Institution: Lancaster University

Unit of assessment: UoA8

Section 1. Unit context and structure, research and impact strategy

1.1 OVERVIEW

The research underpinning this submission to UoA8 originates from one of the newest and fastest-growing Chemistry departments in the UK. Lancaster University (LU) Chemistry was established in 2013, with an initial University investment of >£26M and £11.3M from the European Regional Development Fund (ERDF). LU Chemistry has rapidly gained a reputation as a leading Chemistry department, with top-ten 2020 league table rankings in the Guardian, the Times and Sunday Times. Seizing the rare opportunity for ground-up design, LU Chemistry has focused and grown our diverse research portfolio around key emerging global research priorities. With a recruitment strategy targeting the major LU themes of **energy** and **energy storage**, **healthcare**, **security** and **advanced materials**, we have swiftly gained expertise in these areas. From a starting position (2014) of having virtually no track record in generating research income or outputs and with little physical infrastructure, we have established a reputation for delivering world-class, impactful research (delineated in Section 4). An extensive building refurbishment/extension programme delivered (in 2016) a state-of-the art space for Chemistry, comprising academic research facilities over three floors with additional embedded industry-facing office and research laboratory space (§1.3).

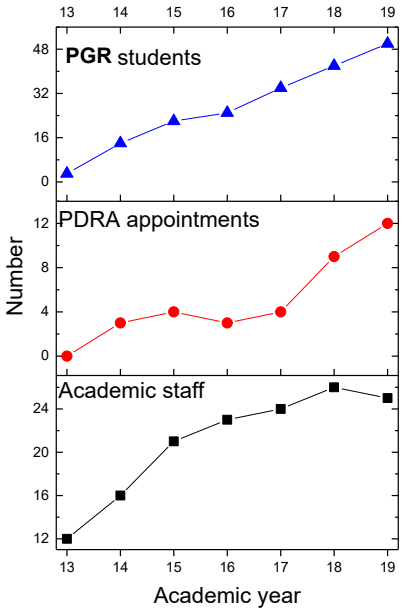

Figure 1. Key indicators of the Chemistry department's growth.

Key quantitative performance indicators have shown a clear upward trajectory since our first REF submission: research-active academic staff numbers have doubled (from 13 to 26 PIs), more than £16M in research income has been gained, and both PGR admissions and PDRA appointments have increased substantially (Figure 1). Chemistry staff–authored publications have attracted more than 8k citations since 2014. Engagement with commercial partners (a core element of the LU Chemistry business plan) has been particularly successful. Since 2014, we have engaged with 126 industrial research partners, providing > £5.5M in income, and have implemented new initiatives to bring in many further partners and clients

(e.g., §1.3 (iv)). Perhaps uniquely in UoA8, our structures and staffing strategy have been designed from the ground-up, allowing agile consideration of future needs for innovative and impactful research. The strategic appointment of a high proportion (42%) of early career academic staff has brought fresh ideas, ambition and a strong collegial, inclusive and collaborative spirit. The development of the department has been a team effort, with each one of our academic, research and professional service staff playing a vital role. Consequently, our staff members, at every level, have a particularly strong sense of ownership. We intend to preserve this culture in the next phase of our development.

1.2 RESEARCH ORGANISATION

LU Chemistry research is organised across 3 Research Groups (RGs, Table 1) and strikes a balance between breadth of scope and critical mass, and between applied and fundamental chemistry. The RGs serve as research focal points, enabling the interchange of innovative ideas, encouraging interdisciplinarity, and the development of research proposals, and as administrative groupings with a line management structure. The Chemistry Research Committee, comprising the Director of Research (a Deputy Head position), Head of Department (HoD), PGR Director, Research Group leads, and representation from early career and technical staff oversee the development of the Department's research and impact strategy.

Table 1. Summary of the Research groups, membership and research activities.

Group	Lead and composition	Research focus	Applications
Chemical Theory and Computation	Anwar 4 academics 2 PDRAs 4 PhDs	Structure prediction of molecular assemblies and porous materials; first principles electronic structure theory; fundamentals of bonding in actinide complexes.	Energy; Healthcare.
Chemical Synthesis	Sweeney 8 academics 4 PDRAs 15 PhDs	Synthesis of biological imaging and sensing organometallics with novel fluorescence properties; innovative chemical methodologies accessing new pharmaceutical space; design of smart, self-assembling molecules.	Energy; Materials; Healthcare.
Physical and Analytical	Middleton 12 academics 21 PDRAs 27 PhDs	Novel transition metal materials for new generation energy storage systems; spectroscopic characterisation of materials; chemistry for healthcare.	Energy; Materials; Healthcare; Security.

Within our research groups, significant research discoveries have attracted widespread attention and are leading to tangible academic and economic impact. In the **Chemical Synthesis Group**, work on iron-catalysed arylative spirocylisation (Sweeney) has been developed in collaboration with industry partners (including the SME Liverpool ChiroChem), while Sweeney's work on nickel-catalysed N-allylation (*Angew.* **2018**, featured in *Hot Topic: Sustainable Chemistry*) provides another new catalytic method using Earth-abundant catalysts.

In the **Physical and Analytical Group**, novel manganese hydride materials for energy-dense hydrogen storage have been developed (Antonelli). The research, partly supported by Hydro Quebec and Chrysler and published in *Energy and Environmental Science*, received extensive news coverage including CNBC, as well as science, engineering and environmental news outlets with a print and digital reach of 2.6M. In an interdisciplinary collaboration, Middleton discovered that the green tea polyphenol EGCG disrupts plaques associated with

atherosclerosis. The work, published in *J. Biol. Chem*. (Altmetric score of 350) attracted widespread media coverage by CNN, *The Guardian* and other news outlets across the world.

In an international and interdisciplinary team, predictive computational work by Trewin in the **Computational Group** led to the first organically synthesized sp-sp^3 hybridised porous carbon, with electron conductivity, high porosity and high lithium uptake. This new carbon variant shows exceptional potential as an anode material for lithium-ion batteries. The work received international news coverage and *The Times* published a leader article on this discovery, which emphasises their opinion of this discovery.

1.3 PROGRESS AGAINST STRATEGIC AIMS 2014-2020

With an appointment strategy predicated on inclusivity and diversity (§2.1.2), driven by the vitality, commitment and collegiality of our academic staff, and underpinned by an exceptional research environment, we have achieved our 2014 research and impact aims and are well placed to meet future goals.

AIM 1: To advance research in synthetic chemistry; chemical theory & computation; and chemical measurement science & spectroscopy

This has been delivered through targeted appointments to address emergent areas of chemistry and by establishing 3 research groups (Table 1). Several key factors have contributed to the advancement of Chemistry research. We have:

- gained a diverse portfolio of over £13M research funding in targeted research areas (§3.2.1);
- developed a thriving and vibrant postgraduate research community of UK, EU and overseas PhD and MSc by Research students (§2.2.3);
- established and consolidated a world-leading centre for solid-state NMR spectroscopy (§3.4.1);
- developed a diverse range of partnerships with industry and clinical centres (§3.2.2);
- showcased our research at LU Chemistry-organised conferences, firmly establishing our identity among peers (§4.1.4).

Our collective citations data over the REF period testify to the success of our strategy: many of our citation metrics are comparable to, or exceed, those of well-established Russell Group Chemistry departments (§4.1.1).

AIM 2: To advance chemical sciences at inter-disciplinary interfaces of chemistry and physical sciences, and chemistry and biology

Interdisciplinary research was promoted through the strategic appointment into Chemistry, of the Directors of Energy Lancaster (EL; Hoster), a Faculty-based Research Centre, and the Materials Science Institute (MSI; Short), one of 4 University flagship interdisciplinary Research Institutes. Chemistry takes a leading role in shaping strategic development of EL and the MSI (Figure 2) and benefits from enhanced connectivity with other disciplines through joint grant bids and studentship awards. Griffin and Hardy, are joint appointments with the MSI, appointed through the 2014 “50 for 50 Anniversary Lectureships” scheme (see institutional statement - ILES) and are major contributors to our output submission. Our departmental footprint is further enhanced across the institution by participating in a number of ERDF initiatives that bring together multiple departments and faculties. For example, the EU-funded Cumbria Innovations Platform (CUSP) combines capabilities from Chemistry, Engineering, Physics, Computing and the Management School.

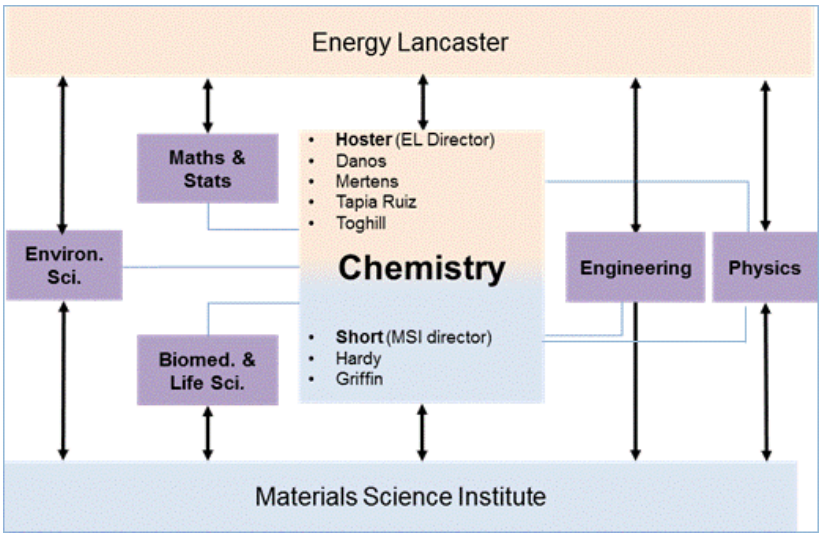

Figure 2. Interface between Chemistry, Energy Lancaster Research Centre, Materials Science Institute and other departments in the Faculty of Science and Technology.

AIM 3: To pursue all strategic aims within a framework of research sustainability

Our strategy has been to provide an environment in which all academic staff have the strongest support for the aspiration to build and sustain an international research profile. Many of our early career staff had no track record of research fund capture when appointed, and so effective mentoring and management systems were put in place to facilitate the preparation of high-quality grant applications (§2.1.3). As a result of these measures, we have seen a 600% increase in research income (exceeding our business plan target of £150k per FTE per annum in 2018/19 and 19/20) and a 24% success rate across a diverse range of funding streams since 2014 (§3.1) and have forged collaborations with commercial stakeholders at the local and national level.

AIM 4: To embed research in all aspects of our organisation and practice, and provide an enabling environment

We put in place a management process to monitor and enable the development of staff research profiles. The Chemistry Management Group monitors and adjusts workload models to enable staff to devote 40% core workload for research and associated impact and engagement activities. Group leads have line management responsibilities for academic group members; with an active mentoring system working alongside this (see Section 2).

AIM 5: To develop a culture of identifying and tackling research problems of significance and impact

We have established an environment that enables our academic staff to work closely with commercial partners and end-users to identify and address their needs in areas where our expertise can have the greatest impact. A major driver has been the **Collaborative Technology Access Programme** (cTAP), the result of a successful bid to the EU, in collaboration with the Lancashire Local Enterprise Partnership, with £11.4M of matched funding being awarded in 2014. This funding provided bespoke research laboratory and office facilities (1,070m^2) and equipment, embedded within the Chemistry space, for use by emerging companies in partnership with Chemistry academics and professional services staff. Many external collaborations have already been fostered, enabling us to translate the department's expertise into economic, commercial and societal benefits (§3.2.2). Through these activities, we are supporting the University's strategy goal to maximise the benefits and impacts of the knowledge and intellectual property we generate through work with external stakeholders.

1.4 IMPACT STRATEGY

The Department Management Group encourages and pump-primes collaboration opportunities for staff with regional partners, and provides support to enable staff to work flexibly with companies, to provide solutions to challenges identified by industry. To ensure that all opportunities for impact are explored, the Chemistry Impact Champion works closely with the Faculty and central University Research Enterprise Services to record, support and stimulate impactful interactions with new partners, with further support from the Faculty of Science and Technology Partnerships and Business Engagement (PBE) Team. To rapidly develop an effective Impact portfolio, it was essential that a robust strategy was implemented early in the departments development, as Chemistry had no legacy of impact to exploit. That all three of our Impact Case Studies were identified and grown via these mechanisms - **entirely within the assessment period** – testifies to the success of our strategy.

1.5 STRATEGIC AIMS 2020-2029

Our core mission is to deliver internationally leading research around focused challenges where our Chemical excellence has maximum impact – **energy, materials, security and healthcare** – by appointing, nurturing and retaining the best talent, and scoping and accessing funding opportunities that align with our strengths. Our strategic plan will consolidate current research and recognise emerging global scientific priorities, with aims that are relevant and realistic in the context of the post-COVID funding landscape. Specific objectives are:

(i) To strengthen our key strategic areas. Our ambition is to increase headcount to 35 FTE, enabling LU Chemistry to strengthen research power in strategic areas and to enhance our collaborative and interdisciplinary reach. Future appointments will build on our strengths in energy storage and materials chemistry, by attracting exceptional chemists at all levels. Additional appointments in healthcare chemistry will integrate the Department firmly within the University's commitment to biomedical research and clinical practice, aligning with the recent completion of the £41M Health Innovation Campus (HIC) (details given in the ILES). These appointments will provide access to future collaborative funding opportunities with healthcare professionals and businesses. Further, we will attract talented fellowship candidates aligned with our key areas, as well as in new and emerging areas of Chemistry. The increase in staff and PGR numbers envisaged will require expansion of the physical space for research and the department management team is actively working with University senior management to develop and implement a blueprint to accommodate our growth strategy.

(ii) To ensure the long-term sustainability of Chemistry at Lancaster. We have successfully transitioned from obtaining low-to-medium value funding, from sources such as the British Council, KTP and EPSRC first grants in the early stages of our development, to obtaining medium-to-high value grants from (amongst others) the EU, Leverhulme Trust and Faraday Partnership. As our staff progress out of the early–career stage we will increase our income by diversifying our funding portfolio and securing longer-term and larger value grants.

(iii)To broaden our impact portfolio. We will continue to exploit and expand our facilities to engage and work with new commercial partners in conducting cutting-edge research with tangible economic and social outcomes. We will encourage and support the career progression of our academic staff who engage in impactful and innovative research and we will work closely with our academic colleagues who our impact team have identified as the most likely to deliver impact over the next 5-10 years (§3.2.2). We will work closely with the PBE team, who provide logistical support in establishing, delivering and maintaining strong, fit-for-purpose interactions with industry partners. Two major European Structural Investment Fund projects, with a combined value of > £9M began in 2020 and will drive our impact agenda forward. These are Next Generation Chemistry (NGC), which is developing innovative synthesis, formulation and chemical processes and delivery of bespoke research support (£4.9M), and Greater Innovation for Smart Material Optimisation (GISMO), which is improving

the performance of chemicals and chemistry in products and processes (£4.4M). These initiatives will interact with 540 businesses in the North West of England.

(iv) To instil a culture of open and ethical research. We are committed to the University's ethos of establishing a fully open research environment. Working with Library services, we will strive to adopt open practices across the research lifecycle by all Chemistry researchers. An open research champion serves as an intermediary between our Research Groups and the Library, in order to communicate best practice for data storage and sharing according to FAIR (finable, accessible, interoperable and reusable) principles. We will build on work already taking place, including Data Conversations and Open Research Cafes run by the library. Underpinning these plans is our commitment to maintaining the highest research quality and integrity; we will ensure that all current and incoming staff and PGR students conform to this commitment through effective induction, supervision and mentoring.

Section 2. People

2.1 STAFFING STRATEGY AND STAFF DEVELOPMENT

2.1.1 Effectiveness of our staff recruitment policy

LU Chemistry offers an enthusiastic, supportive and vibrant working environment, as evidenced by our high academic staff retention (96% since operations commenced), growing PGR and PDRA numbers (Figure 1) and positive feedback in annual staff surveys (over 80% mean satisfaction across 38 indicators). The University's investment and commitment to Chemistry has enabled the recruitment of excellent academic staff from leading Russell group and non-UK (TUM Asia; KU Leuven; University of South Australia) Chemistry departments. Of our 26 academic staff, 25 are research active (98%) compared to an 80% average for Russell group and 78% for 1994 group comparators (HESA Chemistry cost centre data).

Having been designed from the ground-up, our policies and practices are well–tailored to deliver research excellence and impact. A rigorous and inclusive appointments procedure is in place; all job advertisements are approved by the departmental EDI committee and checked for gender bias content and related bias to other protected characteristics of individuals. Search committees are used to promote a diverse applicant pool for appointments. As of 31st July 2020, the total headcount of academic staff is 26 (19 male and 7 female) and 14 professional services staff (7 male and 7 female). Seniority by gender is: Professor (8 male), Senior Lecturer (2 female, 6 male), Lecturer (5 female, 5 male), although 3 female staff have been promoted to SL since the end of the assessment period. The department has recruited 57 early-career staff since 2014, comprising a mixture of academic (13) appointments and PDRAs on indefinite contracts (45). Of our PDRA staff, 19% are EU, 38% overseas and 43% UK, with 35% BAME and 2% with notified disability. In line with strategic aim 1 (§1.5) we are seeking to strengthen key areas with the strategic appointment of additional staff. The demographic profile and balance of the department will continue to be closely monitored at regular time points, which underpins our future looking research management plans. Recruitment statistics and techniques for application, interview and appointment rates are monitored to promote all forms of diversity.

2.1.2 Staff support strategy

Key tools in the attainment of research excellence are mentoring, probation appraisal and training, supporting staff throughout their careers and in all aspects of the challenges they face. The following summarises the mechanisms, structures and policies in place to ensure equitable access to career enhancing activities:

(i) Academic staff. Training and support is offered at University, Faculty and Departmental level on a wide range of aspects of research and engagement to all staff and research students. Whilst support is offered to all our academics, we are cognisant of the specific needs of the large proportion of staff appointed as ECRs, and have tailored our support measures accordingly. Examples of these measures are:

- All staff are provided with an annual department QR research fund, supplemented by further funds up to £5k awarded on a competitive basis. Although small-scale, this support has proved highly successful in pump-priming Early Career grant bids (Ashton, Toghill), other larger awards (Tapia Ruiz, Evans), generating patents (Coogan) and fostering industrial collaborations (Coote).
- Probationary agreements facilitate lower teaching time for ECRs for 3 years from appointment, with additional mentor support and review.
- Uncharged access to equipment is granted to staff and PDRAs to generate preliminary results for grant/fellowship bids.
- A PhD student allocation panel has been established to ensure, where possible, that all staff supervise at least one PGR student at any time, to develop and maintain their research profile. PGR provision has supported successful first grant bids to Toghill and Ashton (EP/R015333/1, EP/R000301/1).
- Senior academics actively involve junior members as co-investigators in grant bids, and exploit established industrial collaborations to engage junior staff with partners in the commercial sector (e.g., Fielden and Peach, KTP with Process Instruments; Fielden and Evans, KTP with Compact Instruments).
- Group Leads have attended a comprehensive Leadership Development Programme spanning 12 months (4 masterclasses and learning sets and a residential session), in preparation for their roles.
- A succession plan for administrative role handover involves junior staff deputising or shadowing senior roles for up to 6 months.

(ii) PDRAs. We actively implement the principles of the Concordat to Support the Career Development of Researchers, by working with all our PDRAs to develop the skills necessary to deliver research excellence, both now and in the future. PDRAs are encouraged to attend courses on high-impact paper, grant and fellowship writing skills. We aim to develop both the research and personal skills of our PDRA colleagues, to prepare them for their next career phases (whether in industry or academia).

(**iii) *Experimental Officers (EOs).*** In recognition of the vital role our 4 EOs play in supporting research and impact, we encourage them to seek external on-line and on-site training in their specialisms, providing funding whenever possible. For example, Halcovitch attended an energy dispersive X-ray fluorescence training course that was funded by the Faculty Staff Development Fund with matched funding from the department. Opportunities and funding are also provided for conference attendance e.g., Baldock has attended the BCA Spring conference Electrochem annually since 2015. Akien, the Experimental Officer in NMR, was granted a 2-month sabbatical to City University of Hong Kong to advance his skills in experimental inorganic chemistry to strengthen his NMR support in this research space.

2.1.3 Staff and research student wellbeing

The wellbeing of staff and students is central to delivering research excellence and our Health and Safety Committee has extended its focus to include staff wellbeing, in accord with the University People Strategy, referenced in the ILES. We actively support the health, wellbeing and safety of our staff and offer relevant interventions and services. The department has developed and implemented supportive and flexible policies to enable staff to deliver research excellence. We encourage staff to access the Employee Assistance Programme and adopt the Five Ways to Wellbeing framework, and to engage with programmes such as The Balanced Academic and the Resilient Researcher, which is oriented to all research-active staff. In addition to the generic support mechanisms available in the department, a number of other tailored staff development policies and tools enable colleagues to deliver excellence in research and underpin their own career development. Good exemplars of these practices include the reshaping of workload models for colleagues returning after family-related leave (4 staff), and the use of flexible working patterns to support all colleagues for any reason.

2.1.4 Career development and rewarding excellence

Development of individual careers is implemented through mentors and line managers, who meet regularly for progress meetings, conduct yearly Progress-Development-Reviews (PDRs), and proactively identify cases for promotion. Annually, staff are invited to a promotions workshop, which explains the promotion criteria and the mechanism by which applications may be submitted. Junior staff are further supported by the Chemistry Management Group, who identify roles that permit academic leadership to be gained facilitating development and providing evidence for promotions. The annual PDR identifies achievements and sets short- and long-term goals. Any barriers to achieving ambitions are discussed, with training and support needs identified. Through active mentoring we are seeing the development of research leaders from the cohort of staff recruited as early career researchers in 2014.

Line managers suggest candidates for promotion via the departmental Management Group, who carefully consider each case. Line managers encourage and guide staff to ensure their future performance and outputs will aid their trajectory towards promotion. There is no quota, or limitation within our Department. Staff who are considered ready for promotion are mentored by the HoD, who guides them through their promotional paperwork to ensure their case fully reflects their achievements, experience, and trajectory. Our promotional support is particularly sensitive to the diversity of contributions from across the spectrum of protected characteristics and those who may not naturally self-nominate for the promotions scheme, which is the necessary first step. There are several instances where staff have been actively encouraged to make an application for promotion, with success. Eight staff have already been promoted to senior lecturer (3 male and 5 female) during the REF assessment period, with a 60% success rate on first submission; an excellent indicator of the career opportunities within the department.

Research excellence and impact delivered by staff is recognised in a number of ways in addition to promotion: we celebrate staff success (through internal emails, press releases, etc.), and we support staff seeking to build on research achievements by providing funding to extrapolate existing collaborations, and to develop new ones. We believe that simply taking the time to publicly acknowledge and congratulate staff on their research achievements is a valuable and impactful support mechanism.

2.1.5 Supporting impact

Our environment provides a unique opportunity for academics, PDRAs and graduate students to understand the needs of modern chemistry-using industrial partners, and this opportunity is used to provide superb core training for all of our early-career research team, and enables accelerated impact from research outputs.

Outreach and engagement is recognised as part of the promotions process and given equal weighting with teaching and research excellence, as described in the institutional statement. We have also developed strong links with local industry, enabling 'reverse' secondments (of industry partners into the department) which stimulates and accelerates career development of PIs. We also encourage staff to engage in extra-departmental engagement and in public forums; we see the development of skills engaging with these partners as a core part of career development.

2.2 RESEARCH STUDENTS

2.2.1 Overview

The department offers PhD and MSc by Research degrees in Chemistry and a PhD in Natural Sciences. All staff are committed to maintaining an environment that ensures the highest possible quality of postgraduate research through supervision and mentoring; indeed, the Chemistry building was user-designed with this objective at the forefront. Students are embedded in at least one of the research groups, to enhance the student experience through group scientific discussions and provide a platform for presentations.

2.2.3. Recruitment

Our inclusive PGR recruitment strategy is tailored to provide incentive and support for all applicants. Since 2013, 456 applications have been received, of which 13% have been from EU applicants and 60% from overseas applicants. In this assessment period, we have attracted a total of 78 PGR students who are either still enrolled or have graduated, with a 96% completion rate. The gender rebalancing seen in our PGR intake over this assessment period (Figure 3) is evidence of the success of our EDI policy. Of our registered students, 16% are EU, 14% overseas and 70% UK, with 38% BAME and 14% with notified disability. As of July 2020, 9 students have successfully completed.

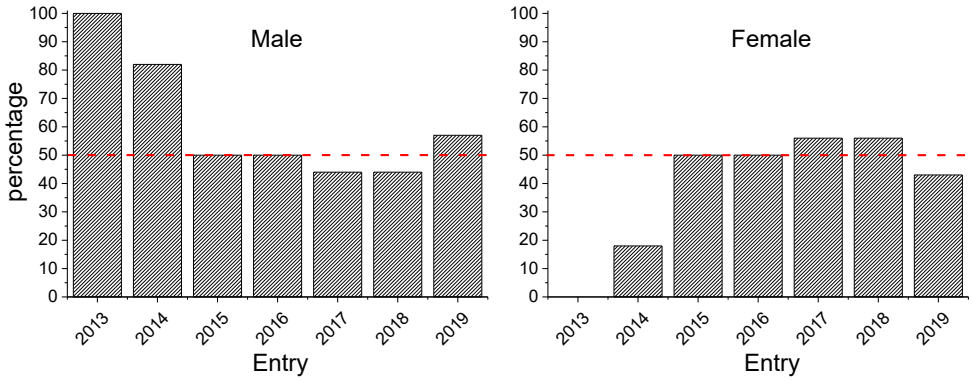

Figure 3. PGR registrations by gender and year (from August 2013).

2.2.4. Training

Students are assigned a primary and a secondary supervisor, at least one of whom must have a track record of successful PGR supervision. Each year, nine training sessions are held, focused on careers, transferable skills and problem solving, and students are required to complete a skills portfolio. This is part of our strategy to provide top-level training in skills development and in preparation for their future career. During the coronavirus lockdown, PGR students have been offered remote training in computational chemistry, such as molecular mechanics and DFT, as an additional opportunity to develop new skills.

2.2.5. Appraisal system

We monitor the supervision and progress of each student through an appraisal system, which is overseen by the department PGR Director. Successful completion, within allotted funding periods, is one of the department's most valued metrics, and monitoring and support mechanisms are designed to ensure timely completion of all research students. The appraisal system follows the University-wide system, with progress assessed at key meetings as described in the ILES. The success of our policies and practices are strongly supported by the data on progress and successful completions, with a 96% on-time completion rate.

2.3 EQUALITY AND DIVERSITY

LU Chemistry is passionately committed to ensuring the research trajectories of our staff and students are not compromised because of inequality. We were successfully accredited for Athena-SWAN at Bronze level (2015) at our first application, and our then-lead on EDI (Franckevicius) also served as chair of the Faculty EDI Forum, 2015-2019. All staff undertake mandatory Diversity Training in the first 3 months of employment and is refreshed every 3 years.

We are building on our proven commitment to ensuring equality by developing new practices and policies to support any staff undergoing lifestyle changes, which may impact upon their ability to carry out research activities. These changes could include family-related leave (staff are encouraged to seek centrally available LU funding), gender reassignment,

marriage and civil partnership or health matters. In addition to high-visibility issues, we are firmly committed to helping staff who have less-visible lifestyle burdens. We work actively with staff to help (where possible) reshape workload models (for instance, by flexible working/telescoping) to ensure that maintaining connection to or reintegrating within the department during/after a period of leave is a smooth process. Our Athena-SWAN policy is predicated on the belief that gender issues are complex, and we are committed to providing career development policies, which present non-traditional but attractive reward structures to all researchers. We encourage and expect our research community to look for more than personal success to define a successful research career, and we provide strong support to ensure that PI success has maximum impact within and outside the department.

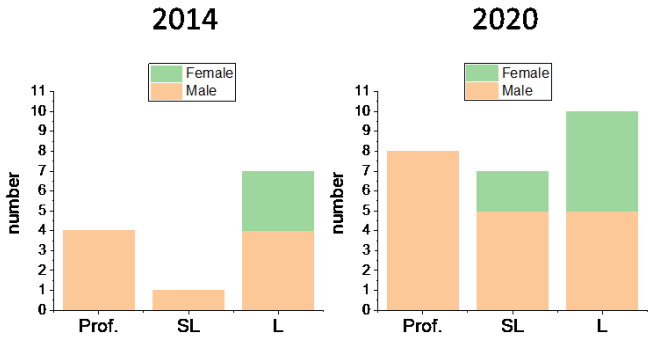

Figure 4. Chemistry academic staff numbers by gender.

As a demonstration of our commitment to EDI, we have identified imbalances in our staff profiles (Figure 4). Through our appointment strategy, in this REF period we have achieved gender parity at Lecturer level and have overseen the successful promotion of 2 female staff to Senior Lecturer (3 further female staff have been promoted to SL since 31st July 2020). We are actively seeking to reduce the academic gender pay gap, exacerbated by our currently exclusively male professoriate, by putting in place measures to support the promotion of our female staff into senior roles and in redressing the balance in future appointments. We are also taking action to improve our record of appointments of BAME staff at all levels. The action plan includes active engagement with on-campus (cross-faculty) BAME representation, to develop a practical and effective means to ensure we secure applications from the entire ethnic talent pool of the global research community. For instance, our EDI committee has a nominated BAME representative, and acts as a focal point for staff and students, with responsibility for working within and outside LU to develop and strengthen the inclusivity of all of our activities, policies and practices. This commitment to ensure a level playing field for the entire LU Chemistry community, driven from HoD level (the HoD is a member of every EDI committee and group within the Department), thereby demonstrating a high-level buy-in to the fundamental importance of EDI.

EDI considerations have been embedded in our REF preparations, with the departmental EDI lead providing overview of the process. Outputs were selected in accordance with the University's REF Code of Practice, including the voluntary and confidential declaration of personal circumstances. Each member of staff returned was attributed their best output, as judged by experienced internal and external reviewers in a fully transparent process.

SECTION 3. INCOME, INFRASTRUCTURE AND FACILITIES

3.1 OVERVIEW

LU Chemistry has seen enormous improvements to the research environment since 2014: at that time, our research was conducted in temporary laboratory space and the Chemistry department consisted of 12 FTE academic staff and two PhD students. The expansion to 26 FTE academic staff and 4 EOs, and the provision of new, bespoke research laboratories and

equipment, has enabled us to secure £13.8M in academic research funding since 2013/14, of which £5.5M involves external collaborators. The decision to appoint the Director of the Materials Science Institute (MSI) within Chemistry has also contributed substantially to our progress in obtaining grant funding. Co-ordinated through the MSI, Chemistry led the Leverhulme Trust Doctoral Training Centre programme "Material Social Futures", which brings in a regular number of high-quality PhDs each year. Additionally, MSI's co-ordination of GISMO (§1.4) has led to the recruitment of 5 graduate researchers into Chemistry in 2020.

3.2 INCOME

3.2.1 Research income

LU Chemistry has seen growth in the number and value of grant applications submitted and awarded since 2014, with an average success rate of 24% across a range of funding streams (Figure 5). The appointment of established world-class academic staff and early career rising stars has resulted in a number of recent large grant awards. Toghill secured an ERC Starter Grant of £1.3M for a project to electrochemically convert CO_2 into high-value hydrocarbon products. Tapia Ruiz, with Co-Is Griffin and Mertens, was awarded £4.4M from the EPSRC Faraday Battery Challenge to develop next generation lithium and sodium battery technologies. It is gratifying that these large grants were awarded to two of the early career members of the department, who were appointed during the strategic development of the Energy Lancaster Research Centre. The department has a broad portfolio of funding, with grants awarded from the European Commission and other EU institutes, UKRI and STFC, the Royal Society and Innovate UK.

Funding sources for PGR studentships are also diverse. We have been awarded 5 CASE studentships since 2013, with partners including the Nuclear Decommissioning Authority, AstraZeneca and Jaguar-Land Rover. Other externally funded studentships have been awarded by the Royal Embassy of Saudi Arabia, Higher Education Commission of Pakistan, Unilever, Leverhulme Trust, the British Heart Foundation and the ERC. Chemistry has benefited from the MSI Material Social Futures Doctoral Scholarship programme (Leverhulme Trust > 21 students), with 5 studentships awarded to Chemistry since 2018.

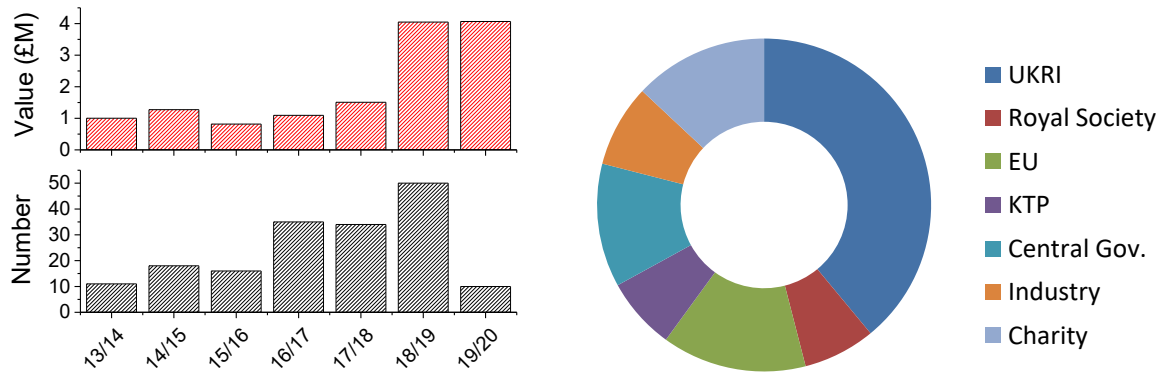

Figure 5. Numbers, and value of grant awards (left) and diversity of funding streams (right).

In-kind support, equivalent to the value of over £650k, has been secured from industrial partners, including support for our hydrogen storage research from Hydro Quebec and Fiat Chrysler, USA. In-kind support has also been leveraged through BBSRC NIBB Business Interaction Vouchers and an MRC Industry fund In-kind funds from Galvani Bioelectronics supported a successful EPSRC first grant.

3.2.2 Income from business interactions

The increasing number of business interactions seen over this REF period is testimony to the success of the **Collaborative Technology Access Programme**, which has provided

expertise, access to Chemistry facilities and laboratory and office space for commercial partners and clients. There are currently 13 resident companies in the Chemistry space, including Antonelli's spin-out company Kubagen, which is developing novel, patented energy-efficient fuel technologies; Kubagen took up residence in 2020 in order to expedite impact delivery over the coming years.

We also work closely with off-site partners and clients within Lancashire (such as ThermoFisher, Crown Paints), and in neighbouring areas (e.g., Liverpool Chirochem and Apex Molecular) on industry-relevant problems. Examples of the diversity of our client base include fine chemicals, breweries, electronics and electro-optic manufacturers, hydrogen fuel cell manufacturers and the police force. Chemistry academic staff and EOs act as expert consultants for clients, which not only includes analysis and diagnostics, but also report writing and the undertaking of feasibility studies. For example, Ashton works closely with the bioprocessing community and has a project with ISI instruments, Sanofi /Genzyme and others, funded by the Innovate UK, Materials and Manufacturing call, advising on instrumentation, software and data analysis requirements.

We have established a range of business interactions through diverse funding mechanisms (Table 2), which has generated over £5.5M of income. Around 60% of this income originates from our engagement with commercial partners (36), 25% from contract research (77 partners), 6% from consultancy (7 clients), 5% from regeneration income and the remaining 4% from a combination of facilities, equipment and co-location (£39.6k facilities use / £32.4k from co-location). Chemistry is one of the main beneficiaries of Lancaster's Impact Acceleration Account (IAA) funding, having been awarded £483k (matched funding) to support interactions with 16 business partners. Additionally, KTPs with a total grant value of £940k have supported interactions with 4 businesses, and pump-primed the impact case study from Fielden and Crown Paints, *Eliminating waste in paint manufacture*.

Table 2 Sources of business collaborations.

Business Interaction	Number of Business Collaborations
IAA (EPSRC)	16
CUSP (ERDF)	10
CGE (ERDF)	6
KTP	4
Govt Dept (e.g. BEIS)	4
Total	**40**

3.3 INFRASTRUCTURE AND FACILITIES

3.3.1 Building space

The Chemistry building houses high-quality, well equipped research laboratories for synthetic, physical and analytical chemistry and a computational chemistry cluster supplemented by the University's high-end computing facilities. In designing the building, we recognised the benefits for graduate students of open-plan office space, in terms of networking and mentoring, and computational facilities (PC and Linux). As a result, we have attracted a thriving and diverse postgraduate community. The building also incorporates office space for emerging companies on the ground floor and two further research laboratories on the two floors above.

3.3.2 Research technical support

From the outset, the Department's business plan recognised that having a strong team of highly experienced EOs is an important investment in the research environment. The EOs offer the two-fold advantage of being specialists - able to optimise the performance and maintenance of our equipment base, and trainers - of research staff, students and industrial

partners to maximise the use and effectiveness of our equipment within any given research programme. The department currently has four EOs who oversee the maintenance and use of clusters of equipment: NMR (Akien); MS and Separations (Rochester); X-ray diffraction and fluorescence (Halcovitch); and spectroscopy, SEM and nanofabrication (Dr Sara Baldock). They also actively recruit industrial collaborators and manage instrument access and charging processes.

3.3.3 Research and impact development

Chemistry staff work closely with the Lancaster Research and Enterprise Services teams across the whole research life-cycle from pre-award proposal development and costing, to post-award financial administration; governance including contracts, ethics and clinical sponsorship; impact development; and reporting. Local redeployment of a research development officer into Chemistry, following a 2014 review of research support, enabled dedicated Research Support cognisant of Chemistry's needs, leading to improvement in the quality and impact of submitted grant applications. Lancaster's commitment to Open Research (OR) is driven by our Library's Research Service team and is included in institutional policies approved by Senate in 2015.

We work closely with our Faculty PBE team to foster our links with industrial research partners. The PBE team have been a vibrant interface between the technical needs-driven research agendas of industrial partners, and the knowledge base amongst our academic staff. An additional interface between our PBE team and our EO team has also generated many applications-driven, short-term research projects and we are already seeing these interactions translate into substantial grant-funded research partnerships.

3.3.4 Specialist facilities

Over £7M has been invested in state-of-the-art research facilities, all coming on-line within the assessment period. The equipment serves Chemistry users and supports a wide range of external activities, which is an important mechanism for the sustainability of facilities (i.e., funding the maintenance, repair and replacement costs) as we look ahead. The expansion of our equipment base has gone hand-in-hand with new staff appointments, giving us the unique opportunity to match all of our equipment to staff expertise and to meet exactly the needs of our strategic research areas.

(i) A flagship solid-state NMR facility has been established to enhance the Department's interface with materials, energy and biomedical science. Solid-state NMR is a core technology for the physical and life sciences and with a combined £2M investment from the University and the ERDF an internationally-leading centre has been established, equipped with 700 MHz (the highest-field spectrometer of its kind in the North of England) and 400 MHz solid-state NMR spectrometers. It is led by a cross-disciplinary team of NMR researchers (Griffin and Smith, materials science, Middleton, biological chemistry and Wimperis, method development). The instrument purchase also included an upgrade to an existing EPR system for materials and biological chemistry support.

(ii) A class-leading Raman microscopy suite was purchased to match the appointment of Ashton and strengthen our links with Biomedical and Life Sciences and the MSI. The instruments are equipped with three excitation lasers at 532nm, 785nm and deep UV at 244nm resulting in an extremely flexible Raman set-up for use with a wide range of material, chemical and biological samples. The instrument is equipped to carry out line scan, area mapping, volume scans as well as time series, temperature studies and live cell imaging.

(iii) Our lifetime fluorescence-equipped laboratory matches the research activities in energy harvesting (Danos) and fluorescence cancer markers (Coogan), whilst circular dichroism spectroscopy supports Fletcher's research into novel DNA intercalating agents.

(iv) A microscopy and nanofabrication suite has supported new research ventures in materials science and energy storage research for Fielden, Hardy, Hoster and Tapia Ruiz. The suite is

equipped with atomic force microscopy, scanning electron microscopy and 3D printing, together with X-ray diffraction (single crystal and powder).

Less specialised, but still class-leading separation and mass spectrometric facilities have supported the polymer/liquid crystal research of Platel and Gortz. Most equipment is located in bespoke instrument laboratories, including ground floor rooms that offer good vibration resistance and access to support facilities.

3.3.5. Access to external facilities

Chemistry staff have benefited from access to national and international facilities, awarded on a competitive basis (equivalent value £561k). Middleton and Tapia Ruiz are regular users of the Diamond Synchrotron. This access has, for example, enabled development of a new high-throughput synchrotron radiation circular dichroism method for drug screening, which led to the identification of salbutamol as a potential Alzheimer's treatment (highlighted in the Sunday Times, 2020). Chemistry staff are also regular users of the National High-Field Solid-State NMR Facility (Smith, £68k; Middleton, £21k; Griffin, £21k; Wimperis, £45k, since Aug 2013, a total of 95 days' access), with time being awarded on a competitive basis.

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

4.1. CONTRIBUTION TO THE RESEARCH BASE

4.1.1 Research outputs. As a compact Chemistry department, the focus has not been on scale, but on the quality and impact of our research, brought about by careful management and mentoring and by proactive engagement with business, industry and other end-users. LU Chemistry staff have authored a total of 428 journal publications in the assessment period, attracting over 8k citations. In the same period, 5 book chapters, 11 conference papers, 2 letters, 3 notes and 30 reviews have been published. Our research is highly collaborative and over 56% of all publications arise from participation in international teams with a further 30% arising from national external collaborations. Original research and review publications authored by Chemistry staff have attracted an average of 24.1 citations per output (compared to 17.9 for Russell group chemistry publications) and an average of 37.4 views per publication since 2014. Of our outputs, 17.4 % rank in the top 10% most cited (comparable to Russell group Chemistry outputs) and the field-weighted citation impact is 62% higher than the global average. The research published in Chemistry outputs underpin 34 patents awarded during the assessment period (Source: SciVal).

4.1.2 Prizes and awards. Early career and established staff have received prestigious awards. Coote won the Thieme Journals Award 2015, awarded to the most promising young academics in organic synthesis; Coote was also invited as the UK's delegate to the EuCheMS Young Investigator Workshop. Short was elected Fellow of Australia Academy of Science, Technology and Engineering (25 Fellows elected annually on a peer-review basis). Sweeney was the recipient of the 2015 Tennant Lectureship ("*Chemistry: what use is it now?*"), one of the Society of Chemical Industry's most prestigious honours. Tapia-Ruiz won one of the five CAMS Fellowship awards in 2019, to support early career analytical chemists, and was selected as one of 2020 young chemists by *Chemistry – A European Journal*.

4.1.3 Invited lectures. Chemistry staff members have given over 70 invited presentations at international conferences in this REF period, many as plenary or keynote speaker. A substantial number have been given by staff appointed as early career researchers, increasing their international profiles and fostering new collaborations. For instance, Ashton gave the keynote talk at the RSC-Tokyo International conference on single cell analysis and Toghill gave a keynote lecture at MRS Boston, 2018, one of the major international conferences on materials research. Since his appointment as an ECR, Hardy has built up an exceptional external profile, with invited presentations at conferences across the EU and in Egypt, Turkey, USA and China. Chemistry staff have given over 100 invited presentations at national meetings. Again, staff appointed as early career researchers have been particularly active in this regard. Coote was one of five invited speakers at the GlaxoSmithKline Emerging Academics meeting

and Franckevicius has been a regular presenter at the EPSRC Dial-a-molecule annual meetings and the Gregynog Synthesis Workshops.

4.1.4 Conferences organised. A major contributing factor to the upward trajectory of our profile has been the vitality and enthusiasm of our staff in organising conferences in the new Chemistry environment, cementing our position as a new and key player in the UK chemistry community. The Raman expertise and capabilities at Lancaster were showcased in an Infrared and Raman Discussion Group 2019, organised by Ashton. Gortz, Hardy and Griffin organised a Recent Appointees in Materials Science Conference at Lancaster (2016), raising the profile of both the MSI and Chemistry research. In the synthetic chemistry space, Fletcher organised a National Meeting on Coordination and Organometallic Discussion Group, 2017 and Evans was the lead organiser of RSC Macrocyclic and Supramolecular Chemistry, 2018. In the physical and analytical chemistry arena, Fielden (chair of the RSC Electroanalytical Sensors and Systems Group) and Toghill organised Electrochem 2018.

Externally, Chemistry staff have served on organising committees for over 50 national and international annual conferences. Toghill is a convenor and coordinator of the UK Redox Flow Battery (RFB) Network (3 annual meetings to date), which she established in 2017 with funding from the Centre of Advanced Materials for Integrated Energy Storage. It has ensured that the UK is included in international energy storage networks, has brought dedicated funding to the field in the UK. This is raising the prominence of RFB stationary storage and the importance of this technology going forward in a renewable low CO_2 economy. Coote is the Secretary-Treasurer of the RSC Heterocycle & Synthesis Group and is the main organiser for all events. She is a committee member for the UK National Retrosynthesis Competition, organising 11 events in London and across the UK since 2015. Trewin is on the RSC Theoretical Chemistry Group committee and Sweeney has been extensively involved in chairing and organising national (e.g., *Mastering Medicinal Chemistry*, [2015–present], *Nucleosides and Nucleotides: Synthetic and Biological Chemistry* [2017, 2021]) and international RSC conferences (including *Bioactive Natural Products: Translating Promise into Practice* [Oxford July 2016]).

4.1.5 Communication and outreach. Hoster, Toghill and Evans are contributors to the Conversation, attracting over 30,000 reads and 63 comments. Evans authored an online article in the Conversation to celebrate the 2016 Nobel Prize in Chemistry, *From muscles to motors: 2016 chemistry Nobel goes to creators of the world's tiniest machines,* which was also republished by Elsevier's SciTech Connect. Hoster has also given media interviews on national radio and on TV on topics including batteries. Toghill gave an interview for the Naked Scientists radio show and podcast (2020) and participated in a TV Panel Show for TRT World News Channel (2017). Sweeney chairs the Royal Society Industry Fellows' College, a world-leading knowledge transfer network: as Chair, Sweeney leads the 2-3 annual events of the College, thus giving LU Chemistry a high-profile amongst top level scientist, entrepreneur and business communities.

4.1.6 Collegial activities. Every Chemistry staff member is an active and frequent reviewer of external national and international grant applications and as reviewers for chemistry journals, including all the major scientific publishing organisations. Wimperis was the Journal of Magnetic Resonance top reviewer (2016) and Hardy won the Publons Peer Review Award (top 1% of reviewers of Chemistry Research and Review papers). The majority of our staff have acted as external examiners of PhD and MRes/MPhil candidates, with over 50 theses examined, including internationally (Germany, Netherlands and Denmark).

4.2 COLLABORATION AND INTERDISCIPLINARITY

LU Chemistry is highly collaborative and our publications are co-authored with 369 academic institutions as well as 20 corporate, 68 government and 8 medical organisations. We have integrated and consolidated our research teams to maximise synergies via joint projects and grant bids and developed many interdisciplinary and industrial collaborations. From the outset, the University has recognised the vital interdisciplinary reach and collaborative nature of

Chemistry as a discipline, across campus and externally. Energy Lancaster brings together world-leading expertise in a wide range of energy-related areas covering demand, supply and storage, as well as their environmental and societal impacts. The MSI comprises over 200 academic and research staff across campus, and is active in interdisciplinary research, development, commercialisation and education of new materials science. Chemistry staff (Danos, Fletcher, Platel, Toghill, Tapia Ruiz, Griffin) all have PhD students from the MSI through the Leverhulme *Material Social Futures* project (£1.55M; PI Short), and Hardy and Griffin have further DTP PGR students through the MSI. Through the interface of MSI with Chemistry, studentships have been supported in solar cell chemistry, biodegradable plastics, battery technology and energy storage materials.

LU Chemistry has rapidly developed collaborations with external academic and industrial partners. The EPSRC/Faraday Institution-funded project led by Tapia-Ruiz, to develop next generation lithium and sodium-ion batteries, is multidisciplinary and brings in partners from Lancaster Physics, the University of Sheffield, UCL, the University of Cambridge and STFC Laboratories. Tapia-Ruiz, with Griffin, is also involved in the FutureCat programme, led by the University of Sheffield, to deliver cathodes to withstand prolonged cycling and promote ion mobility. Hoster in partnership with AGM Batteries Ltd, the Centre for Process Innovation Ltd and other commercial and academic partners led a 2-year Innovate UK project UK Niche Vehicle *Battery Cell Supply Chain* (total funded value £3.2M; £436k to Lancaster). He also leads another Innovate UK project, *Pozibot: Quantum-secured remote monitoring and data logging technology that enables a dynamic insured warranty for battery packs* (Total project costs: £2.4M; Lancaster share: £527k). He is also part of a consortium with Imperial College (lead, PI Gregory Offer), Lancaster (Chemistry and Engineering), Oxford, UCL, Bath, Warwick, Birmingham on *Multiscale Battery Modelling* (The Faraday Institution/EPSRC; total project £10M with £1.2M to Lancaster). LU Chemistry's prominence in solid-state NMR (§3.4.1) has been enhanced further by Griffin's membership of the consortium responsible for the UK High-Field Solid-State NMR National Research Facility (funded by EP/T014997/1), which serves physical, biological and medical research in the UK.

Anwar has held 3 visiting professorial positions, at the Shanghai Institute of Materia Medica, University of California, Santa Barbara and Friedrich-Alexander-University Erlangen Nurnberg, resulting in 5 collaborative publications. Chemistry at Lancaster has hosted a number of international visiting and honorary staff in this REF period– a total of 36 years FTE from visiting students and academic staff from the EU, the Indian sub-continent, North and South America, China, Turkey and Australia (Figure 6). For example, Danielle Nascimento, INQUISUR (Instituto de Química del Sur) - UNS (Universidad Nacional del Sur), Bahía Blanca, Buenos Aires, Argentina, self-funded, 1st June - 1st December 2018. Dr Branislav Dzurnak (Centre for Advanced Photovoltaics, Czech Technical University, Prague) from 14th – 21st June 2019 resulting in the publication 'Hot photons and open circuit voltage in molecular absorbers in Semiconductor Science and Technology' (2019). Laurence Savignac, PhD student from University of Montreal, Research visit from 1st May – 1st November 2019 Funded by Fonds de recherche du Québec - Nature et technologies (FRQNT). Hardy has hosted 12 externally-funded PhD students from Pakistan, Iran, Germany and India since 2016, and Dr Rania Hathout resulting in a paper in *Materials*.

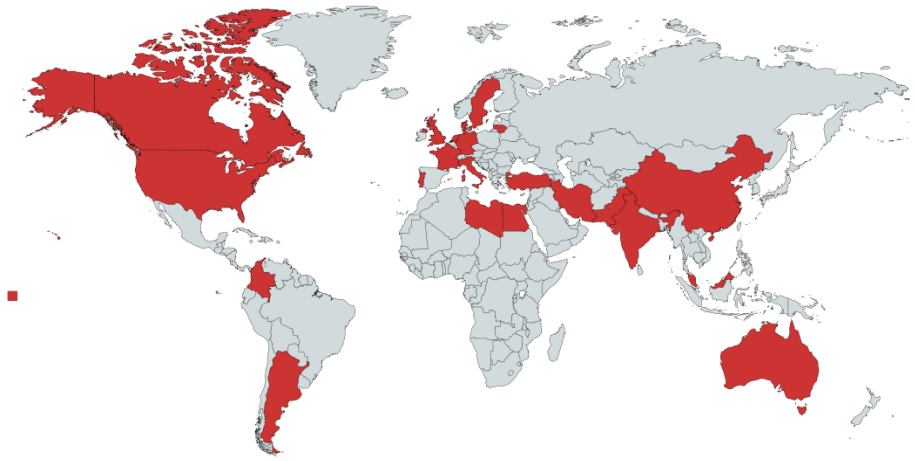

Figure 6. Origins of international visitors and honorary staff.

4.3 CONTRIBUTION TO ECONOMY AND SOCIETY

LU Chemistry's approach to impact has borne fruit in a remarkably short time frame, with our case studies being grown entirely within the assessment period. In collaborations with Crown Paints, Nimtech and Process Instruments, and supported by £650k KTP funding, Fielden has developed innovative and sensitive analytical chemical methods for waste water analysis, forming one of UoA8's ICS. Hoster is Chief Technology Officer of the start-up Altelium Ltd, which supplies batteries to the London insurance market, forming another of our Impact Case Studies.

Further LU Chemistry innovations are expected to become notable success stories in the next 3-5 years. Imaging technologies devised by Sweeney are currently being commercialised, via a spin-out vehicle: Lancaster Imaging IP has been obtained for the Peroxiplat peroxisome-specific imaging (Coogan) and amine tagging (Sweeney) methodologies, and Peroxiplat is currently available on Ximbio's website, with discussions underway for joint Ximbio/Merck commercialisation. This commercialisation strategy is the first phase of an across-the-board strategy to leverage societal and commercial impact from the novel chemical matter produced by Lancaster Chemistry. As co-PI (with Gallagher, Bristol) on the RSC-funded *National Compound Collection* project, Sweeney has superb connections with industry and academic partners, to ensure uptake by end-users of the new small molecule libraries accessible using Lancaster chemical innovations, and he will lead on this to ensure successful marketisation.

In an IAA-enabled project, Fielden with eBiogen has developed a prototype lactate in blood measurement system based on single-use disposable technology and single droplet of blood (thumb prick). Antonelli's patented energy storage materials form the basis for the spin-out company Kubagen, which has attracted investment of £4M from a range of external backers. Ashton is an EPSRC funded Researcher in Residence at the Gene and Cell Therapy Catapult, which provides funding and consumables for 3 to 4 days a month residency at the centre to implement a Raman-based system to monitor and control viral production in real time. Short has a strong track record of research commercialisation, developing technology that underpins > 10 products sold worldwide (decadal sales > £250M). Currently he is on the Board of TekCyte (Australia) developing novel blood-contacting implantables and a living cell wound patch. In the EPSRC funded project 'Smart Wound: reducing the risk of amputation via improved diabetic foot ulcer treatment', Short developed a Plasma activated wound dressing (IP 2019) which could be rapidly accelerated with GAMA Healthcare into preclinical trials. Coote has a licence agreement signed with Key Organics for the marketing of new cubane derivatives (to be prepared at Lancaster and sold via Key Organics).