Institution: University of Lincoln

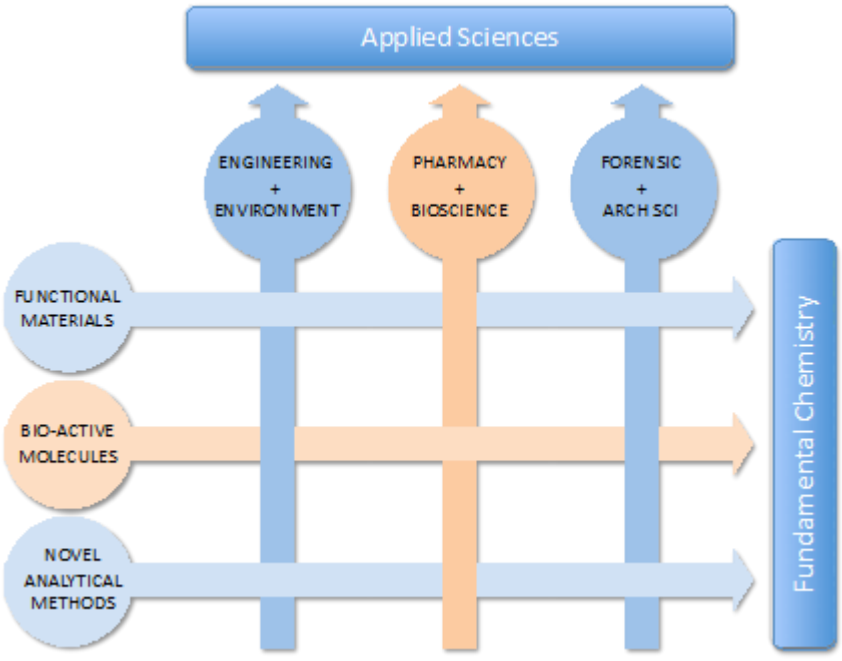
Unit of Assessment: 8 - Chemistry

1. Unit context and structure, research and impact strategy

1.1 Context and Structure

This is the first submission to Unit of Assessment by the University of Lincoln. It is based on the new School of Chemistry, founded as a recent venture at Lincoln in April 2014 – the first new School in Chemistry to be established *de novo* in the UK for several decades. The new School represents a major investment in chemistry and a significant intervention for a region hitherto identified as a 'cold-spot' for the influence of Higher Education. The development has enabled the University to re-profile its academic footprint towards STEM and to engage with key international, national and local priorities - Greater Lincolnshire hosts one of the UK's four key Chemical Industry Clusters centred around the Humber Estuary and its industrial strategy identifies Manufacturing, Agri-food, Low Carbon and, Health and Care as priority sectors for the future. New chemistries provide impetus for progress in these areas.

The School was **founded to introduce chemistry as a central enabling science** to Lincoln and generate leading research that facilitates interventions with impact that address regional, national and international priorities. As a consequence, the ethos for chemistry at Lincoln firmly reflects the University's on-going commitment to producing 'purposeful research with impact' and these principles guided the successful delivery of the HEFCE Catalyst project 'Driving Economic Growth through Employer-Engaged STEM Provision' - a £24.3m project, including a funding injection of £6.8m, to establish the new Schools of Chemistry and Mathematics. The establishment of Chemistry at Lincoln has been highly successful and the standing of its taught programmes (e.g. No. 3 Guardian University Guide Subject Table for Chemistry 2021), with sector-leading graduate prospects and student experience, has driven remarkable success and from a first student intake in 2014, over 350 students currently study chemistry at Lincoln. This now provides a sustainable basis for the subject at Lincoln. In the period, we have focussed on building research capability in chemistry to drive all aspects of the new School and, reflecting the University's forward-looking strategy, we are ambitious to grow the discipline from this foundation.



Our developmental strategy for chemistry was centred on building fundamental research themes that have synergy with our commercial and social contexts. Research capabilities at Lincoln have grown strongly and our strategy converges into three chemistry-led research groups. In parallel, we have engaged successfully with industry to establish the application of our research and have pursued wider engagement with the University's interdisciplinary themes, particularly Sustainability, Health and Wellbeing, Rurality and Heritage. The new School has grown rapidly, and 14.2 FTE staff are included in this submission.

Unit Structure

In the census period, strategic investment to build staffing and infrastructure has been focussed at the Chemistry-Materials and Chemistry-Biology interfaces supported by cross-cutting support in Analytical Methodologies. This has fostered distinctive fundamental chemistry in concert with innovative approaches to enable its application for societal and commercial needs. Three research groups are centred around our enabling chemistry themes. The groups operate on an inclusive basis offering staff opportunities flexibility and opportunity to engage broadly to pursue their areas of interest.

The Advanced Functional Materials Group pursues insight into the design and development of materials across length-scale hierarchies to address future applications:

- supramolecular and nanoscience methodologies for electronic and optical sensor applications (Adriaenssens, Baron, Gil-Ramirez, Gonzalez-Rodriguez)
- insight into molecular surface modification of materials for heterogenous catalysis, especially development of energy-efficient chemical transformation and valorisation of waste streams (Chutia, Floris, Iqbal, Munshi, J. Zhang)
- engineering crystalline order and nano-scale domains for materials with interdisciplinary application, e.g. pharmaceutical products, conservation (Blagden, Colston, Lloyd, Munshi, Scowen, Wuttke)
- structuring materials for energy capture, transduction and storage (Floris, Roy, He, Scowen)

More broadly, chemistry introduced a University-wide interdisciplinary discussion forum - the Materials Platform – to promote broad engagement with researchers across the institution (particularly, Schools of Mathematics and Physics, Engineering, Life Sciences, Architecture, Art and Design, Conservation). As a consequence, significant strategic investment has been leveraged (e.g. the ERDF/GLLEP-funded centre 'The Bridge' – see below) and the group's wider engagement has generated significant inter-disciplinary outputs. Alongside the academics return to this unit, Floris is returned to Physics (UoA 8) for his innovative development of modelling methods for surface science, and Colston, particularly for application of nano materials conservation, is returned to Art and Design: History, Practice and Theory (UoA 32). Blagden from Lincoln's School of Pharmacy is returned in this UoA through his long-standing participation with this group. The group provides an exciting base for future developments aligned to the University's interdisciplinary theme in Sustainability especially with the Humber region set for major growth in sustainable energy generation and processing.

The Chem-Bio Interface Group pursues insight into the design and development of bio-active molecules and their fate in organisms and the biosphere:

- development of organic synthetic and molecular transformation methodologies for natural product synthesis, targeted molecular synthesis and new synthetic organic methodologies (Adriaenssens, Lear, Gathergood)
- biological macromolecules (peptide and protein) for next generation antibiotics and anti-microbial applications (Lear, Taylor, Prior)
- use of biological and green chemistry alternatives in product development and their fate in the environment (Gathergood, J. Zhang)
- formulation strategies for the development of pharmaceutical materials (Blagden, Lloyd, Munshi, Scowen,)

The focus of this research group is the transformation of (particularly organic) molecular species. This group interacts strongly with Lincoln's Schools of Pharmacy and Life Sciences, co-

located in our shared research facilities, providing coherent pathways linking drug discovery and formulation to development and trialling. For example, Prior has contributed significantly to outputs relating to development of novel anti-microbials (returned in UoA 3 by Taylor). This group provides an exciting base for future developments with Lincoln's new School of Medicine and the University's interdisciplinary theme in Health and Wellbeing.

The Novel Analytical Methodologies Group address cutting-edge challenges requiring design and innovation of analytical techniques for complex materials, challenging measurement scenarios and changing societal contexts (e.g. novel psycho-active substances)

- Application of sensor systems to specific forensic and security-relevant analytes including forensic toxicology, explosives, drugs of abuse, trace analysis (Baron, Gonzalez-Rodriguez, Gil-Ramirez)
- Development of omic methodologies for challenging biological, environmental analytes (Gill, Thakker)
- Development of structural and spectroscopic methods for structure determination, in-situ analysis, process analysis and materials transformation (Iqbal, Lloyd, Munshi, Prior, Scowen)
- Translation of characterisation methods for heritage materials and the built environment (Colston, Iqbal, Scowen)

This group is highly active in interdisciplinary contexts providing solutions to industrial problems and bringing molecular interpretation to interdisciplinary research contexts (e.g. geosciences, forensic sciences, history and heritage). As an example, new methods for forensic analysis of novel psychoactive substances (Baron, Gonzalez-Rodriguez) contributes to Impact Case Study 1.

1.2 Achievement of Research Strategy

As this is the first REF submission by the University of Lincoln to UoA 8, we do not have a REF 2014 research or impact strategy to compare with. Instead, this section reviews the strategy followed to embed chemistry research at Lincoln, the central objective in the founding of the School of Chemistry.

Our overall aim is to develop fundamental chemistry research of relevance to regional, national and international priorities that can be summarised in a mission statement that describes the **advancement of the discipline of chemistry through research that is contextualised by, and brings benefits to, social and commercial contexts and enables progress for chemistry and its adjacent disciplines.**

To achieve this aim, we have pursued the following strategic objectives in the REF period:

1. *To **create a vibrant chemistry research community** at the University that advances the core discipline of chemistry across chemistry-biology and chemistry-materials interfaces facilitated by the development of innovative (analytical) methodologies broadly across chemistry and applicable to interdisciplinary contexts.*

The establishment of the School of Chemistry and construction of new research environments has transformed the landscape at Lincoln. In parallel, realisation of our staff recruitment strategy has created three Research Groups resulting in outstanding research outputs in leading journals (Nature Group, ACS, RSC, Wiley). We have become able to provide a modern research facility for chemists joining Lincoln and foster a supportive environment to develop academic research careers. We have graduated the first Chemistry PhDs at Lincoln and are building a vibrant research community with an international perspective, incorporating staff and students from across our programmes and engaging widely with Universities across the world. Alongside this, researchers in chemistry are active in co-supervision of PhDs across other disciplines (e.g. Pharmacy, History & Heritage, Psychology). Our work to commercialise research methods has met with considerable success and the School now has an active CRO arm (see below) supporting regional, national and international industries.

2. *To **establish a modern research environment** with innovative, integrated workflows and efficient and sustainable operating structures*

This approach has been met with considerable success. The University is now equipped with modern chemistry facilities for research and the substantial investment in laboratories and instrumentation has yielded a number of facilities with advanced cutting-edge capabilities. For example, our integrated thermo-analytical system interface with GC-MS, quad-MS and FT-IR for evolved gas analysis, our Raman spectroscopic systems offer near-IR mapping and our X-ray diffraction facilities have controlled environment, micro-diffraction and high resolution. The facilities have attracted visiting scientists from across the world, and we continue to work with manufacturing partners to showcase the capabilities of instrumentation and collaborate on development projects, e.g. our work with Bruker on the use of In-Situ X-Ray (ISX) Stage for single in-situ structure determination. Furthermore, the engagement of experienced instrument specialists has considerably expanded the scope for research at Lincoln, e.g. extending the research methods used for our Impact Case Studies (particularly Gonzalez-Rodriguez's work in hydrometallurgy and waste recovery, ICS2). We host and support researchers from 10 Schools across the University and, alongside the research returned to chemistry, this has contributed significantly to research returned under other UoAs.

3. To ***engage with regional, national and international communities*** and offer opportunities for staff and students to engage widely with internationally-leading collaborators and networks.

We have now successfully established wide networks in regional, national and international chemistry and these have led to significant high profile outputs as well as enriching the chemistry research culture at Lincoln. At local level, the founding of chemistry at Lincoln was widely supported by regional industry (several of these interactions led to subsequent R&D studies with our commercial CRO - the CATCH consortium of Chemical Industries in the Humber Estuary was a primary sponsor of the HEFCE Catalyst bid and continues to partner with us. Alongside regional industry engagement, we have developed valuable links with regional academic institutions, and these have yielded significant research success. For example, Sharma continued links with the Moses group at Nottingham after joining Lincoln in 2013, yielding a number of RSC and ACS publications led to an EPSRC New Investigator Award in 2016. Adriaenssens engages with the Avestro group in York in development of electrochemical sensors devised under an RS grant award alongside co-supervision of research student with the Ball group in Nottingham yielding a recent JACS publication.

At national level, examples of our success with this strategy include Chutia's collaborations with UK Catalysis Hub, Harwell and UCL that have led to high profile Nature group and ACS publications and recent success with securing ISIS-STFC co-funded studentship. His on-going collaboration with Chemistry and Chemical Engineering at UCL has delivered a number of high profile papers in ACS and Wiley journals and has led to a recent EPSRC NIA award. Gil-Ramirez's engagement with the Anderson group at Oxford yielded a JACS publication. Lloyd continues to co-supervise PhDs with Heriot-Watt University supporting student visits to use specialist facilities at Lincoln.

We continue to raise our profile internationally through this strategy. For example, Blagden co-led the EU Crystallize COST Action CM1402 group (including hosting the 2017 meeting at Lincoln for participants from 27 countries). Adriaenssen has secured RS-funding to foster collaboration with the Raston group in at Flinders University (Australia) and his engagement the Bowman-James (University of Kansas) yielded a student exchange in 2020. Gathergood has linked the University with the Erasmus Mundus programme in Green Chemistry at Talinn (Estonia) for research exchange and generated outputs with a number of European groups. Lear remains highly active with collaborators in Japan and has hosted a visiting academic from Osaka in advance of student exchange; his collaborations with

Tohoku University have yielded a number of high-profile outputs in JACS and Angewandte Chemie.

1.3 Achievement of Impact Strategy

The University had several applied chemistry projects in train before the new School was opened and these continued through the current census period. Two of these form the impact case studies in this submission: (i) the development and deployment of methods for identification of Novel Psychoactive Substances that supported prosecutions relating to contravention of Trading Standards in advance of the root-and-branch change in legal classification of illicit drug substances in 2017 (ICS 1); and (ii) the development of technologies for extracting precious metals from fuel ash residues that has positioned a local company to expand significantly and engage in international oil-producer markets, e.g. Venezuela, Saudi Arabia (ICS2).

At inception of the School of Chemistry in 2014, we engaged in systematic consultation with industry to position a set of objectives for the impact of research in the new School alongside creating employer-engaged curricula. These yielded the following objectives to promote the impact of chemistry at Lincoln:

1. **Identify and pursue commercial opportunities** with experienced industry-facing specialists able to translate the needs of the user and formulate projects using relevant research capabilities in the University.

2. **Establish a team of scientists focussed on industry R&D project delivery** and capable of contributing to the research environment with specialist expertise and through sustainable income streams.

3. **Establish a track-record of successfully accomplished R&D projects** in industry and create a diverse portfolio of case studies for future reference.

4. **Escalate impact through successful working relationships** with organisations facilitating scale-up of initial projects to future larger-scale collaborative studies. A diverse project portfolio thereby creates a pipeline of R&D programmes to drive future impact.

Central to our response to these objectives was the formation of a 'Contract Research Organisation' (CRO) function – initially branded as JBL Science. These activities have been directed by Scowen as Head of School with Gill (ex. Roslin Institute) and Riess (ex. British Steel, Smith and Nephew) recruited for project design, delivery and management. Latterly, as this CRO approach has evolved to 'The Bridge' and the group has expanded with Eaton (ex. U Porto, Seville) and Roebuck (ex. National Nuclear Lab, Warwick) joining recently. This approach has met with considerable success and yielded *ca.* £350k revenue from some 150 projects to date with SME, national and multinational companies. These funds provide for contingency costs for research infrastructure, particularly instrumentation, and are reinvested for maintenance and development of the chemistry facilities. Our work with Luxus Ltd on the evolved gas speciation from recycled plastics provides a good example of the escalation of impact. From an initial small-scale study though JBL Science, the School helped develop a £1m IUK programme for deodorising plastic waste.

The Joseph Banks Laboratories is placed as an anchor institution for the Lincoln Science and Innovation Park. Our synergistic relationship with LSIP, facilitated by our CRO approach, has played a part in encouraging companies to locate R&D functions in the LSIP's Boole Technology Centre opened in 2018. Collaborative R&D programmes have been undertaken with four companies based here (GSAe, Arden Biosciences, Nutrapharma and B-hive) and the long-standing relationship with GSAe forms the basis of ICS2.

1.4 Research Strategy for the Next 5 Years

The next phase of development of the School of Chemistry is predicated on expanding our research capability. It is clear that there is considerable scope for expanding our research intensity within the established environment. To achieve this, we will pursue the following Strategic Objectives for Research and its Impact in the period 2021-2027:

1. Promote a research culture proactively celebrating diversity and ensuring equality of opportunity though delivery of our EDI Objectives and Athena SWAN Bronze Award Action Plan.

2. Make strategic appointments of academic staffing to our three groupings which will be supported by the continuing growth of the School of Chemistry, realisation of business plans for strategic initiatives such as The Bridge (see below) and building diversified research income streams. We will seek to double numbers of academic staff with research responsibilities from 14.2 to 30 FTE in this period.

3. Extend academic research teams to provide greater scope for research delivery. We will target external funding sources (and, where appropriate deploy strategic internal matching funds) to achieve growth of research staffing to approach 2 per member of research-responsible academics – while ambitious, expansion of this order has been achieved in other parts of the University in the current REF period (e.g. Lincoln Institute of Agri-food Technology).

4. To achieve strong growth in our research effort through diversification of funding streams supporting fundamental themes (research councils, international bi-lateral academic partnerships, EU consortia) and their future application (generating innovation funding, industry sponsorship, spin-out, IP exploitation). We will seek to quadruple our annual research funding income to exceed £1m *per annum* as our academic groups mature and enhance their standing. While we are building from a modest base here, annual income is accelerating and income for 2019-20 represents *ca*. 50% of the total returned in the census period.

5. To increase the research student cohort by re-investment of enhanced funding streams and by initiating/partnering with doctoral training consortia. This remains a challenging agenda for a relatively new School although we have grown the research student cohort through recent access to the University's EPSRC-Funded Doctoral Training Partnership funding and with industry- and collaborator-sponsored support.

6. To develop strategic partnerships with academic institutions to foster research collaboration for staff and student mobility and to develop opportunities for research training. We will continue to add international partners through collaborative networks and present meaningful opportunities for research staff and student exchange. We target a level of 1-2 student exchange collaborations per member of academic staff. Similarly, we will pursue opportunities for extra-mural and collaborative research degree programmes with overseas partners.

7. Extend the support infrastructure for research through sustainable investment. Our business planning for multi-user instrumentation includes maintenance and contingency funding throughout its lifetime while the University's initiative 'Financing the Future' references replacement of major capital assets, such as high-value instrumentation, on a 10-year cycle. Furthermore, the University now accesses UKRI infrastructure funding sources - e.g. UKRI World Class Laboratory scheme supported a recent upgrade to single crystal diffraction facilities – and we will engage with strategic deployment of such initiatives to develop our research facilities.

1.5 Impact Strategy for the Next 5 Years

Impactful application of chemistry is central to the founding mission of the School. To achieve this purpose, we propose to build on commercial engagements initiated in the current period and pursue the following objectives

1. Translate 'platform' technologies arising from fundamental research to emerging strategic needs. An immediate opportunity emerges in sustainable energy with Greater Lincolnshire and the Humber region – the UK's 'Energy Estuary' – and we will seek to target opportunities for application of our energy research in partnership with industry and academic collaborators.

2. Evaluate potential IP from discoveries from our growing research portfolio and pursue suitable pathways for commercialisation

3. Evolve our CRO approach providing applied research for industry. These will be primarily fulfilled through delivery of outputs for ERDF-GLLEP funded programmes associated with 'The Bridge' (see below) and JBL Science. For the latter, we will focus our footprint to bio-, agri and food sectors. In parallel, we will utilise the infrastructure for reporting developed for the Bridge to as a resource for systematic documentation of research impact.

4. Facilitate targeted development of research solutions and methodologies to provide specific solutions informed by sector needs and, thereby, enhance the profile of chemistry in interdisciplinary applications. This will be driven by targeted re-investment of commercial revenues and is explicitly supported under The Bridge's ERDF objectives. We anticipate that such interactions will provide of the order of 5-10 mature projects yielding impactful application studies in the 2021-27 period.

The University has secured European Regional Development Fund (ERDF) and Greater Lincolnshire Local Enterprise Partnerships (GLLEP) funding for a £6.4m project for a new facility for advanced engineering materials - 'The Bridge' - a collaborative initiative between School of Chemistry and Engineering. Reflecting the University's 'local-to-global' principle, The Bridge will support the discovery of solutions to problems identified by regional industries that can be translated across the world. The has been conceived over a 3-year consultation with an industry consortium combining multinational industry partners, e.g. Siemens Energy, Dynex Semiconductor, Teledyne e2v, Praxair Semiconductors alongside local SMEs covering a diverse range of materials, e.g. biofuels, vehicle catalyst, polymer manufacture, coatings and formulation, and active in international supply chains. Consequently, it identifies research challenges of relevance to our locality – i.e. materials engineering relevant to our locale, particularly energy, formulation and electronic supply chains - with future global significance. We see The Bridge as the future centrepiece for driving research impact at the Chemistry-Materials-Energy interface and offering a coherent forum for industry-academia liaison. The Bridge will be accommodated in a new facility, housing specialist laboratories for instrumentation (electron and atomic force microscopy; thermal analysis, tribology and rheology) and purpose-built accommodation facilitating industry interaction (a training and exhibition centre, and a collaborative 'innovation' centre promoting business-to-business engagement alongside University support).

Alongside The Bridge, we will continue to expand utilisation of our research capabilities in the context of the regional (major) agri-food sector in collaboration with the Lincoln Institute of Agri-Food Technology and National Centre for Food Manufacturing, e.g. building on pump-priming HEIF-funding to explore opportunities for valorisation of Food Waste (£65k), and these will be specifically promoted under JBL Science branding working in collaboration with the Chem-Bio Interface Research Group and other University departments e.g. the National Centre for Food Manufacturing and the Lincoln Institute of Agri-Food Technology.

1.6 Approach to Interdisciplinary Research

The integrated strategy for research at the chemistry-materials and chemistry-biology interfaces lends itself to interdisciplinary implementation of research. The School has been at the heart of establishing an open forum for materials science research - the Materials Platform - engaging researchers across Chemistry, Maths and Physics, Engineering, Architecture and Conservation Science. A primary outcome of this initiative has been 'The Bridge' (see above). We will seek to replicate this approach to address emerging research opportunities in energy.

Similarly, at the Chemistry-Biology interface interactions between chemistry academics and colleagues in the Schools of Life Sciences (SoLS) and Pharmacy (SoC) have resulted in several collaborative projects including co-supervisions of PhD programmes (see Section 2.3), European project collaborations (ERC, Montelegre-Zapata (SoLS) and Gonzalez-Rodriguez and regional level projects (e.g valorisation of waste: Kyne/Flint, BBSRC; extraction of protein from agricultural streams, Taylor, Flint (SoLS), Scowen. The development of consortia for multidisciplinary bidding has also been facilitated at this interface for development of antibiotic agents [e.g. AAS Lear/Dixon (SoLS) with Newcastle University and The Crick Institute] and soil science [e.g. ESPRC-NSF Gonzalez-Rodriguez/Goddard (SoLS) with Yale University (US)].

The University's reputation for interdisciplinary research in forensic science has led to a number of international collaborations (e.g. Gonzalez-Rodriguez, Baron in Spain, Brazil and Netherlands) that have developed analytical technologies implemented in the field. Where appropriate, outputs have been flagged as interdisciplinary research in Forensic Science although other outputs not selected for return are cited in ICS 1. We will pursue future opportunities in this field, guided by the School's growing staff base of forensic practitioners and their connections with national and international professional networks, to create 'next-generation' methods in forensic science supported by chemistry innovation.

1.7 Progress towards Open Research Environment

All outputs submitted to this UoA are open access and these are funded through a number of avenues and academics are provided with resources to support open access costs.

Academics routinely collaborate in deposition of open-source research data e.g. deposition of X-ray structures with the CCDC Crystal Structure database. The School has initiated the development of an open database of its spectroscopic data for Novel Psychoactive Substances. Although returned to UoA 9, the School of Chemistry supports Floris's work on code development of Quantum Expresso – an integrated suite of Open-Source computer codes for electronic-structure calculations and materials modelling at the nanoscale.

1.8 Support for Research Integrity

We are fully aligned to the University's infrastructure for assurance in research integrity and all research in the School is mandated to comply with the University-wide Ethical Approval process. This is administered at local level with a School of Chemistry Ethics Working Group (chaired by Lear).

Considerable progress has been made in establishing QA systems for validity of research results in the instrumentation facilities of the Joseph Banks Laboratories. Instrument scientists have devised QA systems for calibration and maintenance of equipment, standard operating systems for training and routine instrumental experiments, and secure storage of primary data. In addition, user training records and equipment access are managed under these systems. Project proposals using the pooled resources are reviewed by instrument specialists allowing methods to be optimised and experimentation to be efficiently scheduled. This approach is consistent with our CRO-approach to commercial work and allows efficient interchange of resources for the diverse calls that are made on the research facilities, enabling an inclusive pan-University utilisation of advanced research instrumentation and laboratory facilities.

2. People

2.1 Staffing strategy

This submission includes 14.2 FTE academic staff. Prior to 2014, research in chemistry at Lincoln was focussed towards applications of analytical science in forensic contexts. Selective return of staff in REF14 was limited to one early-career chemist (Sharma, UoA 3) and one established staff member to conservation (Colston, UoA 34). The current assessment period has coincided with our recruitment of an essentially new group of academics. Seventeen new chemistry academic appointments were made to the School since it opened in 2014 (one Professor as Head of School, one as Deputy Head of School; 13 to Lectureships), of which four were replacement posts. Three instrument scientist positions and four commercial positions were established. Additionally, five technical positions aligned to the School were established, including three with doctoral qualifications.

Our recruitment strategy targets staff that establish critical mass in our research groups. A pleasing outcome of our recruitment processes has been appointments of high-calibre staff with diverse and international backgrounds (e.g. staff qualifications include degrees awarded at leading Universities in US, China, Germany, India, Japan, Spain, Italy, South Africa). Of the staff submitted to the UoA, approximately one-third are international.

The staffing profile of the School has been systematically developed though the REF period: Scowen [UNL, Bradford (UK), 2014-present]; Lear [Tohoku (Japan), US (Singapore); 2015-present]; Adriaenssens [UC Davis (US), ICIQ (Spain) 2015-present]; Kyne [Strathclyde (UK), UPMC (France) - 2015-2018]; Munshi [Bradford (UK), 2016-present]; Turyanska [Nottm (UK), 2015-2020]; Gil-Ramirez [Manchester, Oxford (UK), ICIQ (Spain), 2016- present]; Zhang, W – [Oxford (UK), US (Singapore), 2016- 2018]; Johnson [Warwick (UK), Utah (US), 2017-2019]; Wuttke [Munich (Germany), IKER (Spain), 2016-present]; Zhang, J – US (Singapore), Peking (China), 2017-present]; Chutia [UCL (UK), Tohoku (Japan), 2017-present]; Floris [Berlin (Germany), Minnesota(US), Kings (UK), 2017-present]; Lloyd – Heriott-Watt, Cambridge (UK), Stellenbosch (SA) – 2018-present], Gathergood [U Talinn (Estonia), DCU (Ireland), 2019-present]; He [UCL (UK), 2019-present]; Roy [Cambridge (UK); Uppsala (Sweden), Arizona State (US), 2020-present].

Academic appointments have been dominated by early career appointments with nearly half of the staff profile in this submission in the age group 25-44 and a further third of the group between 45-55. In this period, two academics progressed to Senior Lecturer (Sharma, Adriaenssens), one was prompted to Associate Professor (Lear) while two others transitioned from Reader/Principal Lecturer titles to Associate Professor (Baron, Gonzalez-Rodriguez) as the University restructured its academic role profiles. Wuttke was appointed to a prestigious IKER Basque Research Chair in BCMaterials in 2019 but retains a fractional appointment (0.2 FTE) to continue work with the AFM Group and support the internationalisation agenda of the School.

We created specialist Instrument Scientists roles to establish the research environment adding experience in NMR, X-ray diffraction, thermal analysis, spectroscopy and mass spectrometry as new instrumentation was commissioned. Graded in parallel with academic positions, these research roles fulfil a three-fold purpose: (i) provide expertise/experience in advanced instrumental methods supporting research; (ii) give specialist training for researchers and, (iii) support maintenance and development of the research environment. The appointees to these positions all have significant post-doctoral track records and experience with international groups: Prior [Missouri (US), Soton (UK), 2016-current]; Nauha [New York (UAE), Jyväskylä (Finland), 2016-2018]; Sarmad – Nottm (UK) 2017-2019]; Iqbal [Cardiff (UK) 2018-current], Thakker [Birmingham(UK), UHI(UK) - 2019-current.

2.2 Staff Development

All research staff complete an annual Individual Research Plan (IRP) and undertake complimentary Academic Development Appraisals (ADAs). The IRP details publications,

grant income, research supervision and esteem factors for the past year and outlines research and bidding intentions for the next period. All academic researchers have an explicit annual time allocation for research as part of their workload. Early Career Researchers receive an extra allocation for research development and time is made available for all staff for specific research duties, for example, Gonzalez-Rodriguez and Baron have benefitted from University support to develop impact case studies.

We have particularly supported early career staff for study visits [Kyne (University of Gronigen, Girona, 2018), Adriaenssens (Flinders University, Australia, 2019), Lear (Tohoku, Tokyo, Osaka 2015, 2016, 2019), Wuttke (Ludwig-Maximillans Univeristat Munich , UC Berkeley 2017, 2018) Gil-Ramirez (Oxford, 2018), Turyanska (Riken, Shanghai, 2017, 2018). In some cases, visits have been leveraged with external awards [Kyne, COST action; Adrienssens, Royal Society; Gil-Ramirez, Royal Society of Chemistry; Turyanska, Lear, JSPS - Japan Society for Promotion of Science).

Flexible working arrangements for more regular research visits (e.g. weekly off-site lab visits) have been established with several collaborating institutions (Sharma, Nottingham 2014-16; He, UCL 2020-, Zhang, Imperial 2020-) alongside joint appointments (Turyanska, 80:20 with School of Physics, Nottingham 2016-19) and Wuttke (IKBasque / Uni Bilbao, 20:80, 2019-current).

PhD studentship support for early-career staff has been provided by the School to support first grant applications, e.g. the EPSRC New Investigator Award Scheme. Staff are routinely allocated 2-4 Masters research students per annum through MChem and PG-r programmes and many host international exchange students, particularly through a number of EU Erasmus collaborations (e.g. Modena, Cordoba, Malaga, Paris). These have resulted in collaborative research outputs for Gonzalez-Rodriguez, Baron, Johnson and Kyne.

Early career staff are supported with School funds covering research costs. Access to research facilities is managed on a project-by-project basis and therefore is not restricted by an individual's funding position. Support in this way has led to significant outputs for researchers, e.g. Adrienssens work on chiral amplification of polyurethane polymers and Gil-Ramirez's work on supramolecular magnets, both leading to publications in JACS.

The University's Research Infrastructure Fund supported Kyne to develop methods for valorisation of agricultural waste with academics in Schools of Life Sciences and Engineering (£40k). Three subsequent BBSRC NIBs awards (£5-10k) resulted from this. Gonzalez-Rodriguez received studentship funding from the University that led to two Knowledge Transfer Partnership (KTP) awards and outputs described in ICS 2. Adriaenssens was supported to develop synthetic methodologies for Alzheimer drug candidates with the School of Pharmacy staff (£20k). Additionally, specialist equipment for new appointees has been procured/upgraded through investments of School funds (see Infrastructure and Facilities below).

2.3 Support for PGR Students

The School of Chemistry administers research degrees in Chemistry (PhD/MPhil/MSc by Research), Analytical Chemistry (PhD/MPhil/MSc by Research) and Forensic Science (PhD/MPhil/MSc by Research). To date, in the census period, 13 students completed their research degrees and a further 13 students are enrolled to PG-r programmes in the School of Chemistry. Additionally, staff are active in co-supervision of interdisciplinary PhD programmes with other Schools: Pharmacy (4); Life Sciences (2), History (2) and Psychology (2). The University Alliance Collaborative Doctoral Training Centre supported a collaborative doctoral programme between Chemistry (Croxton, Gill) and Psychology (Pennington) utilising innovative application of mass spectral methods to evaluate stress in infants.

Support for research students is led by the School's PG Research Coordinator (Munshi) and student progress is monitored by a monthly PG-r Progress Panel that provide recommendation

to the College of Science Research Degrees Board for formal approval of progression (e.g. MPhil to PhD transfer) and award.

Student experience is addressed formally through an elected representative at the School's Postgraduate Subject Committee and quarterly 'Town Hall' meetings with School management. In addition, the PG-r Coordinator provides further pastoral support alongside the supervisory team. Data from PRES2018 indicates that PGR students are generally happy with their time at Lincoln: the School-based data of 100% for overall satisfaction compares favourably with sector average of 80.4%, as do the good ratings for supervisory support, research skills and personnel development. Students are required to complete training needs analysis annually and engage with training from University's Doctoral School. Specialist training through the School's M-level short courses (7.5 credit equivalent at Level 7) in Advanced Topics (for cutting-edge research developments) and Advanced Methods (advanced instrumental methods) courses. Similarly, students are encouraged to engage with the School's M-level module in Personal and Professional Development. One-to-one engagement with the School's Instrument Scientists allows students to extend experience and advance their formal training levels through their projects.

The School has established a vibrant research seminar programme inviting academics from leading UK and international universities – seminar speakers have included Trauner (Munich), Yamashita (Tohoku), Schofied (Oxford), Faul (Bristol), Acher (Paris Descartes), Proctor (Manchester), Wirth (Cardiff), Smith (York), Waldmann (MPI-Dortmund), Beeby (Durham), Clark (Yorks), Hunter (Cambridge). Proactive participation of research students with these events is an expectation.

2.4 Equality, Diversity and Inclusion

Within the current REF cycle, the University's Institutional Athena SWAN Bronze Award was retained and the School of Chemistry successfully secured a Bronze award in 2019.

The UoA return comprises staff dominated by males (93%) and with BAME representation of 42%. Senior staff (professor, readers, principal lecturers) submitted are 17% female and 17% BAME. In the period, staff promotions to senior roles have a 50% gender balance across the School.

The School of Chemistry EDI Committee works closely with the Eleanor Glanville Centre (the University's Centre for EDI policy research, led by Colston) in delivery of the School's Athena SWAN Actions Plan. Explicit interventions for research are: active promotion of balance in research role-models (e.g. gender balance in research leadership roles, seminar speakers, external examiners); enhancement of mentoring support for PDRA (particularly females) transition to academic careers; diversifying opportunities for collaborative working for developing research ideas. The School is pro-active in providing flexible working arrangements for academics and developing balanced workloads using the University's workload procedures.

Furthermore, the School has embraced University initiatives to address the disproportionate impact of maternity and caring responsibilities (seven staff members took maternity/paternity leave in the census period). This has included deployment of the Academic Returner's Fund (AR2F) for two academics (Sharma, Croxton) to enable staff to sustain their research before, during and after leave of absence (£15k). The School hosted two Research Fellows through the back2science programme aimed at mentoring researchers returning after longer career breaks. One fellow securing an academic position at the University. We have hosted research student (supervised by N Blagden) funded by British Council's Higher Education Scholarship Palestine and hosted a Syrian national as Fellow from the Council for At-Risk Academics (CARA), who subsequently secured a research position in the School.

In the REF period, the University secured £125k in grants from the South Nottingham Centre Fund to enhance accessibility in JBL (above DDA compliance levels), including safety equipment and specialised laboratory furniture and workstations.

3. Income, infrastructure and facilities

3.1. Research Income

The School was founded with HEFCE Catalyst funding (£7.8m). As a new School, no previous research income was recorded and this has grown to *ca*. £700k in the census period with *ca.* 20% from Research Councils. While modest, our income profile is accelerating and the income in 2019-20 accounts for 50% of this total.

The School has received the following major awards in the census period. Sharma received an EPSRC award through its First Grant Scheme (£120k) exploring new approaches to heterocyclic scaffolds with potential in drug synthesis under our chemistry under our Chem-Bio theme. The School of Chemistry augmented this award with a full PhD studentship to run alongside the programme. Gonzalez-Rodriguez (PI) and Baron secured two successful Knowledge Transfer Partnership awards from IUK with GSAE Ltd valorising fuel ash waste for precious metal content (£180k+£140k). These form the basis of Impact Case 2. Gonzalez-Rodriguez (PI) and Gil-Ramirez were recently supported for development of pesticide sensors (£17k, Ceres Agri-Tech). Baron was co-I in collaboration with Lincoln Institute for Agri-Tech and Anglian Water for MRes studentships (40k). Munshi (PI) and Scowen were awarded a Innovate UK grant (£240k) for a project developing novel methods for deodorising waste plastic with a consortium led by Luxus Ltd involving hyphenation of thermal analytical methods with chromatographic evolved gas analysis. Colston (PI) and Scowen received a British Council - Newton award (£240k) for nanotechnology in cultural heritage in collaboration with Damietta University (Egypt) and Colston received a separate award from British Council (£42k) related to this topic. In addition to monetary income, Chutia secured high-performance computational time worth £108k (EPSRC RAP) and £229k neutron-source beam time (ISIS/STFC) supporting his work with the UK Catalysis Hub.

We have encouraged early career staff to pursue start-up awards to develop bidding experience with considerable success: Royal Society small equipment (Adriaenssens £20k, Johnson £20k, Sharma £20k) and collaboration [Adriaenssens (£6k, Flinders University, Australia), Zhang (£15k, Peking University), Johnson (£20k, China Central Normal University)]; Royal Society of Chemistry (Gil-Ramirez, Kyne, Johnson, Zhang £5k each, Roy, £10k) and BBSRC Bioinnovation Fund (Kyne, £15k)] .

PG-r sponsorship funding has been secured from industry sponsors: Dupont (£16k, Scowen, Munshi); GSK (£15k, Blagden, Scowen), RB (£8k, Baron); GSK (£8k, Baron); AZ (£15k, Blagden, Scowen), Juhel Nigeria Ltd (£54k Scowen, Munshi), Yara International ASA (£20k, Gathergood, Scowen). Alongside these we have received full scholarship funding from Brunei Govt, Kaduna State Govt, (Munshi, Scowen), Thai Police (Gonzalez-Rodriguez).

Revenues from industrial R&D collaboration through our CRO has yielded *ca*. £350k to date. The Bridge project is supported with an ERDF revenue award (£200k, Scowen) within a total project value of £6.3m.

3.2 Infrastructure and Facilities

The School has led the installation of major capital facilities investment for the College of Science and a high-quality research infrastructure is now in place in the University's Joseph Banks Laboratories. Reflecting our positioning of chemistry as an enabling science, the facility supports research across the University and provides an interdisciplinary platform for scientific research across a wide range of disciplines. Primary use of these facilities resides with Schools of Chemistry, Life Sciences and Pharmacy although increasing utilisation by Schools of Engineering, Geography, Maths and Physics, Psychology and the Lincoln Institute of Agri-Food Technology and National Centre for Food Manufacturing has led to significant outputs. The facilities have hosted over 350 research projects since 2015.

The research instrumentation commissioned between 2015-18 includes: NMR (500MHz including broad band solution and solid state probes, £650k), X-Ray Diffraction (dual-source SCD, multi-stage PXRD, £490k), Mass Spectrometry-Chromatography (GC- triple quadrupole, LC-Orbitrap, LC-triple quadrupole, £385k), Vibrational (NIR-MIR-FIR, FT-Raman, Vis/NIR-Raman, £254k) and Electronic Spectroscopy (UV-vis, fluorescence, £99k) , Elemental Analysis (ICP-OES, £47k), Thermal Analysis (STA-MS, STA-IR, Thermomicroscopy, £108k), Nanoscience (DLS, Zeta-potential, Nano-sight, £63k). Opportunities for 'packaging' at procurement yielded significant benefits in costs and partnerships with established with Bruker and Thermo Fischer continue to yield on-going benefits: technical training, flexible maintenance support and collaborative development projects. These facilities were combined in the JBL Labs with existing instrumentation (GC-MS, LC-UV, electrochemistry and SEM).

Laboratories are assigned to research function, e.g. synthesis, crystallisation, formulation, nanoscience, promoting inter-disciplinary use. Specialist preparative equipment includes nanoscience and formulation (spray/freeze drying, milling/mixing, dissolution, £175k), crystallisation robotics (£56k), molecular synthesis (glove box and solvent purification, £34k), peptide synthesis, £34k), forensic trace analysis and elemental sample preparation (microwave digestion and specialist fume extraction).

Further investment to support new staff [e.g. Isothermal Calorimetry, £45k; Circular Dichroism upgrade, £36k ; microwave synthesis, £20k, electrochemistry, £44k] and for grant-funded research [GCMS-thermoanalytical equipment, (IUK,£90k), photochemistry and spectro-electrochemistry, (RS, £35k)] . Single crystal facilities have been recently upgraded with new CMOS detector (£60k, UKRI-WCL). Further investment for materials characterisation will be commissioned in 2022 for The Bridge including TEM and dual-beam SEM, Atomic Force Microscopy, Tribology and Rheology (ERDF, £1.5m total)

In addition, chemistry facilities were upgraded in 2015 (£1.5m) in the Janet Layne-Claypon teaching laboratories including 24 double-aperture fume hoods and an analytical suite with FT-IR, UV/fluorescence spectroscopy, GC-MS and HPLC and graphite-furnace AAS.

Combined these resources provide a powerful modern environment to support chemistry research at Lincoln.

3.3 Organisational infrastructure

The research activity of the School is guided by three working groups (Research Outputs, Impact and PG-r Progress Panel) that report formally into the School's quarterly Academic Committee, chaired by the Head of School, and onwards to the College of Science Board of Studies. Additionally, these working groups inform standing agenda at monthly academic staff meetings. The groups are led by the School's Research Director, the School's Impact Champion and the School's PG-r Coordinator. Each report to College Research Committee, the University's Impact Champion Forum and the College of Science Research Degrees Board.

The School's research direction is informed by a myriad of industry interactions and academic collaborations (see below) and is reviewed annually at 'away-day' events involving all staff in the School. These school-level committees interface to College of Science's Research Committee and College Research Degrees Board, and ultimately to the University's Academic Board.

Consultancies and professional services

Our CRO function serves as the focal point for consultancy and contract professional services, extending both the reach and impact of our research. Alongside this, academics participate in collaborative consultancy with industry and this has led to extended studies in areas of novel psychoactive substances (with Trading Standards, Baron), precious metal recovery (Gonzalez-Rodriguez), forming the basis of our Impact Cases and in conservation science (Colston). The School also provides broad support for its spin-out company, Metnano, a joint venture between Lincoln and the BHR Group for metallic nanoparticle products. Our scientists have

provided consultancy for product development and QA systems (Baron, Reiss), while our CRO provides on-going QC services for production batches.

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

4.1 Research Collaborations, networks and partnerships

Significant international collaborations have resulted in joint publications and on-going research collaborations including Catalan Institute of Research and Advanced Studies (Gil-Ramirez, Adriaenssens), University of Malaga (Gonzalez-Rodriguez), University of Utah (Johnson), Ludwig-Maximilians-Universität München (Wuttke); Tohoku University (Lear), UPMC Univ-Paris 06 (Kyne); University Chemical Technology, University chemical Technology Prague (Munshi); Riken Institute (Turyanska), Philipps Universitat Marburg University of California-Berkeley (Wuttke) . Additionally, Lear was appointed as Adjunct Professor at Tohoku University (2014-19, Japan), Wuttke is Visiting Lecturer, Ludwig-Maximilians-Universität München and at University of California, Berkeley, Munshi is Visiting Professor at Shanghai Institute of Technology and Zhang is Visiting Professor at Hunan University of Technology.

4.2 Relationships with users, beneficiaries and society

Researchers in the School are pro-active in developing activities to establish the direct impact of the School's research capabilities in social and commercial contexts and to engage effectively with regional, national and international communities to inform and direct research, and thereby enhancing the School's future influence and relevance in national and international communities. Significant industrial collaboration underpins the School's strategic direction and several collaborative R&D projects with regional and national industries have been undertaken in the period: for example, RB (characterisation of piezoelectric materials), Luxus (recycled plastics), Astra Zeneca (crystallisation of pharmaceutical materials, with School of Pharmacy), GSK (development of pharmaceutical API salts, with School of Pharmacy), Piramal (process development of pharmaceutical hydrates), British Chlorophyll (development of protein extraction), Dupont (speciation of degradants), Grimley Smith Associates (precious metal extraction).

To further the influence of the establishment of a School of Chemistry in the region, we have sought to attract research symposia to the University. To date, these include the Bruker Single Crystal User Group Meeting (2015), RSC Thermal Analysis Interest Group Meeting (2016); Suspensionology - an industry consultancy/workshop (2015, 2017)); Annual Meeting of the EU Crystallize COST Action CM1402 group (2017), involving scientists from 27 different countries, the Materials Chemistry Consortium (2018); East Midlands Proteomic Workshop (2018); and RSC-sponsored regional Organic and Biomolecular Symposium (2018) and the RSC Macrocycles and Supramolecular Chemistry Young Persons Symposium (2019), Nanotechnology Workshop (2020) (bridging the gap between idea, innovation and enterprise organised across four schools (co-organizer Scowen with Pharmacy, Chemistry, Physics and Engineering), which ran for the second time in 2021 with research students attending virtually from across the globe.

The Bridge initiative targets a variety of interactions with partners (see above). In parallel with its R&D business support objectives, there is a strong impetus from its directing industry consortium to invigorate the engineering community in the region. In response, The Bridge will host expert seminars and community clinics amongst other community events throughout the programme. The inaugural expert seminar event attracted 70+ on-line attendees.

4.3 Wider Contributions to research base

In keeping with our objectives to establish our engagement with national and international research communities, the majority of academics are pro-active in refereeing with leading journals (ACS, RSC and Wiley). We have established representation on editorial boards: Wuttke serves on the Editorial Advisory Board for Advanced Functional Materials and edited a special

edition in 2020; Gathergood is Associate Editor for ACS Sustainable Chemistry and Engineering; Gonzalez-Rodriguez is Editor of journal Open Chemistry (de Gruyter). Lloyd was co-editor for a special issue of CrystEngComm - 'Supramolecular Gels in Crystal Engineering' (2015).

Similarly, the School's academics are playing an increasing role in grant review: e.g. (i) Scowen, SFI (Ireland) Research Infrastructure (2018); (ii) Colston, Member EPRSC College (2016-); British Council (Newton) Reviewer (2018-), EU-JPICH (Joint Programming Initiative in Cultural Heritage) Reviewer (2018-), The Netherlands' Research Council peer-reviewer, NWO (Council for the Humanities of Netherlands Organisation for Scientific Research) (2014-) Association of Commonwealth Universities Promotions Reviewer (Professorial) (2014-) EPSRC CDT (short-listing panel (2018)(iii) Gonzalez-Rodriguez, EU Horizon 2020 (2014-), International Training Network-Secure Societies (2017, 2016), Marie-Curie (2017-), Member EPRSC College (2016-), Portuguese FCT (2017, 2018); (iv) Gil-Ramirez Associate Member EPRSC College, (2016-); (v) Lear, Member EPRSC College (2017-). Lear and Gonzalez-Rodriguez received commendations for their contributions to grant review from EPSRC in 2019 (vii) Munshi, Leibniz Association (Germany), Innovation Fund (Denmark).

In line with its objectives to introduce the new School to the wider UK community and raise its profile, we have attracted a number of national research group meetings to the University. To date, these include Bruker Single Crystal User Group Meeting (2015), RSC Thermal Analysis Interest Group Meeting (2016); Suspensionology - an industry workshop (2015, 2017); the Materials Chemistry Consortium (2018); East Midlands Proteomic Workshop (2018); and RSC-sponsored regional Organic and Biomolecular Symposium (2018) and the RSC Macrocycles and Supramolecular Chemistry Young Persons Symposium (2019).

Outreach to schools and colleges enhances the wider societal relevance of the University's research environments. Funded programmes operating in the School include: RSC Spectroscopy in a Suitcase programme (Munshi, 2016-) providing school students with hands-on experience of spectroscopic equipment; the Newton Academy for Girls that provides Saturday morning science and technology-themed workshops for school-age girls (Colston, 2014-); Discovery Science for Teachers (RCUK) providing hands-on experience of structural science methods in Chemistry and Biology for school teachers (Blagden, Scowen, Taylor, 2015). Importantly, the research environments play a crucial role in the hands-on experience we offer to local Schools and Colleges – e.g. use of our 500 MHz NMR facilities. Additionally, the School contributes to University-wide large city-based events such as LiGHT Nights (a €130k Marie Sklodowska Curie funded European Researcher Night).

4.4 Closing Comments

Establishing chemistry at Lincoln has transformed the research landscape of the University and the region. We are seeing the growing influence of these developments with increasing leadership shown by our academics in their respective fields and significant benefits derived for our commercial and social partners. From a standing start, the progress in chemistry has been remarkable and we now have a strong and sustainable base for the subject in the University that is led by our research. We are ambitious to extend the influence of our research in chemistry for the future and are well set to develop from this base.