis**, 2013-2016); *Scientific Reports* (**Hopkinson**, 2019-present); *Russian Journal of Electrochemistry* (**Hillman**, since 2017), and *Sensors* (**Piletsky**, since 2015). **Hillman** is Editor-in-Chief of *Electrochimica Acta* (since 2014).

Honours and awards: The accomplishments of both senior researchers and ECRs in the School has been recognised by a number of awards. The former category includes: Joseph Wang award for Nanoscience (**Yang**, 2015); the Institute of Materials Finishing Westinghouse Prize (**Ryder**, 2016); elected Fellow of the Electrochemical Society (**Hillman**, 2016); Services to Science & Engineering, British Muslim Awards (Karim, 2017); RSC East Midlands Golden Anniversary Award (Cullis, 2018); Royal Society Wolfson Merit Award (Raven, 2017-2022). Among the ECR appointees, **Hopkinson** and Suntharalingham were awarded the RSC Inorganic Biochemistry Discussion Group Young Investigator Award in 2018 and 2020, respectively.

Invited keynote/plenary lectures: Research from all four groupings has featured in invited/keynote lectures at international conferences. Some examples include the following. **CB**: 8th International Conference on Molecular Imprinting, Jiangsu (**Piletska**, 2014); 17th International Meeting on Chemical Sensors (IMCS2018), Vienna (**Piletsky**, 2018); 10th International conference on Molecular Imprinting, Jerusalem (**Piletska**, 2018); Gordon Research Conference on Chemistry and Biology of Tetrapyrroles, Newport, Rhode Island (**Hudson**, 2020). **MI**: Solvay Conference on Ionic Liquids, Brussels (**Abbott**, 2017); International Society of Electrochemistry annual meeting; Providence, RI (**Hillman**, 2017); 255th ACS Meeting, New Orleans (**Ryder**, 2018); Electrochemistry, Ulm (**Hillman**, 2018); International Fingerprint Research Group (Jerusalem 2015, Beijing 2017, Sheffield 2019, **Hillman**); ISE Belgrade online (**Hillman**, 2020). **SAC**: Workshop on Quantum Fluid Clusters, Toulouse (**Ellis**, 2015); PACIFICHEM, Honolulu (**Ellis**, 2015); 27th International Symposium on Molecular Beams, Nijmegen (**Ellis**, 2017); American Geophysical Union, San Francisco (**Monks**, 2015); International Association for Horticulture, Beijing Expo (**Monks**, 2019). **SSAC**: 9th International Symposium on High Tech Polymer Materials (HTPM-9), Zhengzhou (**Solan**, 2016); 253rd ACS Meeting, San Francisco (**Stuart**, 2017); International Symposium on Catalysis and Fine Chemicals, Bangkok (**Solan**, 2018).

Organisation of international conferences**:** Service to the research community via organising committees of high-profile conferences includes the International Symposium on Fluorine Chemistry 2018 (**Stuart**) and the International Society of Electrochemistry Annual conferences in Bologna (2018, **Hillman**) and Belgrade (2020, **Hillman**). The last of these was a pioneering example of a major online meeting (1878 delegates from 63 countries; 22 symposia, >300 presentations, >1000 posters).

UoA 8 Environment statement overview

During the REF period, the School of Chemistry has undertaken strategic actions that have resulted in: (1) enhanced focusing of research; (2) appointments of new staff, which has

particularly rejuvenated the School's capability in synthetic chemistry; (3) invested in infrastructure to support high quality research; (4) engaged with institutional entities that facilitate inter-disciplinary research with the life sciences, engineering and environmental science; (5) enhanced the quality of published outputs; (6) made impact a priority outcome of all research; (7) expanded the volume of PGR student activity; (8) enhanced the quality and equality/diversity of PGR recruitment; and (9) instituted a professional training regime that has led to more prestigious PGR graduate destinations.