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Alongside the financial crisis, the past decade has been characterised by major geopolitical and societal changes that have set new expectations for scientific R&D. Demographic changes, escalating environmental challenges and growing fears about energy security have highlighted the urgent need for new paths to attaining sustainable prosperity, and R&D has been identified globally as a key enabler to achieve this goal.

The search for sustainable growth through responding to global challenges and driving industrial innovation has become the overarching theme shaping the outlook for R&D globally.

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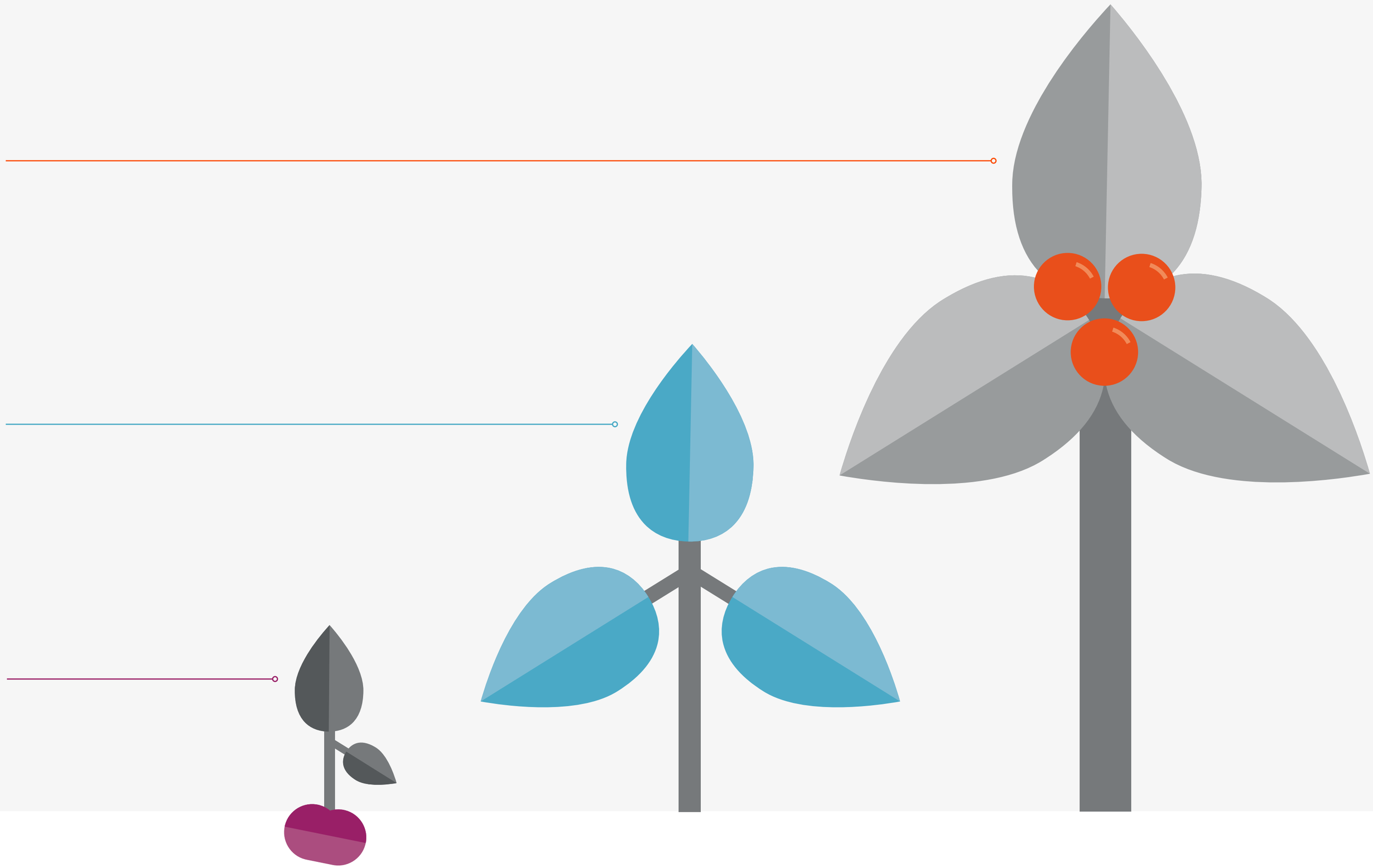

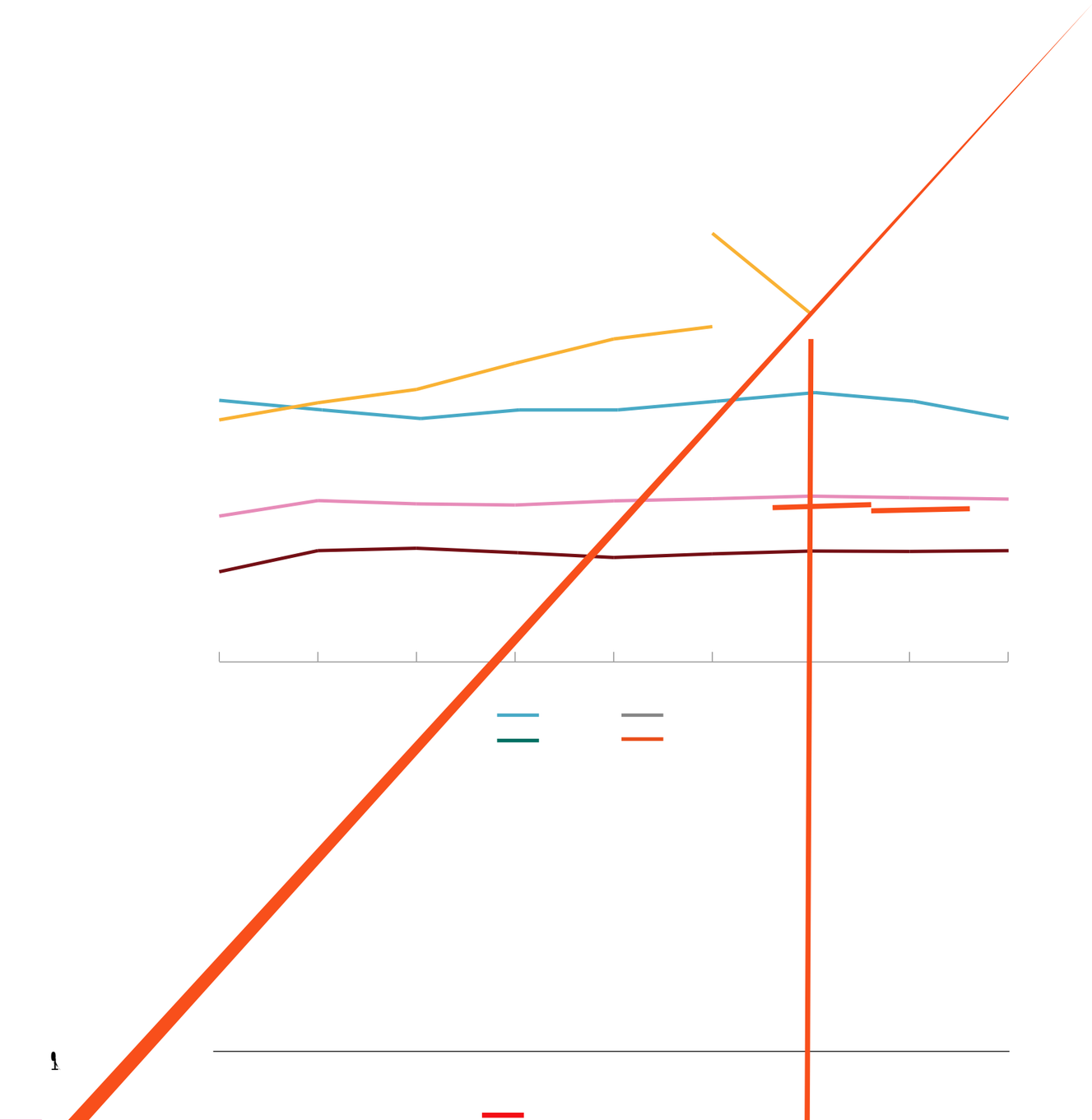

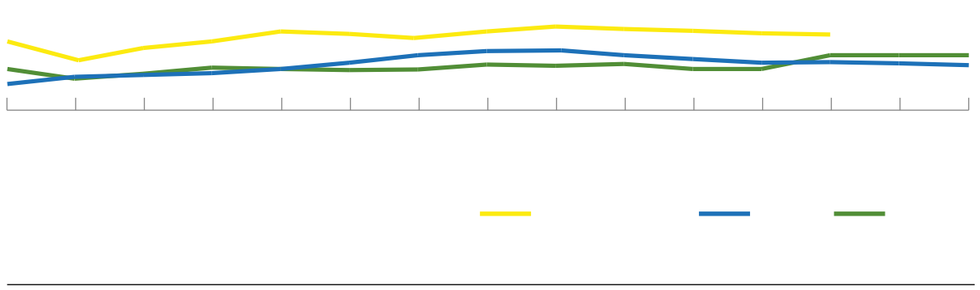

Through our interviews, workshops and survey, we heard that the scope of chemical sciences research today is vast. It encompasses deep questions about the structure and properties of matter from sub-nano to macrosopic scales right through to work with immediate application in fields such as human health and energy. Researchers are working across all of the global challenge areas and are deeply embedded in delivering industrial applications, with high expectations for what they can achieve over the medium term.

This breadth was confirmed in our data science analysis which showed that the top 20 fastest-growing topics in scholarly journals classified as chemistry included topics relevant to all of the major global challenge areas, some with strong industrial implications.

Combining analysis of publication trends with the expert views we heard through our researcher engagement programme, we grouped the mid-term advances we can expect from the chemical sciences into three broad areas:

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Advances in understanding and application of the chemical sciences to major societal and industrial challenges

- Advances in understanding of the cha7TJETEMC /Span <</Lang (en-GB)/MCID 544 >>BDC Beiepan 94.7933 Tm(090007>>> BDC 9 0 0 9 119.7638 536.7933 cw (el31.10 (ation of)]TJETEMC /Span <</Lan 0 0 rial implic)10.2 (ats560.7931 (erm adv)20.1 7JETatiBDC BT9 0 0 9 119.76g (en-GBp), 5on-G27933 Tm[Adv)20 (an

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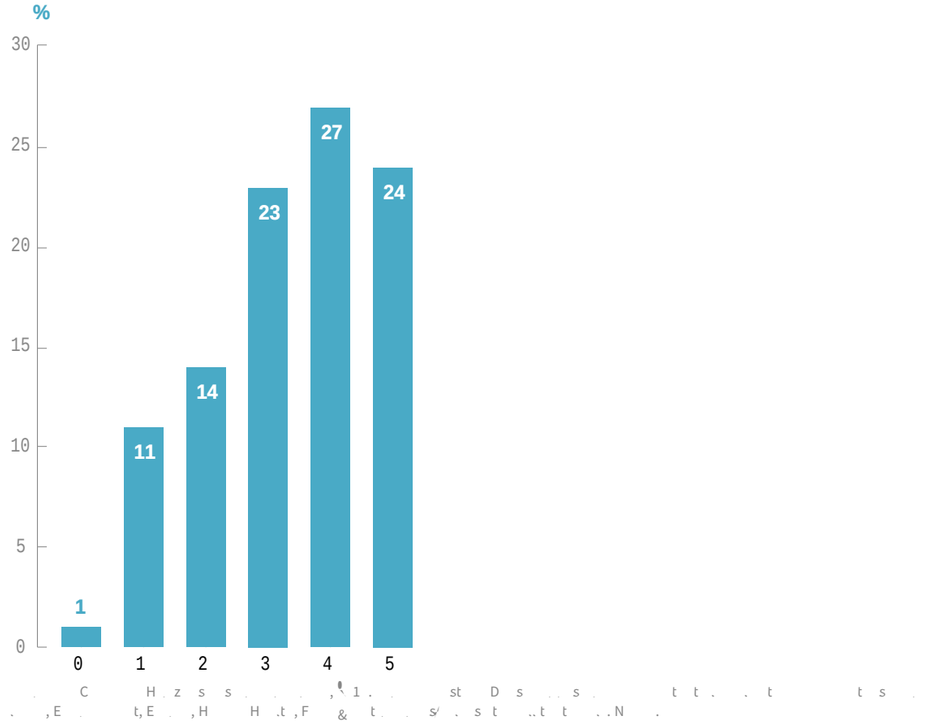
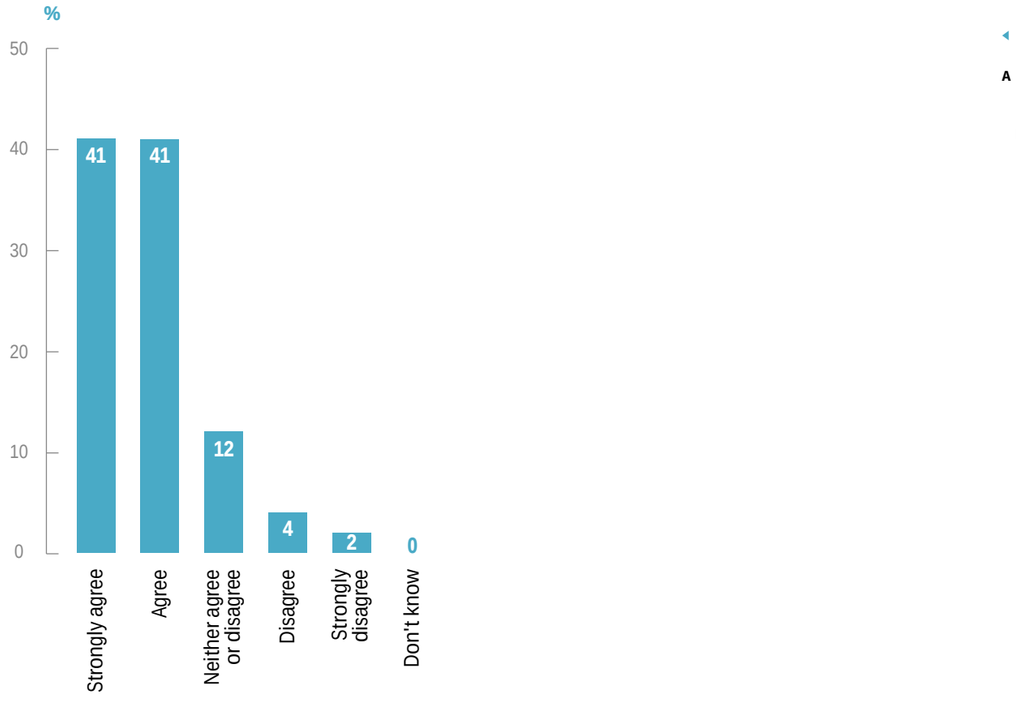
Researchers expect significant advances in the chemical sciences to underpin solutions to major societal challenges from environment and energy to human health and agriculture. In our survey, 99% of researchers stated that their work had potential application in at least one global challenge area with the average being 3.4 areas. Areas with the most potential for application are shown in Figure 8. A more detailed breakdown and list of specific examples of research advances are in Appendix B.

Environment	83%	• Substitution of toxic or hazardous materials • Environmental monitoring and/or remediation • Substitution of critical and scarce materials • Waste recycling
Human Health	75%	• Cancer • Measurement/sensing • Diagnostics • Antimicrobial resistance
Energy	68%	• Solar energy • Batteries • Carbon capture, storage and utilisation • Cleaner fuels and lubricants
Urban Living	57%	• Environmental monitoring and/or remediation • Waste recycling • Energy e□icient buildings • Green transport
Food & Water	54%	• Drinking water quality and safety • Food safety • Water capture and recycling • Food production and security



Researchers consistently highlighted the importance of finding applications for their work and developing scientifically-based solutions to global and industrial challenges. For example, 23% of people who responded ticked three potential application areas. 82% of those surveyed agreed that considering the applications of research is in fact a ‘duty’ for scientists (see Figure 10).



In order to translate research into application and mass adoption, it is critical for academic scientists to have close working relationships with industry partners. Academic chemical sciences researchers are deeply connected with current commercial areas of industry, ranging across everything from electronics to concrete and cement production. In addition, many researchers are engaged in advancing industrial processes, particularly in ‘green industry’ (eg alternative solvents or more e□icient catalysts). Examples of the research chemical scientists are carrying out in partnership with industry are in Table 2.

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A	Advances in corrosion-resistant steel coatings.
	Replacements for toxic metals (eg using aluminium, zinc or nickel as alternatives to cadmium).
h h	Materials for extreme ultraviolet lithography.
	Environmentally-friendly materials for 3D printing.
	Polymer materials for new display technologies (eg chiral helical polymers for 3D screen technologies, semiconducting polymers for flat and flexible displays).
	Molecules and materials that can be used as components of information storage (eg single molecule/crystal magnets and advanced polymers).
	Robust measurement techniques and standards for verification of food contents (eg to detect plastic bulking agents in rice, verify claims about “free-from” or “gluten-free” foods).
	New supply chains based on converting industrial by-products (eg terpenes from paper industry) into useful functional molecules
	'Holistically green' alternatives to commonly used toxic chemicals and chemical processes (eg remove dimethylformamide (DMF), N-Methylpyrrolidone (NMP) and toluene from the production of commercial products including electric vehicle batteries, paints and apparel).
	Replacements for precious metals in catalysis (eg using earth-abundant metals such as iron, aluminium and zinc).
	More e□icient catalysis at industrial scale (eg reduce use of volatile solvents, improve stability in air and at higher temperatures).
	Advances in enzyme-catalysed industrial processes (eg improving enzyme stabilisation, developing enzyme encapsulation materials, optimising flow chemistry).

Through interviews and workshops we heard that academic chemical sciences researchers are actively seeking answers to an incredibly broad range of questions, encompassing everything from the properties of main group elements to understanding the origins of life. The examples we classified in the leading-edge questions category are primarily driven by advancing fundamental understanding rather than seeking immediate practical applications. In many cases answering these questions will contribute to developing future technologies, but more broadly and will enable new solutions to global and industrial challenges in both the short and long term.

We grouped the leading-edge questions being tackled by researchers into four broad themes:

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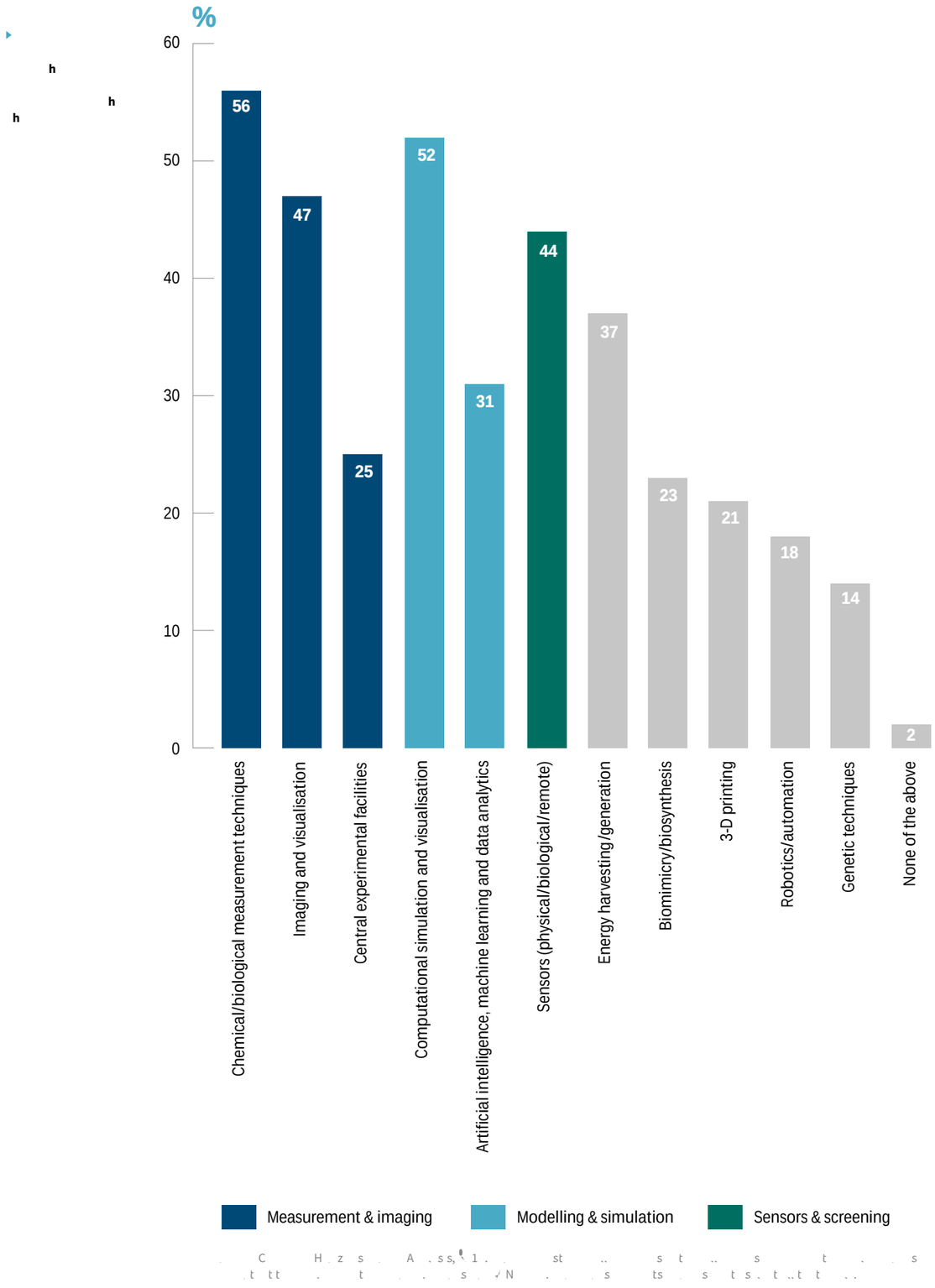

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We heard that advances in analytical measurement techniques are enabling researchers to study systems at greater resolution than ever before, from using single molecule spectroscopy to observe the properties of individual molecules to applying synchrotron X-ray and neutron sources to study catalysis at a molecular level as a reaction is taking place. Developments in ion mobility mass spectrometry provide researchers with greater information on the structure of biomolecules and by employing cryo-electron microscopy researchers can also study how they function.

Over 50% of researchers surveyed highlighted the importance of developments in analytical measurement and imaging techniques (see Figure 11). Advanced measurement techniques were also highlighted as a fast growing area in our analysis of publication trends and were consistently highlighted as critical in our researcher interviews.

In particular, researchers highlighted recent developments in ultra-fast and in operando measurement techniques, as well as advances in the complexity of species that can now be studied.

Researchers from across all fields of chemical sciences described the development of measurement & imaging as important for advancing their work, covering everything from understanding the behaviour of single molecules to studying the dynamics and interactions of complex systems. Specific examples included:

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Developments in sensor & screening techniques were highlighted as important for the advancement of their research by over 40% of researchers surveyed (see Figure 11).

Advances in sensor & screening technology was highlighted as critical by researchers in a number of fields, particularly by researchers working in chemical biology and environmental areas. These fields in particular are looking to develop sensors that can detect, monitor and screen with high specificity in a vast array of diverse conditions eg outdoors, in hospitals. Advances in the underlying analytical chemistry will be critical to improving the sensitivity of the technology and developing tools that work e□ectively in real in-field conditions with high reliability. Developing sensors that can deal with multiple types of data in complex samples – for example, human secretions, soil etc – was highlighted as particularly important, as was miniaturisation of the technology.

Example applications highlighted by researchers include:

- Measuring atmospheric properties of complex urban environments for environmental monitoring
- Measurement of molecular markers (eg single molecules) in human breath, sweat, tears etc. for use in non-invasive diagnostics
- Tracking the bio-8-8-8-8-t2 m.7638 630.2894 Tm[r)10 (eliability)20 (. D10 (al)-20 n0en-GB)/MCI-20 ( )]TJE (aiabiTmt)10 (or and scr)1 ( )]TJETEM_s highlighted as mtor and scr Measuring attd4 in

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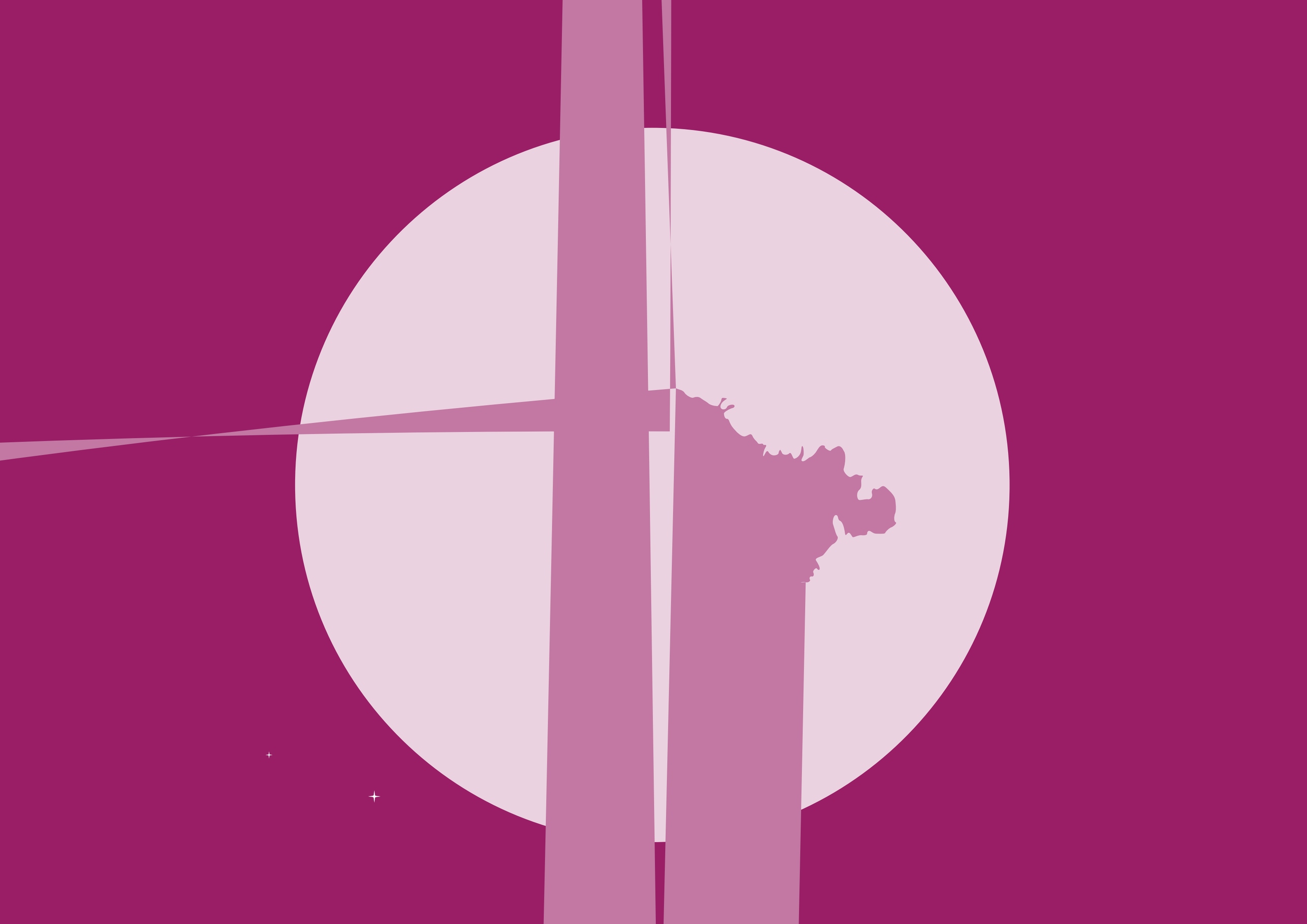
Science and engineering research plays a pivotal role in driving forward the global R&D agenda, contributing to sustainability and prosperity. It is therefore important to ensure an environment that enables research to deliver to its full potential.

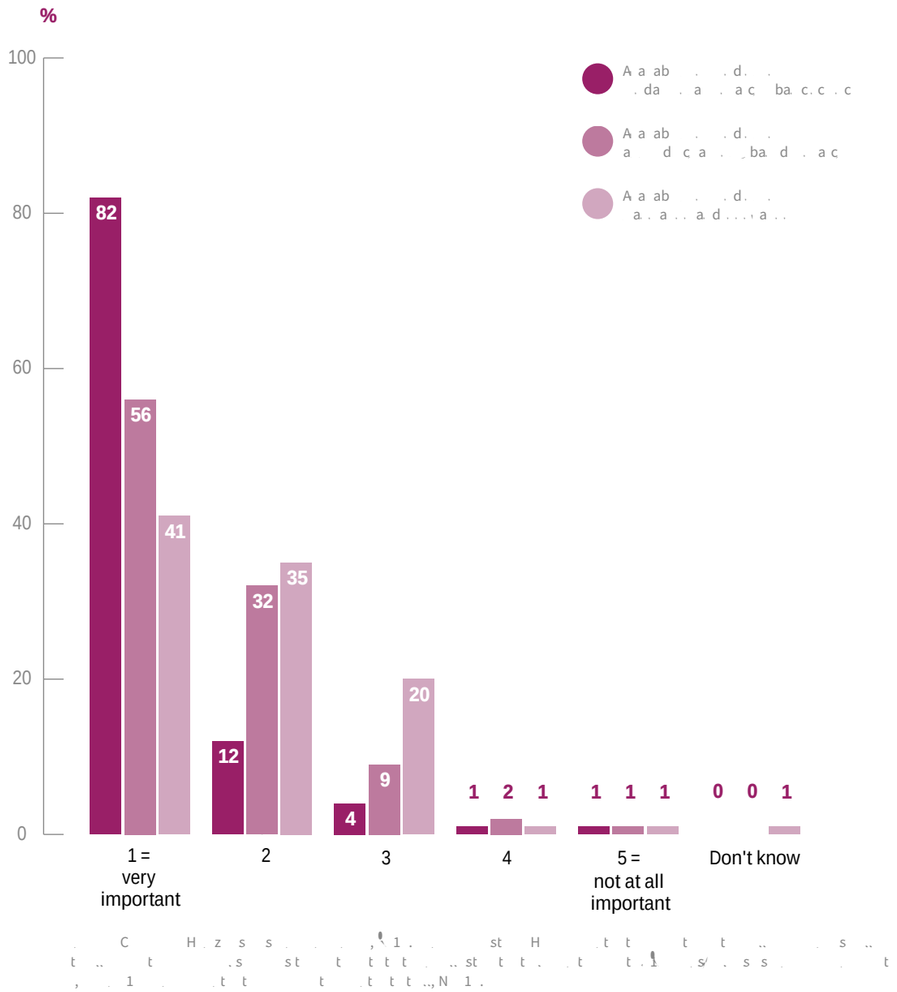
Through our conversations with researchers in interviews and workshops three key contextual areas emerged as critical in order that research contributes to its full potential to society today and in the future:

- Curiosity
- Collaboration
- Leadership

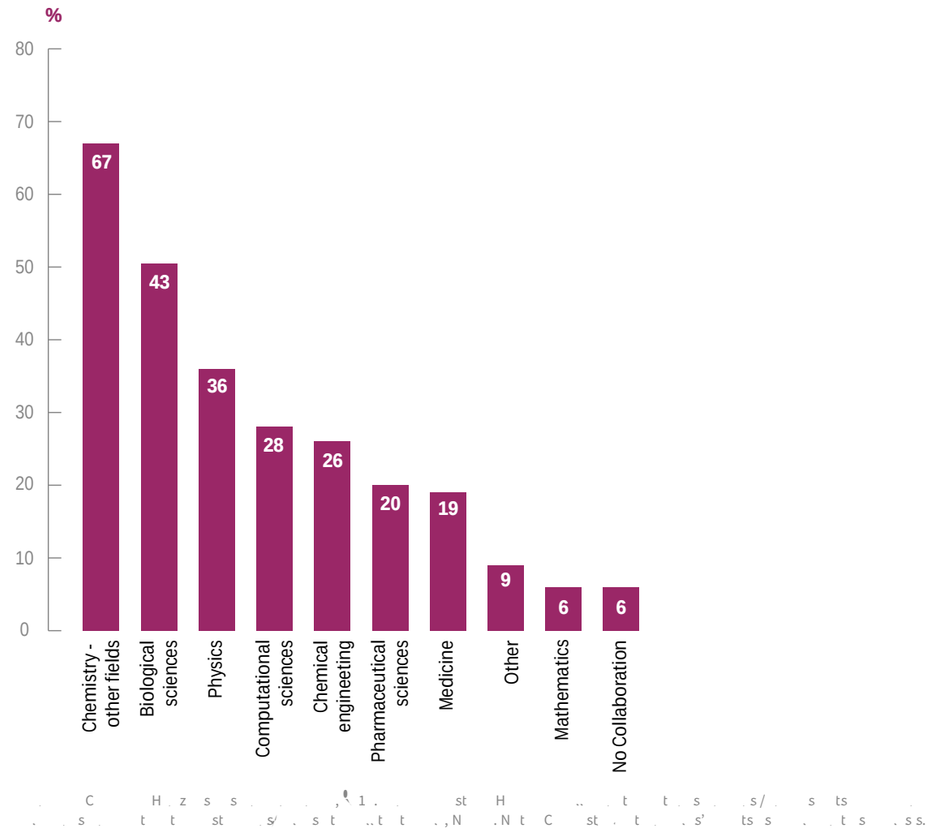


A recent social science analysis of more than 65 million science and technology papers, patents and so□ware products from 1954–2014 (Evans et al Nature, 2019) concludes that both small and large teams are essential to a flourishing ecology of science and technology.

The analysis found that smaller teams (which could include sub-teams within a larger team or centre) have tended to disrupt science and technology with new ideas and opportunities, whereas larger teams have tended to develop existing ones.

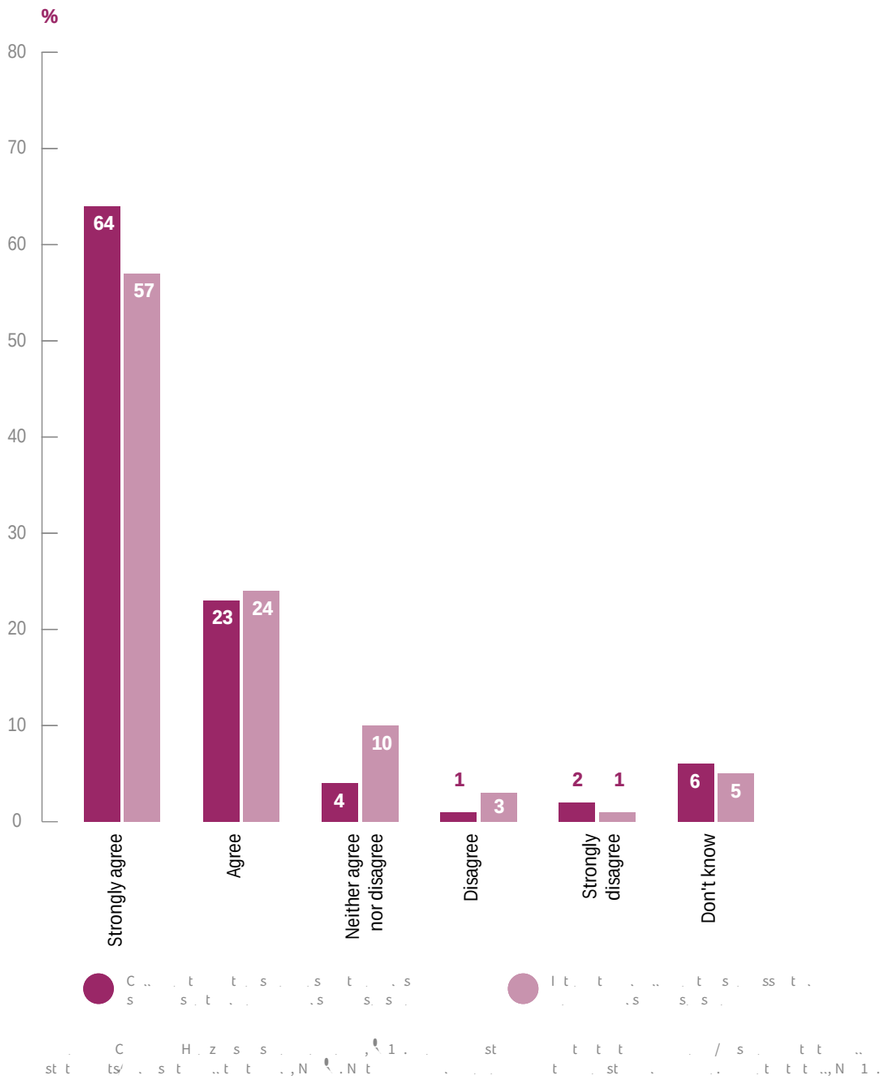


Really exciting science takes place where people cross disciplinary boundaries and work with industry. The way chemists along with other disciplines have used large facilities to really interrogate a problem has been revolutionary and will continue to be. It is essential to continually upgrade and invest in these facilities.



It is of huge benefit to work with interdisciplinary groups and get new perspectives into the research, particularly if you include a researcher from a di□erent sector such as industry.

Bringing people together from di□erent backgrounds lets you make progress really e□iciently. Each discipline brings a unique insight to the problem, however it is increasingly hard to find the boundaries of what is chemistry, biology and physics.

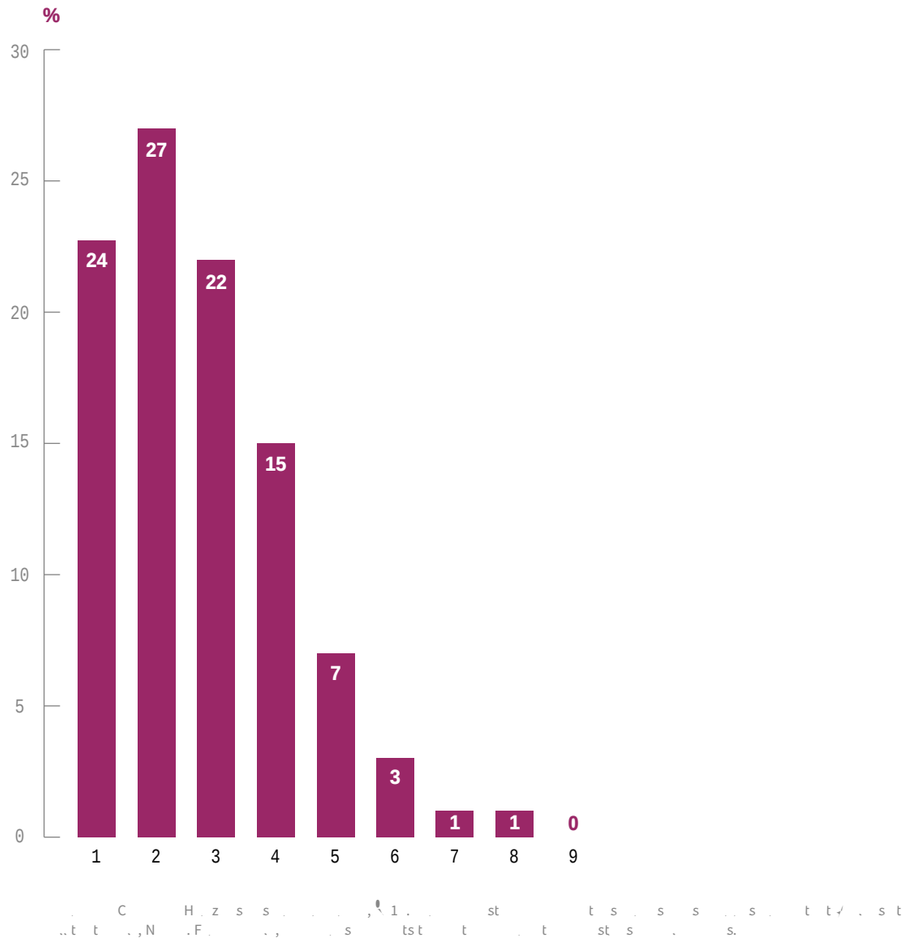


Collaboration with other fields of science was seen as incredibly important:

The highly interdisciplinary nature of the chemical sciences themselves is further illustrated by how survey respondents classified their own research. When asked to classify research into twelve traditional subfields of chemistry, researchers picked on average 2.7 areas. Certain subfields are notably important for overlaps, for example materials chemistry has a particularly strong relationship with all other fields of chemistry. Fields of chemistry that co-occurred in respondents' description of their research > 50% of the time (see table X) are:

- Computational – Physical (64%)
- Environmental – Materials (54%)
- Green – Materials (64%)
- Inorganic – Materials (71%)
- Physical – Materials (61%)
- Synthetic – Materials (56%)
- Synthetic – Organic (68%)
- Theoretical – Computational (73%)
- Theoretical – Physical (73%)

Many interesting fundamental questions are at the boundaries of chemistry and other disciplines. There is a lot of interesting chemistry to be done at the interfaces.



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In our survey researchers highlighted the importance of mechanisms for fostering collaboration (see Figure 19). We also heard about the challenges associated with developing e□ective collaborations.

From the point of view of education, it is a challenge to provide students with enough depth in the chemical sciences, while simultaneously preparing them for the collaborative, interdisciplinary world of academic research or other career paths, for example in industry.

Traditional university career paths do not typically prepare people to build collaborative, interdisciplinary teams and manage them as a research leader. Research leaders need to bring together a team with the right balance and breadth of skills. They must continually secure external funding and develop collaborations to support a long-term research programme. At the same time as team leaders they are responsible for developing and supporting the careers of people in their teams, as well as ensuring team performance and cultivating a positive, motivated culture with e□ective communication.

Researchers also flagged working closely with industry partners as particularly important in translating research findings towards application (see Figure 19). We heard that it can be challenging for potential academic and industry partners to find one another in the first place. Once they have found each other there can also be challenges in bridging di□ering expectations about timescales and levels of certainty required before starting projects.

For example, working with industry can require very tightly defined projects focussed on particular deliverables. This is a challenge if PhD students are involved because it is important for a student to have a broad scientific experience and to develop and pursue their own ideas.

We heard a sentiment that researchers need to be more flexible in the ways in which they respond to industry, but that this needs to be supported by university and funding structures. For example, academic structures need to have people with the flexibility to respond to new opportunities and not only organise in terms of typical 3-5 year PhD or 1-3 year post-doc cycles.

It is important to enable networking between di□erent disciplines – this is something that we should be trying to encourage – it brings very rich outcomes as you 9aan /Lu need to deliver encpnt (enlarHETEMC/span /S9 / /SpO)/MCID 2284 >>BDC BT11 0 0 11 6i73 >>BD

Culturally, there has been a ‘lone wolf’ mentality in academia – scientists are aware that they are judged by their own ideas and results, and it can be hard to manage this in a collaborative context. Universities could do more to encourage collaboration, for example cross-disciplinary positions could be created and these positions would need to be properly supported.

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We need to urgently start training the next generation of PhD students to have a culture of understanding across di□erent disciplines and methods, in the way that is forward-looking, out-of-the-box and beyond the currently accepted concepts and established challenges - to enable them to drive science and innovation to the next level.

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I believe that the depth of understanding provided by traditional disciplines is needed to solve many of the big issues. Deep disciplinary knowledge has great value when working in multidisciplinary research teams who are tackling challenging questions.

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Collaborating is not as simple as saying ‘I need one chemist, one biologist etc.’ To build useful interdisciplinary collaboration you really need to have a clear idea of the problem and topic you are exploring and an understanding of what skills you need to deliver the best outcomes.

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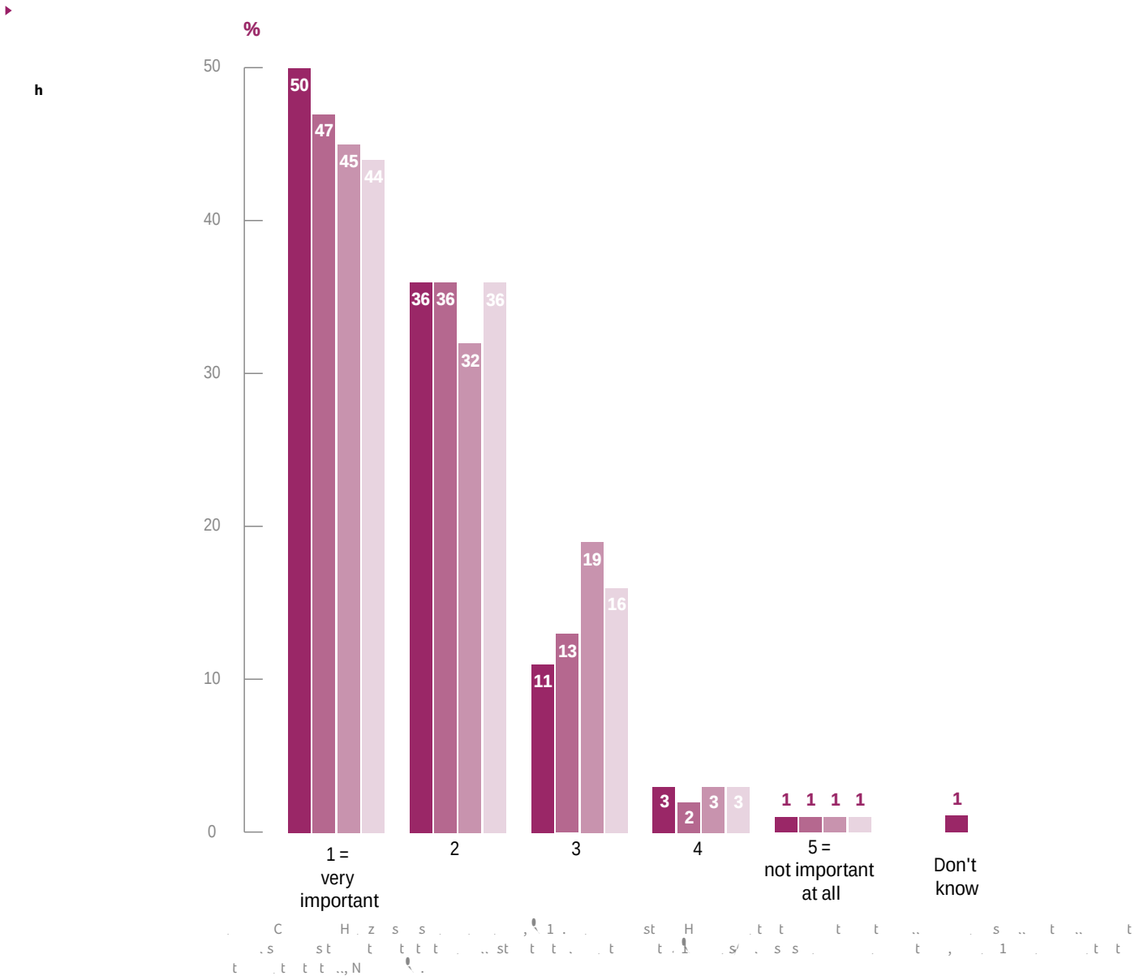
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As well as taking a more prominent role inside the scientific and policy community, researchers also highlighted the importance of greater proactivity in engaging with the public.

Over 80% of researchers surveyed agreed that more needs to be done to engage the general public on the importance of the chemical sciences (see Figure 21).

There is opportunity for us to work with the media to highlight more the role of chemistry. Chemistry underpins our iPhones, the paints on our walls and the medicines we take – chemistry is everywhere.

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The real importance of chemistry in everyday life can sometimes be missed because chemistry is just about everywhere. We need to capture the public imagination about chemistry.

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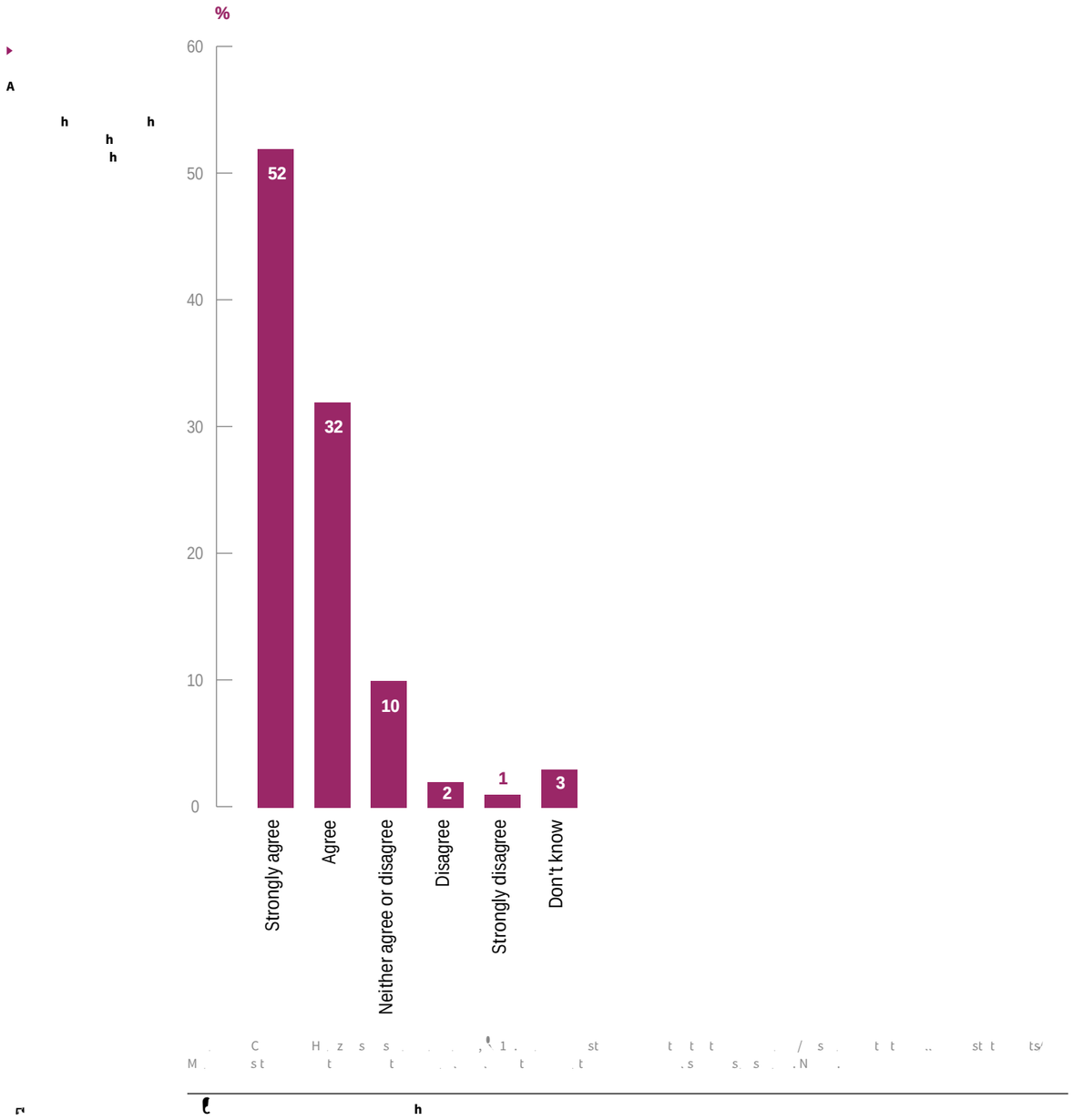

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Chemical sciences research is key to achieving progress against the global agendas of sustainability and prosperity. This twin agenda is reflected in the move towards challenge-based research and the emphasis on R&D stimulating economic output.

In our Science Horizons project we engaged with chemical sciences researchers and found a positive, confident vision for research today and in the future. There is a sense of agency and energy among researchers – people are ambitious, breaking new research frontiers and actively engaged with other disciplines and sectors in translating their research for societal benefit.

Globally, researchers are developing cutting edge techniques and creating new knowledge and understanding about our world. Data and digital technologies are playing an ever-increasing role in scientific discovery, with the potential to accelerate and enable certain areas of science.
We found that researchers are deeply committed to delivering solutions to the urgent global challenges of our time across the spectrum from energy to environment to health.

Key themes that came through when considering how to ensure that academic research contributes to its full potential were balance and flexibility:

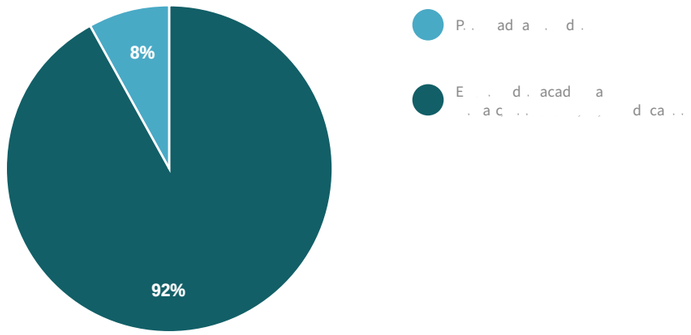
- Balance between funding for curiosity-driven and challenge-driven research
- Balance between funding for large research programmes and smaller groups.
- The need for highly skilled disciplinary experts and to harness interdisciplinary approaches to answering questions and delivering solutions.
- The importance of structures that support long term research endeavours and at the same time mechanisms to enable agile collaboration with industry.
- The importance of scientific research knowledge and competencies and the need for wider skills related to leadership, collaboration and engagement.
- The role of research culture in supporting individuals throughout their careers while fostering collaboration and translation.

The Science Horizons project provides a framework to inform strategy development across the Royal Society of Chemistry as we consider how to most impactfully support our community and work to advance the chemical sciences for the benefit of humanity. We will next host and share the outputs from a series of Strategic Advisory Fora in specific deep dive areas.

The project was informed by three categories of input

- Desk Research: Evidence based on existing reports, information in the public domain into global research and development (R&D) funding landscape and priorities.
- Data Sciences: Evidence based on analysis of publication trends and topics in the chemical sciences.
- Opinion: More than 880 current and future R&I leaders in academia from around the world participated in an online survey, and in interviews and workshops between August and October 2018.

In Spring 2019 we shared and tested initial themes and TEMC /ddDts wit meo o6ßC Cundcil, our Divison



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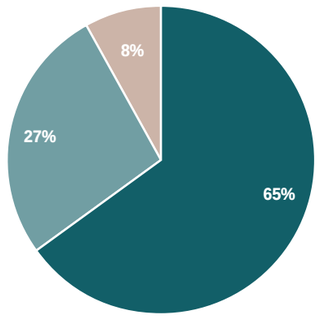

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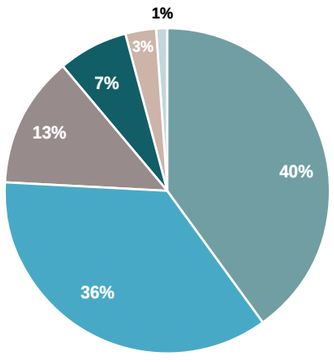

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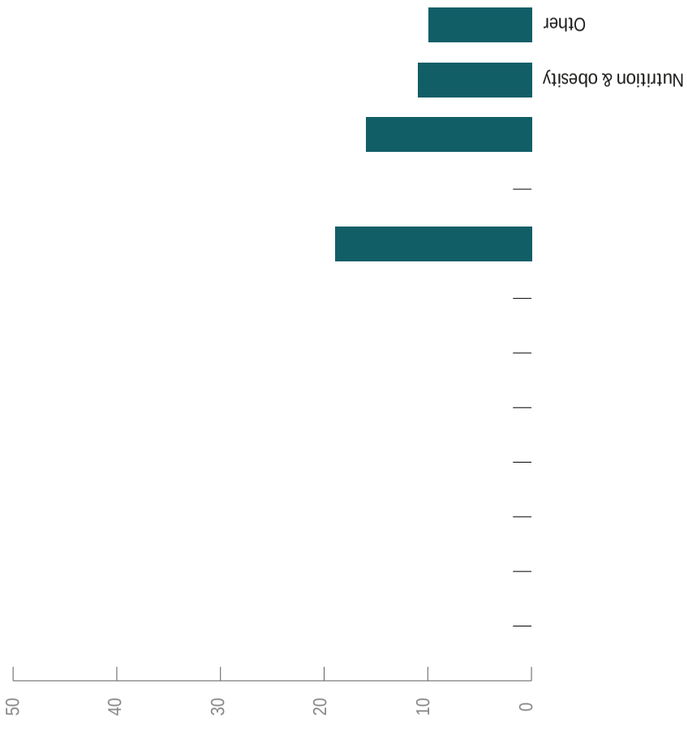

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	Advances in disease diagnosis, including identification of new biological markers and the application of technologies such as mass spectrometry and electrochemical analysis.
	Using new materials to deliver therapeutic molecules to di□erent parts of the body.
	Development of new vaccines and related technologies eg encapsulated vaccines for improved stability and bio-availability, vaccines for malaria or new approaches to control vector borne diseases for example by sterilising mosquitos
	Applying computational modelling of organic synthesis to improve design of molecules for medicine eg using digital technologies such as AI to predict metabolites and optimise drug metabolism and pharmacokinetics, developing new molecules that target di□icult to reach areas of the body such as the brain, understanding disease mechanisms such as target versus o□-target e□ects.
	Applications of MOFs in drug delivery, particularly cancer research. One research direction includes the use of molecular simulation and computational methods, eg using artificial intelligence / machC /.es(9 265B.oing din1pan e st)10.aby sterids,

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We would like to thank all of the researchers who contributed their time, expertise and opinions to the Science Horizons project :

- Interviewees
- Members of our Analytical, Chemistry Biology Interface, Dalton, Environment, Sustainability & Energy, Faraday, Materials Chemistry and Organic Division Councils
- Members of Heads of Chemistry UK
- Members of RSC Council
- Members of RSC Interest Groups and Geographical Networks
- Survey respondents.

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We also acknowledge contributions from the Royal Society of Chemistry leadership team, in particular Dr Jo Reynolds (Director of Science & Communities), Dr Emma Wilson (Director of Publishing) and Sarah Robertson (Director of Education & Professional Practice).

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