From curiosity to commercialisation

The economic impacts of discovery science supported by the Royal Society

THE ROYAL SOCIETY

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President's foreword

Above
Sir Adrian Smith, President of the Royal Society.

Since the 1660s, the Society's mission has been to promote excellence in science for the benefit of humanity. We do this by funding excellent researchers, providing them with the freedom and time to pursue curiosity led research.

With the expansion of our research fellowship programmes, thanks to the funding from the UK Government over the last 40 years, our researchers have discovered new knowledge, established completely new areas of research, developed new technologies, trained the next generation of scientists, and left their footprint in many areas of public life. Many of these wider contributions are documented and celebrated in our career pathway tracker reports, which can be viewed at **royalsociety.org/career-pathway-tracker**

This set of case studies illustrates how the research funded by the Society has also yielded significant economic impacts. In some cases, this was achieved directly through companies started by our funded researchers. In other cases, economic impact was achieved through groundbreaking discoveries, such as new materials, which opened possibilities for applications to be commercialised by others, including existing technological giants. There are examples across the most critical current areas of science, such as artificial intelligence, optical fibres and vaccines.

The link between funding basic research and its economic impact is not always obvious. It can take many years or even decades. It can often require the combined efforts of many individuals and teams. That's why this set of case studies looks across several decades of research.

We don't know yet which of the more than 800 researchers funded today will lead to successful commercialisation in five, ten or twenty years. From our data, we know that, just in the last two years, about 50 startup companies were established by the researchers we fund, and that over half of our alumni take part in some form of knowledge exchange at least annually. The successes of our alumni make a compelling case for funding of research fellowships, and more broadly for the fundamental importance of funding of basic research in the United Kingdom. Such funding is essential to enable the technologies, products, and companies of the future.

The commercial successes of alumni of Royal Society research fellowships build on activities research fellows carry out during their awards. They have the freedom to take their research in any direction they think is best, and this often includes public engagement, policy work and commercialisation of research.

The following statistics reflect the last five years of our active research fellows' commercialisation activities:

24% took part in at least one commercialisation activity

Nearly **600** innovation disclosures have been made

Over **300** patents have been filed

Around **150** spinout companies have been formed

Photonics and optical fibres

Using laser light to transmit information over long distances along a fibre made of glass was first proposed in 1966 by Charles Kao, a physicist, and George Hockham, an engineer, working at the Standard Telecommunications Laboratories in Harlow. In a paper published that year, they described how such a waveguide could work and what the design requirements would be for a system to successfully carry information without being unduly attenuated.

Their idea was widely mocked at the time. It took years of patient experiments from the scientists to show that pure enough materials existed to be able to make useful fibres. It took decades more work to design manufacturing processes that could create the optical fibres of the right dimensions and strength. Dr Kao was awarded the Nobel Prize in Physics in 2009 for his “groundbreaking achievements concerning the transmission of light in fibres for optical communication”.

It is impossible to imagine life without optical fibres today. In our hyper-connected world, messages, calls and data flow near-instantly around the globe, connecting everything from individual smartphones in people’s pockets to smart TVs and racks of servers in gigantic data centres. Virtually all of those bits travel through optical fibres at some point in their journeys.

According to SPIE, the international society for optics and photonics, the components industry in photonics has grown at a rate of more than twice that of global GDP since 2012. The manufacture of photonics-enabled products has created more than five million jobs around the world and global annual revenues for products has reached around $2.5 trillion.

For any industry, these numbers would be impressive. Yet these statistics barely capture the true economic impacts of photonics and optical fibres. These are enabling industries, a layer upon which all modern life and work has been built. Optical communications networks underpin the internet, they allow cloud services and applications to work. They are critical national infrastructure and being at the cutting edge is directly tied to a country's future economic development and prosperity.

…light waves bounce around inside the core and can therefore be 'piped' along the fibre, rather like water flowing through a garden hose.

An optical fibre can be made from glass or plastic and usually consists of a core, around 0.01mm across, that is cladded with glass or plastic with slightly different optical properties. The result is that light waves bounce around inside the core and can therefore be 'piped' along the fibre, rather like water flowing through a garden hose. Information can be encoded within this light and travel vast distances without getting distorted. The electrical currents that transmit information along copper wires, by contrast, can suffer electromagnetic interference – the further they travel, the more degraded and unreadable the signal will get.

Above
Professor Polina Bayvel CBE FREng FRS.

Leading the charge in that development of optical fibre communications systems and networks in the UK is Professor Polina Bayvel, an electrical engineer at University College London and a holder of a Royal Society Research Professorship since 2024. The Royal Society has supported her curiosity-driven research for more than 30 years – she was awarded a University Research Fellowship in 1993, followed by a Royal Society Wolfson Merit Award in 2007.

The first of those awards allowed Professor Bayvel to establish the Optical Networks Group (ONG), the first academic systems engineering group in optical communications and networks research group in the UK, filling a gap at a time when industrial laboratories in the field were on the wane. She eventually built her group into an internationally leading research centre with a state-of-the-art test bed for high-speed communications and networks research, supported by powerful computer modelling.

Professor Bayvel noted that when she started her career in the 1990s, the UK boasted "many industrial research laboratories in the area of optical communications, [but] one by one they closed down, with the ONG becoming a unique resource combining world-leading testbed and experimental capabilities to provide innovations and leadership for the future of the UK's communications infrastructure, a critical national resource".

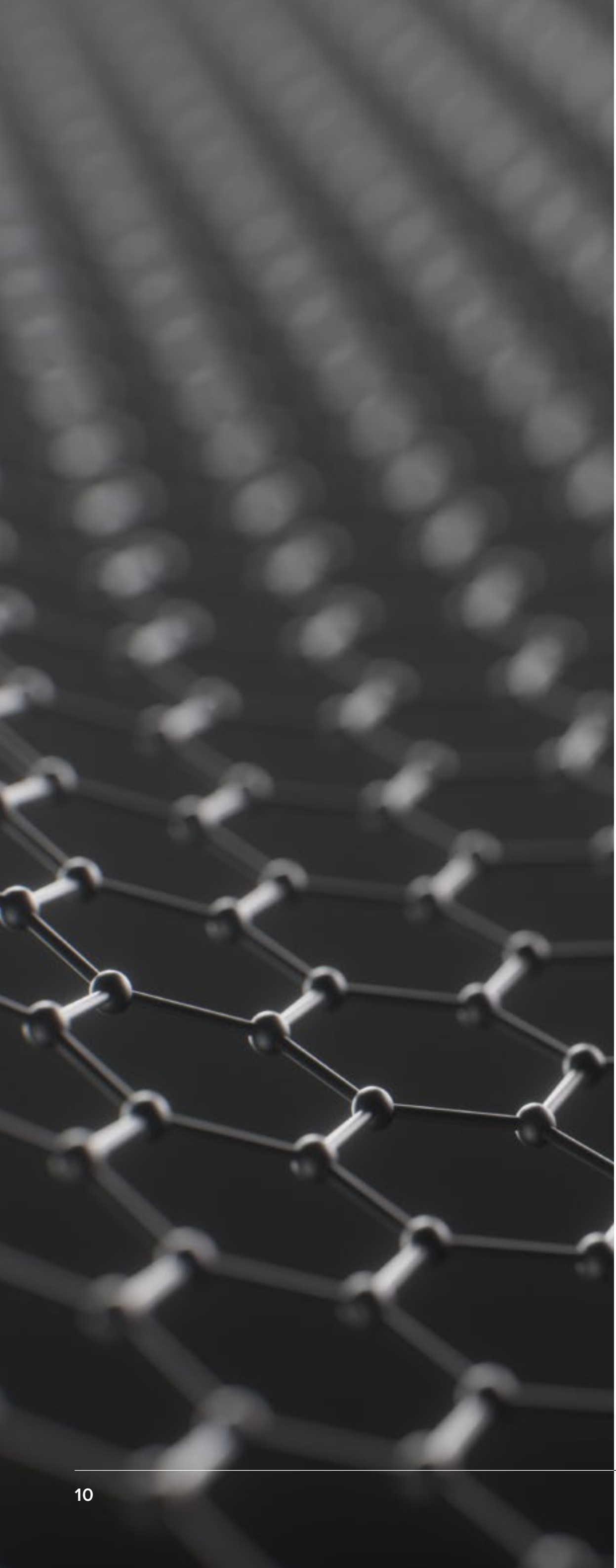
During her career, Professor Bayvel has published more than 500 scientific publications, supervised 40 PhD students and set some world records on the largest amounts of information transmitted over optical fibres. She has also worked with many in the communications industry including BT, Deutsche Telecom and Microsoft, as well as equipment manufacturers (Infinera, Nokia, Xtera) and optical fibre manufacturers (eg Corning).

Professor Bayvel's work is nowhere near done. Her team is already exploring innovative architectures for next-generation optical networks aimed to meet the demands of AI-driven applications. She wants to push bandwidth boundaries and increase network resilience, whilst reducing complexity and energy consumption. The outputs of her work (and those of her research group) will only become more central to people's lives as more of our data and digital services become located in the cloud – those optical-fibre networks will continue to be our umbilical cords to our digital lives.

Photonics is also a core research topic for Professor Kenneth Grattan, George Daniels professor of scientific instrumentation at City University in London and holder of a Royal Society Wolfson Research Merit Award from 2015 to 2019. The focus of his funding was to develop new and better physical and chemical sensors that built on his knowledge of the properties of optical fibres, underpinned by advanced computer modelling.

He has collaborated with Brecknell Willis, a British company, to create new sensors for pantographs, the pole-like devices that connect trains and trams to the high-voltage wires above the tracks and which provide vehicles with electrical power. That collaboration allowed Professor Grattan to found a spinout company – City Optotech Ltd – that markets the products of his research into optical-fibre-based sensors. Another successful collaboration has involved Sydney Water in Australia, for whom Professor Grattan's team developed a new type of fibre-optic-based humidity sensor, so that the water company could do a better job of monitoring its ageing infrastructure (in some cases more than a century old) in sewers and pump stations. The company is a classic case of academic research with impact, creating jobs, products and boosting the local economy in London.

Professor Grattan says says that the award "provided baseline support for a number of activities in the optical fibre instrumentation field and fostered several valuable international links. That support has enabled me to obtain several larger grants and contracts from a variety of sources, including Innovate UK, charitable sources and from industry".



Graphene

First isolated just over 20 years ago, there probably aren't enough superlatives to describe the full potential of graphene. This one-atom-thick layer of carbon atoms, arranged in a hexagonal lattice, is 200 times stronger than steel.

It is an excellent conductor of electricity (as good as copper) and the best-known conductor of heat. It is transparent and can be bent and folded without breaking. Its uses include electronics (faster and more efficient transistors, more flexible displays), energy storage (batteries and supercapacitors), sensing molecules in medical diagnostics or environmental monitoring and making materials such as plastics stronger. According to analysts, the global market for graphene and graphene-based products is expected to grow to almost $2 billion by the end of the decade.

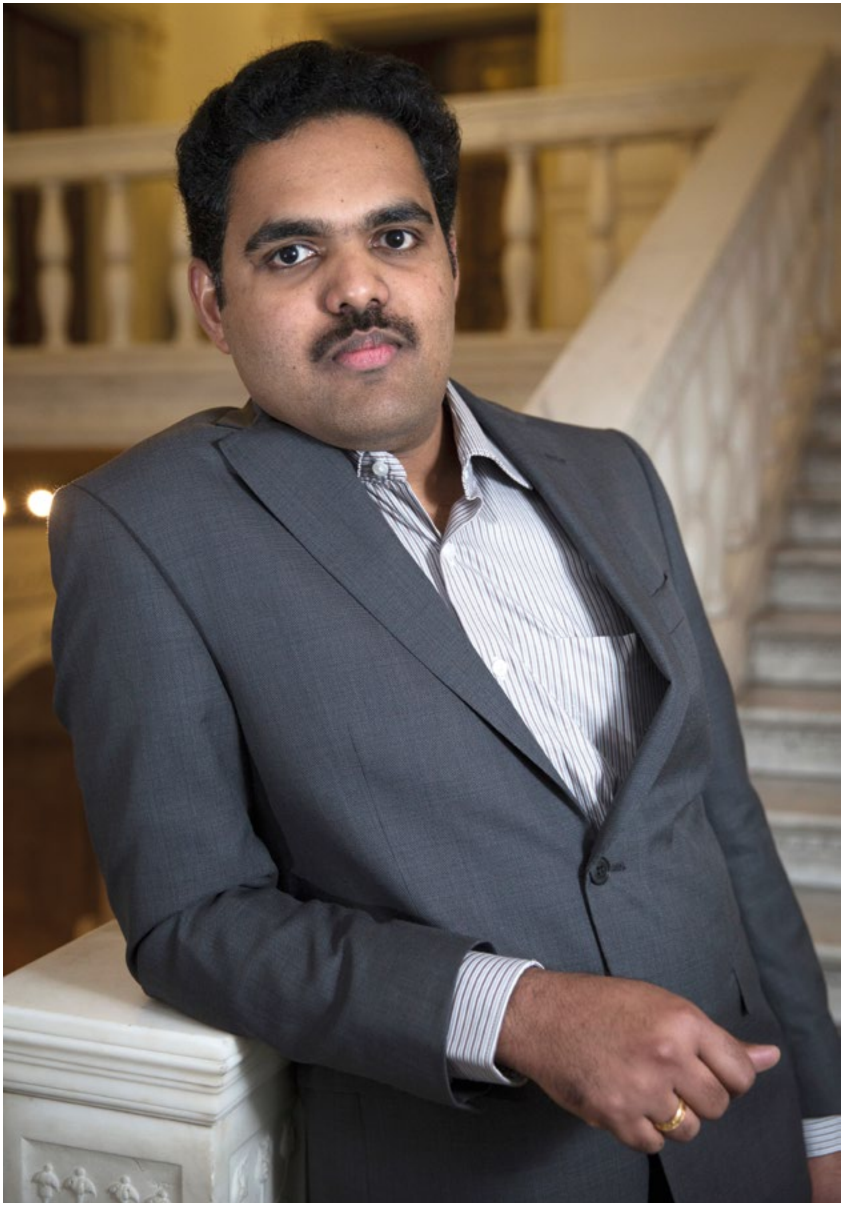
Professor Sir Konstantin Novoselov won the 2010 Nobel Prize in Physics for co-discovering graphene with his supervisor, Professor Andre Geim. He had first isolated the material from graphite six years earlier, using sticky tape to lift off thinner and thinner layers until they got to a single layer of atoms. When he was awarded the Nobel Prize, he was already a few years into his Royal Society University Research Fellowship.

Professor Novoselov went on to be awarded a Royal Society Research Professorship in 2014 and continues to explore the physics of two-dimensional atomic crystals to this day, a field that he helped invent. The awards from the Royal Society helped him buy out the time he needed to set up the flagship National Graphene Institute (NGI) at the University of Manchester, which opened its doors in 2015. "I managed to spend three years of my time working on the National Graphene Institute," he says. "It was partly the flexibility of RS funding that helped me to be able to do this."

"My URF started in 2006, right at the beginning of the graphene era. Graphene started as a completely unplanned, unexpected finding. It immediately offered multiple opportunities, and one would have to choose smart which direction to follow. URF offered exactly the possibility of flexible, sometimes opportunistic, research planning required in such situations.

Professor Sir Konstantin Novoselov speaking about his Royal Society University Research Fellowship

Left
Professor Sir Konstantin Novoselov FRS.



The institute has since become a font of fundamental scientific knowledge on graphene and trained scientists who have gone on to create their own groups or move into industry. One of these is Professor Rahul Nair, who received a Royal Society University Research Fellowship in 2014, just a couple of years after showing that, though graphene is impermeable to water, membranes made from graphene oxide allow water to pass while blocking most other molecules – making graphene oxide a promising material for filtration. He has worked on graphene research with several industry partners including the Defence Science and Technology Laboratory in the UK, Lockheed Martin Corporation in the US, AstraZeneca, BP, Airbus, Tetra Pak, and Neometals. In a project with the Khalifa University in the United Arab Emirates, his team also collaborated with several companies including Veolia, Modern Water (a UK-based membrane-technologies firm) and Neometals (a leading mineral project developer).

Left
Professor Rahul Nair.

Professor Nair has gone on to establish his own research group at NGI and his work on membranes has been enthusiastically received by awards committees and industry alike. In 2024 he was awarded one of the Blavatnik Awards for Young Scientists in recognition of his research in two-dimensional materials-based membranes addressing global challenges.

His team has now gathered plaudits for developing a 'smart' version of his membranes, in which the graphene oxide responds to electrical signals, or how acidic or alkaline a liquid is, and is then able to tune the rate at which water passes through (or even shut down the transport altogether). These membranes' potential applications are being explored in collaboration with industries such as pharmaceuticals, healthcare technology, jet fuel filtration and seawater desalination. He is also working with Carlsberg to bring his filters to the food and drink industry, including developing a way to remove alcohol from beer. His work could also be used to make industrial processes more environmentally friendly and to enhance energy efficiency. Professor Nair credits his Royal Society Fellowship with helping him gain an international reputation in his field and allowing him to focus on his chosen research goals while limiting teaching and administrative commitments.

Professor Krzysztof Koziol of Cranfield University, a material scientist with an expertise in nanomaterials, specifically graphene and carbon nanotubes, received his University Research Fellowship in 2008 when he took up a post at the University of Cambridge. The fellowship gave him independence to move his career forward – his research went on to form the basis of ten spinout companies, including Levidian Nanosystems, one of the largest manufacturers of graphene in the world, who are on a mission to decarbonise the world's most carbon-intensive industries. He is also the creator of the LOOP plasma technology, which seeks to turn waste gases into low-cost graphene and hydrogen.

Professor Koziol also led UltraWire, a €3.3 million EU development consortium with industry partners that include National Grid, PSA Peugeot Citroën, and some of the world's largest cable manufacturers.

Above
Professor Krzysztof Koziol.

Artificial intelligence

British companies don't get more cutting-edge and more talked-about than DeepMind. This artificial-intelligence startup began life in London in 2010, and was bought by Google a few years later. Today, it is one of the world's most high-profile and innovative Artificial Intelligence (AI) companies.

In 2024 its co-founder, Demis Hassabis, was awarded a Nobel Prize in Chemistry for the company's work with AlphaFold, an algorithm that can predict the 3D shape of a protein based on just its sequence of amino acids. Indeed, what sets DeepMind apart from many of its tech rivals is the company's relentless focus on scientific research. Accelerating the creation of new knowledge (in service of solving the world's greatest problems) has always been high on Dr Hassabis's priorities for his company. That means interacting with, and employing, many top academics.

Among them is David Silver, principal research scientist at DeepMind, professor of computer science at University College London, and a recipient of a Royal Society University Research Fellowship in 2011.

Professor Silver's expertise, built on the work he carried out during his fellowship, lies in developing a method of training algorithms called reinforcement learning, where an AI model learns by trial-and-error. The model will carry out an action on some data (guess that an image contains a "dog", for example) and then get feedback from its environment (a person, say, or another algorithm) about whether it was right or wrong. The AI model will then update itself and try its guessing game again on another piece of data, with the aim of making a better guess next time around. This is a core method in the modern iteration of machine learning that underpins generative AI such as large language models.

During his Fellowship, the Royal Society agreed to let Professor Silver go on an extended sabbatical for 18 months (normally only 12 months are allowed) while he tried out working at DeepMind. Ensuring that he had a fellowship (and a job) to come back to if the commercial world didn't work out gave Professor Silver the assurance he needed to make the leap. Things worked out very well – at DeepMind, Professor Silver went on to spearhead the development of AlphaGo, the algorithm that made the company famous in 2016 by beating Lee Sedol, the world's highest-ranked human player of Go, an ancient Chinese board game.

Above
Professor David Silver FRS.

Above
Professor Andrew Blake FREng FRS.

Professor Andrew Blake, a pioneer in computer vision, received an IBM-funded Royal Society University Research Fellowship in 1984 and an Amersham senior fellowship in 1998. He is best-known for the condensation algorithm, which can track objects in video sequences. He and his research team also developed the AI behind the Kinect 3D camera, released by Microsoft in 2010. This motion-sensing device, initially released as a controller for the company's Xbox 360 console, could detect people and their gestures in a room in real time, allowing them to control characters or objects within computer games. The Kinect went on to become a multibillion-dollar business and had multiple lives after gaming, including kickstarting the mainstream development of augmented reality (AR) technology, a way to bring computing and robotics into the physical space around people.

In a distinguished career which has included a stint as director of Microsoft Research in Cambridge, Professor Blake also trained some of the leaders of computer vision research today – for example Andrew Zisserman, a Fellow of the Royal Society, who is one of the world's leading authorities on AI vision.

Professor Blake's work has gone well beyond games and AR – some of his fundamental work on AI vision has been used to improve the detection and treatment of cancers. Not only did he launch Microsoft's AI effort on medical imaging, but Professor Blake also himself benefited from the technology, which has now become routine in some hospitals, as a patient.

Scientists work on algorithms at all levels of complexity. Professor Bernardo Cuenca Grau, a computer scientist at the University of Oxford and a recipient of a Royal Society University Research Fellowship in 2009, focuses on knowledge representation and reasoning (KRR), a type of AI that can make logical and explainable decisions from vast datasets. A typical machine learning algorithm is usually given reams of data and left to its own devices to find associations and patterns. It is powerful but these algorithms can often make 'decisions' without being able to explain why. A KRR algorithm, by contrast, can be encoded with expertise through hierarchies of rules about how to interpret a dataset before being given any data to process. In a bank, for example, millions of transactions might happen every day and a KRR algorithm can autonomously process and make decisions about the data while also keeping track of those decisions – crucial for transparency, explainability and regulatory compliance.

Professor Grau founded Oxford Semantic Technologies (OST) with fellow professors Ian Horrocks and Boris Motik in 2017, with the company specialising in KRR-based knowledge graphs. OST initially sold its services to financial, manufacturing and e-commerce companies across Europe and North America. It was acquired in 2024 by Samsung Electronics and Professor Grau says that the technologies his team have developed will now play a key role in Samsung's AI-on-device initiative and have been deployed in millions of newly released Samsung S25 mobile phones.

Analysts reckon that the worldwide artificial intelligence market was valued at around $230 billion in 2024 and is projected to grow to more than $1.7 trillion by 2032[1].

A lot of the value chain in this market is currently focused in countries with deep pockets, such as the US and China. But the UK has plenty of talent and potential here too. We might not be building the biggest large language models in the world but the depth of the computing talent in this country and their strong links with industry, as evidenced by the scientists supported by the Royal Society above, shows that the UK is not only good at basic scientific discovery (and winning notable international academic prizes) but also has the skills ready to deploy (and lead the development of regulation for) new technologies as they get invented.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DNA sequencing

We all carry genetic information within our cells, inherited from our parents. Our genomes, located in the nucleus of each and every cell, come in the form of DNA, a long molecule made up of units called nucleotides that go by the names adenine (A), cytosine (C), guanine (G) and thymine (T).

A person's genetic sequence is around three billion nucleotides long and contains all the information needed to build them, instruct their bodies how to grow and make all the chemicals and other tools they need to keep them living. The sequences (GTTGACCCCTTAC and so on) code for proteins and there are lots of variations between individuals, leading to all our different physical characteristics – our eye colour, the shapes of our faces, height and, well, lots more that distinguishes us. But errors in the code, even single-letter changes or mutations, can lead to bad outcomes such as cancer or an increased risk of heart disease. Knowing the DNA sequence, therefore, has become a central part of modern biology and medicine, a window into understanding how organisms work and identifying ways to tackle disease.

The revolution in DNA sequencing began with the work of Fred Sanger, a biochemist, in the 1970s. His team, working at the Laboratory of Molecular Biology in Cambridge, developed the 'chain termination method' to read the sequence of letters of a piece of DNA. They started by making multiple copies of the DNA strand in the presence of molecules called dideoxynucleotides, which randomly stopped the copying process and thereby created DNA fragments of different lengths. The resulting fragments were sorted by size and, by looking at the type of dideoxynucleotide that had terminated the specific chains, the fragments could be pieced together to reconstruct the original DNA sequence. Dr Sanger's method proved incredibly accurate and reliable and was eventually used to sequence the first human genome, a task completed in 2003. The chain termination method, however, is slow and labour-intensive – it took more than a decade to complete the Human Genome Project, for example and cost more than one billion dollars.

Enter Professors Shankar Balasubramanian and David Klenerman, chemists at the University of Cambridge. In the late 1990s and early 2000s, they co-invented a new method, known as Next Generation DNA Sequencing (NGS), that led to an extraordinary drop in the time and money it took to sequence DNA. Today, for example, an entire human genome can be sequenced in a day at a cost of less than $200. NGS has transformed the practice of biology (not just to understand humans) and turned it into a data-driven 'big science'.

Below
Professor Sir Shankar Balasubramanian FMedSci FRS.

NGS not only allows scientists to understand how organisms work, its speed and low cost has seen it being adopted in healthcare and diagnostics of everything from cancer and rare disease to infections. Professor Balasubramanian carried out much of his early work that led to NGS while he was a Royal Society University Research Fellow, an award he got in 1995; Professor Klenerman received a Royal Society Professorship in 2017.

After their early idea and proof-of-concept work had invented their NGS technology, they formed a company in 1998, Solexa, where their technology was developed into a working, integrated commercial NGS system. Solexa was eventually bought by Illumina, an American biotech firm, for $600 million in 2007. "To date, over 13 million people have had their genome sequenced, predominantly using the Solexa-Illumina technology", says Professor Klenerman.

For Professor Klenerman, the key benefit of the Royal Society's award was that it freed up his time to focus on research, rather than teaching and administration. He has used that time to establish collaborations with clinical colleagues and this has already led to the development of new ways to make early diagnoses for neurodegenerative diseases and cancer, based on the detection of clumps of specific proteins.

His team has recently filed patents on these techniques. Meanwhile, the worldwide DNA sequencing market continues to grow – it was worth around $17 billion in 2024 and is expected to grow to around $44 billion by 2030[2]. NGS, in particular, was used to spectacular effect during the COVID-19 pandemic. It allowed scientists to identify the SARS-CoV-2 virus within days, and then epidemiologists and public health officials were able to track and study the coronavirus as it moved and mutated into new strains across the globe. Knowing the genetic sequence of the virus in real time allowed scientists to understand how the virus worked, how people's immune systems responded and, perhaps most critically, how to build vaccines to stop its spread in less than a year – a record time. This was also helped, of course, by scientists in the UK and elsewhere already having decades of accumulated basic curiosity-driven research on coronaviruses and mRNA technology under their belts when the pandemic began.

It doesn't stop there. In the future, NGS technology will continue to expand as a major tool in basic biological and biomedical research. The sequencing of the microbiome, the communities of beneficial bacteria that live in our bodies and which provide a host of useful services, is a new area of research made possible by NGS. Another area of potential is the high-throughput genetic sequencing of the immune systems cells, to monitor how people are responding to diseases or drugs.

NGS is also being used to detect rare foetal blood in maternal blood, making non-invasive screening of foetal health possible. And where previously patients with rare genetic diseases did not receive a diagnosis (and many of the causative genes remained undiscovered) these patients are now being diagnosed by NGS and, in many cases, the information can be used to find viable treatments. Sequencing is also helping new-born babies with rare diseases in the UK. In about half the cases, by sequencing the parents and the baby, doctors are now able to diagnose and treat illnesses that once eluded clinical care.

"Sequencing of cancers is used in many clinics to guide therapy improving outcomes for the patient. Non-invasive, blood-based cell-free DNA sequencing is being investigated in trials to detect cancer earlier which means treatment is more effective and to monitor the recurrence of cancer post-treatment."

Professor Sir David Klenerman FMedSci FRS

Net-zero

Moving the world's energy system to greener, more sustainable sources is table stakes in the fight against climate change. It is also going to be a huge economic driver – according to McKinsey, supplying goods and services to enable the UK to become a net-zero country could be a market worth £1 trillion by 2030[3].

This is, however, also fraught with geopolitical issues. Take batteries. The energy transition will need oodles of energy storage of different sizes, for everything from cars to homes to balancing the electrical grid. The problem is that the ingredients needed for the dominant battery technology, lithium-ion, come largely from China. If you're in a country that has your guards up against China (or it has its guards up against you), that could be a problem – where do you get your lithium (and other minerals) for the batteries that you know you'll need?

The good news is that there are alternatives: you can also make batteries out of sodium. Any decent chemistry student will know that lithium and sodium are very similar metals with many similar properties – they are in the same group in the periodic table (alkali metals) and they both have solitary electrons in the outermost orbitals of their atoms. But sodium, which is found in the salt in seawater (or on your kitchen table) is orders of magnitude more common on Earth than lithium.

Professor Serena Margadonna, who holds a chair in chemical engineering at Swansea University, is one of those working on making sodium-ion batteries a commercial reality, in collaboration with Welsh battery manufacturers, Batri Ltd. Professor Margadonna received a Dorothy Hodgkin Fellowship in 2003, which helped launch her career as a researcher, and a Royal Society Industry Fellowship in 2024. She is currently supporting Batri Ltd in the development of carbon-based anode materials for sodium-ion batteries, a technology that has now been commercialised and sold to British and European companies.

Sustainable energy is the topic of another recipient of a Royal Society University Research Fellowship – Professor Deborah Greaves of the University of Plymouth. She has spent her career working out how to harness energy from the waves and tides (perhaps unsurprising for someone who grew up on the Devonshire coast). She began her fellowship in 2000 after a PhD in computational fluid dynamics, studying the behaviour of ocean waves.

Today, she leads the Coastal, Ocean and Sediment Transport laboratory at the University of Plymouth. She also leads the Supergen Offshore Renewable Energy (ORE) Hub, a project that brings academic and private researchers together with policymakers and the public to work on future technologies to extract energy from the wind, waves, and tides. She also does plenty of work beyond the laboratory too – Professor Greaves has been part of her university's delegation to the United Nations' climate summits since COP26 in Glasgow in 2021.

"Our research on sodium-ion batteries aims at establishing a UK battery manufacturing plant with precursor materials and components all sourced within the UK and EU," she says. "This will reduce dependence on China and strengthen supply chain resilience." In addition, all the manufacturing processes she and Batri use are circular, including eventual recycling of the used batteries.

Professor Deborah Greaves

Above
Professor Deborah Greaves.

Above
Professor Richard Templer.

Another way to push the net-zero agenda forward is demonstrated by the long (and strikingly multidisciplinary) career of Professor Richard Templer, formerly head of the chemistry department at Imperial College London. He received a Royal Society University Research Fellowship, which lasted for five years, in 1989. He also won a Paul Instrument Fund grant through the Royal Society in 1991. He began his research career working on the biophysics of the lipid membranes of living cells, gained insights into how tumours grow and developed important techniques (still used today) for X-ray imaging. He eventually went on to lead the Department of Chemistry before turning his attention to climate innovation.

In 2010, Professor Templer co-founded the Climate Knowledge Innovation Community (KIC) and became its UK director. Supported by the European Institute of Innovation and Technology (a body of the European Union), the KIC is an innovation agency working to address the challenge of climate change by bringing together experts from the business, public, academia and non-profit sectors. As its director of education, Professor Templer oversaw the teaching of more than 2,000 students from around the world on environmentally sustainable innovation and entrepreneurship.

After the UK's departure from the EU, Professor Templer continued the work under the guise of Undaunted, which was launched by King Charles in 2021.

Professor Templer's leadership has led to around $1.5 billion of investment in 160 climate start-ups since 2011. These companies are operating not only in the UK but dozens of other countries around the world and created around 2,000 jobs. A significant proportion of them are thriving businesses, for example Krakenflex (now a part of Octopus Energy), Grow Up Farms (which makes sustainable salads sold in Tesco), Naked Energy (which makes photovoltaic and solar thermal systems on major buildings such as the British Library), Truck Labs (automotive efficiency in the United States), Notpla (algal replacement for plastic packaging and a winner of the Earthshot Prize) and Adaptavate (carbon-negative replacement for gypsum board).

Professor Templer says that his interest and leadership on climate innovation came out of the biophysics work he did during his University Research Fellowship, right at the start of his career. He saw the potential to use that research to design systems to grow feedstock for biomass energy plants that could replace petroleum products.

> Professor Templer calculates that, by the end of the decade, the companies supported by his projects will have been responsible for emissions reductions of at least 29 megatonnes of carbon dioxide, avoided the use of 76 megatonnes of freshwater and prevented the creation of almost 50 megatonnes of agricultural and industrial waste.

The importance of good training early in his career also made its mark – along with David Klug, another former University Research Fellow, Professor Templer proposed what would go on to become the Centres for Doctoral Training (CDT), a way to give PhD students basic multidisciplinary skills that would help get their own careers off to the best possible start. Their CDT for chemical biology has become the longest-running programme of its kind in the UK and has trained around 300 researchers, many of whom have gone on to become notable academics in their own right or found science-based companies.

Vaccines

Vaccines have saved more lives than any other medical intervention in history. The usefulness was made clear to the world during the COVID-19 pandemic and, in 2023, underlined by the award of the Nobel Prize in Medicine or Physiology to Katalin Karikó, a biochemist, and Drew Weissman, an immunologist, for their decades of work to develop the mRNA technology platform upon which some of the first covid vaccines were based.

Modern vaccines – an almost $90 billion global market in 2024 and projected to rise to $160 billion by 2032[4] – have a problem, though. They can be very difficult to distribute. These biomolecules are unstable outside their usual environments (ie inside people) and they can lose their effectiveness if not stored correctly. That usually means they need to be kept in a refrigerator (between 2 to 8°C) as they travel from lab to manufacturing plant to clinic. The mRNA covid vaccines, from Pfizer-BioNTech and Moderna, had to be kept even colder – below -80°C – to avoid their delicate ingredients from falling apart in transit.

The dedicated 'cold chain' can cost billions of dollars per year and account for up to 80% of the costs of vaccination. These hurdles mean that vaccines can often not reach places that are far away from major population centres and transport links, where refrigeration might not be available. This ends up punishing resource-limited locations in the developing world – such as Mali or Bangladesh, where up to 90% of health facilities lack adequate refrigeration – which often need vaccine doses the most.

Opposite
Professor Asel Sartbaeva.

"The University Research Fellowship's flexibility allowed me to pursue alternative research ideas outside of my fellowship. Without the Royal Society there would be no Ensilitech."

Professor Asel Sartbaeva

But what if you could make vaccines that don't need a cold chain? This is what Professor Asel Sartbaeva, of the University of Bath, is trying to do. Awarded a Royal Society University Research Fellowship in 2010, her research focuses on novel ways to improve the stability of vaccines. This interest came from a discovery she made after taking her daughter to get a childhood vaccine, that around half of vaccine doses that are made get spoiled due to failures in the cold chain. She later discovered that 1.5 million infants died prematurely every year with diseases that could be prevented by vaccination. She wondered if her knowledge of silica-based materials could be deployed to keep the active ingredients in vaccines from becoming damaged when they left the refrigerator.

The technique she came up with was to shrink-wrap vaccine molecules in a protective layer of silica, until they are needed. This 'freezes' the biological molecules in space and prevents them from falling apart until they need to be administered. This technology forms the core of EnsiliTech, a start-up that was spun out of the University of Bath in 2022, of which Professor Sartbaeva is the chief executive. The company, based in Bristol, has around a dozen employees and reckons its technology will eventually be useful across multiple vaccine types, from mRNA and beyond.

Professor Sartbaeva credits the flexibility of her fellowship with allowing her to explore "a crazy idea". She had been awarded the fellowship to study zeolites, naturally-occurring porous minerals that are used elsewhere as catalysts in producing petrol, washing powders and in clean-ups of radioactive waste.

In 2024, EnsiliTech was awarded a highly competitive government contract, valued at around £1.7 million, to develop the world's first thermally stable mRNA vaccine. By the end of that project, it is expected that the company's vaccine technology will be ready for human trials.

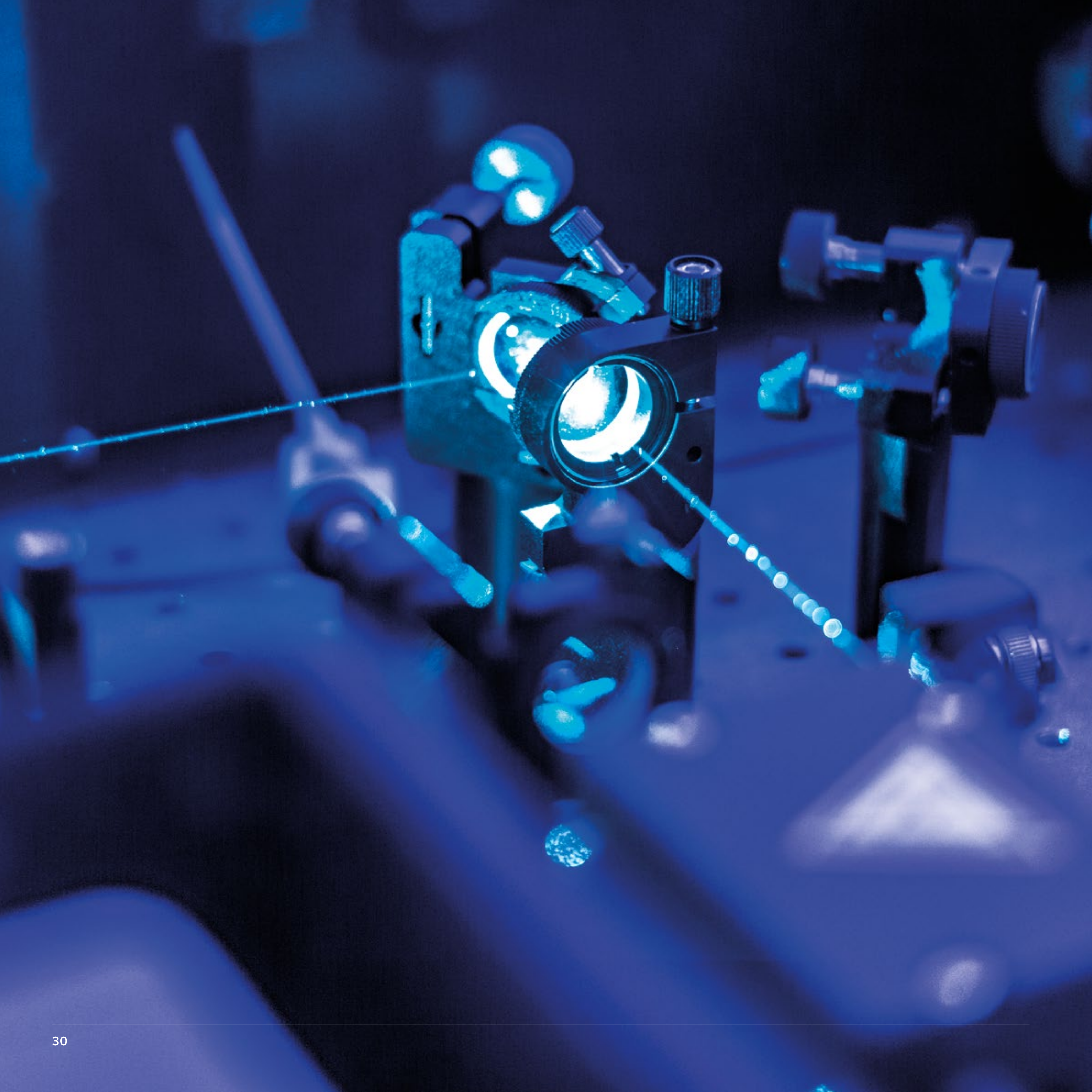
Another promising frontier in vaccine research comes from Dr Helge Dorfmueller of the University of Dundee. He was awarded a Sir Henry Dale Fellowship by the Royal Society and the Wellcome Trust in 2016 and is developing vaccines to prevent human infections caused by the pathogenic bacterium Streptococcus pyogenes, also known as Group A Strep.

This bug can cause a range of problems, from mild throat infections to severe invasive diseases like necrotizing fasciitis (flesh-eating disease) and toxic shock syndrome. It causes 500,000 deaths around the world every year, is increasingly resistant to antibiotics and no vaccine works against it.

In 2019, Dr Dorfmueller's team developed a technology to produce a novel type of vaccine candidates against Group A Step. The so-called RHAPSEDA technology allows to produce dual-hit vaccines comprised of Group A Step carbohydrate and a disease-specific protein, without the need of conducting technically complex chemistry. Dr Dorfmueller' spinout company, also named RHAPSEDA, won funding from Scottish Enterprise's High Growth Spinout Programme to support an early opportunity qualification and company creation phase to build a global vaccine development business in Dundee. The team already has commercial and scientific links with partners across Europe, the United States and South Korea.

Left
Dr Helge Dorfmueller.

There are big gains to be had – a recent study showed that, if a vaccine was available for Group A Strep, there could be aggregate societal benefits worth between $1.7 to $5.1 trillion[5], and it could avert 2.5 billion episodes of pharyngitis[6], 24 million episodes of cellulitis, and 6 million cases of rheumatic heart disease around the world.



Quantum computing and other quantum technologies

In an information economy, information is everything. Keeping data secure – from tax and medical records to military or commercial secrets – has been an obsession for cryptographers for thousands of years. As their methods of encryption get stronger, so do the techniques used by codebreakers who would like to see through the veil.

Modern cryptography on the internet, which is based on a decades-old system that relies on factorising enormous prime numbers, has taken us far. But its security is not guaranteed in the coming quantum age.

One of the most widely-used encryption mechanisms on the internet is called 'RSA'. Here, data is encrypted using a very, very large number that comes from multiplying together two enormously-long prime numbers – hundreds or thousands of digits long. If a hacker got their hands on the encrypted data, they would face a near-impossible job to decrypt it since they would have to work out exactly which pair of prime numbers were originally multiplied together to make the code for the encrypted data they had found. They could try to use a classical digital computer to do the factorisation by brute force (ie trying random guesses) but, even the most powerful computer, it would take millions or billions of years to finish the required calculations.

All of that makes RSA encryption functionally unbreakable with modern technology.

Quantum computers, though, could solve these 'prime number factorisation' problems exceptionally quickly. Instead of billions of years, it might take a quantum computer just a few hours (or less) to crack a typical RSA code. And that, it goes without saying, would be very bad news for all of us and our security.

Professor Artur Ekert is among those who have been thinking about this problem, ie how to keep data safe in the age of quantum computers. In 1991 he became one of the inventors of quantum cryptography, linking the foundational concepts of quantum theory with the study of secure communication, paving the way for the most secure communication systems to date: device-independent quantum key distribution. This breakthrough sparked a surge in global research efforts and continues to inspire new research directions.

Above
Professor Artur Ekert FRS.

In 2024, Professor Ekert won the Royal Society's Milner award for his pioneering contributions to quantum communication and computation, which transformed the field of quantum information science from a niche academic activity into a vibrant interdisciplinary field of industrial relevance.

Professor Ekert received a Royal Society Howe Research Fellowship in 1994, an equivalent of a University Research Fellowship, and this helped him establish a research group to build on his ideas in quantum cryptography. He is the founding director of the Centre for Quantum Technologies at the National University of Singapore, and professor of quantum physics at the University of Oxford.

Professor Ekert's solution to the coming problem of quantum computers breaking classical encryption can be summarised simply as "use quantum to fight quantum". If two people share entangled particles – say you have one and I have another one – when we perform measurements on them, they will respond in a very highly correlated way. If you know the quantum state of your particle, you will necessarily also know the quantum state of mine. They both end up with a random but identical sequence of zeros and ones, known only to them. Any attempt at eavesdropping introduces unavoidable errors, which both parties can detect.

Making these ideas move from a researcher's brain to useful products is the job of people like Professor Tim Spiller at the University of York. Awarded a Royal Society University Research Fellowship in 1986, he is now a leader in the UK's quantum efforts.

Quantum cryptography is going to become an enormous global market, with one estimate for the size of the opportunity at more than $7.5 billion by 2030[7].

He has been director of the £50 million Quantum Communications Hub, part of the National Quantum Technologies Program in the UK, since 2014. Each of the country's quantum hubs bring together universities, industry and national laboratories and institutions who collaborate to push forward quantum technologies. Researchers in York have collaborated with numerous partners, including Toshiba Europe, BT, the National Physical Laboratory and Rutherford Appleton Laboratory (RAL) Space.

The hub's first phase lasted five years and involved developing the basic technologies in quantum key distribution; phase two, which is nearing its end in 2025, sought to expand the distances that quantum keys could be distributed. Professor Spiller's Hub team has built quantum transmitters and quantum receivers. The transmitters will be launched into space on a satellite called SPOQC and the receivers on the ground will be used to demonstrate the feasibility of secure communications from space.

Left
Professor Tim Spiller.

The research led by Professor Spiller has also had an important influence on policy decisions by the government. More than £1 billion has been invested to support the UK National Quantum Technologies Programme and the work at York has also contributed to the creation of the €1 billion Quantum Technology Flagship, launched by the European Commission in 2016. Professor Spiller was invited to speak at its launch, given his role in inspiring and organising the project.

Antimicrobial resistance

Modern healthcare would be impossible without antibiotics – in the century since they were first discovered, these drugs have saved billions of lives and made everything from cancer treatment to surgical operations safer (and in many cases, possible). But their overuse around the world means that these wonderful medicines are losing their potency.

The bugs against which they work are fighting back – some are evolving resistance and an army of superbugs is on the rise. Bacteria divide every 15 – 20 minutes and, in doing so, their genes randomly mutate. If they are dividing in the presence of an antibiotic, and a new mutation protects them from damage or death, the strain will spread quickly. Bacteria can sometimes also pass any protective genes between them when they meet.

Around 70% of all antibiotics are given to livestock as a way to stop the spread of disease as they get farmed more intensively. This creates a huge pool of animals in which resistance can arise. A poor sewage system underneath a hospital can leak drug-resistant bacteria into public waterways and create another pool of potential bacterial resistance; winds can blow over contaminated land or water and pick up genes or superbugs themselves and spread them to other places.

Antimicrobial resistance (AMR) is a terrifying problem and, at current rates, it is expected to kill 10 million per year by 2050, up from around 1 million in 2019. Untreatable infections could cost the global economy $100 trillion by then and, if all antibiotics were removed from doctors' arsenals altogether, life expectancy would drop by a third. The first step to solving this crisis is to prescribe fewer antibiotics, especially in cases where a bacterial infection is not the cause. The longer-term goal should be to develop new drugs but, unfortunately, progress is worrying – scientists have not found a new class of antibiotic for more than 25 years.

Above
Professor Jim Thomas, Royal Society European Fellowship in 1994 and a University Research Fellowship in 1996.

> "I don't think I could have had an independent career without that fellowship."
>
> **Professor Jim Thomas**

The AMR challenge therefore needs ideas from new directions. Professor Jim Thomas, a chemist at the University of Sheffield, wanted to use metals to fight superbugs. Professor Thomas, who received a Royal Society European Fellowship in 1994 and a University Research Fellowship in 1996, had been working on compounds of ruthenium as a way to image the goings-on inside cells. Working in his lab, Dr Kirsty Smitten spent her PhD looking for versions of those ruthenium compounds that might also be able to fight bacteria.

The use of metals against bacteria is not new. Silver is well-known to slow the growth of bacteria and has been used in various medical products including bandages, ointments and catheters. It can also often, in lab tests, work synergistically with a range of antibiotics. Copper has a history of antimicrobial use stretching thousands of years and is used today on the hulls of ships to prevent fouling. Copper-impregnated bandages have been shown to slow the spread of Staphylococcus aureus. Bismuth compounds are used to treat infections of Helicobacter pylori that cause stomach ulcers.

Professor Thomas was interested in 'metal complexes', which are 3D arrangements in which metal ions are surrounded by other chemical species. The arrangement of the other groups of atoms (known as 'ligands') can be manipulated to give the complex useful properties. These structures have been studied for a long time – the antibacterial properties of ruthenium complexes, for example, were first noticed in the 1950s.

In their work, Professor Thomas and Dr Smitten found that ruthenium complexes disrupted the membranes of certain bacteria. In 2021 they founded MetalloBio with a £300,000 award from Innovate UK. The company has gone on to raise more than £3 million in total from venture capital and crowd-funding sources.

Though there are more than a hundred antibiotics used around the world today, they all come from only seven families of naturally-occurring chemicals. Each of these groups of antibiotics have some bacteria that have evolved resistance to them. Since MetalloBio's compounds are based on inorganic chemistry, they represent a new way to fight an infection. The ruthenium complexes could, scientists hope, one day be administered as drugs or be used as coatings for medical devices.

Research by Professor Thomas and MetalloBio shows that the compounds they have developed work against all six of the ESKAPE pathogens designated as being of most concern by the World Health Organisation: Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa, and Enterobacter spp. The company is starting small – the company only employs four people at present – but is moving quickly. If all goes to plan, they will start trials of their novel bacteria-busting technology within five years.

And Professor Thomas continues to innovate. In addition to MetalloBio, his group is collaborating with biologists and medical researchers to investigate compounds for a range of applications, from new imaging probes for state-of-the-art super-resolution microscopy techniques to the identification and development of novel anti-cancer therapeutics. For the latter, his group has recently been awarded a Yorkshire Cancer Research grant to collaborate with medical researchers and develop new chemical compounds as potential light-activated anticancer agents.

Professor Thomas estimates to have published around 150 papers in peer-reviewed literature in his career and estimates that around 90% of that output is built on the opportunity provided by the fellowship he started in 1996.

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Registered Charity No 207043
Issued: May 2025 DES9199

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