Research Consulting

Insights from REF2021

An analysis of the impact of chemistry research submitted to REF2021

Prepared for The Royal Society of Chemistry

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Insights from REF2021

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Foreword from The Royal Society of Chemistry

This report presents an interrogation of the submissions from UK chemistry departments to the Research Excellence Framework (REF) chemistry unit of assessment (UOA8). It highlights insights from the REF impact and environment submissions that evidence contributions of UK chemistry to science, society and the economy. It aims to complement, not replicate, the work of Panel B-8 and is structured around themes important to us and our community.

Chemistry research and innovation underpins a vast range of solutions for a healthier, more sustainable world and a stronger economy: developing new medical products, drug treatments and diagnostic technologies; creating advanced materials; turning waste into products; and so much more.

University chemistry departments in the UK play an important role in this, as is evidenced in the case studies that they submit to the Research Excellence Framework (REF) every 5-7 years. While confined by the REF boundaries, these case studies present a rich source of information on the various impacts of chemistry research at UK universities.

Chemical scientists provide solutions to national and global challenges through developing technologies and processes in material science, catalysis, electrochemistry and medicine, among other fields. Our Science Horizons report showed that this is true globally and evidence from the REF suggests chemistry researchers in the UK play a leading role in the interdisciplinary collaborations that make these breakthroughs happen.

Chemistry research at UK institutions, whether in the chemistry departments reporting to UOA8 or in other departments, also results in significant economic contributions including through the creation of spinouts and new jobs and the development of new products and processes. Industry collaborations are wide-spread and often lead to productivity gains and cost savings in the short term. Impacts such as the development of sustainable manufacturing processes or new diagnostic technologies take much longer to materialise. This chimes with the findings in our Igniting Innovation report that emphasised the unpredictability of chemistry innovation – it can take many years for research and development to lead to new products and processes that improve our lives.

UK chemistry departments are making real efforts to create the environment and conditions that best enable quality science and innovation, with a substantial focus on inclusion and diversity as well as staff and student development. This is an area where we are proud to have taken a leading role in supporting the chemistry community through our rich Inclusion & Diversity work.

The findings and examples in this report articulate some of the great chemistry research and innovation happening at UK universities. They are an addition to our evidence base and will strengthen the RSC's ability to make a compelling case for the value and contribution of the chemical sciences to making the world a better place.

Dr Jo Reynolds
Director Science & Communities, Royal Society of Chemistry

Executive Summary

This report considers the features of the chemistry submissions to REF2021. It provides an aggregated view and provides examples that consider the impact from, and research environment for, chemistry research in the UK.

The Research Excellence Framework assesses the quality, scale and impact of research undertaken across UK higher education institutions

The Research Excellence Framework (REF) is an assessment conducted every 5-7 years to evaluate the quality, scale and impact of research performed in UK higher education institutions. REF2021, the most recent assessment, involved three main elements of assessment: outputs, impact and environment. This report focuses on UOA8 – Chemistry, one of 34 subject-specific units of assessment evaluated by REF. Through an analysis of REF impact and environment submissions, the report provides an aggregated view of chemistry's contributions to the UK and beyond.

The approach has been guided by specific areas of focus outlined by the RSC

Our approach to this project has been guided by specific areas of focus outlined by The Royal Society of Chemistry to contribute to their understanding and communication of the value of chemistry research.

- Firstly, *capability and characteristics* which includes themes such as collaboration, interdisciplinary and intersectoral research; resourcing and capability; and the culture of chemistry research.
- Secondly, *contribution* which considers chemistry's contribution to knowledge generation, transfer and translation to impact, science and technology priority areas, global challenges and local areas and communities.

The evidence base for this report is the publicly available impact and environment submissions for UOA8

This report is based on the analysis of publicly available REF2021 UOA8 impact and environment submissions. This evidence base comprises:

- 113 impact case studies; and
- 40 environment statements (including 1 joint submission).

It is important to note that not all submitted impact case studies were published. Of the 139 submitted, 26 were confidential and were not published.

Key insights and case studies are highlighted

The key insights resulting from this study are highlighted below. They cover the capability and characteristics, and the contribution of UK chemistry research to society, economy, and the environment. A series of case studies are also highlighted through the report, illustrating impacts across a range of research areas and sectors.

Extensive investment into resources and capability for chemistry research

The analysis shows significant investment into chemistry research. Total research income from external funding sources of £1.65bn over the REF2021 period. However, when looking at the average yearly funding between REF2014 and REF2021, in real terms the amount is relatively flat. The picture is mixed for individual universities, with 34% seeing their overall income rise in real terms.

Other investment is evident including new (and reopened) chemistry departments, new and refurbished buildings, and capital equipment all being showcased across the REF2021 submissions.

Looking more closely at the sources of funding for chemistry research, we can see different trends emerging. Chemistry departments have taken advantage of EU government funds for research, with this funding doubling from REF2014 to REF2021.

Less positively, there have been real terms falls in income from UK Research and Innovation (UKRI) and UK industry, with respect to REF2014.

Chemistry contributes to the UK economy in many ways, but the timelines for return on investment can vary

Of the case studies available for analysis, over 80% illustrate economic impact resulting from chemistry research. The return on investment for chemistry research is significant – with new companies, new jobs created, and investment across R&D leading to new products, processes, and technologies. The time between initial research and impact occurring varies with some impacts occurring on a short timescale, but other impact case studies show more than 10 years between the research commencing and the start of impact generation.

Chemistry research contributes to addressing global challenges

Chemistry research is underpinning impacts related to global challenges covering areas such as healthcare, environment, and sustainability. Chemistry is the backbone of many interdisciplinary collaborations that are working towards national and global challenges. A series of national interdisciplinary institutes, some with chemistry leadership, are developing technologies and processes in materials, catalysis, electrochemistry, biology and medicine.

In addition, chemistry departments are developing more sustainable lab practices, looking to more energy and water efficient facilities, and looking at ways to reduce waste and recycle more.

Chemistry departments have made good use of place-based funding and built connections with their local areas

Chemistry departments have taken advantage of EU place-based funding to invest in new buildings, upgrade equipment and facilities and to enable innovation projects with SMEs. Partnerships with local companies are also evidenced, with co-location of chemistry research departments on local science parks also noted. Outreach to local schools and public engagement activities are also widely showcased.

Chemistry research is highly collaborative, across sectors, disciplines, regions and nations

Chemistry is a hugely collaborative subject with over 800 different organisations mentioned across the impact case studies. Industry collaborations are widespread, from smaller connections through in-house innovation spaces and Knowledge Transfer Partnerships, through to collaborative research with multinational companies, and across a wide spectrum of sectors and activities.

Interdisciplinary collaborations are also high, mostly with STEM related subjects but interestingly also with subjects across the Arts and Social Sciences.

Chemistry researchers across connect internationally and nationally through a variety of different mechanisms: collaborative grants, doctoral training programmes, sabbaticals and visiting researcher programmes, strategic partnerships and regional university networks

Efforts being made to improve research culture within chemistry departments

The promotion of diversity and inclusion is a focus for chemistry departments and efforts are in place to attract a more diverse section of society to the chemical sciences and to showcase positive role models. The number of Athena SWAN awards across the UOA8 submissions evidence these efforts.

Staff development opportunities are widely described in the environment statements for staff at all levels, with support for ECRs, Postdocs and PhD students most widely evidenced. The critical role of technical staff is also recognised.

Contents

1. Introduction

The Research Excellence Framework (REF) is an assessment conducted every 5-7 years to evaluate the quality, scale and impact of research performed in UK higher education institutions. This report focuses on UOA8 – Chemistry, one of 34 subject-specific units of assessment evaluated by REF. Through an analysis of REF impact and environment submissions, this report provides an aggregated view of chemistry's contributions to the UK and beyond, through the lens of REF.

1. Introduction

1.1 Background and introduction

The Research Excellence Framework assesses the quality, scale and impact of research undertaken across UK higher education institutions

The Research Excellence Framework (REF) is a periodic assessment undertaken to assess the quality, scale and impact of research undertaken across UK higher education institutions (HEIs), as well as the environment in which this research is conducted. The results of the assessment directly guide the allocation of ~£2.5bn per year in 'quality-related' (QR) funding, through annual block grants to HEIs from Research England (and equivalent bodies in Scotland, Wales and Northern Ireland), and indirectly influences decision making of the wider UK funding bodies. REF is assessed across 34 subject specific units of assessment (UOAs), with this report focussed on that of UOA8 – Chemistry.

REF2021, the most recent assessment, involved three main elements of assessment: outputs, impact and environment. Each UOA submits against all three elements, with the size of the submission dependent on the number of staff submitted. Their weightings within the overall assessment were Outputs 60%, Impact 25%, Environment 15%.

The impact element of REF2021 was assessed via a series of impact case studies showcasing the submitting universities' most impactful research across the assessment period. The environment element was assessed via a series of data submissions (Research doctoral degrees awarded, Research Income and Research income-in-kind) alongside a narrative element, the environment statement. The environment statement included information about the submitting universities' strategy and resources to support research and enable impact.

The outputs element was assessed via the submission of up to five outputs (mostly journal publications) per academic staff member, with an overall average of 2.5 outputs per staff member across the UOA. For the purposes of this report, the outputs element is out of scope and has not been analysed.

REF2021 covered the period from July 2013 to December 2020, with aspects of the submission delayed due to the Covid-19 pandemic. Results, delayed from December 2021, were released in May 2022.

The aims of the project and details of the outputs

The aim of this review has been to interrogate the available impact case studies and environment statements from UOA8 Chemistry to contribute to the understanding of the value of chemistry research across the UK. By undertaking an in-depth analysis of these documents this publicly available report has been produced which provides The Royal Society of Chemistry with information they can use to showcase chemistry's contribution to society, the economy and the environment, through the lens of REF.

1.2 Approach and methodology

The approach looks for evidence relating to capability and characteristics of chemistry research, and to illustrate the contribution of chemistry research

In our approach to this project, we have been guided by specific areas of focus outlined by the Royal Society of Chemistry to contribute to their understanding and communication of the value of chemistry research.

Firstly, *capability and characteristics* which includes themes such as collaboration, interdisciplinary and intersectoral research; resourcing and capability; and the culture of chemistry research.

Secondly, *contribution* which considers chemistry's contribution to knowledge generation, transfer and translation to impact, science and technology priority areas, global challenges and local areas and communities.

A two-stage methodology was used for this project, with an initial screening review of the data carried out to gain an overview of the content and the extent of evidence. This informed the coding structure for the second stage, a deep dive analysis using NVivo software to undertake thematic coding. Aggregated data from the coding has been used to generate this report and select the examples.

The evidence base comprises the published UOA8 impact and environment submissions

REF2021 was primarily a retrospective exercise, looking back over the previous 7 years since REF2014. This report is based on the analysis of published, and hence publicly available, REF2021 UOA8 impact and environment submissions. This evidence base comprises:

- 113 impact case studies; and
- 40 environment statements (including 1 joint submission).

It is important to note that not all submitted impact case studies were published. Of the 139 submitted, 26 were confidential and were not published.

UOA8 accounts for the majority, but not all of the chemistry researchers in the UK's higher education institutions

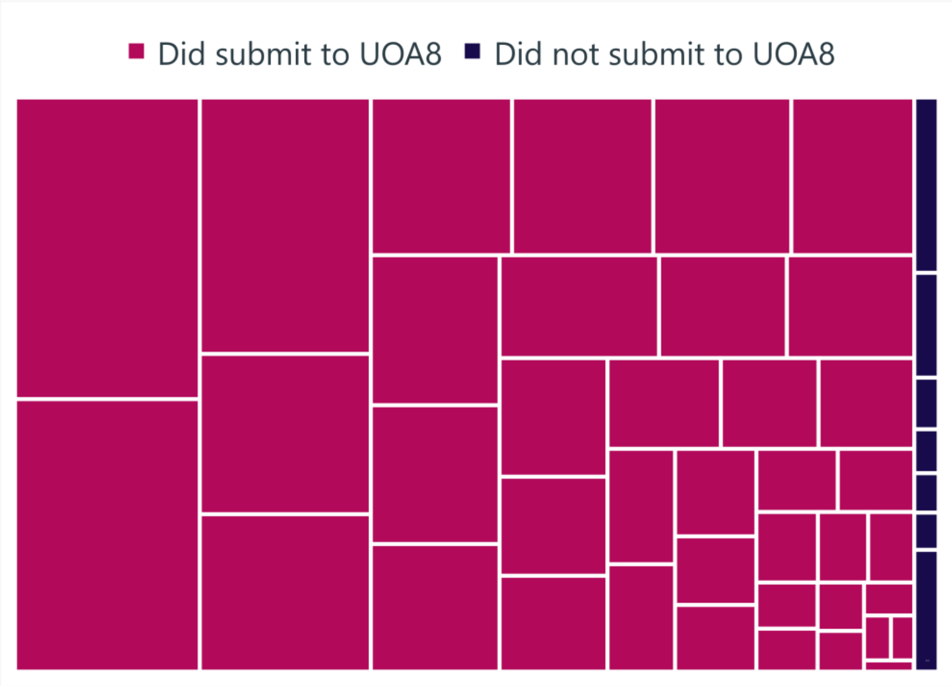
It should be noted that not all academic staff undertaking chemistry research within UK higher education institutions will have been submitted to UOA8. In some cases, chemistry researchers make up part of a wider department that may have submitted to a different REF UOA, for example UOA3 (Allied Health, including Pharmacy – e.g. University of Northumbria) or UOA12 (Engineering – e.g. Nottingham Trent University, Manchester Metropolitan University).

Analysis of Higher Education Statistics Agency (HESA) funding data suggests that out of 61 universities who declared 'chemistry' research grant and contract income for 2019/20, there are 21 who did not submit to UOA8. Figure 1 shows the small proportion of the overall research grant and contract funding that is attributed to those universities not submitting to UOA8. Chemistry research submitted outside of UOA8 has therefore not been considered in this report.

Figure 1. The relative scale of 'chemistry' research grant and contract income (2019-20) for all UK universities

Each block represents one university, differentiated by whether they submitted to UOA8 in REF2021 or not. The area of each block is proportionate to that institution's research grant and contract income in 'chemistry'.

Source: HESA Research grant and contract income



Understanding the structure of impact case studies and environment statements

Impact case studies (ICS) aim to showcase the impact emerging from research undertaken in each submitting UOA. The underpinning research that contributed to an ICS can go back 20 years and eligible impact is looked at from 2013 to 2020. The tightly defined REF guidelines and eligibility criteria mean that some impacts do not qualify for submission. In addition, a specific number of case studies are provided per submission, determined by the staff FTE (full time equivalent) submitted. REF is not designed to be fully representative of all impacts and those case studies submitted are likely to be those which most closely fit the eligibility requirements and were anticipated to score highly.

The UOA8 submissions showcase a broad range of impact case studies spanning economic, health, environment, policy, social and public engagement.

The environment statements include wider acknowledgement of impact as part of highlighting the research and impact strategy of the submitting unit. This is complemented by insights on staffing strategy and staff development, income, infrastructure and facilities and finally collaboration and contribution to the research base.

The very specific REF criteria and limitations on submissions mean that this report can only present a partial view of chemistry research

Every five to seven years, UK chemistry departments submit a set of case studies and narratives evidencing the impact of their research and the supportiveness of their research environment to the REF. While the selection of these examples is by no means representative of all chemistry research that takes place at universities, it is a rich data set that showcases some of the great work that takes place at UK chemistry departments.

Because of the significance of the REF assessment (i.e. results determine QR funding), submitting universities showcase what they perceive to be their strongest REF-qualifying impacts and are looking to demonstrate positive aspects and progress in their research environment. REF is not designed to capture and present the challenges and issues of chemistry departments, and these are only highlighted where positive progress can be showcased.

As previously noted, 26 ICS are confidential with many more having text redacted, limiting some aspects of the analysis. This report is therefore based solely on the information included within the UOA8 impact and environment submissions as they have been made available via the REF2021 results website. The submissions are taken at face value, with no further confirmation of statements made within them, and no judgements on quality.

With its focus on concrete examples, this report should be read as a complement to the REF's own Panel B report, produced as part of the REF process, which includes an overview and observations about the state of chemistry research in the UK.

Acknowledgements

We are grateful to the members of the Advisory Group for their helpful comments and suggestions.

This report is written by Research Consulting, guided by the RSC and members of the Advisory Group. The insights in the report do not necessarily reflect the views of the individuals represented on the Advisory Group. Responsibility for any inaccuracies or errors lies with the authors alone.

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2. An overview of chemistry research in the UK

Across the 7 years of the REF2021 period, chemistry departments submitting to UOA8 secured £1.65bn in research funding. This section also outlines investment into UK chemistry research including the expansion of chemistry departments and capital equipment and facilities, both in-house and in shared national facilities. While the overall funding for chemistry research appears to have increased since REF2014, when taking inflation into account, chemistry research funding remains relatively flat.

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2. An overview of chemistry research in the UK

REF2021 period sees large investments in infrastructure but research funding, in real terms, remains flat

The analysis of REF2021 UOA8 impact and environment statements provide an overview of chemistry research in the UK during the period 2013-2020. There is evidence of widespread investment in capital infrastructure and positive progress in diversification of research incomes to be less reliant on individual funding sources. The data indicates an increase in research funding from REF2014, however considering inflation over the period, in real terms research funding has remained relatively flat.

During the REF2021 period, chemistry secured £1.65bn in research funding

Every UOA8 submission describes investment into their research – ranging from increases in staff and PhD students, through new and upgraded equipment, to in some cases new buildings to support the growth in chemistry research. Total research income from external funding sources (including government bodies, charities and industry in the UK and globally) over the REF2021 period is £1.65bn. The actual investment figure is likely higher due to internal funding from the universities themselves.

2.1 Investment in chemistry research infrastructure

Major investments during the REF period led to new and reopened chemistry departments

There are several instances of investment by individual universities leading to new and reopened chemistry departments (Table 1.Table 1.), and in other cases increased research and innovation capacity, where previously undergraduate teaching was the main focus (e.g. University of Bradford). In contrast, the University of Bangor's chemistry department closed during the REF2021 period, and they did not submit to UOA8.

Table 1. New and reopened chemistry departments by year

New or reopened chemistry departments	Year opened
King's College London (reopened)	2012
University of Chester (UOA8 submission part of new Faculty of Science and Engineering)	2013
University of Lancaster	2013
University of Lincoln	2014
University Swansea (reopened)	2016

Several universities invested heavily in new buildings

Alongside the new chemistry departments, several universities have invested heavily in new and refurbished buildings for their chemistry researchers, for example Imperial College have invested £170m in a Molecular Science Research Hub which houses the research labs of the chemistry department, alongside other related departments[ES3]; Loughborough University moved their entire chemistry department into new purpose built facilities, part of a £59m investment into science, technology, engineering and mathematics (STEM) research[ES5], and the University of Glasgow has invested £17m in refurbishing the Joseph Black building simultaneously preserving the iconic architectural heritage of the building whilst providing state-of-the-art facilities for chemical research[ES19].

Investment in capital equipment is widespread with state-of-the-art equipment highlighted

In-house equipment is showcased across the environment statements and it is clear that there has been widespread investment into capital equipment, with chemistry departments ensuring their researchers have access to equipment and facilities to meet their research needs. Several environment statements highlight equipment or facilities described as state-of-the-art, for example the University of Hull chemistry department hosts one of the few research dedicated Positron Emission Tomography (PET) centres in the UK[ES22], and the University of Liverpool have a bespoke Radiomaterials Chemistry Laboratory[ES28]. The availability of equipment for use by other universities and industry collaborators is also evident.

Use of national shared facilities is widely evidenced

It is also widely evidenced that chemistry researchers are making good use of shared facilities available across the UK. Over 90% of the environment statements reference researchers accessing the Diamond Light Source (DLS) at Harwell and over a third reference the UK's High-Performance computing (HPC) capabilities, e.g. ARCHER. In fact, not only are chemistry researchers using these shared facilities, they are also helping to expand the range of facilities available to users as evidenced by, for example, the University of Reading impact case study which describes the development of the B07 Versatile Soft X-ray beamline at DLS[ICS56].

2.2 Staff and PhD student numbers increase

Investment in ECRs and expansion of research areas including digital chemistry

The number of staff submitted to REF2021 was 1,560 (1,502 FTE) an increase of 23% compared with REF2014. Most of this increase is likely due to the changes in the REF rules for staff submission and the increased numbers of chemistry departments submitting to UOA8. However, the environment statements show clear cases of investment in Early Career Researchers (ECRs) and expansion of certain research areas (including chemical biology, materials chemistry, energy, nanotechnology and computational chemistry). A new area of 'Digital Chemistry' is starting to feature in the future planning of some universities with the University of Glasgow having invested £5.5m over recent years[ES19] and the Universities of Nottingham[ES31] and Southampton[ES35] also noting this as a future area of investment.

7,356 completed PhDs in chemistry

A total of 7,356 completed PhDs in chemistry were reported under UOA8 in REF2021. The average number of PhD completions per year was 1,051 per year, a 10% increase on the yearly average for REF2014 (947). Across the UOA8 submissions, 58% of institutions saw an increase in PhD completions (this figure does not include the new chemistry departments outlined in Table 1). Some universities note that their increase in chemistry PhD students is related to uptake within their Centres for Doctoral Training (CDTs). Other sources of doctoral funding described in the environment statements include: EU Innovative Training Networks (ITNs) and Erasmus Mundus PhD programmes, Industrial CASE awards, direct industry funding (often as part of departmental match funding schemes), and in some places philanthropy.

2.3 Research income over the REF2021 period

Taking inflation into account, the overall picture for chemistry funding is relatively flat

The overall funding for chemistry research reported to REF2021 is £1.65bn and when looking at the average annual incomes for REF2014 (£179.6m) and REF2021 (£235.7m) this appears to have increased, however when taking inflation into account, in real terms the picture is relatively flat[1].

For individual universities the picture is mixed, with only 34% seeing their overall income rise in real terms (this figure does not include the new chemistry departments outlined in Table 1).

Institutions have significantly diversified funding sources between the latest REF exercises

Looking more closely at the sources of funding for chemistry research, we can see different trends emerging. Overall chemistry departments have diversified their portfolios of funding for research.

Large (inflation beating) increases in funding from EU government bodies (e.g. research funding such as that from Horizon 2020), non-UK industry and UK charities are evident. Less positively, these have made up for real terms falls in income from UK Research and Innovation (UKRI) and UK industry, with respect to REF2014.

Most notable of the increases in funding is that from EU government bodies, which has increased from an average of £25m per year in REF2014 to an average of £50m per year in REF2021. In those chemistry departments seeing an increase in their funding in real terms, for the majority the biggest reason for this is an increase in funding from EU government bodies. However, it should be noted that this success in engaging with EU research programmes over the REF2021 period is likely to have reversed in the years post REF2021, due to the UK leaving the EU and the uncertainty regarding association to Horizon Europe.

There is also evidence of universities securing philanthropic donations to support chemistry research in the environment statements e.g. the University of Cambridge is using philanthropic donations to fund a series of 'Next Generation Fellowships' for ECRs[ES15] and at University of York PhD studentships have been funded through similar routes[ES40].

[1] The Bank of England Inflation Calculator suggests an inflation rate from 2008 to 2020 of 28%.

3. Economic impact from chemistry research

Of the 113 impact case studies analysed, over 80% illustrate economic impact underpinned by research undertaken by UK chemistry departments in the qualifying period. Examples of economic impact include the growing number of spin-outs that have emerged from chemistry research, the creation of highly-skilled jobs and cost-saving manufacturing practices that benefit industry. Although the economic impact of chemistry research is clear, it should be recognised that the timeframes for achieving impact are variable and due to the nature of chemistry research and its benefits, some impacts can take many years to be realised.

3. Economic impact from chemistry research

Chemistry research contributes to the UK economy

Understanding how research is contributing to the UK economy and showcasing a return on investment is increasingly important at a time when UK government spending on R&D equates to a lower percentage of GDP than other research active nations[2]. Through our analysis we have looked at the different ways in which chemistry research is having an economic impact and therefore contributing to the UK economy and society. Timescales for return on investment are also highlighted as these can range from a few years to decades.

Over 80% of analysed impact case studies illustrate some form of economic impact

Of the 113 impact case studies analysed, over 80% show some form of economic impact, whether that be incorporation of new companies (e.g. university spin-outs), creation of highly skilled jobs, commercialisation of research (e.g. via patents), industry investing in research and development (new technologies, new processes, new products on the market), or cost savings for companies.

Around a third of the case studies referring to economic impacts have details redacted and this limits the analysis and the examples that can be highlighted. This is in addition to the 26 ICS that are confidential (highlighted previously in Section 1.2) and have not been released into the public domain. These confidential case studies are most likely to be related to commercial impacts. For example, all ICS from the University of Birmingham are confidential; however, their environment statement suggests that these showcase impact from two spin-out companies, Irresistible Materials and NitroPep, and a long-standing collaboration with Proctor & Gamble[ES12].

3.1 Growing number of spin-outs leading to creation of highly skilled jobs

REF2021 identifies 45 spin-outs based on chemistry research, of which 26 were created during the REF2021 assessment period

Chemistry research is underpinning the growth of new companies with the impact case studies showcasing 26 newly created spin-out companies (within the REF2021 assessment period). Impacts from a further 19 spin-outs, launched prior to the REF2021 period, are also evidenced across the case studies. As discussed later, the environment statements mention further spin-outs launched over the REF period, beyond those showcased in the case studies.

The spin-outs cover a wide variety of areas: drugs and therapeutics, diagnostics, graphene and other new materials, fuel cells, medical technologies, circular economy technologies. Examples are shown in Case Study Box A.

Case Study Box A

Spin-out companies

Aqdot, spun-out from the University of Cambridge, has developed a range of products based on encapsulation technology, including the odour-erasing household product 'Oderase' and an agrochemical product used to increase crop yield, Acticote[ICS74].

[2] OECD Main Science and Technology Indicators, March 2022. https://www.oecd.org/sti/msti-highlights-march-2022.pdf

Bramble Energy Ltd, spun-out form Imperial College London has developed hydrogen fuel cells which can be manufactured at high volume and has partnered with users across a wide range of areas in developing new products[ICS11].

Applied Graphene Materials plc, spun-out from the University of Durham, supplies graphene for products developed by a wide range of commercial partners across the automotive, aerospace and materials sectors[ICS80].

Spin-outs are diverse with a range of types, founders, and longevity

There is also evidence of start-up companies being launched to commercialise the use of in-house facilities and equipment and generate knowledge exchange activities. Examples include the University of Sheffield start-ups Farapack Polymers and Sheffield Synthesis Solutions[ES34], and the University College London start-up Finden Ltd, which provides analytical services related to industrial catalysts[ES3, ICS61].

Notably, there are also successful spin-outs co-founded by postgraduate students, for example at the University of Bristol a postgraduate student was part of the group who set up the company Ziylo in 2014 to commercialise new glucose receptors for use in devices monitoring insulin[ICS68]. Ziylo was acquired in 2018 by Novo Nordisk, with funds from the sale being used to create a new incubator facility UnitDX offering facilities for chemistry and biotech start up in the Bristol region.

Impact case studies also evidence the success of long-standing spin-out companies, launched prior to the REF2021 period, with examples showcasing substantial growth and successful flotation on the London Stock Exchange, as shown in Case Study Box B.

Case Study Box B

Long standing spin-out companies

Oxford Nanopore spun out of the University of Oxford is 2005, pioneering new technology for DNA sequencing[ICS91]. During the REF2021 period the company received over £500m in investment and in January 2020 was valued at £1.7bn. Headquartered in Oxford, they also have facilities in Cambridge (UK), Shanghai, Tokyo, Singapore, San Francisco, Boston and New York.

C4X Discovery spun out of the University of Manchester in 2007, with new technology to expedite drug discovery[ICS54]. The technology has delivered drug candidates significantly quicker that traditional methodologies, with lower toxicity and savings of up to 90% of the typical pre-clinical costs. In 2014, C4X Discovery was listed on the London Stock Exchange with a market capitalisation of £31m.

Spin-outs evidenced in impact case studies are likely to underrepresent the number actually created during the REF 2021 period

The environment statements also indicate a growth in spin-outs with evidence from some universities of multiple spin-outs over the REF2021 period, more than could be showcased in their impact submissions. In addition, there are likely to be further spin-out companies showcased in the 26 ICS that remain confidential, as noted above.

Research in chemistry has led to the creation of c.2000 jobs

Spin-out companies are where approximately half of the c.2000 new jobs evidenced across the ICS have been created (mostly within the UK). The other half are created within clean technology start-ups set up through a successful accelerator programme, Climate KIC, pioneered by Imperial College London and their collaborators[ICS9].

There is also evidence in the ICS that chemistry research has had a wider role in the downstream securing of over 40,000 jobs, at least half of which are in the UK. For example, Ilumina Inc employ over 7000 employees worldwide and have revenue exceeding $3b per annum. Their business is almost entirely based on Solexa Sequencing technology, developed at the University of Cambridge [ICS70].

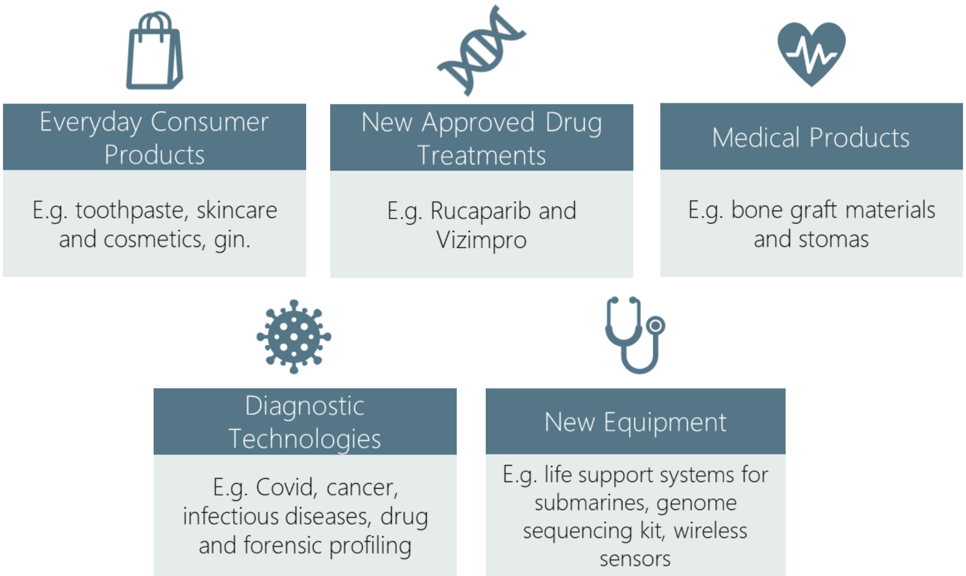
3.2 Chemistry research benefitting industry

Industry research and development efforts are underpinned by chemistry research

Chemistry research with universities is underpinning investment in research and development (R&D) in companies through commercialisation and partnerships. Around half the cases studies showcase new technologies and products, evidenced across a wide range of sectors and highlighted in Figure 2. Examples of the types of products and technologies which have been underpinned by chemistry research. These include everyday consumer products, medical products, new approved drug treatments, diagnostic technologies, and new equipment. A particular example which highlights the return on investment of chemistry research is that of the development of the ovarian cancer drug rucaparib at the University of Newcastle[ICS88]. At the time of the REF2021 submission, the drug had total sales figures of $375m.

With the REF2021 period covering the start of the Covid-19 pandemic, it is notable that 12 impact case studies directly reference impacts related to Covid-19 activities, most notably in the area of diagnostic test development.

Figure 2. Examples of the types of products and technologies which have been underpinned by chemistry research



Industry partnerships are common with a variety of industry types and sizes

Over 40% of ICS reference partnerships with industry as part of the pathways to impact, these range from strategic partnerships with multinational companies through to Knowledge Transfer Partnerships often with smaller local companies (further discussion of KTPs is in Section 6.2). Example partnerships are shown in Case Study Box C.

Case Study Box C

Industry partnerships

The strategic partnership between the University of Durham chemistry department and Proctor and Gamble (P&G) is wide ranging covering various research areas and resulting in new technologies used across P&G's laundry and cleaning functions, with a further partnership between Durham, P&G and Reprocell Europe to commercialise novel human skin models for use in testing new products[ICS77].

The International Centre for Brewing and Distilling at **Heriot Watt University** have developed a Scottish Botanical Library which has been used by partners such as **Edinburgh Gin** and **Highland Boundary**, to help understand the attributes of specific botanicals (flavour, mouthfeel etc) and in turn reduce product development time and process design time[ICS6].

Commercialisation and patent licensing is a common route to impact

Commercialisation and patent licensing is the pathway to impact of over 20% of ICS analysed. Examples of commercialisation activity are shown in Case Study Box D.

Case Study Box D

Commercialisation of research

A serendipitous discovery at **Loughborough University** revealed a highly sensitive new way of revealing fingerprints on various surfaces, which has since been commercialised and is in use by law-enforcements agencies worldwide[ICS15].

The **University of Oxford** have developed a series of electrochemical food sensors which can reliably detect a range of food analytes to measure for example chilli heat, garlic strength and ginger intensity[ICS92]. These sensors have been licensed to an electrochemical sensor manufacturing company, Zimmer & Peacock, and developed into commercial devices which are quick and easy to use.

Cost saving measures have been recognised through a range of mechanisms

While new products and technologies are helping to generate income for companies, the ICS also showcase cost savings measures. 21 (19%) of ICS evidence cost savings through a variety of methods, as showcased in Case Study Box E.

Case Study Box E

Cost saving measures

Reduced manufacturing costs via optimised processes, cheaper alternatives or open access protocols, e.g. new printing technology for microneedles reducing manufacturing costs by 50% (Swansea University[ICS24]).

Reduced costs for the National Health Service (NHS) via new services, reduced time for patients in hospital, cheaper treatments/drugs, e.g. new tools for radiopharmaceutical delivery leading to reduced prostate cancer screening delays at Guy's and St Thomas' Hospitals (Kings College London[ICS14]).

Reduced need for specialist instrumentation and experienced staff to operate, e.g. new low-cost methods for the detection of arsenic in rice, approved by the US FDA, and available to partners in rice growing counties such as Malawi (University of Aberdeen[ICS62]).

Avoidance of the need for specialist environmental waste solutions, e.g. a new manufacturing process for methyl methacrylate which does not use sulphuric acid and therefore avoids the need for acid recovery processes (University of Liverpool[ICS48]).

3.3 Timescales for impact

Timescales for impact from research can be long, but there is evidence of early

Timescales for chemistry research leading to impact can be quite variable as shown in Figure 3. The timescales can depend on various factors including the type of impact translation of research to impact

being generated – for example influencing strategic developments within industry tend to have shorter timescales, compared to bringing new products to market.

It should be noted that in most ICS the underpinning research continues as the impact starts to be generated and helps to drive further impacts. In only 5% of ICS does the research end prior to 2013 (the start of the eligible period for impact generation within REF2021).

Figure 3. Timescales from research to impact

The figure uses data inputted on the ICS regarding the date the underpinning research commenced and the date the impact started to be generated

← research to impact timescale →

<5 years	5-10 years	>10 years
35%	33%	32%

Shorter timescales to impact

In 35% of the ICS analysed, the impact has started to be generated within 5 years of the underpinning research being carried out, as shown in Figure 3. In these cases, the impact often relates to training of other scientists, industry collaboration leading to productivity gains, and the influencing of policy, as shown in Case Study Box F.

Although policy influence can happen on shorter timeframes, our analysis has shown that this can also take much longer, particularly when supporting global policy changes as highlighted in Case Study Box G.

Case Study Box F

Shorter timescales to impact

Training of other scientists e.g. bridging arts and science to transform A level teaching methods on spectroscopy (University of Bradford[ICS29]) and a MOOC in Industrial Biotechnology (University of Manchester[ICS55]).

Collaborative research with industry partners that has led to productivity gains, e.g. self-optimising flow reactors which have helped AstraZeneca accelerate pharmaceutical manufacturing processes (University of Leeds[ICS45]) and detailed analysis of volatile organic mixtures allowing Plastic Energy to optimise their plastic recycling processes (Loughborough University[ICS17]).

Influencing policy e.g. provision of evidence to underpin policy developments in preventing occupational cancer (Herriot-Watt University[ICS7]) and banning the outdoor use of neonicotinoid pesticides (University of Sussex[ICS109]).

Examples of longer timescales to impact

Examples of ICS where the impact has taken longer to be generated are mostly related to product development. It is widely known that new drugs can take 20-30 years from initial research to reaching the patient, and the analysis shows that other applications of chemistry research can also take some years to reach the market.

Over 35% of the case studies analysed draw on underpinning research dating back prior to 2005, this includes most of the case studies that are classed as 'continued' from REF2014. These 'continued' case studies may be underpinned by original research starting prior to 2000 (as per the rules of REF2014). While these case studies do include drug development related impacts, other areas where the impact has taken time to develop are shown in Case Study Box G.

It should also be noted that not all impact from chemistry research is planned. One such example relates to two decades of research carried out at the University of Bristol on aerosol science[ICS64]. The research was used during the Covid-19 pandemic to help understand the airborne transmission of viral aerosol particles during respiratory activities and generated important data used by the UK government in their Covid-19 planning.

The analysis suggests that research being conducted today may not show real world benefits in the short term and therefore when looking at return on investment, e.g. from government funding, it should be taken into account that impact timelines will vary.

Case Study Box G

Longer timescales to impact

New sustainable and environmentally friendly manufacturing processes for widely used chemicals such as methyl methacrylate (Cardiff University[ICS2], University of Liverpool[ICS48]) used in the production of Perspex.

Development of diagnostic technologies e.g. point of care tests for sexually transmitted diseases (University of Bath[ICS25]), lateral flow diagnostics for infectious viruses (University of East Anglia[ICS31]) and DNA sequencing technology used to detect viruses in public health emergencies such as Ebola, Zika and Covid-19 (University of Oxford[ICS91]).

Research in support of global policy developments e.g. related to the Montreal Protocol on substances that deplete the ozone layer (University of Cambridge[ICS71], University of Bristol[ICS65]), new anti-doping regulations in professional sport (King's College London[ICS13]), and driving changes in the petroleum industry (Queen's University Belfast[ICS21]).

4. Addressing global challenges

Research funders have increasingly prioritised global challenge and mission driven research. Chemistry has risen to these challenges, with many universities (and some chemistry departments) reorganising their research to map across to these challenges. This has been achieved through interdisciplinary research collaborations and the implementation of sustainable lab practices, among other approaches. This section also showcases impacts related to global challenges around health, the environment and sustainability.

4. Addressing global challenges

Global challenges and mission driven research are increasingly prioritised

The UN Sustainable Development Goals (SDGs) have become a call to action, highlighting global challenges that need to be addressed for the world to prosper. In the UK the wider political landscape for research has more recently focussed on strategic innovation plans, including a focus on some topics related to the SDGs, specifically health and wellbeing and net zero. As a result, funders have increasingly prioritised global challenge and mission driven research, with many universities (and some chemistry departments) reorganising their research to map onto such challenges.

While this section of the report focusses on global challenges, chemistry research impacts go beyond these areas also impacting on challenges at different levels, as showcased in other sections of this report.

4.1 Chemistry research addressing global societal challenges

Collaborating through interdisciplinary national institutes

Chemistry researchers have risen to these challenges, with the environment statements showcasing involvement across a range of newly funded multidisciplinary national institutes, set up in recent years to address specific global challenge themes by bringing together university researchers and industry partners. The themes of these institutes are shown in Table 1Table 2, with the universities involved in each institute shown in Figure 4. Note that the data in Figure 4 is taken from the submitted environment statements and the universities currently involved in these institutes may have subsequently changed.

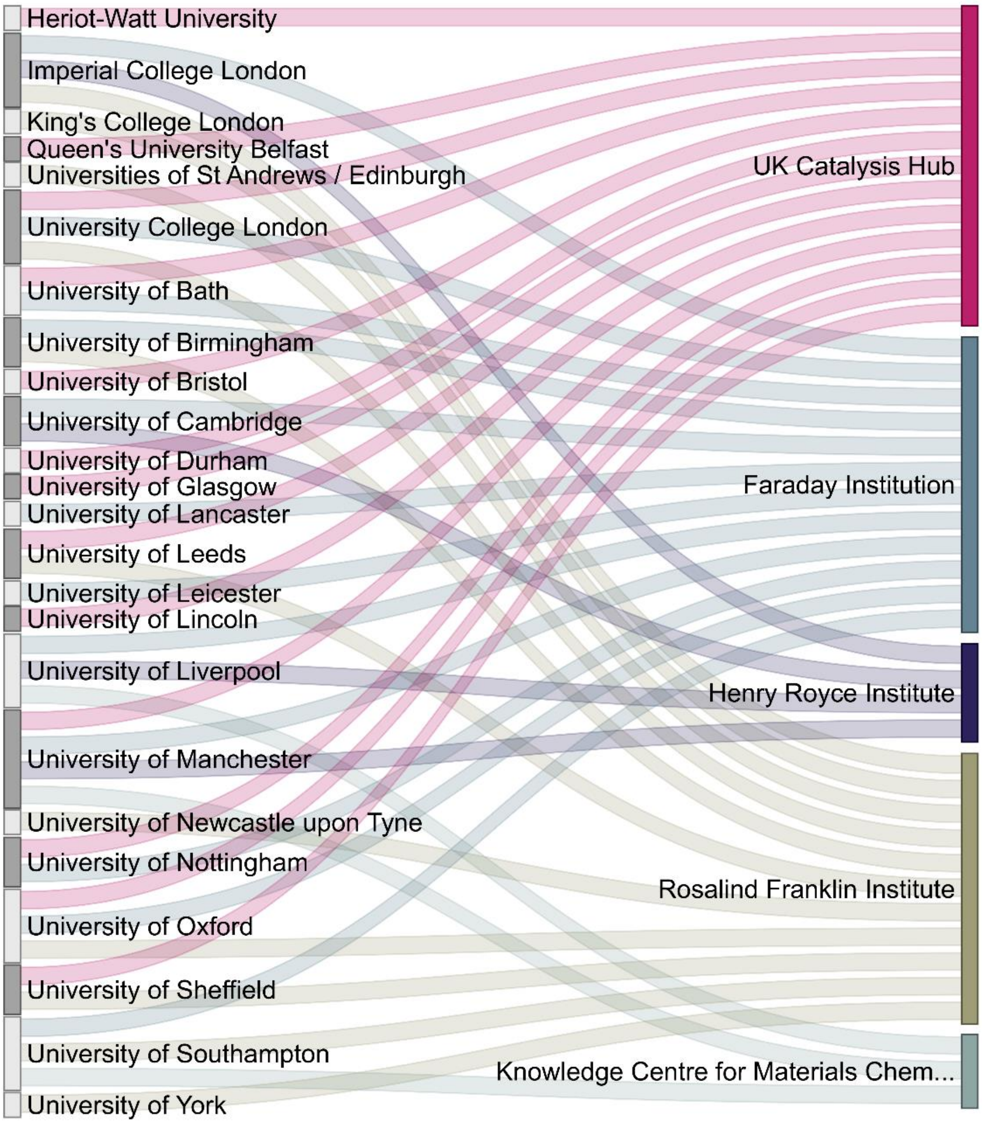
Table 2. UK interdisciplinary research institutes related to chemistry and their themes

UK National Institute	Theme
Faraday Institution	Electrochemical energy storage for improved batteries
Rosalind Franklin Institute	Technologies to tackle important health challenges e.g. infection and antimicrobial resistance
Henry Royce Institute	Advanced materials for a sustainable society
UK Catalysis Hub	Developing catalytic processes
Knowledge Centre for Materials Chemistry	Product and process innovations in advanced materials

Example project from the Faraday Institution on battery recycling

The University of Birmingham highlight an example project funded via the Faraday Institution in their environment statement[ES12]. The ReLiB project, led by Birmingham, uses new recycling and processing techniques to recover and re-use critical materials from end-of-life products. At the time of funding, this project was the largest public investment in electric-vehicle Li-ion battery recycling research globally.

Figure 4. The universities involved in the UK interdisciplinary research institutes related to chemistry, as referenced in the environment statements



Departments are restructuring to focus on addressing global challenges

What is also noticeable from the environment statements is that many chemistry departments have started to restructure their research groupings to focus on these global challenges. The Universities of Cambridge[ES15], Queen's Belfast[ES7], Kent[ES23], Reading[ES33] and Southampton[ES35] make specific reference to reorganising their chemistry research groups to address some of the UN SDGs (including good health and wellbeing, clean water and sanitation, affordable and clean energy, sustainable cities and communities, responsible consumption and production and climate action).

Sustainable laboratory practices are growing within institutions

Another area where chemistry departments are working towards global challenges is in developing more sustainable lab practices. Examples include the upgrading of fume cupboards to be more energy efficient, use of chemical tracking systems to enhance sharing and reduce waste, solvent recycling, and the use of air condensers to reduce water usage. Most notable is the University of Nottingham[ES31] who, in partnership with GlaxoSmithKline, have built a Carbon Neutral Laboratory, opened in 2016, which has been designed to reduce water and energy usage. Their environment statement notes that chemistry research being undertaken within the building has a focus on sustainable process development, and that wider learning on energy and water consumption is influencing the refurbishment of other buildings at Nottingham, with the aim of sharing tested solutions within the wider chemistry community to help others improve their existing facilities.

4.2 Societal impacts from chemistry research

Chemistry research impacts on everyday life in many ways

The impact case studies provide examples that evidence how chemistry research is impacting everyday life, through benefits associated to challenges related to healthcare, the environment and on sustainability.

Healthcare impacts include the development of new drugs

Several impact case studies relate to healthcare, including the development of new drugs in areas of unmet need. Case Study Box H gives three examples of this. As already highlighted in Section 3, there are also ICS illustrating healthcare impacts in relation to medical devices and diagnostic technologies.

Case Study Box H

Development of new drugs in areas of unmet need

A **new cancer drug**, Samuraciclib, in Phase II clinical trials for the treatment of resistant breast and prostate cancers (Imperial College London[ICS8]).

Development of **new drug candidates for Alzheimer's disease**, with lead candidate in Phase III clinical trials (University of Aberdeen[ICS63]).

Discovery of a **new class of compounds leading to a major new antibiotic**, Ridinilzole, to treat Clostridium difficile now in Phase II clinical trials (Queen's University Belfast[ICS20]).

Environmental impacts are showcased through informing policy change

With regard to the environment, there are a number of impact case studies which focus on supporting national and international policy changes.

The Universities of Bristol[ICS65], Cambridge[ICS71] and York[ICS112] have all carried out atmospheric chemistry research that has impacted on the continued development and ratification of the United Nations Montreal Protocol (a multilateral agreement regulating the production and consumption of ozone depleting chemicals), as well as influencing UK government policies such as the Clean Air Strategy (2019) and the Environment Bill (2020). In addition, researchers from Cambridge and York have held highly influential leadership roles either on, or authoring reports for, the Scientific Assessment Panels to the Montreal Protocol. According to the UN Environment Programme, the Montreal Protocol has led to a substantial reduction in ozone depleting chemicals, with evidence that the ozone layer is healing and can recover by the middle of the century[3].

A case study from Queen Mary University of London[ICS19] highlights how policy has been informed and influenced from research that determines rates of biodegradation of plastics. This research has underpinned new UK guidelines on the analysis of plastics in the environment and has informed debate across Europe on the introduction of new regulations governing new biodegradable plastics.

[3] https://www.un.org/en/climatechange/preserving-the-ozone-layer

Sustainability is supported through research to turn waste products into new materials

Impact case studies also highlight research impacts for sustainability and the way that chemistry is impacting on the circular economy. The examples in Case Study Box I showcase how research enabled waste products to be turned into new materials.

Case Study Box I

Turning waste products into new materials

Keracol, a spin-out from the **University of Leeds**, extracts ingredients for personal care products from food waste, saving over 24 tonnes of fruit waste in 2019[ICS43].

A Knowledge Transfer Partnership (KTP) between the **University of Lancaster** and **Crown Paints Ltd** has shown how the company can reuse some of the waste produced from its paint manufacturing processes[ICS41]. Applied research has shown that paint waste from the manufacturing process can be filtered and the waste 'cake' used as a bulking agent in masonry paint and the water filtrate can be used in the manufacture of magnolia paint with no adverse effects in terms of colour and opacity.

The **University of Greenwich** have developed novel technology that enables diversion of industrial solid waste from landfill, that when combined with CO_2 gas from the atmosphere, can form new construction materials[ICS84].

UK chemistry researchers influencing national and international practices

A number of case studies highlight the influence that UK chemistry researchers are having on national and international decision making and regulatory practice. Beyond the influential positions noted above, with regard to the UN Montreal Protocol, further examples of this leadership and influence are highlighted in Case Study Box J.

Case Study Box J

Leadership and influence of UK chemistry researchers

Herriot Watt University led an EU project which resulted in intelligent testing strategies approved for use in risk assessments of nanomaterials under the EU REACH regulations[ICS4]. These testing strategies increase the efficiency of testing and reduce the use of animal testing for regulatory risk assessment.

King's College London research has played a leading role in international efforts to combat doping in sports[ICS13]. Their novel advances in analytical measurement have led to the establishment of internationally accredited standards and guidelines.

The **University of Kent** have designed a new material that can be used to absorb and degrade up to 54 times its own weight of a range of chemical warfare agents[ICS37]. They have collaborated with the UK Ministry of Defence on the wider manufacture of the material to support the UK's defence against chemical warfare agents.

5. Contribution to local areas and communities

The UOA8 environment statements give an insight into some of the activities and connections that are being made by chemistry departments with their local areas. Place-based funding and partnerships are being utilised to deliver local impact and benefits, alongside outreach to local schools and public engagement activities.

5. Contributions to local areas and communities

Contributions to local areas and communities

The UOA8 environment statements give an insight into some of the activities and connections that are being made by chemistry departments with their local areas. Place-based funding and partnerships are being utilised to deliver local impact and benefits, alongside outreach to local schools and public engagement activities.

5.1 Place-based funding to deliver local impact

Collaborations with local enterprise partnerships

During the REF 2021 assessment period, a range of local partners and organisations were engaged, including Local Enterprise Partnerships.

The environment statements from the Universities of Bath[ES11], Chester[ES16] and Lancaster[ES24] reference working with their Local Enterprise Partnerships (LEP).

At the University of Lancaster, a successful European Regional Development Fund (ERDF) bid in collaboration with the Lancashire LEP part funded the Collective Technology Access Programme (cTAP), an £11.4M investment to deliver bespoke research laboratory and office facilities and equipment, embedded into the chemistry space for use by emerging companies in partnership with chemistry academics and professional services staff. This is alongside the £26M the University has invested in setting up the new chemistry department, which has been designed from the bottom up with a research portfolio focussed around key emerging global priorities such as energy and energy storage, security and advanced materials.

Use of EU Structural Funds to set up new chemistry departments and support local SMEs through innovation projects

Further utilisation of EU place-based funding is evidenced in the environment statements through the use of European Structural and Investment Funds (ESIF) (including the ERDF scheme) by various universities. This funding is generally utilised in one of two ways:

- to help set up new chemistry departments or upgrade facilities and equipment, e.g. the Universities of Bradford[ES13], Chester[ES16], Lancaster[ES24], Lincoln[ES27].
- to support local Small and Medium Sized Enterprises (SMEs) through innovation projects and access to facilities, e.g. the Universities of Bath[ES11], Bradford[ES13], Chester[ES16], Durham[ES17], Lancaster[ES24], Nottingham[ES31].

In addition, the Universities of Sussex[ES38] and Southampton[ES35] are both involved in an EU Interreg project with partners in Northern France that brings together world experts in flow and reagent-less chemistry to produce chemical scaffolds targeted to the needs of regional industry.

EU place-based funding is shown across the environment statements to be an important source of income to universities over the REF2021 period and often augmented other types of investment. This type of funding is not included in the income data submitted as part of the REF environment submissions (outlined in Section 1.2) as it is not classed as 'research related' income. In this regard what we are seeing from the environment statements is likely to be an underreporting of place-based funding, as it was not a required part of the REF submission.

5.2 Partnerships with local companies

Chemistry research is providing support for and sustaining partnerships with local companies

Beyond the EU funded innovation projects noted above, business innovation spaces are evidenced in the environment statements, helping local companies to interact with chemistry departments. The University of Strathclyde[ES37] started its Chemistry Clinic in 2014 to support industrial partners on small-scale projects to lower the barrier to interacting with the department. In the South-West region, the chemistry departments at the Universities of Bath[ES11], Bristol[ES14] and Southampton[ES35] evidence engagement with the SETsquared business incubator partnership.

Partnerships with local chemical industries are evidenced by the Universities of Chester[ES16], Hull[ES22], Lancaster[ES24], Lincoln[ES27], Liverpool[ES28], Queen's Belfast[ES7] and Swansea[ES8]. Connections to local science parks are also noted with chemistry research departments co-located on local science parks at the Universities of Chester[ES16] and East Anglia[ES18].

Impact case studies showcasing local impact are evident but few in number

Some impact case studies also provide evidence of impacts on the local area, although explicit mentions of local impact are rare (a likely feature of the assessment process, as submitting units more often highlight national or global impacts in their chosen case studies). An example of local impact is shown in Case Study Box K.

Case Study Box K

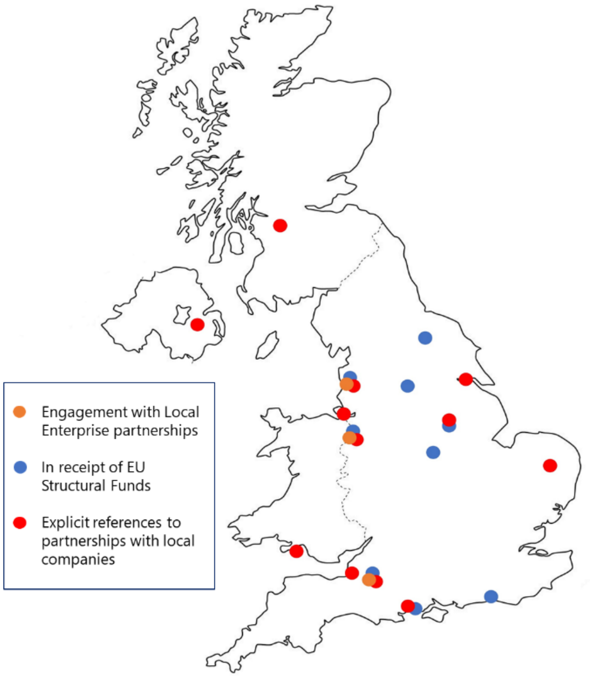
Local impact

Research in radiochemistry at the **University of Hull**[ICS35] has led to improved diagnostic screening capabilities. Through a partnership with a local charity (Daisy Appeal) and the local NHS Trust, they have attracted >£15 M investment to build a bespoke centre where research and clinical services are integrated, leading to an improved cancer diagnosis service for patients in the Humber region.

Universities referencing local interactions form clusters in the North West, South West and Eastern regions of England

Figure 5 below highlights the locations of the universities referenced across this section. These universities have explicitly mentioned their local interactions within the environment statements. There are clusters of universities taking advantage of engagement with LEPs and EU structural funds within the North West, South West and Eastern regions of England. Note: It should not be read that universities not included in Figure 5 do not have local interactions, just that they did not include reference to them within their environment statements.

Figure 5. Map of the UK showing locations of universities who have referenced local interactions within their environment statements



5.3 Outreach and public engagement at the local level

Outreach in local schools and increased public engagement help to widen participation in chemistry

Outreach to schools and public engagement are evidenced across all the environment statements, with a wide range of examples showcased, with many departments having a specific member of staff leading such activity. Notably outreach to Schools has tended to be as part of widening participation activities to support disadvantaged and underrepresented communities and aligns with wider efforts to create a more inclusive and diverse chemistry community, as discussed later.

A variety of on-site and off-site activities are described in the environment statements, for students across all levels and also activities directed specifically at secondary school science teachers (and in some cases school technicians). Royal Society of Chemistry support for outreach activities is widely noted, with several universities mentioning the 'Spectroscopy in a Suitcase' initiative as part of their outreach activities[4].

A notable example of chemistry researchers working with Schools is that of the University of Bradford, highlighted in Case Study Box L.

Case Study Box L

Interaction with local school

The **University of Bradford** worked with **Ilkley Grammar School** to transform their teaching methods for A level chemistry[ICS29]. By translating the vibrations of molecular bonds from their infrared spectrum into the audible, a unique set of musical notes can be produced for any molecular or material. This 'Molecular Music'

[4] Note that this initiative was discontinued by the RSC in 2020 https://edu.rsc.org/enrichment/spectroscopy-in-a-suitcase

is now routinely used at the school to teach spectroscopy, with the link to music helping students to engage and grasp the concepts more easily.

Engaging the public with chemistry research

Public engagement ranges from the very local (e.g. university open days, local Pint of Science events) to national (e.g. Royal Society Summer Exhibitions, various science festival exhibits) and global activities (e.g. You Tube channels such as the Periodic Table of Videos developed at the University of Nottingham[ES31]).

There are several mentions of events to celebrate the 150th anniversary of the Periodic Table of Elements, that were supported by the Royal Society of Chemistry, including the 'Knit the elements' project led by the University of Aberdeen[ES10]. The environment statements also include details of awards received for public engagement activities, e.g. the University of Kent were the first department in the UK to be awarded the Silver Watermark by the National Co-ordinating Centre for Public Engagement (NCCPE)[ES23]; and the University of Hull had the first UK Chemistry Professor for Science and Communication[ES22].

Public engagement type impact case studies are less common than those related to collaborations with industry and development of new products, with less than 10% of the ICS analysed being purely focussed on engaging members of the public. An example of public engagement is shown in Case Study Box M.

Case Study Box M

Web-based resources for students and the public

The **University of Liverpool** impact case study on ChemTube3D[ICS50] showcases a freely available web-based resource that delivers interactive 3D chemistry visualisations aimed at helping students and interested members of the public understand the 3D nature of chemical structures. What started as an in-house resource to enable the understanding of complex structures, has grown to become an Open Educational Resource, so popular that it has also been launched as an app and has users worldwide.

6. Wide range of collaborations

Chemistry is a hugely collaborative subject, and over 800 different organisations are mentioned in the available impact case studies. These collaborations cover interdisciplinary, intersectoral, national and international connections. Typically, STEM disciplines are among the top cited subjects in chemistry-led interdisciplinary research, although art, humanities and social science disciplines are evident. Beyond academia, industry partners of varying sizes and sectors collaborate with chemistry researchers.

6. Wide range of collaborations

Chemistry is a hugely collaborative subject, with over 800 different organisations mentioned in the 113 available case studies

The REF2021 submissions show that chemistry is a hugely collaborative subject, with interdisciplinary, intersectoral and national and international collaborations widely showcased.

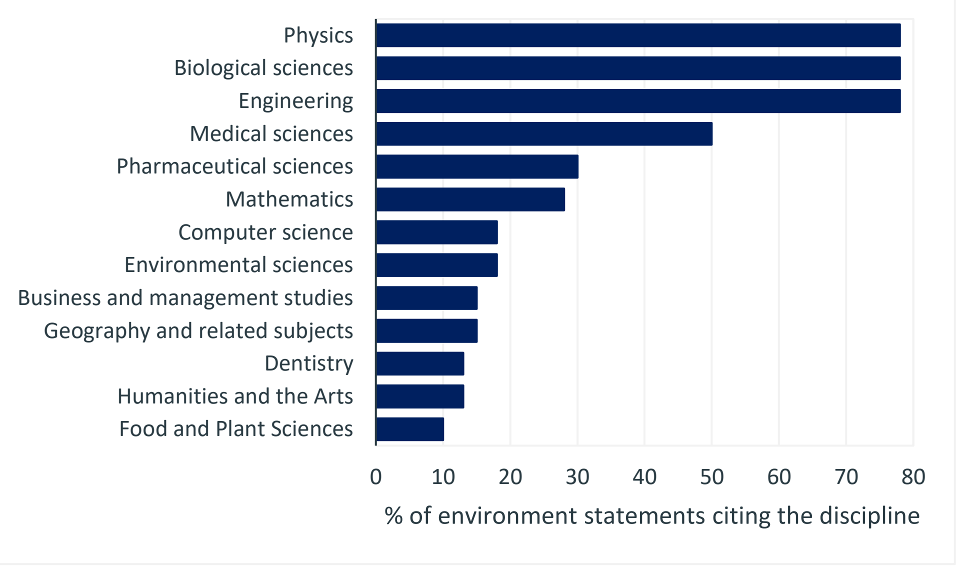
Analysis of the impact case studies alone shows that over 800 different organisations (industry, government agencies, regulatory bodies, universities, charities, hospitals) from across the world are mentioned as helping to generate impact. Many more organisations are referenced in the environment statements although less information is provided about the nature and extent of these collaborations.

6.1 Interdisciplinary collaborations

Chemistry is highly interdisciplinary, with STEM subjects being the most frequently cited disciplines

Interdisciplinary collaborations are highlighted across the environment statements. STEM subjects make up the most frequently cited disciplines (see Figure 6), with Physics, Biological Sciences and Engineering the top three subjects cited as collaborating with chemistry. There are several mentions of subjects from Arts and Social Sciences, including subjects related to Geography mentioned across 15% of the statements, and mentions of Law, Business and Economics (combined under 'Business and management studies' in Figure 6) and Art and design, History and Philosophy (combined under 'Humanities and the Arts' in Figure 6).

Figure 6. Other disciplines cited in the environment statements and linked to collaboration with chemistry researchers



Interdisciplinary collaboration through CDTs and large collaborative grants

The environment statements suggest that many of these interdisciplinary collaborations occur through internal university wide research priority areas, with many universities now supporting more interdisciplinary working around themes related to wider national and global challenges (as previously discussed in Section 4.1).

Other ways these interdisciplinary collaborations manifest themselves are through Centres for Doctoral Training (CDTs), large collaborative grants (e.g. UKRI and EU Horizon 2020), and the national interdisciplinary institutes highlighted in Section 4.1. The environment statements evidence many cases where the chemistry researchers are leading these interdisciplinary activities, showcasing the pivotal role of chemistry in such collaborations.

Some examples of interdisciplinary collaboration showcased in the environment statements include:

- University Research Institutes have been set up at Cardiff University, with the chemistry department leading the Cardiff Catalysis Institute, which has links to major international catalysis initiatives such as the UK Catalysis Hub, Max Planck Centre for Catalysis, and also hosted the Engineering and Physical Science Research Council (EPSRC) CDT in Catalysis [ES1].
- The University of Aberdeen was awarded £1.05M from the Leverhulme Trust for a CDT in sustainable chemicals and materials providing funding for 15 PhD students. This interdisciplinary CDT includes researchers from chemistry alongside researchers from engineering, ecology, economics, and politics [ES10].
- At the University of Leicester, the chemistry department has led the EU-funded INTREPID forensic science project, a collaboration with the Schools of Genetics, Criminology, Psychology, and Pathology, and external partners throughout Europe (notably the University of Lausanne) [ES26].
- The University of Sussex are part of a large consortium of chemists, physicists and astronomers from the UK, USA and Europe awarded prestigious early release science time on the James Webb Space Telescope [ES38].

The impact case studies show further evidence of interdisciplinary connections including those with wider disciplines. For example, at the University of Kent, chemistry researchers have worked with historical conservationists at the Mary Rose Trust, as highlighted in Case Study Box N.

Case Study Box N

Connections with historical conservationists

At the **University of Kent**, chemistry researchers have worked with the **Mary Rose Trust** to monitor the chemical changes in the ship's hull, to inform conservation strategies and develop a procedure to mitigate the threat of acid degradation[ICS38]. Preservation of the Mary Rose and its many artifacts is central to the existence of the museum, which provides cultural, economic and education benefits to the Plymouth region.

6.2 Collaborations with industry

Widespread engagement with industry, large and small

Industry partners from a variety of sectors collaborate with chemistry researchers. Companies of varying size from start-up companies using incubator facilities through to multinational companies investing millions to gain access to the knowledge, skills and expertise available across the academic chemistry community engage with UK universities. For example, the strategic partnership between the University of Liverpool and Unilever has resulted in a new translational research facility built on leadership in materials chemistry[ES28].

The environment statements showcase the different industry sectors collaborating with chemistry researchers, although little information is provided on the scale of some of these collaborations or the duration. These sectors include pharmaceuticals, consumer goods, specialty chemicals, oil and gas, defence, manufacturing, software, food and drink, scientific instrumentation, agrochemicals and car companies. The most frequently cited companies in the environment statements are shown in Table 3. This table clearly shows the extent to which chemistry departments collaborate with pharmaceutical and speciality chemicals companies.

The evidence also highlights how some companies collaborate with many chemistry departments. Table 3 shows the individual chemistry departments that collaborate with the top five cited companies by sector – AstraZeneca, Johnson Matthey, Syngenta, Unilever and BP.

Table 3. The companies involved in chemistry collaborations and most frequently cited in the environment statements

Most cited companies	Sector	No. of environment statements citing the company
AstraZeneca	Pharmaceuticals	28 (70%)
Johnson Matthey	Speciality Chemicals	20 (50%)
GlaxoSmithKline	Pharmaceuticals	19 (48%)
Syngenta	Agrochemicals	17 (43%)
Unilever	Consumer Goods	15 (38%)
BP	Oil and Gas	14 (35%)
Merck	Pharmaceuticals	12 (30%)
Pfizer	Pharmaceuticals	11 (28%)
Roche	Pharmaceuticals	11 (28%)
Novartis	Pharmaceuticals	10 (25%)
Infineum	Speciality Chemicals	9 (23%)
Croda International	Speciality Chemicals	8 (20%)
BASF	Speciality Chemicals	8 (20%)

Industry collaborations and partnerships are formed via various routes

Ways in which industry collaborations are formed include: the use of specialist equipment through university 'services rendered' functions (many universities have analytical services open to industry), joint/visiting researcher appoints (including Royal Society Industry Fellowships), contract research, and also funding schemes such as KTPs and Prosperity Partnerships. Two newly funded EPSRC Prosperity Partnerships are mentioned in the environment statements:

- The University of Edinburgh[ES36] and Imperial College London[ES3] with BP – to research the prevention of surface degradation in demanding environments.
- The Universities of Strathclyde[ES37] and Nottingham[ES31] with GlaxoSmithKline - to research 'end-to-end' processes to deliver novel pharmaceuticals via atom efficient and energy resilient routes.

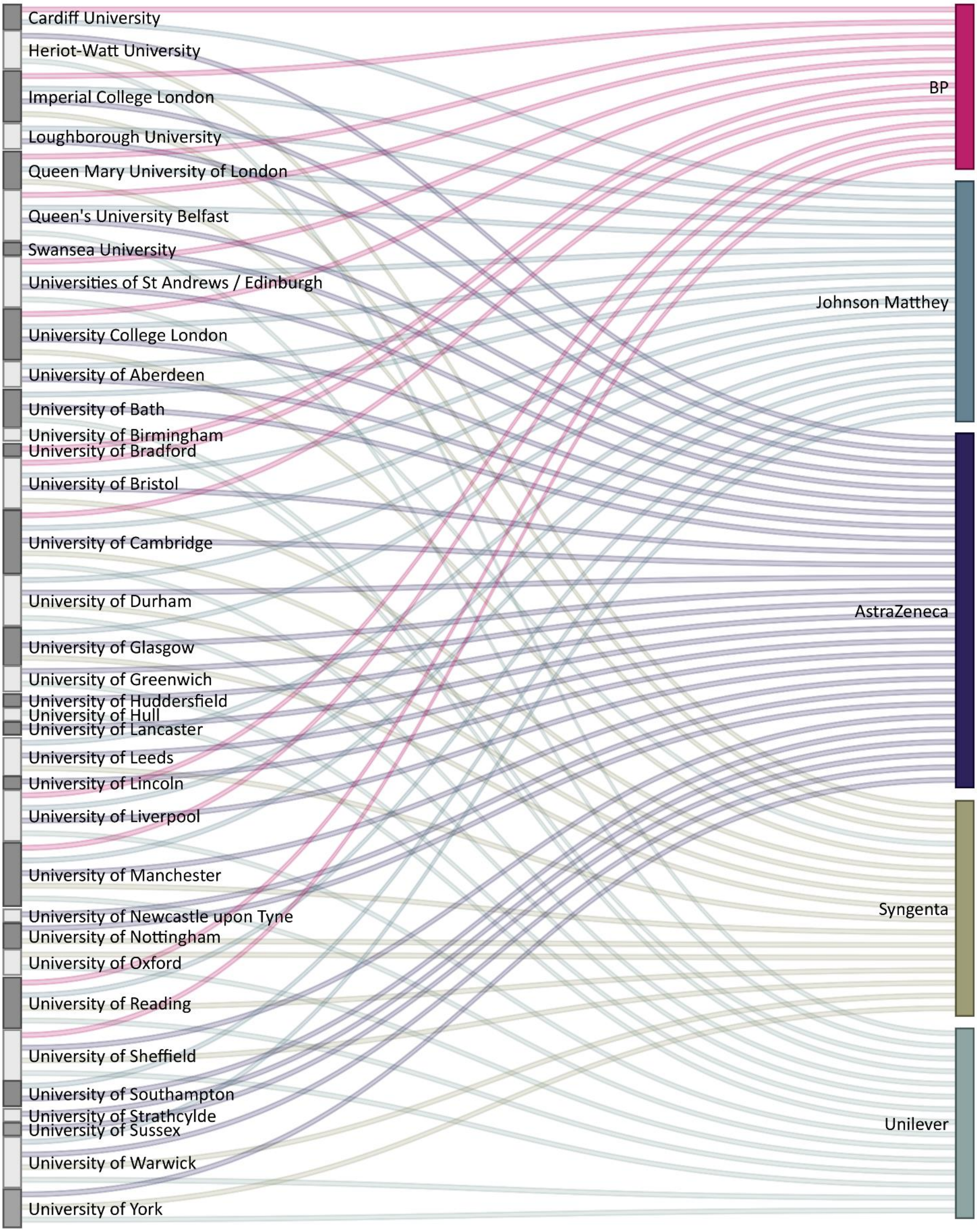


Figure 7. Chemistry departments that collaborate with the top five cited companies by sector – AstraZeneca, Johnson Matthey, Syngenta, Unilever and BP, as referenced in the environment statements.

Knowledge Transfer Partnerships were the main pathway to impact in 8 of the available case studies

Knowledge Transfer Partnerships (KTPs) are a long-standing scheme supporting university-business projects that are designed to deliver business benefits. KTPs form the main pathway to impact in 8 of the case studies available. This scheme can have valuable impacts for the companies involved as examples show in Case Study Box O.

Case Study Box O

Collaboration through the KTP scheme

ParagonID partnered with the University of Hull through two KTP projects to develop an in-house manufacturing and quality control facility for new printable magnetic inks used for smart ticketing for mass transport systems and for radio frequency identification tags used on electronic ID documents such as passports[ICS36].

Innoture Ltd partnered with Swansea University through a KTP project to optimise their microneedle print manufacturing processes to be more efficient and help develop their product pipeline, with a new product Radara® being bought to market a year earlier than planned[ICS24].

Industry partners are widely involved in doctoral training programmes

Industry links within doctoral training programmes are also common. CDTs bring in intersectoral collaborations, with industry partners widely involved, and in some cases part-funding PhD students (Collaborative Awards in Science and Engineering (CASE) studentships are also widely noted). In a unique example of an intersectoral partnership, the University of Strathclyde and GlaxoSmithKline (GSK) have a flagship Doctoral Programme whereby GSK have invested >£7.7M to upskill their workforce, alongside funding additional joint PhD students. During the REF2021 period, 165 postgraduate researchers had been active on the programme, of which 94 had already graduated[ES37, ICS106].

6.3 International and national collaborations

International collaborations are strong, but many were enabled by funding sources that have been cut or are currently uncertain in terms of UK participation

International collaborations are also widely evident from the environment statements, with connections to academic institutions across the globe widely cited. Such collaborations are evidenced through visiting researchers, joint appointments and sabbaticals, alongside more formal strategic partnerships such as the PLuS Alliance involving Kings College London, University of New South Wales and Arizona State University[ES4], set up in 2016 to help solve global challenges.

European collaborations are highlighted across many environment statements, including participation in Horizon 2020 (H2020) grants and also EU COST Action networks and Erasmus partnerships, examples include:

- Heriot-Watt University[ES2] have coordinated four H2020 grants: GRACIOUS and PATROLS on developing classification and safety assessment tools for nanomaterials; MARISURF to discover, isolate and scale up fermentation of microbial biosurfactants and bioemulsifiers; and CATACURE to develop non-invasive photonic theranostics.
- The University of Durham[ES17] has led three EU ITN networks training PhD students and also has close ties with their Erasmus partners, including FU Berlin, JMH Wurzburg and KULeuven, leading to 39 student research placements since 2015.
- The University of Newcastle[ES30] led the COST Action "Polyoxometalate Chemistry for Molecular Nanoscience" (PoCheMoN) which coordinated research across 22 European countries, plus Russia and Australia.

The Global Challenges Research Fund (GCRF) and Newton funding enabled further international collaborations across lower- and middle-income countries including: India, Pakistan, South Africa, Kenya, Nigeria, Mexico, Vietnam and Malawi. These have since ended as funding programmes.

The University of Swansea led a £6.5M GCRF project SUNRISE[ES8]. This collaboration bought together 5 UK universities (including Imperial College London's chemistry department) with universities in India, Mexico, Kazakhstan and South Africa, plus 5 UK industrial partners and 5 Indian industrial partners. The project implemented low-cost Solar PV and has impacted deprived communities in rural India through building installation demonstrators for next-generation Solar PV and electrochemical storage platforms.

Collaborations taking advantage of location

Closer to home, many of the London-based universities have profited from their co-location in the capital and have created alliances and collaborative opportunities which many local chemistry researchers take advantage of, such as partnership with the Francis Crick Institute (Biomedicine), the London Centre for Nanotechnology (Nanoscience and nanotechnology), the Thomas Young Centre (Theory and simulation of materials and molecules) and the London Interdisciplinary Doctoral Programme (Biosciences).

Further regional networks are evidenced across the environment statements, including:

- Midlands Innovation (MI) – the Universities of Leicester[ES26] and Loughborough[ES5] reference their involvement in the MI led Energy Research Accelerator.
- GW4 Alliance - the Universities of Bath[ES11], Bristol[ES14] and Cardiff[ES1] reference several initiatives across the alliance that chemistry researchers take advantage of, including equipment sharing, access to a regional HPC facility, and UKRI funded Doctoral Training Partnerships covering Freshwater (NERC) and Biosciences (BBSRC).
- Northern 8 Research Partnership (N8) – the Universities of Durham[ES17], Liverpool[ES28], Manchester[ES29], Newcastle[ES30], Sheffield[ES34] and York[ES40] all references their engagement with N8, including through equipment sharing and access to a regional HPC facility.

7. Research culture within UK chemistry

Various aspects of research culture are outlined in the environment statements. The promotion of diversity and inclusion is a focus for chemistry departments and efforts are in place to attract a more diverse section of society to the chemical sciences and to showcase positive role models. The number of Athena SWAN awards mentioned across the UOA8 submissions evidence these efforts. Staff development opportunities are widely described in the environment statements for staff at all levels.

7. Research culture within UK chemistry research

Research culture, with a focus on EDI, is widely discussed in the environment statements reflecting the RSC's research in this area

Various aspects of research culture are discussed in the environment statements, with an emphasis on equality, diversity and inclusion (EDI), as per the REF2021 guidelines. Staffing strategies and ongoing support and training for staff and PhD students were outlined, alongside measures in place to monitor and promote EDI.

All chemistry departments provide individualised commentary on their policies and practices, making further analysis limited. This section provides details on some of the more common practices evidenced and highlights notable examples of extended support. The analysis of REF2021 data reflects the Royal Society of Chemistry's significant contribution to increasing understanding of and improving the diversity of the chemistry workforce.

7.1 Supporting equality, diversity and inclusion

Efforts are being made on diversity and inclusion via EDI committees and providing role models

Efforts are in place to attract a more diverse section of society to the chemical sciences and to showcase positive role models. All chemistry departments within the UOA8 submission describe having an Equality, Diversity and Inclusion (EDI) Committee (or equivalent) in place to monitor and support their department's activities in this space. These committees are usually made up of research staff from all levels, including PhD students, so that diverse views can be considered.

The University of Warwick highlight their Black students society[ES39] which was set up by chemistry students, and who make recommendations to the department to help with the recruitment, integration and performance of Black, Asian and Minority Ethnic (BAME) students.

There are also several mentions in the environment statements of the use of Royal Society of Chemistry funds to run events on, or to study, the experiences of a diverse range of chemistry researchers.

Female staff numbers are increasing across all levels

The Royal Society of Chemistry's 2018 report 'Diversity landscape of the chemical sciences'[5] is commonly referenced when discussing the male/female ratio of staff in chemistry departments. The environment statements suggest that numbers of female researchers are rising across all job levels compared to REF2014 and increases in Black, Asian and Minority Ethnic (BAME) researchers are also noted by some universities – as shown in Figure 8. The environment statements discuss these increases in different ways (specific numbers, proportions, percentages) making it difficult to analyse further.

[5] https://www.rsc.org/globalassets/02-about-us/our-strategy/inclusion-diversity/cm-044-17_a4-diversity-landscape-of-the-chemical-sciences-report_web-2.pdf

Figure 8. Percentages of environment statements discussing increases in female and BAME researchers

The figures do not include the new chemistry departments and therefore relate to 35 out of 40 environment statements.

57%
of environment statements specifically discuss increases in female staff/students

29%
of environment statements specifically discuss increases in BAME staff/students

Diversity is benefitting from the adoption of new and amended practices.

It is suggested these increases have been helped by new recruitment practices described across the environment statements which include: changes in the language of job adverts to make them more attractive to underrepresented groups, ensuring all shortlists and all interview panels have a gender balance, obtaining a wider input into recruitment decisions by inviting candidates to present to the whole department, and monitoring diversity statistics throughout recruitment and taking positive action where required.

The number of female staff being promoted also appears to be increasing. New promotional practices are mentioned by the Universities of Birmingham[ES12], Edinburgh/St Andrews[ES36] and Sheffield[ES34], whereby all staff are reviewed for promotion each year, which allows the departments to seek potential beyond those staff who put themselves forward. University College London highlight their strong record in promotion of female staff and also the development of a 'Women in Supramolecular Chemistry' mentoring network[ES9]. In other cases, there is evidence of female staff being promoted having undertaken leadership courses, with the Aurora Leadership development initiative for women, run by AdvanceHE, mentioned in several cases, alongside in-house courses.

Chemistry departments provide support for staff with caring responsibilities and disabilities

Over 60% of chemistry departments have noted in their environment statements schemes to support staff with caring responsibilities or with disabilities. An example referenced several times is the provision of funds for those with caring responsibilities to help them to attend conferences, often funding a partner to travel to take care of young children. Mental health first aiders and wellbeing champions are also mentioned across many environment statements, alongside additional support put in place for staff during the Covid-19 lockdowns (e.g. IT support to help to develop online lectures).

Chemistry departments are receiving formal recognition for progress made on diversity and inclusion

Recognition of these efforts and the progress being made to tackle issues related to diversity and inclusion are evidenced in the Athena SWAN awards secured by chemistry departments, as highlighted in Figure 9. Note that in some cases multiple awards are given per university where their UOA8 submission is made up of researchers from different departments. In addition to these awards, two chemistry departments stated that they are working towards Bronze (two submissions did not mention departmental Athena SWAN awards). It is notable that the University of York's chemistry department was the first university department of any discipline to be awarded an Athena SWAN Gold award in 2007[ES40]. They have retained this status ever since, becoming leaders in EDI both nationally and internationally and sharing best practice with others.

Additionally, Stonewall Champion and Race Equality Charter statuses are mentioned in some environment statements.

Figure 9. Athena SWAN awards held by the UOA8 submitting universities.

Gold	Silver	Bronze
2	18	19

7.2 Support for researchers at all levels

Staff development opportunities are showcased for staff at all levels

Another aspect of research culture discussed widely in the environment statements is that of staff and student development. Staff development opportunities are showcased for staff at all levels. Leadership development courses are widely noted for the more experienced staff, including courses specifically designed to help female staff into leadership positions, as noted above. Many environment statements describe an increase in the number of teaching-only staff to address workload issues and decrease the teaching load on those members of staff who have higher research and leadership commitments.

Support structures in place for other staff and students are highlighted in Figure 10. 'Commonly observed support' refers to initiatives that are widely seen across most of the environment statements, whereas 'Examples of extended support' are those initiatives that are less widely reported in the environment statements but notable in their support.

Early Career Researchers	Commonly observed support: department funded PhD student, start-up funds, travel support, mentoring, access to Higher Education Academy (HEA) teaching qualifications as part of development. Examples of extended support: low teaching loads for first few years to help establish career.
Postdoctoral Researchers	Commonly observed support: transferable skills courses, support for those applying for internal fellowships, PDRA forum and representation on departmental committees. Examples of extended support: career development programmes including 'Academia to Industry' events.
PhD Students	Commonly observed support: regular supervisory meeting, progress reviews, transferable skills courses, travel bursaries for conferences. Examples of extended support: supervisor training, career support showcasing careers beyond academia, additional PG Certificates in professional development.

Figure 10. Details of commonly observed support and examples of extended support for researchers at different levels

Technical staff are recognised as critical part of chemistry departments

The critical role of technical staff is frequently highlighted in the environment statements, with 8 departments referencing that they are a signatory to the Technician Commitment. The development of technical staff is not as widely showcased as that of other research staff, however some examples of the support reported include:

- Support for technical staff to gain chartered scientist status (e.g. Imperial College London[ES3], University of Southampton[ES35]) or to undertake part-time degrees (e.g. University of Durham[ES17]) or PhDs (e.g. University of Glasgow[ES19]).
- Technical staff being recognised through journal authorship (e.g. Imperial College London[ES3], University of Glasgow[ES19], University of Liverpool[ES28], University of Newcastle[ES30], University of Warwick[ES39]).
- Funding to attend training events and conferences (University of Lancaster[ES24], University of Leeds[ES25], University of Southampton[ES35]).

The Universities of Lincoln[ES27] and Warwick[ES39] specifically mention that technical staff have parity with academic staff with parallel grading structures up to Professorial level, and the Universities of Loughborough[ES5] and Southampton[ES35] highlight technical staff who have transferred from the technical career pathway to the academic pathway.

8. Key Insights

The following section presents the key insights resulting from this study which has analysed the REF2021 impact and environment submissions for UOA8 – Chemistry. These insights cover the capability and characteristics, and the contribution of UK chemistry research to society, economy, and the environment.

8. Key Insights

Key Insights from the analysis of REF2021 impact and environment submissions for UOA8 - Chemistry

Investment into chemistry research is extensive, with total income from external funding sources of £1.65b over the REF2021 period. However, when looking at the average yearly funding between REF2014 and REF2021, in real terms the amount is relatively flat, and UKRI and UK industrial funding have decreased.
Chemistry departments appear to have taken advantage of EU government funds for research, with this funding doubling from REF2014 to REF2021 (when looking at yearly averages across the two REF cycles).
Return on investment of chemistry research is significant – with new companies, new jobs created, and investment across R&D leading to new products, processes, and technologies. The time between initial research and impact occurring varies with some impacts occurring on a short timescale, although a third of impact case studies show more than 10 years between the underpinning research commencing and the start of impact generation.
Chemistry is the backbone of many interdisciplinary collaborations that are working towards national and global challenges. A series of national interdisciplinary institutes, some with chemistry leadership, are developing technologies and processes in materials, catalysis, electrochemistry, biology and medicine.
Chemistry research is underpinning impacts related to global challenges covering healthcare, environment, and sustainability.
Chemistry departments have taken advantage of EU place-based funding to invest in new buildings, upgrade equipment and facilities and to enable innovation projects with local SMEs. With this funding no longer available, it is unclear how chemistry departments will fund such projects in future.
Industry collaborations are widespread, from smaller connections through in-house incubators and Knowledge Transfer Partnerships, through to collaborative research with multinational companies, and across a wide spectrum of sectors and activities.
The research culture within chemistry research shows evidence of staff and student development across the board and efforts being made on the equality, diversity, and inclusion front, with an acknowledgment that there is still more to be done.

Appendix A. Impact Case Studies

Table A1 below includes all 113 publicly available Impact Case Studies that have been analysed as part of this work. The case studies have been given reference numbers for use within this report. The full case studies can be found on the REF website https://results2021.ref.ac.uk/impact (filter for UOA8 Chemistry) where they can also be downloaded.

Note that there were 139 Impact Case Studies submitted to UOA8 in REF2021, however 26 of these were confidential and are not publicly available.

Table A1. Reference numbers for all publicly available UOA8 Impact Case Studies

Reference no.	University	Case study title
ICS1	Cardiff University / Prifysgol Caerdydd	Improved catalysts to enable air purification in life-saving applications
ICS2	Cardiff University / Prifysgol Caerdydd	Scaling-up the environmentally friendly production of Perspex®
ICS3	Cardiff University / Prifysgol Caerdydd	Novel gold-based catalyst methods for PVC production
ICS4	Heriot-Watt University	Intelligent Testing Strategies for Nanomaterial Safety
ICS5	Heriot-Watt University	Horizon Proteins: Circular economy innovation from whisky by-product to fish feedstock
ICS6	Heriot-Watt University	Library of Botanicals to boost worldwide sales of Scottish gin
ICS7	Heriot-Watt University	Preventing occupational cancer
ICS8	Imperial College of Science, Technology and Medicine	The Invention of Samuraciclib, a Highly Selective CDK-7 Inhibitor, the Formation of Carrick Therapeutics and Clinical Trials on Treating Patients with Resistant Cancers
ICS9	Imperial College of Science, Technology and Medicine	Green chemistry research and innovation policy driving a world-class cleantech cluster in London
ICS10	Imperial College of Science, Technology and Medicine	ECONIC – Catalysis to Deliver Polymers from Carbon Dioxide
ICS11	Imperial College of Science, Technology and Medicine	Bramble Energy – Exploiting Materials Chemistry to Manufacture Practical Hydrogen Fuel Cells
ICS12	Imperial College of Science, Technology and Medicine	Interdisciplinary Chemistry-led research leading to new ventures in Drug Discovery, Diagnostics and Personal Care
ICS13	King's College London	Analytical advances in anti-doping shapes international standards for professional sports
ICS14	King's College London	The therapeutic impact of hydroxypyridinone chelators
ICS15	Loughborough University	Transforming the forensic capabilities of criminal investigation with the Recover fingerprint development system
ICS16	Loughborough University	Enabling rapid analysis of diagnostic biomarkers for improved health screening
ICS17	Loughborough University	Closing the loop - new plastic from old
ICS18	Queen Mary University of London	A New Generation of Synthetic Bone Graft Material That More Reliably and Effectively Stimulates Natural Bone Healing (Inductigraft™/AltaPore™)

ICS19	Queen Mary University of London	Informing the Public Debate on the Environmental Impact of Plastic-based Pollutants
ICS20	Queen's University of Belfast	Synthesis of a new class of chemical compounds leads to discovery of Ridinilazole: a major new antibiotic to treat Clostridium difficile.
ICS21	Queen's University of Belfast	Building on the success of mercury capture to drive change in the petroleum industry
ICS22	Queen's University of Belfast	Replacement of hydrogen fluoride (HF) by ionic liquids in the alkylation of gasoline- increasing the efficiency and safety of global clean fuel production
ICS23	Swansea University / Prifysgol Abertawe	Development of plasma technology processes has increased process tool sales and company growth at SPTS Technologies
ICS24	Swansea University / Prifysgol Abertawe	Improving microneedle manufacturing efficiency and developing a product pipeline in a leading microneedle technology company
ICS25	The University of Bath	"Test and Treat" diagnostics for infectious diseases
ICS26	The University of Bath	Development of Polylactide (PLA) as a market-leading bio-based plastic
ICS27	The University of Bath	WasteWater-based Epidemiology for environmental and public health assessment
ICS28	The University of Bradford	Controlling Polymer – Solvent Interactions to Improve British Manufacturing Performance
ICS29	The University of Bradford	'Molecular Music' and the Sound of Chemistry: Bridging arts and science to move students and the public beyond a traditional separation of discipline fields
ICS30	The University of East Anglia	Industrialisation of olefin polymerisation catalysis
ICS31	The University of East Anglia	Iceni Diagnostics Ltd. - Therapeutics and Point of Care Diagnostics for Infectious Diseases
ICS32	The University of East Anglia	Intelligent Fingerprinting Ltd. - Drug screening using the sweat of a fingerprint
ICS33	The University of Huddersfield	Novel biorefining strategies for reprocessing agricultural waste, bioethanol production from sea water and the recycling of textiles.
ICS34	The University of Huddersfield	Arabinoxylans, oligosaccharides and xylanases: enhancing prebiotic benefits in animal feed
ICS35	The University of Hull	Integrated radiotracer synthesis and scanning to improve patient access to state-of-the-art diagnostic PET-CT scans for cancer treatment and other healthcare advances
ICS36	The University of Hull	Novel Magnetic Inks – Design, Formulation, Manufacture & Printing
ICS37	The University of Kent	Project Earthlight: Enhancing the UK's Defence Strategy for the Immobilisation and Degradation of Chemical Warfare Agents through Absorbent Polymer Technologies
ICS38	The University of Kent	Mary Rose: Protecting Our Heritage through Chemistry
ICS39	The University of Lancaster	Lancaster University research results in a step change in UK and global battery insurance policy, practice and understanding
ICS40	The University of Lancaster	Transforming the assessment of global health risks from chemical exposures through the development and implementation of systematic review methods

ICS41	The University of Lancaster	Lancaster University research improves the monitoring, control and optimisation of paint wastewater processing at one of the UK's largest paint manufacturing companies
ICS42	The University of Leeds	C-Capture: a University spin-out for the commercial application of novel CO2 capture technology
ICS43	The University of Leeds	Keracol Limited: a University of Leeds spin-out developing and commercialising sustainable personal care products
ICS44	The University of Leeds	Critical contribution to a small-molecule screening collection that has changed European drug discovery practices
ICS45	The University of Leeds	Accelerating pharmaceutical manufacturing development using automated self-optimisation platforms
ICS46	The University of Leicester	The future of air quality: shaping environmental strategy
ICS47	The University of Leicester	NanoMIPs: Transforming Diagnostics with Molecularly Imprinted Polymer Nanoparticles
ICS48	The University of Liverpool	Enabling the Lucite ALPHA Process for the sustainable production of methyl methacrylate (MMA)
ICS49	The University of Liverpool	High Throughput Polymer Discovery through the Centre for Materials Discovery
ICS50	The University of Liverpool	ChemTube3D: a worldwide Open Educational Resource
ICS51	The University of Liverpool	Laboratory study of asymmetric catalysis leads to a spin out
ICS52	The University of Manchester	DOSY and Pure Shift NMR: from changed practice in the chemical, pharmaceutical and scientific instrument industries to a multimillion pound new food ingredient
ICS53	The University of Manchester	New paradigms for 3D materials analysis using polyatomic projectiles: changing capacity and industrial practice
ICS54	The University of Manchester	C4X Discovery: generating market-leading drug candidates from cutting-edge technology
ICS55	The University of Manchester	Driving the industrial biotechnology revolution: cheaper and more sustainable chemical manufacturing through enzyme discovery, engineering and scale-up
ICS56	The University of Reading	Development of synchrotron facilities at Diamond Light Source for ambient pressure X-ray spectroscopy
ICS57	The University of Warwick	Interface Polymers
ICS58	The University of Warwick	Warwick Electrochemical-Scanned Probe Microscopy (WEC-SPM) platform
ICS59	The University of Warwick	New medical adhesives for transdermal drug delivery – Medherant Ltd
ICS60	University College London	Pitolisant: a novel therapy for narcolepsy and other rare neurological disorders
ICS61	University College London	Application of experimental and computational methods for improved performance of industrial catalytic systems and processes
ICS62	University of Aberdeen	Providing an evidence base for a maximum permissible level of inorganic arsenic in rice
ICS63	University of Aberdeen	Targeting Tau protein as a treatment for Alzheimer's disease

ICS64	University of Bristol	Aerosol science informs global clinical and public health policy on COVID-19 transmission
ICS65	University of Bristol	Bristol research shapes national and global decision making on emissions of greenhouse gases and ozone depleting substances
ICS66	University of Bristol	Organic residue analysis delivers a step change in knowledge generation from commercial archaeology
ICS67	University of Bristol	Bristol and Snow Business co-create eco-friendly artificial snow and reduce environmental impact of film and TV industries
ICS68	University of Bristol	Breakthrough in glucose receptor development leads to a multimillion-dollar deal for a radical new diabetes treatment, and a new science incubator to kick-start Bristol's biotech industry
ICS69	University of Cambridge	Fragment-Based Drug Discovery
ICS70	University of Cambridge	Next Generation Sequencing
ICS71	University of Cambridge	Supporting, contributing to and validating the Montreal Protocol
ICS72	University of Cambridge	Sphere Fluidics
ICS73	University of Cambridge	Cambridge Epigenetix
ICS74	University of Cambridge	Supramolecular encapsulation technology
ICS75	University of Chester	Graphene Nanoflake Manufacture and Commercialisation by Ultrasonic Cavitation
ICS76	University of Chester	Development of a novel hydrogen fuel cell with associated water treatment spin-off technologies
ICS77	University of Durham	Durham Chemistry P&G Strategic Partnership
ICS78	University of Durham	Structural science – software and solutions
ICS79	University of Durham	Fluorescent Retinoids
ICS80	University of Durham	Applied Graphene Materials plc
ICS81	University of Glasgow	Enhanced heat recovery, catalyst conditioning and feedstock flexibility in industrial scale phosgene synthesis
ICS82	University of Glasgow	Selective breeding of spruce for cellulose orientation improves the timber supply chain in the UK
ICS83	University of Glasgow	Commercial exploitation of novel mitochondrial probes
ICS84	University of Greenwich	Carbonation as a Circular Economic Solution: Innovating the waste management and the construction sectors through commercialisation of carbon-negative building aggregate
ICS85	University of Greenwich	Pheromone Traps: providing new Tools across Europe for the Prevention of Spread of Pine Wood Nematode, an Invasive Disease of Pine Forests
ICS86	University of Lincoln	Recovery and Recycling of Rare Metals
ICS87	University of Lincoln	Supporting the Correct Identification of New Psychoactive Substances
ICS88	University of Newcastle upon Tyne	Discovery of PARP inhibitors for cancer treatment – Rucaparib
ICS89	University of Nottingham, The	Increasing Public Understanding of Green and Sustainable Chemistry

ICS90	University of Oxford	Oxygenases – from Chemistry to Medicine
ICS91	University of Oxford	Oxford Nanopore: Nucleic acid sequencing and diagnostics on any scale from laboratory to point of care
ICS92	University of Oxford	Electrochemical sensors for food and drink: Ensuring quality and safety
ICS93	University of Oxford	Mass photometry: enabling next generation research and development of biologics
ICS94	University of Oxford	OMass Therapeutics: New technology for drug discovery with economic benefit to the UK
ICS95	University of Oxford	SCG-Oxford Centre of Excellence in Chemistry: New functional materials with economic impact
ICS96	University of Southampton	08-02 Novel oligonucleotide technologies improving targeted cancer therapies and disease diagnostics
ICS97	University of Southampton	Ilika Plc: Delivering economic impact through novel combinatorial approaches to solid state materials.
ICS98	University of Southampton	The Electrochemical Circus and the Water Transistor: Increasing public understanding of the role of electrochemistry research in modern electronic devices.
ICS99	University of St Andrews	Expert witness testimony on protein structure and binding in Amgen vs Sandoz leads to a multibillion-dollar verdict that secures the future of Amgen and enhanced protection for biopharmaceutical patents
ICS100	University of St Andrews	Expertise in solid-state materials and techno-economic analysis leads to Scottish policy implementation and demonstrator projects to accelerate the use of hydrogen fuel for public transport
ICS101	University of St Andrews	Development, scale-up and formulation of porous materials leading to commercialisation, and the implementation of innovation investment policy in Sweden.
ICS102	University of St Andrews	New companies formed to develop therapies that control immune system response as a result of research on protein factor H
ICS103	University of St Andrews	Direct detection of microRNA enables business growth through commercialisation of fast, accurate and quantitative detection of disease biomarkers
ICS104	University of St Andrews	New phase-change materials enable commercialisation of energy-efficient, sustainable and cost-effective domestic heat storage, resulting in robust company growth and a reduction in fuel poverty
ICS105	University of Strathclyde	A new class of anti-infective drugs from DNA Minor Groove Binders
ICS106	University of Strathclyde	Creating enhanced capabilities in drug discovery research with GSK
ICS107	University of Strathclyde	Accelerating drug development through novel iridium catalysts for enhanced hydrogen isotope exchange labelling
ICS108	University of Sussex	The impact of novel photochemistry and automated chemistry methods in the search for new medicines
ICS109	University of Sussex	Protecting pollinators: Influencing policy and retail to reduce and remove harmful pesticides
ICS110	University of York	Software and instruments supporting air pollution management

ICS111	University of York	Software for crystallography supporting new drug development
ICS112	University of York	Halogens, stratospheric ozone and the Montreal Protocol
ICS113	University of York	Influencing UK air pollution policy and legislation

Appendix B. Environment Statements

Table B1 below includes all 40 Environment Statements that have been analysed as part of this work. The statements have been given reference numbers for use within this report. The full environment statements can be found on the REF website https://results2021.ref.ac.uk/environment (filter for UOA8 Chemistry) where they can be downloaded via the 'Environment Narratives (REF5)' tab.

Note that the environment statement for the Universities of St Andrews and Edinburgh is a joint submission covering chemistry research in both institutions. All other environment statements are single institution submissions.

Table B1. Reference numbers for all publicly available UOA8 Environment Statements

Reference no.	University
ES1	Cardiff University / Prifysgol Caerdydd
ES2	Heriot-Watt University
ES3	Imperial College of Science, Technology and Medicine
ES4	King's College London
ES5	Loughborough University
ES6	Queen Mary University of London
ES7	Queen's University of Belfast
ES8	Swansea University / Prifysgol Abertawe
ES9	University College London
ES10	University of Aberdeen
ES11	University of Bath
ES12	University of Birmingham
ES13	University of Bradford
ES14	University of Bristol
ES15	University of Cambridge
ES16	University of Chester
ES17	University of Durham
ES18	University of East Anglia
ES19	University of Glasgow
ES20	University of Greenwich
ES21	University of Huddersfield
ES22	University of Hull
ES23	University of Kent
ES24	University of Lancaster
ES25	University of Leeds
ES26	University of Leicester
ES27	University of Lincoln

ES28	University of Liverpool
ES29	University of Manchester
ES30	University of Newcastle upon Tyne
ES31	University of Nottingham
ES32	University of Oxford
ES33	University of Reading
ES34	University of Sheffield
ES35	University of Southampton
ES36	University of St Andrews / Edinburgh
ES37	University of Strathclyde
ES38	University of Sussex
ES39	University of Warwick
ES40	University of York

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