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Molecular science and engineering: a powerful transdisciplinary approach to solving grand challenges

Claire S. Adjiman, Nicholas M. Harrison and Shoshana Z. Weider

Executive summary

The concept of **molecular science and engineering** – melding a deep understanding of molecular science with an engineering mind-set – is emerging as a powerful way to create novel, effective and sustainable solutions to global grand challenges, such as the growing threat of antimicrobial resistance. By blurring the boundaries between scientific and engineering disciplines, in this holistic approach, final function and end-use requirements become an integral part of the underlying scientific research. Commercially ready materials can thus become a reality in an accelerated, flexible and economic manner. In other words, molecular science and engineering can fundamentally alter the way molecules are identified and designed for real-world usage. **It is not enough to simply make molecules; we must make molecules work for a complex world.**

The notion of bringing researchers, industry and government communities together to work on grand challenges has a long and illustrious history – think, for instance, of the Manhattan Project, the industrial scale-up of penicillin and the Moon landings. More recently, the idea of ‘convergence’ – tackling grand challenges with a multifaceted array of scientists, engineers, clinicians and beyond – has become more formally recognised as a valuable way to stimulate societally important and ground-breaking research. Molecular science and engineering is a specific, yet far-reaching, part of this convergence landscape.

Within the growing worldwide molecular science and engineering community, the Institute for Molecular Science and Engineering (IMSE) was founded in 2015 as Imperial College London’s newest Global Institute. The Institute’s overarching aim is to bring the College’s engineers, scientists, medics and business researchers together with a wide array of external stakeholders – and to remove the boundaries between these disciplines – to find innovative molecular-based science and engineering solutions to pressing grand challenge problems. Imperial’s world-class researchers and facilities, together with its existing culture of collaboration, multidisciplinary, research translation and grand challenge goals, make the College the perfect home for IMSE.

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The Institute's three guiding pillars – advancing integrated transdisciplinary research, transforming education and enabling effective translation of research to industry – are used to steer the Institute's community-building activities and to help overcome obstacles that are commonly encountered during convergence-style and transdisciplinary research. Such issues include organisational barriers in academic institutions, personal motivational issues for researchers (e.g., measures of success), poor communication between traditionally separated disciplines and between academia, industry and government, as well as a scarcity of suitably trained (i.e., collaboration-ready) science and engineering graduates.

To that end, IMSE manages a range of activities that foster innovation and collaboration. For example, IMSE co-ordinates bespoke workshops to bring its large community of Imperial-based affiliates, as well as external partners, together to focus on specific grand challenge problems and industrial needs. IMSE catalyses new collaborations through seed-funded projects that enable the first steps towards transformative research goals. IMSE's unique Master's of Research in Molecular Science and Engineering has been designed to train the next generation of scientists and engineers, who are equipped to work across the important molecular science/engineering interface.

Introduction

A molecular science and engineering approach to global grand challenges

As a global society, we currently face many pressing challenges. The list is long (see, for instance, the list of 15 global challenges compiled by the Millennium Project¹) and specific examples include:

- clean and affordable water supplies are not yet available to everyone around the world, and some existing supplies are now threatened;
- growing resistance of microbes to vaccines means that more-effective ways to inhibit the spread of infections are required;
- anthropogenic climate change brings the need for a sustainable and viable global energy supply, and for a reduction in greenhouse gas emissions.

To solve grand challenges such as these, it is becoming ever-more apparent that radical changes to research practices are required.

The concept of **molecular science and engineering** – melding a deep understanding of molecular science with an engineering mind-set – is emerging as a powerful way to create novel, effective and sustainable solutions to global challenges. Whereas the work of molecular scientists generally involves innovation at the molecular scale, engineers tend to focus on the integration of components, at a larger scale, to build better systems. The current level of communication and co-operation between these two communities, however, is typically insufficient to adequately tackle these challenges. To find solutions that are both scientifically feasible and fit for purpose, the gulf between the two communities needs to be narrowed and bridged. **It is not enough to simply make molecules; we must make molecules work.**

The holistic molecular science and engineering framework provides an opportunity, for example, to confront the growing threat of antimicrobial resistance² and to stop bacteria in their tracks. Drug-resistant infections are now the cause of more

than half a million deaths around the world every year, and it is predicted that this number will rise to more than 10 million by 2050³. Addressing this complex global health challenge successfully will undoubtedly require a multifaceted approach. Indeed, many different ways to tackle this problem have already been suggested. Such proposed solutions include raising public awareness, improving sanitation and hygiene conditions, reducing antibiotic use, as well as producing new vaccines and drugs. As part of this arsenal of strategies, it is easy to imagine how the design and deployment of new 'smart' surfaces to kill microbes or prevent their spread could be introduced into all parts of modern society (e.g., in public transport and infrastructure, food preparation areas and medical equipment).

To turn such ideas into reality, molecular (and biological) understanding needs to be linked – through a multistep process chain – to an engineered final product (see [Figure 1](#)). To ensure successful end-use, it is also important to involve the wider industry, policy and governmental communities, as well as the general public, at the early stages of research. Often, however, there are large divides between the various stages of this process, reflecting that research endeavours are traditionally focused on only one part of the chain and draw on deep discipline-centric expertise.

By drawing on this kind of discipline-centric approach, it is possible to utilise current empirical understanding and state-of-the-art techniques to link molecular information (e.g., composition and structure) to key physical properties of a material (e.g., chemical, mechanical, electrical and thermal characteristics) and thence to the performance of a molecule or material. These structure–property–performance 'maps', however, are frequently a poor indicator of actual product or system function, and the molecular innovations they point towards often fail to deliver in reality (e.g., they are too costly, unstable, unsafe, or hard to manufacture). This can arise for two different reasons: either the maps are not sufficiently accurate, or some stages of the molecule-to-product process are not given the appropriate consideration.

In contrast, molecular science and engineering provides the opportunity to establish better links along the molecule-to-final-product innovation chain. By removing the boundaries

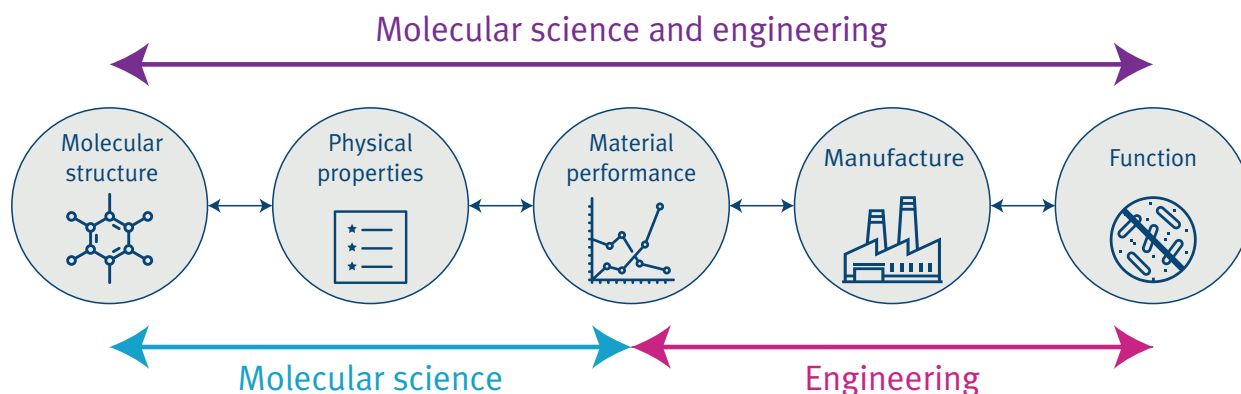


Figure 1. Schematic illustration of the multistep process chain that links molecular-scale insight to engineered final products (e.g., a ‘smart’ surface that can prevent the spread of bacteria in a range of situations). Current molecular science research often allows molecular structure information to be linked accurately to physical properties of molecules, and physical properties of molecules can sometimes be correlated to the performance characteristics of a material. Likewise, engineering approaches can be used to design materials with specific performance characteristics and to choose appropriate manufacturing techniques to achieve a particular function. Nonetheless, a direct link – from final system function to molecular structure – is established in only a few situations. The molecular science and engineering concept, however, allows the innovation circle to be closed. The desired final function of a system can be realised in an accelerated, flexible and cost-effective manner by considering each of the process stages in tandem.

between scientific and engineering disciplines, final function and end-use requirements become an integral part of molecular-scale scientific research (i.e., the process stages can take place concurrently rather than consecutively). Rather than testing huge numbers of different molecules and materials to find one that exhibits a particular set of performance parameters (like searching for needle in a molecular haystack), molecules can be designed with due consideration for end use. In this all-encompassing methodology, molecular solutions to important problems can thus be evaluated in an accelerated, flexible and cost-effective manner, to rapidly bring successful discoveries to fruition. **In other words, the molecular science and engineering approach can fundamentally alter the way molecules are identified and designed for real-world applications.**

What makes molecular science and engineering work?

The holistic molecular science and engineering framework is enabled by a recent conjunction of technological advances (see Figure 2) that allows scientists to make, measure and model molecules for specific purposes, with unprecedented accuracy and predictive power. For example:

- novel approaches to making molecules and materials (e.g., click chemistry, advanced polymerisation techniques, self-assembly processes or biomimicry) allow them to be made with unparalleled precision and structural control;
- with new characterisation and analytical techniques it is now possible to image materials at almost every spatial scale (atomic structures to macrostructures), on a variety of temporal scales and in operando (i.e., where processes take place);

- multiscale modelling techniques – spanning the sub-atomic, micro- and macro-scales, and incorporating first-principles (e.g., quantum theory) and data-driven methods – allow many processes to be accurately simulated prior to conducting expensive and lengthy experiments and tests;
- ground-breaking and innovative manufacturing techniques, including 3D printing and colloidal lithography, allow the detailed structure of fabricated materials and products to be increasingly controlled;
- incorporating state-of-the-art systems engineering principles and modern computer-assisted decision-making techniques means that the best molecules and materials can be created and optimised for specified applications and functions.

Molecular science and engineering thus brings the potential to make intelligent and informed molecular decisions (i.e., on very small scales) in tandem with system-scale decisions, so that the full end-to-end design process can be rapidly optimised for industrial-scale success.

Ozone and OLEDs: Examples of molecular science and engineering ‘in action’

Mitigation of the ‘hole’ in the ozone layer (the atmospheric layer that protects the biosphere from harmful ultraviolet radiation) is an illustrative – albeit accidental – example of the molecular science and engineering concept in action. Human activity – specifically the release of chlorofluorocarbons (CFCs) – is known to be the cause of the atmospheric ozone depletion that was first observed in the 1970s and 1980s (see Figure 3)⁴. CFCs were originally invented in the 1920s as safe alternatives to toxic refrigerant gases and went on to find widespread use as refrigerants, aerosol propellants, foam-blowing agents and

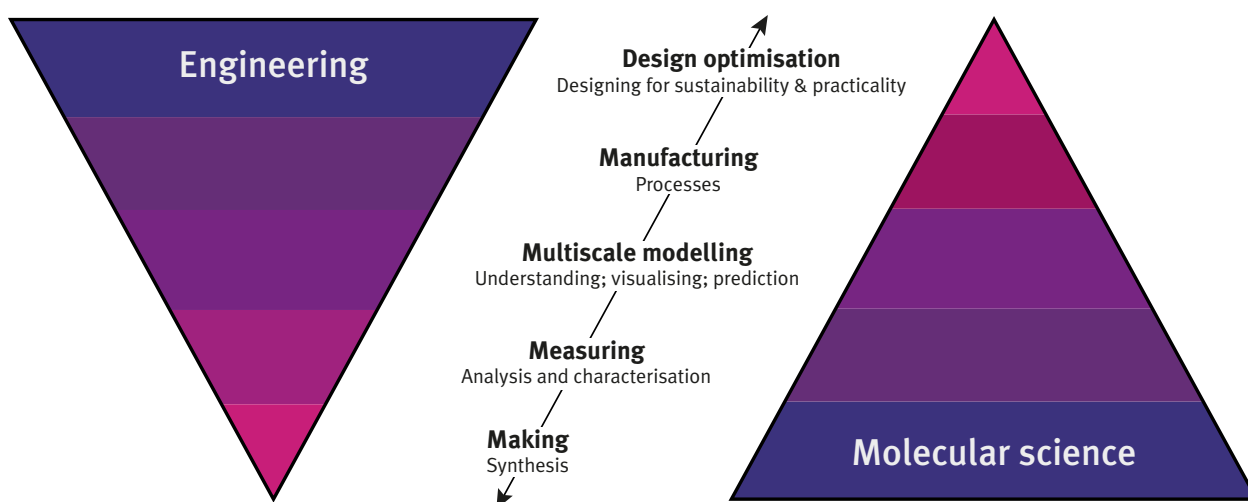


Figure 2. The molecular science and engineering research framework merges molecular-scale science with cutting-edge engineering. Where the capabilities of one are strong (at present) the other is weak. The molecular science and engineering approach aims to close the gap between the science and engineering components and to strengthen the whole end-to-end process, so that a variety of societal challenges can be tackled in an optimised and accelerated manner.

solvents in the electronic industry⁵. However, it later became apparent that CFC molecules can be broken apart by UV radiation in the higher levels of the atmosphere⁶. The chlorine thus produced can then enter into a catalytic cycle and contribute to the destruction of ozone.

Following this discovery, a decade-long battle between the industrial (i.e., CFC producers) and scientific communities ensued, and the damaging use of CFCs continued⁷. Eventually, with the 1987 Montreal Protocol agreement⁸, the use of CFCs has been steadily phased out and the ozone layer has begun to heal. Meanwhile, the chemical industry – by using both scientific and engineering insights – has developed a number of safer alternatives (i.e., hydrochlorofluorocarbons and hydrofluorocarbons) to replace CFCs. By combining scientific and engineering insights, it has been possible to find safe and practical molecules to replace CFCs in many applications.

Although this problem, and its subsequent resolution, are a good example of international scientific, engineering, industrial and political communities coming together to address a worldwide environmental problem, before the ozone crisis was resolved, it involved a long-lived conflict between science and industry. It also required intervention by non-governmental organisations, such as Greenpeace, to lobby governments and industrial groups into taking action. This molecular-based emergency is therefore precisely the kind of situation that can be avoided (or solved efficiently) by enhancing the level of collaboration and exchange of knowledge between molecular science, engineering and industrial communities.

Another example of unplanned, yet successful, molecular science and engineering in action, is the story of organic light-emitting diodes (OLEDs). OLEDs – which now constitute the displays of many everyday items, including television screens, computer monitors and mobile phone screens – are devices in which light is emitted in response to an electric current, from an organic electroluminescent layer (see Figure 4). Compared with other light-emitting devices, such as flat panel liquid-crystal displays, OLEDs present a number of benefits and advantages. For example, OLEDs are based on naturally light-emitting materials and therefore do not require backlighting, which in turn leads to their superior power efficiency. It is also relatively easy, through chemical means, to tune the properties of OLEDs. In addition, the relative flexibility, good processability, light weight, transparency and scalability of the devices gives rise to their wide applicability.

Although the first OLED was fabricated in 1963⁹, its operating voltage was too high to be practical. Despite years of efforts to improve the performance of similar devices, it took more than 20 years for the first practical OLED – a green-emitting thin-film device – to be realised¹⁰. With the introduction of a two-layer (i.e., emissive and conductive) structure for the organic material, the operating voltage of the devices was reduced and their efficiency correspondingly increased. It was only after the performance of red/green-emitting OLEDs surpassed that of incandescent bulbs and fluorescent lights, however, that these devices were finally considered as serious alternatives for solid-state lighting applications (i.e., to compete with inorganic LEDs). Major areas of current research also include the pursuit of white-light-emitting OLEDs for displays¹¹ and the use of OLED-like molecular configurations in ‘spintronic’ devices¹².

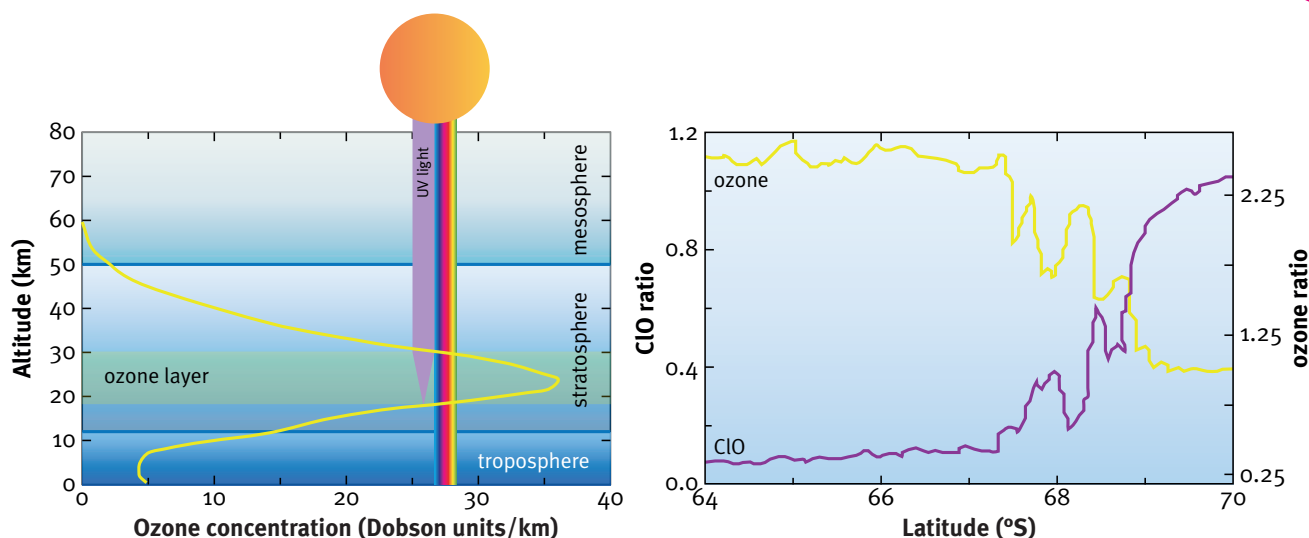


Figure 3. Left: Schematic cross section of the lower 80 km of the Earth's atmosphere. The ozone layer, at an altitude of about 20–30 km (within the stratosphere), has an enhanced ozone concentration and is an efficient absorber of ultraviolet (UV) light. **Right:** Striking evidence of the ozone 'hole' over the Antarctic. Measurements of ozone and chlorine monoxide (ClO) mixing ratios (defined as the ratio of the number of moles of the compound to the number of moles of air), as a function of latitude, are inversely correlated.

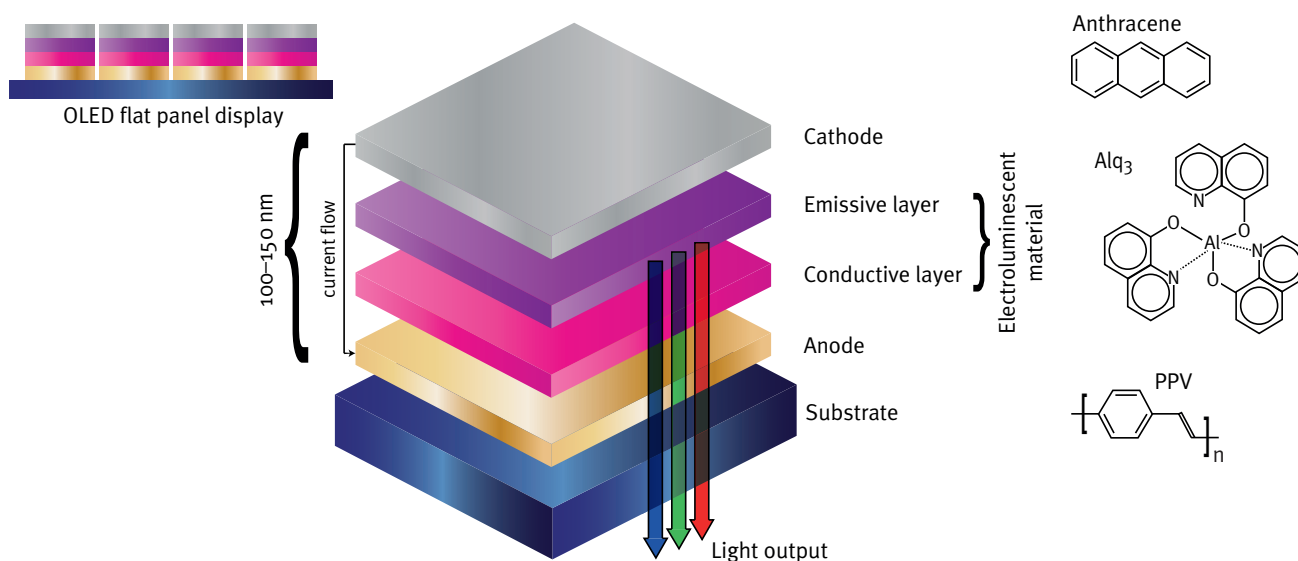


Figure 4. Flat panel displays (e.g., for television or mobile phone screens) can be made up of organic light-emitting diode (OLED) pixels. A typical OLED structure consists of electroluminescent organic material sandwiched between a transparent anode and a cathode, and which sits atop a transparent substrate of plastic, foil or glass. Originally, OLEDs were produced with a single organic layer, e.g., of anthracene or tris-(8-hydroxy quinolone) aluminium (Alq₃). Alternatively, polymers – such as poly(paraphenylene vinylene) (PPV) – can be used as the electroluminescent material. In modern OLEDs, however, a simple bilayer structure (i.e., emissive and conductive layers) is usually employed to improve the device properties. When a voltage is applied across the OLED, current flows from the cathode and anode. Electrons are thus injected from the cathode to the emissive layer, and holes in the conductive layer travel from the anode to the emissive layer. As the holes 'jump' to the emissive layer and are filled by electrons, energy in the form of light is released.

The now ubiquitous use of OLEDs is the result of substantial amounts of investment into their research and development, as well as collaborations between a variety of fields (e.g., chemistry, physics and materials science, as well as electrical and chemical engineering). This tale of development is thus exactly the kind of endeavour that can be enabled more frequently and speedily, and directed to specific problems, with the molecular science and engineering approach.

Molecular science and engineering as part of the ‘convergence’ revolution

The concept of bringing individuals from separate disciplines (in academia and industry) together to address grand challenges – in the manner of molecular science and engineering – is not new. Think, for instance, of the Manhattan Project and the industrial scale-up of penicillin. Both these large-scale collaborative endeavours were precipitated during the Second World War to deal with critical needs.

In more recent years, the potential of this concept has become more formally recognised and has become widely known as ‘convergence’. Indifferent to traditional disciplinary boundaries, convergence has been defined as “the integration of knowledge, tools, and ways of thinking from life and health sciences, physical, mathematical, and computational sciences, engineering disciplines and beyond”¹³ to create frameworks that can be used to address many of the world’s most pressing problems.

Unlike in more traditional interdisciplinary research, where individual specialists come together from separate ‘silos’ to share skills as and when necessary¹⁴, in convergence-style projects, multidisciplinary collaboration is embedded from the very start. The convergence framework therefore allows diverse areas of expertise (i.e., in science, engineering, humanities and government) to be inherently merged – in an accelerated, creative and well-managed manner – in a network of mutually beneficial partnerships. Furthermore, it provides fertile ground for stimulating innovation – all the way from basic science discovery through to translational applications¹⁵.

The potential utility of convergence for biomedical and health-based problems is already widely recognised¹⁶. For example, at the Broad Institute of MIT and Harvard a mission-driven community is being galvanised to propel understanding and treatment of disease¹⁷. Elsewhere, convergence strategies are being used to provide important insights for fighting infection and improving immunity, and for understanding brain disorders and injuries¹⁸. In the USA, a number of government-supported initiatives¹⁹ have been launched since the 2012 publication of the National Bioeconomy Blueprint²⁰, in which the importance of conducting research across the boundaries of traditional disciplines, and of translational efforts, was acknowledged.

There are, however, important global challenges not directly related to healthcare and life sciences that can benefit from a convergence-style multidisciplinary effort. Indeed, convergence efforts are being expanded with the launch of transdisciplinary institutes at many US universities (e.g., Harvard University, the Georgia Institute of Technology, the University of Texas at Austin and Tufts University)¹⁸. The value of convergence-style problem-solving approaches is also being recognised in the corporate space, e.g., at Verily, Apple, IBM, Microsoft and IDEO^{18,21}.

Apart from this initial US-centric surge of interest, the concept of convergence is gaining popularity in the UK and Europe. Concepts that share features with convergence research are evident in the recently published ‘Nurse review’²², the recent creation of UK Research and Innovation (UKRI)²³, the £1.5 billion Global Challenges Research Fund²⁴ and the EU’s Horizon 2020 Research and Innovation programme²⁵. The Nurse review highlighted that the boundaries between discovery (pure-basic), translational (use-inspired) and applied research (see Figure 5) are blurred, and that progress between them is not unidirectional (i.e., discoveries can be made during applied research, and applications may emerge during discovery research). Furthermore, it was noted that all three modes of research “must be pursued if a national research endeavour is to be effective in bringing about social and commercial benefits”²². Convergence takes this idea even further by intimately integrating the different research modes and focusing them on specific challenges. Indeed, the overarching aim of the UKRI will be to ensure that the UK’s “research and innovation system is sufficiently integrated, strategic and agile to meet future challenges, and to deliver national capability for the future that drives discovery and growth”²⁶.

The emerging molecular science and engineering landscape

Molecular science and engineering can be seen as a particular example of convergence, and several initiatives based on this concept have lately emerged on the academic landscape (see Table 1). Although these initiatives take a variety of forms – including departments, institutes, virtual hubs and physical spaces – they all tend to have similar and complementary aims, i.e., to facilitate increased collaborations between scientists and engineers from a host of disciplines, around a range of molecular-science and engineering-focused themes and applications. Many of these organisations and institutes are based in the USA, but a number have been established in Europe (including the UK) and Asia. Funding for these initiatives comes from multiple sources, e.g., government agencies, industry partners, university capital, as well as private/philanthropic donors and foundations.

Another feature of the emerging molecular science and engineering landscape is the recently launched *Molecular Systems Design & Engineering* journal, which is a joint venture from the Royal Society of Chemistry and the Institution of Chemical Engineers²⁸. The journal aims to disseminate

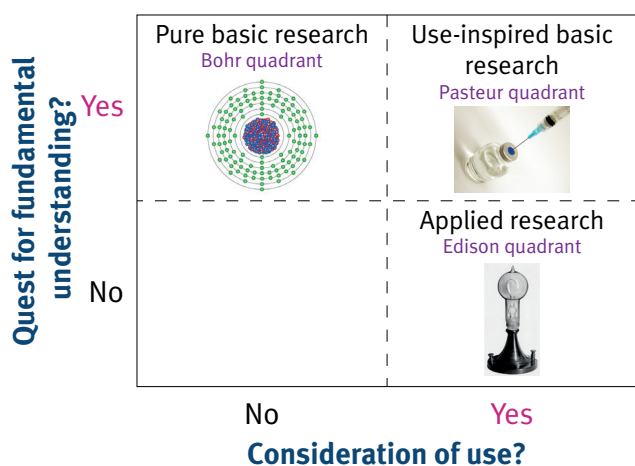


Figure 5. Classification²⁷ of scientific research endeavours according to primary motivation, i.e., as a quest for a fundamental understanding of nature, or for solutions to specific problems. The classes of research are defined as: pure basic research (as exemplified by the work of Niels Bohr in the field of atomic physics), pure applied research (as exemplified by the work of inventor Thomas Edison) and use-inspired basic research (as exemplified by the work of the chemist/microbiologist Louis Pasteur). The boundaries between these types of research, however, are permeable and progress between them is multidirectional.

cutting-edge research that is focused on understanding how molecular properties, behaviour and interactions can be used to design and assemble better materials, systems and processes to achieve specific functions. The journal has a truly interdisciplinary nature, bringing together experimental, theoretical and computational research in physics, biology, chemistry, engineering and materials science. Such initiatives can play an important role in building the molecular science and engineering community.

Barriers to successful molecular science and engineering research

Despite the growing popularity of the convergence and the molecular science and engineering concepts, there are a number of obstacles within the current research ecosystem that need to be overcome before the ‘convergence revolution’ can be fully realised¹³ within molecular science and engineering. Such barriers include:

- **The traditional organisational structures of academic institutions are not ideally set up to promote convergence-style research.** Within molecular science and engineering, academics who have been trained and work within diverse (and normally distinct) subjects come together for collaboration. Existing organisational structures (i.e., with delineated departments and faculties or schools), however, do not facilitate the necessary flexible and permeable exchange of knowledge between disciplines. For example, allocating funding between different university departments for collaborative projects can be a complex undertaking. Similarly, it can be problematic to share equipment between departments and to realize flexible laboratory space (ideal for enabling collaborative work) because of space, safety and accountability issues.
- **Motivational influences for academics can be damaging to the pursuit of multidisciplinary and interdepartmental collaboration.** For instance, conventional hiring and promotion procedures within university departments do not normally reward scientists and engineers – particularly in the early stages of their careers – who work across disciplinary

boundaries, nor do they recognise the wider benefits of their collaborative work. Moreover, there can be heterogeneity between the standards of different departments, faculties and institutions. Likewise, department rankings (e.g., Times Higher, US News, QS) do not tend to recognise (and can actively discourage) multidisciplinary.

- **As the molecular science and engineering approach continues to strengthen, a suitably trained workforce will be required.** Although it is vital for all researchers to have a strong and in-depth grounding in their individual subjects, it is becoming increasingly important within the convergence landscape for scientists and engineers to be conversant and knowledgeable over a broad range of disciplines. In this way, complex problems can be approached from a variety of angles with colleagues from different backgrounds. In addition, education across the full breadth of molecular science and engineering (and other similar convergence fields) will create a population of individuals who – in their pursuit of knowledge – are more willing to take risks and who are more supportive of colleagues from other academic disciplines.
- **A greater integration between academia, industry, government and other (e.g., charitable foundations) groups is required.** Excellent management (of personnel and resources), and non-traditional academic skills (e.g., entrepreneurship) are necessary to accelerate translational molecular science and engineering research (i.e., from fundamental science to end-use applications). Suitable organisational support is required to maintain, nurture and strengthen current partnerships, and to seek new mutually beneficial relationships. Such partnerships should be a source of knowledge transfer (and application), but also represent a way to increase and diversify funding opportunities (and thereby increase the likelihood of success in tackling grand challenges).
- **Funding opportunities need to be better optimised for transdisciplinary research.** Historically, the majority of research within different molecular science and engineering fields has been supported by discipline-specific organisations (e.g., the UK’s separate research councils, or assessment

panels within them) and programmes that do not easily enable transdisciplinary research²². For instance, transdisciplinary proposals may be reviewed by experts who are not adequately equipped to understand and appreciate the multifaceted nuances of the proposed work. The peer-review of translational and applied (and often transdisciplinary) research proposals therefore requires a wide pool of expertise – which can be problematic given the lack of suitably trained workforce – and potentially a different set of review criteria (e.g., it is important to recognise that alternative approaches to long-standing problems can often bring unexpected solutions and outcomes). In addition, proposing non-conventional applications of an existing technology (e.g., imaging or analysis techniques) to new problems may not be identified as novel by expert reviewers (who may prefer to support next-generation development of the technology), but it may indeed represent ground-breaking and highly significant work.

The Institute for Molecular Science and Engineering

Imperial College London founded the Institute for Molecular Science and Engineering (IMSE) in 2015, as part of the growing and strengthening worldwide molecular science and engineering (and convergence) community. IMSE brings the university's engineers, scientists, medics and business researchers together to find molecular-based science and engineering solutions to grand challenge problems facing our world. We believe that by adopting this kind of grand challenge focus, we can generate and harness a substantial amount of interest from people with a diverse range of backgrounds (see [box 1](#)). Our overarching goal for the Institute is to blur the boundaries between molecular science and engineering, and to serve as an example of how scientists and engineers can work together across the entire science and engineering community – in academia and industry.

Imperial College London: a perfect home for IMSE

As the newest of Imperial College London's Global Institutes, IMSE is hosted at a world-class university with an existing culture of collaboration, multidisciplinary and grand challenge goals. This ethos is evidenced by several established, recently launched and forthcoming initiatives at Imperial, including:

- the five other Global Institutes: the Grantham Institute (Climate Change and Environment), the Institute of Global Health Innovation, the Energy Futures Lab, the Institute for Security Science and Technology and the Data Science Institute. These institutes have been established to promote interdisciplinary working, to meet some of the greatest challenges faced by society. Alongside traditional academic departments, they are intended to interface with a wide range of external customers and stakeholders, and to lead the College's input to policy-setting across government and business;

- the Institute of Chemical Biology²⁹, created more than a decade ago, supports multidisciplinary research that focuses on the development and application of novel tools and technology for solving major problems in the life and biomedical sciences;
- the Engineered Medicines Laboratory (EML)³⁰, established in 2015, is a collaboration between Imperial and GlaxoSmithKline. The EML aims to make transformative advances in the discovery, development and manufacturing of future medicines by assembling cross-disciplinary teams of engineers, medics and scientists;
- the Department of Chemistry will soon be partly housed in the brand-new Molecular Sciences Research Hub³¹. This move will contribute to a new way of doing chemistry that transcends disciplinary and institutional boundaries in the search for solutions to some of the great challenges facing humanity;
- the Michael Uren Biomedical Engineering Research Hub³², will facilitate collaboration between engineers, scientists and medical researchers in the development of new and more-affordable medical technology. The hub – funded by government (through the UK Research Partnership Investment Fund) and a philanthropic donation – will house research laboratories, an outpatient clinic, an auditorium and social spaces to create an atmosphere that encourages the informal exchange of ideas;
- the Imperial College Advanced Hackspace (ICAH) provides College students and staff free access to a unique suite of prototyping technologies, workshops and laboratories around the College campuses, with the aim of turning novel ideas into reality³³.

Furthermore, Imperial is an ideal home for IMSE because the College already harbours a critical mass of researchers in molecular science and engineering and a wide range of the world-leading technologies necessary to conduct research in this field. We are also able to draw on Imperial's long tradition of effectively translating innovative research into economic and societal benefits. By creating IMSE at Imperial we are thus in a strong position to deliver – in collaboration with external partners – novel products and solutions that are firmly based on current advances in molecular science and engineering. With our style of managed convergence, we provide an effective mechanism for stimulating and nurturing cross-faculty holistic and translational molecular science and engineering projects. With our activities, we aim to broaden the reach of each individual's expertise rather than just strengthen the links between independent researchers.

IMSE's three guiding pillars

To achieve IMSE's ambitious aims, we co-ordinate a range of integrated activities that are based upon three guiding pillars: (i) advancing integrated transdisciplinary research, (ii) transforming education and (iii) enabling effective translation of research into practice (see [Figure 6](#)). Moreover, by taking full advantage of Imperial's state-of-the-art facilities, collaborative ethos and outstanding ties with industry, IMSE is well-placed to address the most commonly encountered barriers to convergence endeavours (as described above), and to enable ground-breaking research and discoveries. In particular, through our range of activities, we hope to:

- encourage more 'convergent-friendly' academic infrastructures;
- better reward and motivate individual researchers who engage in convergence-style research;
- create a well-equipped workforce of 'convergence-trained' scientists and engineers;
- increase the level of integration between academic institutions and external organisations;
- secure the resources to execute convergence-style research projects successfully.

Pillar 1: Advancing integrated transdisciplinary research

Continuous and increasing engagement of researchers and academics at all career levels is crucial to the success of IMSE. We therefore encourage any Imperial academic, whose work and interests align with the Institute's mission, to become an IMSE affiliate. Affiliates are provided with the opportunity to actively participate in our events and to thus meet, communicate and potentially collaborate with other researchers from a diverse range of backgrounds. In this way, our affiliates play a key role in developing our agenda and defining the grand challenges we choose to address.

As evidence of the appetite for molecular science and engineering research at Imperial, 97 academics from 15 departments (see [Figure 7](#)) became IMSE affiliates³⁵ within the Institute's first 18 months of operation. We have also established a group of 12 research champions³⁶ from different Imperial departments that provide a substantial base of IMSE-related activity and a more formal mechanism to engage researchers across a variety of disciplines. These champions were intimately involved in establishing the Institute, and continue to help define IMSE's research strategy (as members of the Institute's Research Board) and to conduct grass-roots engagement at Imperial.

Box 1: Power of a 'grand challenge' approach

Driving research and collaborative working in the pursuit of grand challenges has a long history. For example, the 'space race' of the 1950s and 1960s created a massive challenge for scientists and engineers. From the common goal of landing a man on the Moon before 1970, an unimaginable level of excitement, interest and support across the whole of US society (e.g., in research, industry, government and the general public) was generated.

This style of bold and ambitious research also has a long tradition at Imperial College London. In 1856, William Henry Perkin – an 18-year-old student at the Royal College of Chemistry (which was later incorporated into Imperial) – tried to meet the French Society of Pharmacy's challenge: to find a way to prepare synthetic quinine (i.e., as a cheaper and more reliable route to malaria treatment). Although Perkin failed to synthesise quinine and win the prize (the first chemical synthesis of quinine was not achieved until the 1940s³⁴), in the process he accidentally produced the first synthetic organic chemical dye. In doing so, his discovery of mauveine (also known as aniline purple) helped give rise to the synthetic dye industry (in a twist of fate, BASF secured the patent for a process for the manufacture of the red dye alizarin one day before Perkin).

These two grand challenge examples illustrate some of the many benefits of this approach to scientific research. For instance, grand challenges:

- generate excitement and inspire ideas from a wide range of disciplines, thereby tapping into a diverse talent pool;
- help focus efforts (e.g., time, money, creativity, brainpower) on important, relevant and pressing topics;
- create a necessity for new infrastructures that facilitate increased levels of collaboration;
- can give rise to unexpected and serendipitous outcomes.

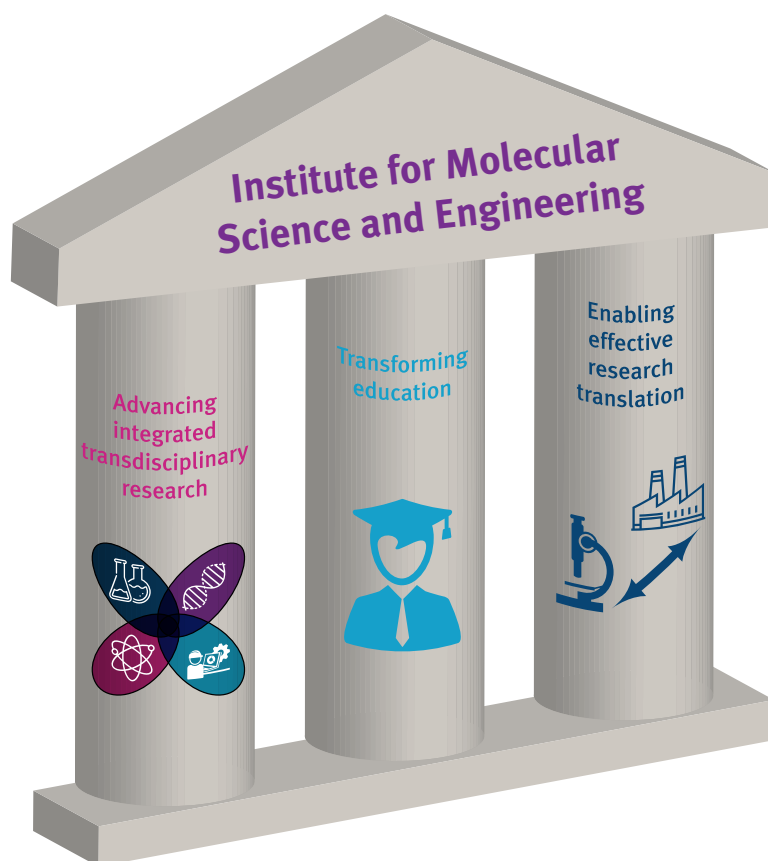


Figure 6. The three pillars of IMSE: advancing collaborative transdisciplinary research, transforming education and enabling effective translation of research to industry.

Pillar 2: Transforming education

IMSE is set to launch a unique and innovative molecular science and engineering Master's of Research (MRes) course in October 2017³⁷. We have specifically designed this one-year course to create a new generation of 'multilingual' scientists and engineers who can work across the important molecular science/engineering interface. Graduates will be equipped with an unparalleled perspective, as well as a set of fundamental and applied skills that will serve them well in their careers. Their ability for collaboration will be enhanced through a six-month research project conducted partly at Imperial and partly at an industrial partner. The course will also serve as a way to broaden understanding, communication, collaboration and translation of research within the disparate areas of molecular science and engineering.

We believe that the unique nature of our MRes programme stems from its transdisciplinary and translational focus (across science and engineering) and the exposure to a variety of industrial sectors. It will build on Imperial's strengths and reputation for translating fundamental research advances into solutions to real-world problems. Furthermore, by leveraging Imperial's well-established links to industry, students will be provided with unprecedented access to companies as they engage in their applied research projects. We envisage the programme's outputs as:

- a group of high-quality candidates for PhD research within the field of molecular science and engineering;
- postgraduates with enhanced job prospects in industry who can help to break down barriers to innovation and to enhance collaboration;
- high-quality research publications, articles and conference papers;
- enhanced levels of collaboration between members of the multidisciplinary teams involved in the research projects (at Imperial and with industrial partners), and thus a strengthened molecular science and engineering community.

Pillar 3: Enabling effective research translation

The effective commercialisation and translation of research into practice requires close collaboration between academic researchers – in science and engineering – and industry. As part of a mutually beneficial relationship, industrial partners are thus an integral part of the IMSE framework. Industrial partners who are committed to working with us to solve the emerging and pressing grand challenge problems they face can support the research conducted by IMSE researchers. We welcome support for our whole range of activities, e.g., participation in grand challenge workshops, sponsoring events, co-creation of research proposals, funding research, providing

student scholarships, hosting an MRes student for their industrial placement or facilitating staff exchanges. Partnering stakeholders are provided with a number of benefits, including:

- the opportunity to make a substantial impact in the field, i.e., to share the effort of working towards grand challenges with leading researchers and to help shape research directions;
- the opportunity to engage with a team of experts who can develop innovative solutions to important problems;
- the opportunity (i.e., through the IMSE MRes programme) to help educate and recruit graduates who are specifically trained to work across the interface of molecular science and engineering;
- the opportunity to participate in translational activities and to benefit quickly from the realisation of research ideas;
- the opportunity to interact with other companies and stakeholders to discuss pre-competitive grand challenges.

IMSE's activities: managed convergence

Building a community

Community-building efforts are central to the success and sustainability of IMSE and we therefore organise a range of activities to increase the level of interaction between Imperial, and external, stakeholders. For example, we currently co-ordinate two seminar series to promote ongoing molecular-science-and-engineering-based research. Our aim is for these seminars to provide the stimulus for lively discussions and networking. In our Highlight Seminar Series³⁸ we bring eminent speakers from around the world to Imperial. In this way, we increase awareness of areas where molecular science and engineering can make a valuable contribution and we boost our level of interaction with other academic and industrial centres of excellence.

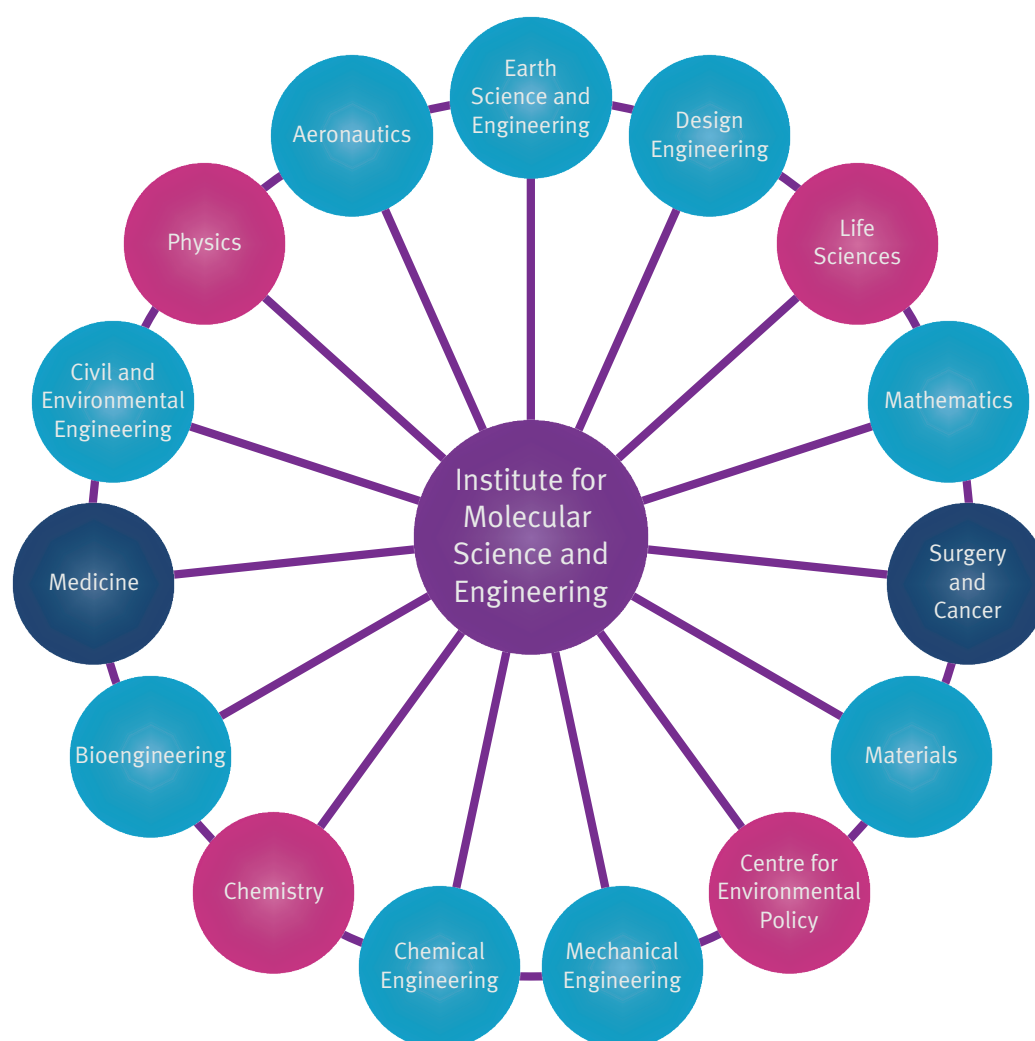


Figure 7. IMSE's 97 affiliates³⁵ (as of March 2017) are based within 15 different Imperial departments (across the Faculty of Engineering, Faculty of Natural Sciences and Faculty of Medicine).

In addition, in our Lunchtime Seminar Series, we highlight areas of current molecular-science-and-engineering-activity at Imperial. We bring together two researchers from different faculties or departments, but who work in a broadly similar field (e.g., different aspects of nutrition), to present their research to a diverse internal audience, and to engage in further discussion and networking.

Identifying grand challenge areas

Given the myriad problems that face society, the process of identifying areas in which Imperial's academic strengths can be best applied to important societal or industrial needs is a critical IMSE activity. To promote and facilitate the collaborations between Imperial academics and external partners that are necessary to meet IMSE's aims, we have therefore developed a flexible, multistep workshop–research initiative model (see Figure 8). In this iterative process we first consult and consider the needs of a number of internal and external stakeholders (e.g., from industry, government and academia), to identify a specific grand challenge topic around which to focus our efforts.

During an initial consultation with the Imperial research community, we identified a number of key areas where the College's core capabilities can provide unique contributions and can guide our ongoing activities, including:

- novel manufacturing processes to bring new chemistries to fruition;
- molecular engineering of 'smart' interfaces;
- development of engineered composites and tissues;
- design of novel formulations;
- molecular engineering to address energy challenges.

Through this consultation process we also identified a number of initial grand challenge topics around which to focus much of our work, including carbon utilisation³⁹ and molecular engineering solutions for antimicrobial resistance.

In the next stage of our process, we start to build a community of Imperial researchers who are interested in contributing to the identified problem. To achieve this, we have so far organised three different types of meeting (depending on the specific needs and aims):

- **Research showcase.** We bring a few Imperial academics to briefly share aspects of their work that are relevant to the topic at hand. In this way, we mine the College for interest and spark ideas for potential research. By spanning Imperial's faculties and departments with our speakers and audience, we also create fertile ground for new collaborations.
- **Internal workshop.** An opportunity for Imperial researchers to come together and flesh out collaborative research projects, in response to specific problems. These workshops can follow – and build upon – a previous research showcase, or if there is already a sufficient level of interest, we can hold an internal workshop as the first step in addressing a particular grand challenge.
- **Co-creation workshop.** Designed to connect a number of different stakeholders (i.e., our established Imperial community and external industry partners) so that they can explore and shape future molecular science and engineering research. Each workshop is focused on addressing particular subset problems of grand challenges or stakeholder needs, with the specific aim of generating new project ideas and research proposals.

IMSE workshops (2015–2017)

Within our 'engineering solutions to antimicrobial resistance' grand challenge theme, we held a research showcase (Molecular Engineering of Antimicrobial Surfaces) in 2016. Following this successful event – and to complement the ongoing Imperial activities around this theme (e.g., through the Antimicrobial Research Collaborative⁴⁰) – we will be holding a more-focused internal workshop, in April 2017, entitled Development of 'Smart Surfaces' to Tackle Antimicrobial Resistance Via a Multidisciplinary Approach.

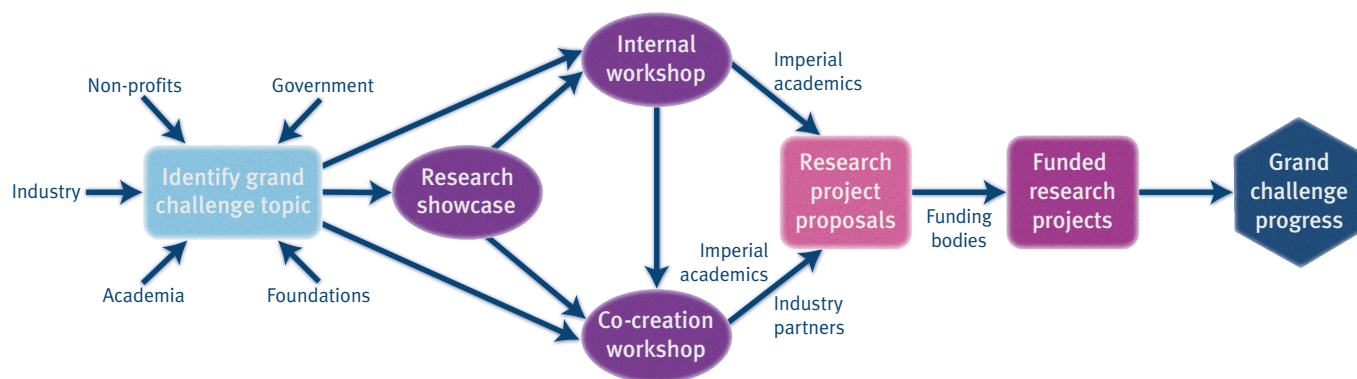


Figure 8. Schematic illustration of IMSE's flexible multistep workshop–research initiative model, designed to create new collaborations between Imperial academics and external partners. The collaborations are focused around specific grand challenge topics (e.g., carbon utilisation or antimicrobial surfaces) and should ultimately result in progress on the grand challenge, by way of appropriately resourced transdisciplinary research projects.

As the first stage of work on the topic of carbon utilisation, we held an internal workshop – in collaboration with the Energy Futures Lab⁴¹ – in September 2016. During this workshop, 25 attendees (from eight of Imperial's departments, centres and institutes) discussed the themes of carbon capture, transformation and usage, and began to develop a map of Imperial's capabilities within these areas for pitching to potential business partners, as well as an outline of the specific problems and opportunities that can be tackled within this overall grand challenge.

We held our inaugural co-creation workshop in conjunction with BASF in September 2015. This was attended by 25 Imperial academics and early career researchers (from six departments), as well as 12 representatives from BASF. The workshop focused on two challenges that are of industrial relevance and where Imperial's capabilities can be harnessed to deliver holistic and innovative solutions (see [box 2](#)). The wide-ranging discussion covered subjects such as novel isotropic materials, self-healing materials, as well as necessary improvements in manufacturing methods and computational modelling for the realisation of these materials. An immediate outcome of the meeting was the establishment of new internal collaborations at Imperial, as well as at the Imperial/BASF interface (e.g., through exchange of research materials). In addition to highlighting the potential for long-term collaboration between BASF and Imperial,

the success of this first co-creation workshop underlined the benefit of building much stronger links to connect different molecular science and engineering stakeholders.

We organised another co-creation workshop, in partnership with the Cancer Research UK Imperial Centre⁴², in December 2016. During this event, speakers and attendees from many Imperial departments (e.g., from the Department of Chemical Engineering, Department of Mathematics, Department of Earth Science and Engineering, Department of Chemistry, Department of Medicine, Department of Life Sciences, and Department of Surgery and Cancer) explored areas of on-going cancer-related research being conducted across the College. The day also featured discussions concerning future areas for collaboration, pilot project initiatives and sources of funding.

Seed-funded projects: promoting convergence

Within IMSE's first full year of operation, we exploited an exciting opportunity to catalyse bottom-up investigator-led research within College. With funds received from the Engineering and Physical Sciences Research Council (EPSRC), we have been able to support a set of transdisciplinary 'seed-funded' research projects that foster new collaborations at the molecular science/engineering interface and that align with EPSRC's Prosperity Outcomes⁴³.

Box 2: IMSE–BASF co-creation workshop topics

Topic 1: Functionalised surfaces for thermoplastics and composites

Although plastics are ubiquitous in today's world, and find practical use in a wide variety of industries (e.g., automotive, packaging and sports industries), some technical and economic challenges with these materials remain. For example, reinforced plastics that are isotropic, light and affordable are required, but all three of these properties have not yet been achieved in a single material. Furthermore, there is a desire for integrated functionalities (such as heat and electrical conductivity) and for materials with self-healing properties in commercial markets. Plastics are an important part of BASF's work (representing sales worth more than €6.88 billion in 2016), but the necessary materials, resources and expertise for solving problems along the value chain are not always available in house. For instance, to fabricate reinforced plastics, it is necessary to buy fibres (carbon or glass) from external suppliers. Understanding the properties of the materials can therefore be difficult because the exact production and treatment conditions may not be accessible. By partnering with IMSE and Imperial, it is the aim to economically incorporate new functionalities (e.g., isotropy, self-healing) into BASF's products, and to thus strengthen the company's position in the plastics industry.

Topic 2: Technology-supported formulation

In many device manufacturing applications, properties such as loss of material, degradation and segregation mean that some materials cannot be used directly and the materials must instead be formulated. In other words, material modifications – to maintain or enhance the original properties – are required to improve processability and to produce sophisticated materials for specific applications. For example, BASF is working on the formulation of innovative battery materials. In this case, tailor-made surfactants are usually required to stabilise the battery materials and to thus achieve very fast kinetics (e.g., reaction, mixing). New technologies (such as microfluidics), however, enable very fast processing of these materials and can be used instead of surfactants. This kind of 'technology-supported formulation' is possible because of improved modelling and simulation techniques, and can be used to design the appropriate technology for chosen materials and applications. Nonetheless, it remains a difficult task to combine the chemical, physical and engineering skills necessary to foster the integrated-style of thinking required for developing full-system methodologies. In collaboration with IMSE, BASF thus aims to create novel approaches to technology-supported formulation that can be deployed in various aspects of its business.

In September 2016 we held an informal ‘sandpit’ event, which brought together Imperial researchers from ten departments to share and explore the challenges encountered in their research. In this way, we facilitated new encounters between Imperial academics, and inspired innovative and multidisciplinary research ideas. Stemming from this event, seven transdisciplinary research projects (see Table 2; box 3) were selected for funding by a specially convened panel. Each of these projects is led by at least two principal investigators in different Imperial departments, and addresses a range of topics that fall within IMSE’s remit. The results of these projects will be used to help cement the new collaborations and to provide proof-of-concept results upon which to base larger funding proposals in the future. An event to showcase the results of the projects to the wider community will be held in April 2017, providing another opportunity to foster collaboration.

Although the amount of funding available for these projects was relatively small, the programme we set up can be viewed as a pilot for similar transdisciplinary research programmes going forward. This kind of programme has a valuable place in the wider funding landscape because it offers the opportunity to support work that may otherwise be seen as risky, but that can lead to high-gain results. Indeed, the flexibility of the original award from EPSRC allowed us to fund work that involves brand-new collaborations and previously unproven approaches. In addition, by formalising transdisciplinarity in this small-scale programme, we have been able to identify and dissolve some of the barriers to facilitating convergence-style research in an academic environment.

Summary and outlook

Making molecules work for relevant societal needs is a complex and multistep undertaking. Nonetheless, the emerging molecular science and engineering concept provides a holistic framework in which to conduct innovative translational research. To ensure that this – and other convergence-style endeavours – continue to be supported in the academic landscape, however, a number of transformations are required:

- flexible academic infrastructures that ensure the smooth transfer of resources (e.g., personnel and facilities) between traditionally separated disciplines and sectors;
- new ways to recognise and reward individual researcher’s collaborative, transdisciplinary successes;
- transdisciplinary education and training of students (at undergraduate and postgraduate level) so that they are primed for conducting collaborative translational work in their future careers;
- consideration of external stakeholder needs at all stages of research planning and development, for the realisation of accelerated and cost-effective translational projects;
- diversification and optimisation of funding opportunities for transdisciplinary research.

Through our wide range of carefully chosen community-building, education and research-driving activities, IMSE is an exemplar of how to drive these changes in the academic–industrial landscape. The Institute is ideally placed at Imperial – i.e., with the College’s embedded culture of collaboration and large community of world-class researchers – to promote molecular science and engineering as an effective way to tackle global grand challenges. Future briefing papers in this series will focus on topics within IMSE grand challenge themes, including a molecular science and engineering paradigm for antimicrobial resistance, and a systems-based view of carbon capture and utilisation.

Acknowledgements

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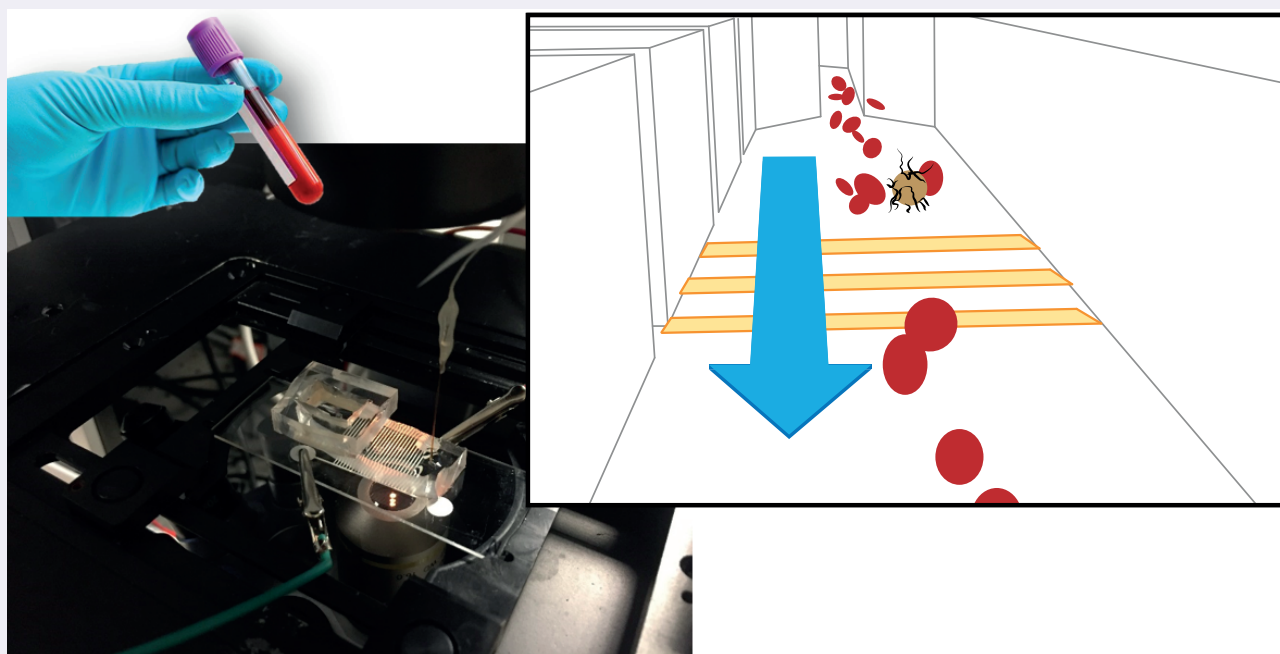
1. Global challenges for humanity, <http://www.millennium-project.org/millennium/challeng.html>.
2. Antimicrobial resistance is a naturally occurring process whereby microbes (e.g., bacteria, viruses, fungi and parasites) mutate and evolve such that they resist the action of drugs. Over time, antibiotics thus become less and less effective for treating the infections caused by these ‘superbugs’. This substantial modern danger has arisen for two main reasons. First, the increased use of antimicrobials over the past few decades has exposed microbes to a much larger number of drugs, to which they have grown resistant. Second, economic and commercial factors mean that there are very few new drugs (particularly antibiotics) being developed, i.e., the demand for new drugs continues to increase, but the supply has stagnated.
3. Review on Antimicrobial Resistance, Tackling drug-resistant infections globally: Final report and recommendations (2016).
4. Farman, J. C., Gardiner, B. G. & Shanklin, J. D., Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x , *Nature*, 315, 207–210 (1985). doi:10.1038/315207a0
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Box 3: Can novel solar cell polymer technology be used to detect cancer cells in the blood?

Metastasis – the process whereby cancerous cells migrate from a primary tumour and seed new tumours – is a function of many human cancers (e.g., breast cancer) and is the cause of 90% of cancer deaths. Moreover, the life expectancy of patients with metastatic breast cancer is normally on the order of months. An intense level of ongoing research is therefore focused on isolating such metastatic cancer cells from the blood. It is also the aim to develop functional drug screens to guide patient therapy and to ultimately improve patient life expectancy and outcomes. Within this wave of research, the feasibility of using organic electrochemical transistors (OECTs) to measure key molecules excreted by cultured breast cancer cells is being investigated as part of a new transdisciplinary collaboration between Imperial's Department of Surgery and Cancer, Department of Chemistry and Department of Life Sciences. The aim of the work is to set the ground for a larger multidisciplinary project, in which specific hypotheses of resistance in breast cancer patients could be tested.

This IMSE-funded proof-of-concept study represents a novel use of OECTs, which have been developed as technology for solar energy harvesting applications. The investigation builds upon previous work⁴⁴, and this novel application of OECTs is possible because the increased anaerobic metabolism of cancer cells gives rise to a higher lactate output compared with non-cancer cells. It should therefore be possible to use biofunctionalised OECTs to detect if a cell has an altered metabolic expression, and to develop these devices for the detection of cancer cells in the blood.

In the project, the baseline relationship between lactic acid concentration and voltage of the novel biofunctionalised (with phosphate-buffered saline) polymer electrodes is being established. The biofunctionalised electrode is then used as a medium for cell growth and to monitor increases in lactate concentration from the electrical signals produced. As part of the project, the biofunctionalisation is also being extended to include other enzymes (e.g., glucose oxidase or cholesterol oxidase) and to thus increase the potential detection range of the OECTs. In a parallel aspect of the project, whole-cell patch-clamp recordings on drug-resistant and non-resistant breast cancer cell lines are being made. In particular, differences between the cells' resisting potentials and ionic currents are being examined. In this way, ion channels – which can be easily targeted with both drugs and antibodies – may be developed as novel clinical tools. By comparing the preliminary OECT and patch-clamping data, it is hoped that key differences between the different cell line strains will emerge. Understanding these differences on a single-cell scale is the first step to the realisation of new technology that will hopefully make a substantial difference to patient lives.



The use of biofunctionalised organic electrochemical transistors (shown left) is being investigated as a way to measure biomarker metabolites excreted by cancer cells (depicted on the right), and thus to detect rare cancer cells in the blood. Image provided by Ali Salehi-Reyhani.

Table 1: Examples of convergent-style research initiatives in the field of molecular science and engineering (external to Imperial College London). Funding sources/partners are given where known.

Organisation	Activities and research	Funding
Institute for Molecular Engineering, University of Chicago (USA) Established 2011	Housed in a state-of-the-art research centre, with six research themes: • Arts, sciences, and technology • Energy storage and harvesting • Immuno-engineering and cancer • Molecular engineering of water resources • Quantum information and technology • Nanopatterning and nanolithography	University of Chicago Argonne National Laboratory Private donors
Molecular Engineering & Sciences Institute, University of Washington (USA) Established 2011	Shared physical space for interdisciplinary teams from across the university's departments. The translational research is focused in the areas of 'clean tech' and 'biotech'.	Federal start-up support University operating budget
Continuous Manufacturing and Crystallisation Centre, University of Strathclyde (UK) Established 2011	Part of the university's Technology and Innovation Centre. The physical hub is at Strathclyde University, with researchers at other UK universities contributing to the multidisciplinary academic team. The aim is to create an effective partnership with industry, academia and public bodies. Research vision (based around a number of key initial challenges) is to accelerate the adoption of continuous manufacturing and crystallisation processes, systems and plants for the production of high-value chemical products, and to quickly and sustainably improve their quality at lower costs.	Scottish Funding Council (initial funding), EPSRC, HEFCE Industrial partners (e.g., GSK, Novartis and AstraZeneca)
MIT.nano, Massachusetts Institute of Technology (USA)	A new building (due for completion in 2018) will house advanced nanoscience and nanotechnology facilities, open to the entire MIT community, for high-precision synthesis and manipulation of molecules for application in: • Computing and communications • Energy • Health/healthcare • Manufacturing • Materials and structures • Prototyping • Sustainable futures • Tool making	
Princeton Institute for the Science and Technology of Materials (PRISM), Princeton University (USA) Established 1993	The physical building houses several laboratories and large scale multiuser research facilities for the integration of sciences and engineering. Research addresses long-term global and societal challenges, in six main directions (from fundamental theory through to application): • Quantum materials and structures • Large-area materials and devices • Optics and sensors • Bio/nano interface • Patterning and self-assembly • Computational materials science	Federal/State government agencies Industrial partners Charitable foundations

Organisation	Activities and research	Funding
Molecular Foundry, Lawrence Berkeley National Laboratory (USA) Established 2003	The nanoscience research facility provides visiting scientists with access to cutting-edge expertise and instrumentation. Research is based on the theme of “discovering the future, atom by atom”, following four scientific drivers: • Combinatorial nanoscience • Functional nanointerfaces • Multimodal nanoscale imaging • Single-digit nanofabrication and assembly	US Department of Energy (Office of Basic Energy Sciences)
National Centre of Competence in Research: Molecular Systems Engineering, University of Basel/ETH Zürich (Switzerland) Established 2014	Explores and enables interdisciplinary research by bringing together researchers from life sciences, chemistry, physics, biology, bioinformatics and engineering. Research addresses existing/future global challenges to develop new applications within four work packages/project groups: • Molecular modules • Molecular systems • Molecular factories • Cellular systems	Swiss National Science Foundation
College of Chemistry and Molecular Engineering, Peking University (China) Established 2001	The college encompasses several academic departments, research institutes and key laboratories: • Departments of Chemical Biology, Applied Chemistry, Polymer Science and Engineering • Institutes of Inorganic Chemistry, Organic Chemistry, Analytical Chemistry, Physical Chemistry, and Theoretical and Computational Chemistry • Synthetic and Functional Biomolecules Center • Beijing National Laboratory for Molecular Science • State Key Laboratory for Structural Chemistry of Unstable and Stable Species • National Laboratory for Rare Earth Material Chemistry and Application • Key Laboratory of Bio-organic Chemistry and Molecular Engineering of Ministry of Education	
Stanford Bio-X, Stanford University (USA) Established 1998	The James H. Clark Center (completed 2003) brings together researchers in a variety of disciplines (including biology, medicine, chemistry, physics and engineering) under one roof. The mission is to catalyse discovery, education and innovation by crossing the boundaries between disciplines, and to thus bring interdisciplinary solutions and create new knowledge of biological systems, to benefit human health.	
Molecular Science and Engineering Building, Georgia Institute of Technology (USA) Established 2006	The building houses many of the faculty and staff from the College of Sciences and the National Science Foundation for Organic Photonics and Electronics, and is part of the Coulter Department of Biomedical Engineering. Faculty, students and collaborators are brought together to advance the boundaries of biomedical engineering research.	

Table 2: Recipients of IMSE seed funding awards (2016–17).

Project title	Principal investigators
High-pressure investigation of aza-polycyclic aromatic heterocycles and their role in cosmology and origins of life	Professor Mark Sephton (Department of Earth Science and Engineering) Dr Matthew Fuchter (Department of Chemistry)
Can novel solar cell polymer technology be used to detect cancer cells in the blood? (see box 3)	Professor Eric Lam (Department of Surgery and Cancer) Dr Ali Salehi-Reyhani (Department of Chemistry) Professor Mustafa Djamgoz (Department of Life Sciences)
Elaborating molecular design rules for organic spintronics	Professor Martin Heeney (Department of Chemistry) Dr Sandrine Heutz (Department of Materials)
Towards industrial scale-up of ionic liquids: Understanding the reaction of ionic liquids with metal infrastructure	Dr Kyra Sedransk Campbell (Department of Chemical Engineering) Professor Mary Ryan (Department of Materials) Dr Jason Hallett (Department of Chemical Engineering)
Impact of inorganic on the development of antimicrobial resistance	Dr Gerald Larrouy-Maumus (Department of Life Sciences) Professor Mark Rehkämper (Department of Earth Science and Engineering) Dr Valeria Garbin (Department of Chemical Engineering)
Engineering a scalable sensing platform for biomolecular detection	Professor Martyn Boutelle (Department of Bioengineering) Dr Pantelis Georgiou (Department of Electrical and Electronic Engineering)
Advanced ionic-selective membranes in aqueous redox flow batteries for energy storage applications	Dr Qilei Song (Department of Chemical Engineering) Professor Nigel Brandon (Department of Earth Science and Engineering)

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- Sharp, P. A. & Langer, R., Promoting convergence in biomedical science, *Science*, 333, 527 (2011). doi:10.1126/science.1205008
- Scientific research can be characterised as one of three (not mutually exclusive) types: discovery (i.e., pure/basic research aimed at acquiring new knowledge), applied (goal-oriented work aimed at achieving specific objectives and outcomes) or translational (the bridge between discovery and applied) research.
- Sharp, P. & Hockfield, S., Convergence: The future of health, *Science*, 355, 589 (2017). doi:10.1126/science.aam8563
- The Broad Institute, <https://www.broadinstitute.org/>.
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- Such projects include the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative, the Precision Medicine Initiative and the National Cancer Moonshot Initiative.
- White House, *National Bioeconomy Blueprint* (2012).
- IDEO: A global design company, <https://www.ideo.com/us/>.
- Nurse, P., *Ensuring a successful UK research endeavour: A review of the UK Research Councils* (2015).

23. The UKRI will bring the UK's seven current research councils, Innovate UK and the research funding functions of the Higher Education Funding Council for England (HEFCE) together into a single umbrella organisation.
24. The UK government's Global Challenges Research Fund (<http://www.rcuk.ac.uk/funding/gcrf/>) is designed to support cutting-edge research that address the challenges faced by developing countries through: (i) challenge-led disciplinary and interdisciplinary research; (ii) strengthening capacity for research and innovation; and (iii) providing an agile response to emergencies.
25. Horizon 2020: The EU framework programme for research and innovation, <https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020>.
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31. The Molecular Sciences Research Hub, <http://www.imperial.ac.uk/white-city-campus/the-campus/molecular-sciences-research-hub/>.
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35. See <https://www.imperial.ac.uk/molecular-science-engineering/people/affiliates/> for a full list of IMSE's current affiliates.
36. IMSE's current research champions can be found at <https://www.imperial.ac.uk/molecular-science-engineering/people/research-champions/>.
37. Full information regarding Imperial's MRes in Molecular Science and Engineering can be found at <https://www.imperial.ac.uk/molecular-science-engineering/education/>.
38. IMSE's Highlight Seminar Series, <https://www.imperial.ac.uk/molecular-science-engineering/events/highlight-seminar-series/>.
39. As a global society, we currently face the urgent need to reduce the effects of anthropogenic climate change. As a potential solution, carbon capture and storage (CCS) techniques may be used to transfer industrially generated carbon dioxide to geologic formations, and to thus protect the atmosphere from increased greenhouse gas emissions. As an alternative and complement to CCS, carbon utilisation involves converting the industrially produced carbon dioxide into commercially valuable products (e.g., bio-oils, chemicals, fertilisers and fuels).
40. The Antimicrobial Research Collaborative @ Imperial <https://www.imperial.ac.uk/arc/>.
41. Imperial College London's Energy Futures Lab, <https://www.imperial.ac.uk/energy-futures-lab/>.
42. The Cancer Research UK Imperial Centre, <http://www.imperial.ac.uk/cancer-research-uk-imperial-centre/>.
43. EPSRC's Prosperity Outcomes Framework has four arms: (i) productivity (creative, innovative, competitive economy), (ii) connectedness (surviving and thriving in a digital world), (iii) resilience (adaptive, prepared, protected, secure, safe, sustainable) and (iv) health (improved quality of life through better mental and physical health). For information see: <https://www.epsrc.ac.uk/about/plans/deliveryplan/prosperityoutcomes/>.
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About the authors

Claire Adjiman is Professor of Chemical Engineering at Imperial College London and a founding Co-Director of the Institute for Molecular Science and Engineering. She holds an MEng from Imperial and a PhD from Princeton University, both in chemical engineering. Her research interests lie in the area of integrated process and molecular/materials design, including the development of design methods, property prediction techniques and optimisation algorithms. She works extensively with industry, particularly across the oil and gas, pharmaceuticals and agrochemicals sectors. She is a Fellow of the Royal Academy of Engineering, the Institution of Chemical Engineers and the Royal Society of Chemistry, is a member of the editorial boards of *Molecular Systems Design & Engineering*, *Computers & Chemical Engineering*, and *Fluid Phase Equilibria*, and is an associate editor for the *Journal of Global Optimization*.

Nicholas Harrison is Professor of Computational Material Science at Imperial College London and a founding Co-Director of the Institute for Molecular Science and Engineering. He obtained his PhD from the University of Birmingham and has more than 25 years of experience in developing and exploiting theoretical models for the discovery and optimisation of advanced materials. He has previously managed a theoretical and computational research team at ICI Ltd, spent a year as a visiting scientist at the Pacific Northwest Laboratories, Washington, and worked as a senior research scientist at Daresbury Laboratory. He is a Fellow of the Institute of Physics and of the Royal Society of Chemistry.

Shoshana Weider is the Institute for Molecular Science and Engineering's White Paper Coordinator. She obtained her Master's in Earth sciences from the University of Oxford and a PhD in planetary science from Birkbeck College. From 2011 to 2014 she was a postdoctoral fellow at the Carnegie Institution of Science, Washington DC, where she worked as part of NASA's MESSENGER mission science team. She has since worked in a variety of communication roles as a freelancer, and at major science and engineering organisations in the UK and Europe, including the European Space Agency, Network Rail and the Science Media Centre.

About the Institute for Molecular Science and Engineering

Founded in 2015, the Institute for Molecular Science and Engineering is the newest of Imperial College London's Global Institutes. The Institute brings engineers, scientists, clinicians and business researchers together from Imperial's four faculties to find molecular-based solutions to grand challenges facing our world. By blurring the boundaries between molecular science and engineering, and changing the way scientists and engineers work together, the aim of the Institute is to accelerate the pace of development to address these challenges. The Institute co-ordinates a range of integrated activities to enable researchers at Imperial and elsewhere to engineer novel products and solutions that are firmly based on advances in molecular science and engineering.

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