Science & Technology Facilities Council

UK Research and Innovation

Delivery Plan 2019

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1. Foreword

Mark Thomson
Executive Chair, STFC

STFC supports research in particle physics, astronomy, nuclear physics, and space science, most of which is undertaken as part of international collaborations. We also plan, design, construct and operate world-class multidisciplinary facilities used by academic and industrial researchers across the remit of UK Research and Innovation (UKRI). Our national facilities (the ISIS Neutron and Muon Source, the Central Laser Facility and Diamond Light Source) are the powerful 'microscopes' of the 21st century, imaging matter at the atomic scale. They also drive innovation, leading to the creation of new businesses, supporting the delivery of the UK's Industrial Strategy and generating wider social and cultural impacts. Our national research and innovation campuses at Harwell and Sci-Tech Daresbury bring together world-leading facilities, academia and business, providing a coherent focus for this activity.

Our science and facilities enable researchers to answer fundamental questions about the nature of the Universe. Success typically requires long-term strategic investment, international collaboration on a global scale and the capability to push the limits of technology and engineering. To remain internationally competitive in our areas of science and to keep our facilities at the leading edge, we have to develop bespoke technology that cannot be reliably sourced on the open market, for example in detectors and instrumentation, accelerators, specialist engineering, optics and e-infrastructure. These technologies are often also applied to address broader societal and industrial challenges and we actively promote their translation and commercialisation.

We have played a major role in some of the most important discoveries and advances of the 21st century. For example, in 2012 the Higgs boson was observed almost 50 years after its existence was first theorised; it was a remarkable technological achievement to discover a particle that only lives for 10^{-22} second. 2016 saw the announcement of the first detection of gravitational waves; a century after the development of Einstein's theory it was finally possible to develop the technology necessary to measure distortions that 'change' the distance between Earth and the Sun by less than the width of an atom. The observation of gravitational waves has opened up an entirely new way to sense objects in the Universe, launching a new era in astronomy. Nobel Prizes were awarded for both of these discoveries in which UK researchers and technologists played a crucial role. Our technology also supported the work of Professor Richard Henderson in developing cryo-electron microscopy (Cryo-EM), for which he shared the 2017 Nobel Prize in Chemistry. Radiation hard-sensors first developed by STFC for particle physics and further adapted for space science have revolutionised this technique.

Looking to the future, the creation of UKRI provides an important opportunity for the UK to consolidate and build on its existing strengths as a leading research nation and to support the government's ambition for the UK to become the most innovative country in the world. In this, our delivery plan (DP) as part of UKRI, we set out our longer-term ambitions together with the shorter-term actions we will take to deliver our strategy.

I look forward to working closely with my colleagues across UKRI and with our wider community to ensure we deliver our collective ambitions.

2. Vision and objectives

Science, research and innovation lie at the heart of the UK's continuing prosperity. The ability to innovate – in other words, to develop new ideas and apply them – is central to the government's Industrial Strategy with its commitment to raise total investment in R&D to 2.4% of GDP by 2027 and 3% in the longer-term. Whilst the UK is a global leader in science and research, we know that we must do more to translate research into practical applications and exploitable outcomes, supporting the delivery of the Industrial Strategy Grand Challenges as a route to greater economic and social prosperity. The formation of UKRI in April 2018 marked an important step towards realising this goal.

STFC is one of the nine component parts of UKRI. Our research seeks to understand the Universe from the largest astronomical scales to the tiniest constituents of matter, yet creates impact on a very tangible, human scale. From cancer treatment to airport security, high-tech jobs to hydrogen-powered cars, energy generation to accident-scene emergency care, our impact is felt across and beyond the UK in many aspects of daily life.

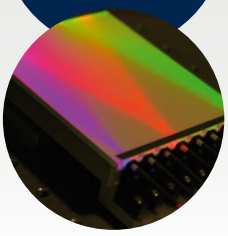
We deliver through three interrelated long-term strategic programmes (frontier research, scientific facilities and national research and innovation campuses) underpinned by five world-leading capabilities in technology and computing infrastructure, as illustrated below:

Frontier research:
Developing and exploiting a world-leading programme of frontier research in particle physics, astronomy, nuclear physics and space science.

Scientific facilities:
Planning, designing, constructing and providing stewardship for world-leading multidisciplinary facilities used by academic and industrial researchers across the whole spectrum of science.

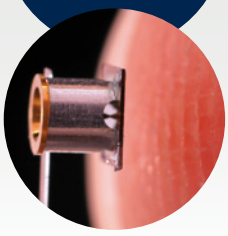
National research and innovation campuses:
Built around our UK facilities and laboratories, promoting academic and industrial collaboration and accelerating the commercialisation of novel ideas.

Detectors and instrumentation



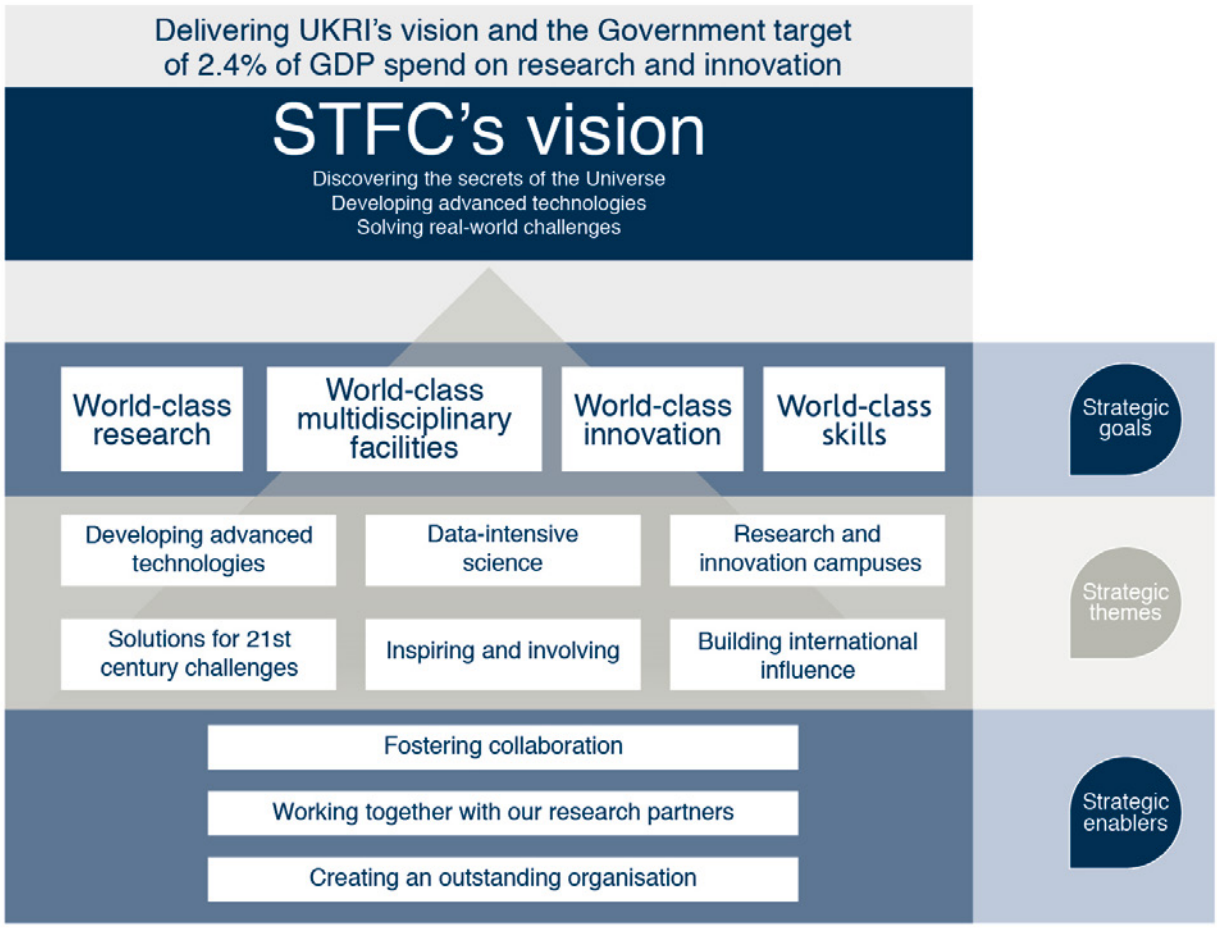
Accelerators

Specialist engineering



Optics

e-infrastructure



Our frontier research in particle physics, astronomy, nuclear physics and space science is delivered through activities at UK universities, in our national laboratories and by working globally through a wide range of long-term collaborative research projects. The UK enjoys excellent international standing in these disciplines through technological and scientific leadership built up over many years. Progress increasingly relies on sophisticated experiments at a range of large-scale bespoke facilities, often at the leading edge of what is technically possible.

STFC uses these same skills and technologies to plan, design, construct and provide world-leading multidisciplinary facilities used by academic and industrial researchers across the whole spectrum of science. From physics to chemistry, engineering to biology, the environment to archaeology, these multidisciplinary facilities (using synchrotron X-rays, neutrons and lasers) help solve industrial, societal and academic challenges across the remit of UKRI.

This inventive technology and instrumentation, including the e-infrastructure increasingly needed to generate and analyse research results, opens up new ways to investigate matter, enables Nobel Prize winning discoveries and attracts world-leading researchers to the UK. It also drives economic growth and societal impact, with our national research and innovation campuses providing important hubs for academic and industrial collaboration.

Our distinctive capabilities and contribution as part of UKRI are encapsulated in our vision and set out in more detail in the following sections of this document. Our strategy is centred on four enduring long-term strategic goals, supported by six strategic themes, intended to influence the focus of delivery over the medium term. Three strategic enablers underpin our ability to deliver and play a major role in making UKRI greater than the sum of its parts, ensuring we use our collective resources across the entire research and innovation community to generate maximum scientific, economic, social and cultural impact.

OUR ACHIEVEMENTS

Since our formation in 2007, we have been at the forefront of some of the most important discoveries of the 21st century. Here are just a few of our achievements:

2007

- STFC is formed through the merger of PPARC and CCLRC.
- Diamond Light Source opens with its first seven beamlines.

2008

- Research and innovation campuses are launched by government.
- The LHC comes into operation at CERN – the UK played a leading role in its design, development, operation and subsequent exploitation

2009

- ISIS Target Station 2 is completed on time and to budget, providing seven new neutron instruments.

2010

- Research using ISIS's Engin-X instrument enables 5-year extension of the life of two nuclear power stations.
- ESA selects the Harwell Campus to host its first UK Business Incubation Centre.
- The Research Complex at Harwell officially opens, a multidisciplinary laboratory for cutting-edge research in physical and life sciences.

2011

- £500 million in economic benefit is realised through long-standing collaborations with Oxford Instruments and e2v.
- STFC's OCTOPUS laser facility provides a breakthrough in understanding a biological process that causes common cancers.

2012

- The UK's DiRAC supercomputing facility is upgraded, improving the exploitation of observational and experimental facilities for physics and astronomy.
- An STFC-led international collaboration delivers the MIRI instrument to NASA to form part of the James Webb Space Telescope.

2013

- Discovery that atomic nuclei can be 'pear-shaped', through research at CERN supported by STFC and other international funding and research organisations.
- UK astronomers, supported by STFC, play a leading role in the discovery of 11 exoplanets.
- The Hartree Centre is founded in collaboration with IBM to accelerate adoption of data-centric computing by industry.
- Discovery of the Higgs boson at CERN in experiments designed, run and supported by STFC staff and STFC-funded scientists from UK universities.

2014

- Professor Peter Higgs shares the Nobel Prize for Physics for his part in the discovery of the Higgs boson.
- A new methodology is developed to produce a non-infectious vaccine for the foot-and-mouth virus, based on research at Diamond Light Source.
- STFC spin-out KEIT Ltd improves manufacturing processes based on technology developed to measure water vapour on Mars.
- The ALMA Observatory, one of the world's largest ground-based astronomical projects, becomes fully operational.

2015

- The UK secures the global headquarters of the SKA project, to be located at Jodrell Bank.
- STFC spin-out Cobalt Light Systems develops an airport-security liquid scanner and wins the Queen's Award for Enterprise.
- UK announces its intention to become a full member of the European XFEL project.
- Rosetta becomes the first spacecraft to successfully rendezvous with a comet – STFC funded UK participation and designed Ptolemy, one of the Philae lander's instruments.

2016

- STFC-funded researchers involved in the Nobel Prize winning experiment at SNO on neutrino science.
- STFC designs and builds the most powerful laser in the world for the HiLASE project.
- First detection of gravitational waves is announced, supported by STFC technology and STFC-funded scientists from UK universities.
- STFC engineers deliver the first piece of prototype equipment to the ESS in Sweden, which will become the world's most powerful neutron source.

2017

- A Nobel Prize for Physics is awarded for the detection of gravitational waves, drawing on technology and research developed and supported by STFC.
- ISIS instrument ChipIR comes online, offering new capabilities for the electronics industry to test vulnerability against cosmic rays.
- STFC spin-out The Electrospinning Company becomes a leading provider of clinical-grade electrospun biomaterials for the medical device industry.
- Cryo-electron microscopy transforms structural biology, based on sensors developed by STFC.

2018

- A Nobel Prize for Chemistry is awarded for work on cryo-electron microscopy, drawing on sensor development with STFC.
- Diamond Light Source Phase III is completed: 32 beamlines are now operational.

The future – a few examples of future milestones

- First results from DUNE.
- The SKA begins delivering results.
- 2021: Launch of the James Webb Space Telescope.
- 2024: The ELT begins operation.
- 2026: The High-Luminosity LHC at CERN begins operation.

3. Research and innovation priorities

3.1 STRATEGIC GOALS

We will realise our vision through our four strategic goals: world-class research, world-class multidisciplinary facilities, world-class innovation and world-class skills.

3.1.1 WORLD-CLASS RESEARCH

The UK as a global leader in the search for a deeper understanding of the Universe

Long-term strategic goal

Through the development and implementation of a long-term research strategy, maintain the UK's position as a global leader in fundamental science, pursuing new opportunities to drive the development of advanced technologies, high-tech skills and new international collaborations.

Context

Ambitious, curiosity-driven research and sustained strategic investments have established the UK as a world-leader in STFC's areas of science. We support a strong research base and, in our disciplines, the UK regularly ranks among the top three leading scientific nations, measured by citation impact. Our long-term world-leading programme seeks to understand the Universe from the largest astronomical scale to the tiniest constituents of matter, addressing these key questions:

- How did the Universe begin and how is it evolving?
- How do stars and planetary systems develop and how do they support the existence of life?
- What are the basic constituents of matter and how do they interact?

Our distinctive capabilities

Our research into particle and nuclear physics, astronomy and space science are by necessity long-term endeavours achievable only through the collaboration of our whole community, including international partners, to address our highest-priority science goals and push the boundaries of knowledge. A cornerstone of our programme is membership of international organisations such as the European Organization for Nuclear Research (CERN) and the European Southern Observatory (ESO), and participation in global strategic priority projects such as the Square Kilometre Array (SKA); these provide the ground-breaking discoveries necessary to advance our understanding of fundamental science.

Our contribution as part of UKRI

Our investment consistently delivers some of the most technically challenging instrumentation and missions ever undertaken, to resolve the most ambitious and demanding science questions ranging from the search for the 'dark energy' driving the acceleration of the Universe to landing a space probe on the surface of a comet. Tackling such challenges drives the development of novel and innovative technologies that can often be commercialised or applied to help solve industrial or societal challenges. Breakthroughs in our fundamental understanding of the Universe can transform our economy decades in the future.

Long-term ambitions

- Strengthen the UK's position as a global leader and international partner of choice in frontier research, ensuring our programme remains world-leading, vibrant and ambitious.
- Seize new opportunities to retain UK leadership in science and technology by focusing our cutting-edge programme on the highest-priority:
  - science goals that explore the limits of energy, space and time
  - science projects that drive novel and innovative technologies.
- Increase opportunities for our early-career scientists to develop into international leaders with highly developed skills in data-intensive science, analysis and instrumentation, relevant to the future needs of science, industry and society.
- Exploit the opportunities presented by UKRI cross-cutting funds to build deeper collaborations with partners across the globe.
- Strengthen strategies to attract, retain and develop talent from diverse communities and backgrounds.

Near-term actions

- Ensure, through an ambitious, long-term strategy for our research programme, that we are optimising our use of resources to stay at the cutting edge:
  - This will include completion of the short-term UK deliverables for the upgrades of the four detectors (ATLAS, CMS, LHCb and ALICE) at the CERN Large Hadron Collider (LHC) and analysis of the vast amount of data from the first operations.
  - The SKA will be the world's largest radio telescope, situated in South Africa and Australia and with its international headquarters at Jodrell Bank in Cheshire. As one of the three hosts, the UK will play a leading role in the formation of the international intergovernmental organisation.
  - The UK is now part of the next generation of neutrino experiments that are being built in the USA. A new accelerator system, the Long Baseline Neutrino Facility (LBNF) at Fermilab in Illinois, will fire neutrinos underground to the Deep Underground Neutrino Experiment (DUNE) in South Dakota. Working closely with our UK and US partners, we will agree

Detection of gravitational waves

The detection of gravitational waves has been hailed as the discovery of the century, receiving the Nobel Prize in Physics in 2017 and providing important insights on black holes, neutron stars and the evolution of massive stars. An international team of scientists made the breakthrough at the LIGO facility in the USA with technology developed by researchers at the Universities of Glasgow and Birmingham and STFC's Rutherford Appleton Laboratory that increased the sensitivity of the instrument and its ability to detect gravitational waves. This discovery is revolutionising the way we study the Universe.

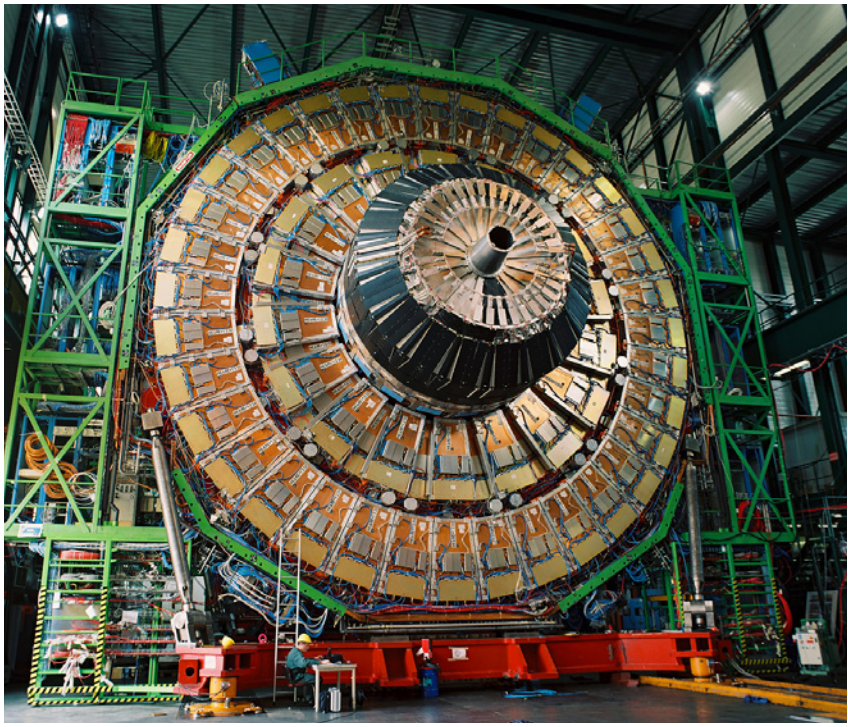
Discovery of the Higgs boson

In July 2012, teams including British researchers at CERN confirmed they had discovered the Higgs boson, marking a significant breakthrough in our understanding of the fundamental laws that govern the Universe. Professor Peter Higgs from Edinburgh had theorised the existence of the particle almost 50 years earlier. Our scientists and engineers played a central role in this discovery, contributing to the design, build and exploitation of the LHC (one of the most complex scientific instruments ever constructed) and its experiments. Professor Higgs shared the Nobel Prize in Physics in 2013. As well as advancing our knowledge of the Universe, UK industry wins an average of £25 million every year in contracts from CERN.

the detailed project plan ahead of formal project approval, which will mark the start of construction of our hardware contributions to the detector and accelerator systems.

- The Extremely Large Telescope (ELT), part of ESO, is under construction in the Atacama Desert of northern Chile. The next steps for the UK are to complete our contributions to the first light instruments, HARMONI and METIS, and continue to develop leadership in the future science programme.
- The ALIGO+ project to upgrade the Advanced Laser Interferometer Gravitational-wave Observatory (ALIGO) in the USA will increase its detection sensitivity and capability. We will agree the project plan, supported through the Fund for International Collaboration, with the US National Science Foundation and begin construction of the UK hardware contributions.

- Explore pioneering new approaches to the field of fundamental physics using novel quantum techniques, building on collaborations across UKRI and in particular with EPSRC.
- Work with our international partners to develop the next European Strategy for Particle Physics.



- Exploit the opportunities presented by the Fund for International Collaboration to develop even stronger links with the US National Science Foundation and the US Department of Energy.

3.1.2 WORLD-CLASS MULTI-DISCIPLINARY FACILITIES

World-leading multidisciplinary infrastructure enabling research across UKRI

Long-term strategic goals

- Ensure the UK's multidisciplinary facilities remain world-class through a balanced suite of major upgrades and targeted developments.
- Develop and deploy our facilities to address the needs of the broader UKRI community and industry, targeting the highest-impact national priorities.

Context

STFC has a strong tradition of developing ground-breaking research infrastructures that other nations strive to emulate. Our internationally competitive and inherently multidisciplinary facilities provide the foundation for the UK's thriving research communities in their quest to develop a new understanding of the structure and dynamics of the material and living world, and address the industrial and societal challenges of the 21st century across the whole spectrum of research.

Our distinctive capabilities

With the UK's large-scale multidisciplinary facilities (the ISIS Neutron and Muon Source, the Central Laser Facility and Diamond Light Source) we have unique capabilities and expertise for academic and industrial researchers across a wide range of research fields. We are also partners in international facilities such as the X-Ray Free-Electron Laser (XFEL) facility, the European Synchrotron Radiation Facility (ESRF) and Institut Laue-Langevin (ILL) that complement our national capabilities. Collectively, these enable researchers to explore and understand the structure of the world around us, from advanced materials science for the aerospace industry to the fundamental processes affecting life, health and wellbeing.

Our contribution as part of UKRI

Our facilities underpin a very broad range of research programmes, such as the pursuit of novel energy technologies and quantum information studies for EPSRC and structural biology pathways for novel drug discovery for MRC. To this end, we take the lead in planning upgrades of the UK's large-scale multidisciplinary facilities, developing a programme of design studies and technology R&D that is paving the way for next-generation capabilities such as Diamond II and ISIS II, and exploring the potential for a UK free-electron laser facility. We also lead the UK's participation in two major new international facilities: the European XFEL in Germany and the European Spallation Source (ESS) in Sweden.

Johnson Matthey

As part of Johnson Matthey's £200 million per year R&D programme, their scientists utilise our facilities and laboratories, gaining access to cutting-edge experimental tools, advanced computational modelling and world-class expertise to enhance and complement their in-house R&D activities and ongoing product development. These collaborations have made an impact in the environmental, automotive, chemical, medical, recycling, oil, gas and refinery sectors.

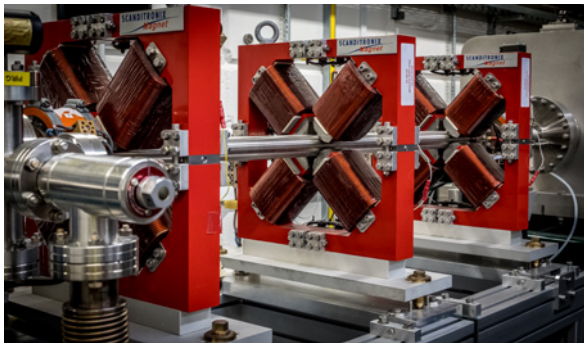
Major upgrade to the ESRF

A €150 million ESRF upgrade programme (the Extremely Brilliant Source, or EBS) has now entered its second phase, with construction of a new storage ring, new state-of-the-art beamlines and an ambitious instrumentation programme that will be available to users by 2020. We manage the UK's membership of the ESRF and UK companies have won significant contracts to deliver the ESRF-EBS upgrade. The new storage ring, together with the most advanced portfolio of new beamlines, will enable researchers across multiple disciplines to bring X-ray science into research domains and applications that could not have been imagined a few years ago. It will provide new tools for the investigation of materials and living matter from the macroscopic world down to the nanometre scale, and even down to the single atom.

In addition, we are leading on the development of the first UK research and innovation infrastructure roadmap. This will bring together a comprehensive long-term view of the capabilities required by the UK research and innovation communities in order to strategically plan, strengthen capability and optimise investment in new facilities for the nation's benefit.

Long-term ambitions

- Develop and deliver a strategic long-term plan for the coherent evolution of the UK's world-class, large-scale facility portfolio, based on the UK research and innovation infrastructure roadmap, that:
  - strengthens the UKRI programme of multidisciplinary research and enables delivery of the Industrial Strategy
  - ensures that the UK national facilities remain at the leading edge
  - places UKRI in a position to host a new international facility on UK soil, delivering scientific and economic benefit.



- Contribute UK technical expertise and advanced technology for the construction of the next-generation flagship European facilities ESS and XFEL, to ensure their success.

Near-term actions

- On behalf of UKRI, continue to provide leadership of the UKRI research and innovation infrastructure roadmap, delivering a coherent and integrated approach to improve future infrastructure planning and investment.
- Produce a phased roadmap for the development of the UK's national facilities, for example to strengthen their contribution to interdisciplinary research, remain internationally competitive and respond to the highest-priority scientific challenges.
- Ensure the world-leading international research facilities ESRF and ILL remain internationally competitive and continue to provide UK researchers with capabilities that complement our national facilities.
- Work with our partners to develop a strategy for the future of ILL beyond 2023.
- Develop a clear plan for a possible national free-electron laser facility, driven by science needs, with clearly defined critical decision gateways.
- Optimise the exploitation of our national facilities with sustainable operating budgets, enabling efficient science delivery and maximising the use and return from these significant assets.
- Deliver ongoing major projects, including ISIS Target Station 1 target/moderator replacement, the Central Laser Facility Artemis upgrade and the Diamond Dual Imaging and Diffraction (DIAD) beamline.
- Work with BBSRC and MRC to complete planning for the sustainability of funding for the Electron Bio-imaging Centre (eBIC) at Diamond Light Source beyond 2020.
- Provide access to UK national facilities with operational delivery scaled to our available funding during 2019-20 at the levels of:
  - 200 days per year operation at Diamond, including operation of all Phase 2 and 3 beamlines available within the period
  - 140 days per year operation at ISIS Target Station 1 and 2
  - 98 user-weeks operation for the high-powered lasers of the Central Laser Facility
  - 188 user-weeks operation for the Lasers for Science Facility.
- Initiate the construction of the Extreme Photonics Applications Centre (EPAC), funded through the Strategic Priorities Fund.
- Implement triennial reviews of each UK national facility, beginning with the ISIS Neutron and Muon Source in 2019, to assess scientific and technical excellence and advise on future strategy by benchmarking against international comparators.

3.1.3 WORLD-CLASS INNOVATION

Harnessing the innovative capacity of our research, facilities and campuses to create new business opportunities

Long-term strategic goal

Accelerate the commercialisation of novel ideas and technologies arising from our science, supporting the government's commitment to raise total investment in R&D to 2.4% of GDP by 2027.

Context

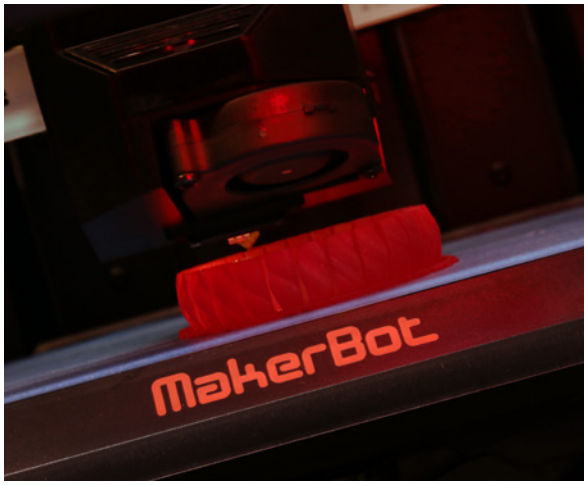
Technological breakthroughs and an innovative culture drive novel products for industry, new ventures and clusters of high-growth businesses with huge potential benefits. We play a key role in mobilising the UK's inventive capacity. By delivering world-leading facilities for extraordinary industrial and academic research, translating discoveries into practical applications and exploitable outcomes and developing our research and innovation campuses, we help to create high-value jobs and high-tech businesses.

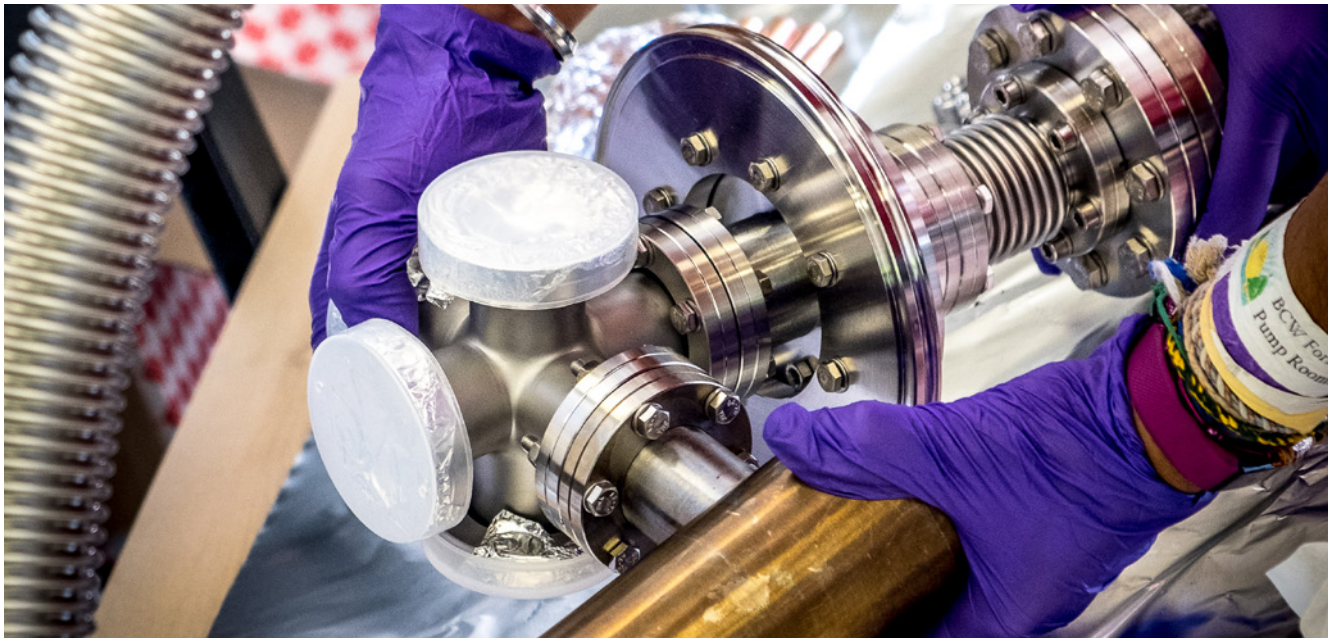
Our distinctive capabilities

To exploit the multifaceted nature of our science and research we have developed approaches and support mechanisms to actively drive innovation right from the very early stages, fostering novel ideas and spinning-out new ventures. Our translational activities combine challenge-led approaches to stimulate the application of our science to address grand challenges, technology-push initiatives to explore the possibilities for our innovative discoveries, and activities to promote innovation within our national laboratories and wider university community. Our national research and innovation campuses are home to a variety of research-intensive organisations, from disruptive start-ups to blue-chip companies, co-located with world-leading research infrastructure. Our business incubator programmes, delivered with international science partners, provide tailored support to meet the needs of start-up enterprises, with their roots in STFC's research base, applying technology in sectors such as biomedicine, energy and security.

Our contribution as part of UKRI

To support the ambitions set out in the Industrial Strategy, we must ensure that businesses can exploit the opportunities offered by the UK's global strength in scientific research. Our facilities and laboratories provide industry with unique insights into materials challenges, accelerating the development of new products and new processes. The approaches developed to answer the needs of our multidisciplinary research community offer a range of techniques spanning length-scales from atoms to metres and timescales from femtoseconds to months, combined with computational analysis and modelling. These techniques allow industrial partners to access unrivalled capabilities to accelerate their R&D programmes. We will





strengthen our collaborations with established businesses and other partners, working across UKRI, to respond to specific industrial and societal challenges, together creating an innovation ecosystem where new and developing high-tech companies can flourish.

Long-term ambitions

- Enhance the position of our national research and innovation campuses as a platform for the growth of high-tech businesses, to contribute to the UK's goal of becoming the world's most innovative economy.
- Make our national laboratories more accessible to companies, ensuring that businesses of all sizes can leverage UKRI's infrastructure investment to enhance their competitiveness.
- Accelerate the commercialisation of novel ideas and technologies arising out of our frontier research and facilities through our targeted translational activities.
- Work with our UKRI partner organisations to smooth the commercialisation pathway for opportunities arising from our laboratories, university communities and campus companies, making the UK the best place to start and grow a technology business from our excellent research base.

Near-term actions

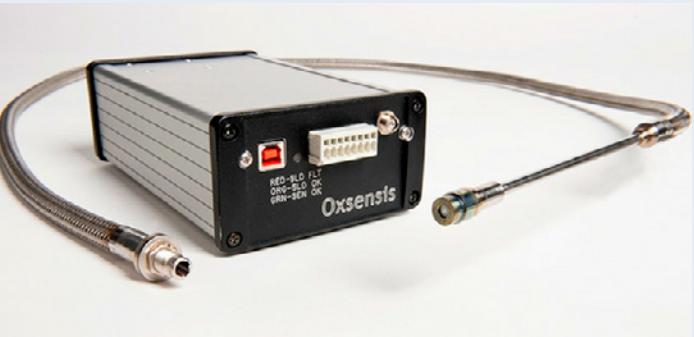
- As lead partner on the UK Innovation & Science Seed Fund (UKI2S, formerly the Rainbow Seed Fund), stimulate co-investment with the private sector in early-stage, high-potential technology businesses, working with the partners to secure the fund's position in the early-stage investment landscape.
- Accelerate the commercialisation of digital assets arising from Hartree Centre investment, including supporting a spin-out company based on our in silico formulation expertise.
- Work across UKRI to simplify the translational funding schemes and develop a more coherent interface for our communities, enabling commercialisation of our science and technology and facilitating collaboration with industry.
- Harness the ability of our national science and innovation campuses to convene and lead regional consortiums in sectors aligned to our capabilities, such as satellites and data in Scotland and data and materials science in North west England, to provide a strong base for industrial growth.
- Establish a new Industry and Business Partnership Board, reporting to STFC Council, to further strengthen links to and partnerships with industry.
- Develop a stronger partnership with Innovate UK through the establishment of a Joint Innovate UK/ STFC Council Forum, reporting to and providing a stronger link between the two councils, smoothing the commercialisation pathway for technologies developed and exploited by our research communities.

MIRICO

Technology originally developed for exploring Mars has been adapted for a range of commercial applications including monitoring greenhouse gases, studying air quality and measuring emissions from industrial processes. After developing the business proposition under an STFC Royal Society of Edinburgh (RSE) Enterprise Fellowship award, a new company called MIRICO was established in 2015 with an initial £1 million investment from Longwall Ventures and the Rainbow Seed Fund (now UKI2S). Based on research carried out at STFC's RAL Space, the company is developing new instruments for gas analysis that deliver laboratory-standard performance in a highly compact design. MIRICO has developed a prototype system for remote detection of emissions for use in industrial facilities and scientific applications around the world. In 2018 they secured a follow-on investment of £3.5 million, drawing in new investors Foresight Williams Technology EIS Fund, enabling MIRICO to complete product development and to build manufacturing capability.

UKI2S

STFC is a lead partner in the UK Innovation & Science Seed Fund, along with BBSRC, NERC, the Defence Science and Technology Laboratory (DSTL) and the National Nuclear Laboratory (NNL). Run by private-sector fund manager Midven Ltd, this fund provides 'ultra-patient capital' to support very early-stage, high-risk investments. Through a total investment to date of approximately £14.9 million, UKI2S has invested (in a majority of cases as a founder investor) in over 50 companies, which export over 90% of their sales globally. These companies have also created over 330 high-value jobs, attracted approximately £440 million of private investment and returned £97 million in Gross Value Added to the UK economy. These are innovative, research-intensive businesses which commit around 70% of investment to R&D, resulting in approximately £28 of R&D spend for every £1 invested by UKI2S.



3.1.4 WORLD-CLASS SKILLS

Skills to deliver cutting-edge science and the Industrial Strategy

Long-term strategic goal

Use our inspirational high-tech facilities and programmes to develop a pipeline of skilled engineers, technicians and scientists from diverse backgrounds, at a scale to make a significant contribution to filling the skills gap and so underpin the commitment to increase R&D spending to 2.4% of GDP by 2027.

Context

Cutting-edge research, innovative technologies and world-leading facilities are our platform for developing the knowledge and expertise vital to our science, and for building the skills and talent pipeline required by the UK to remain competitive in the 21st century. Securing this scientific, technical and engineering expertise in the highly competitive international market will require a new and sustained approach which promotes opportunities, reaches out and attracts talent from diverse groups and communities.

Our distinctive capabilities

Our long-term strategic programmes critically depend on the thousands of highly skilled people we employ, train and support as apprentices, graduates, doctoral students, postdoctoral researchers, research fellows, scientists, technologists and engineers in universities, our laboratories and national and international facilities. Collaborations involving the wider UK research community and our staff support the design, construction, operation and exploitation of large-scale world-leading facilities; these include designing and building scientific instrumentation operating at the heart of telescopes in the Atacama Desert, and ensuring smooth, continuous operation of the major experiments at CERN, the UK national facilities at Harwell and the Tokai to Kamioka (T2K) experiment in Japan. Delivering projects and technology on this scale requires a distinctive combination of technical, engineering, scientific and collaborative skills.

Our contribution as part of UKRI

We have an important role in training enough people to maintain the health of our world-leading science and technology and to support the UK's Industrial Strategy, creating jobs and raising productivity. This is challenging given the highly competitive international market for scientific, technical

and engineering expertise, and particularly for mechanical, electrical and software engineers, data scientists, IT system and security specialists and, increasingly, artificial intelligence (AI) experts. Our needs in these areas are not currently being met reliably through the open market. We must develop new ways of attracting, developing and retaining a diverse mix of people to address these technical skills shortages and create the research leaders of the future. Our campuses, national facilities and major technology programmes provide a beacon to attract people from across the world and a robust platform for through-life training and deployment of skills across the sector.

Long-term ambitions

- Capitalise on the unique opportunities presented by our inspirational science and advanced technology to design a world-class training programme – a skills factory in science, technology, engineering and mathematics (STEM) – to provide the pipeline of highly skilled technicians and engineers necessary to deliver our science and technology programmes and the government's commitment to increase R&D spend to 2.4% of GDP by 2027.
- Use our programme to give early-career scientists the experience needed in leading-edge technology development, data science and AI to maintain UK leadership in modern science and engineering.

Near-term actions

Working with partners in the higher education and further education sectors, we will grow both our own and the UK's skills base through enhanced support for the STEM skills pipeline. This will involve:

- Developing a business model for a sustainable engineering and technology talent pipeline that addresses critical skills needs, including detector specialists, systems engineers, software developers and AI experts, based around our high-tech facilities in the UK and abroad.
- Continuing to expand the apprentice and graduate programmes at our national laboratories and incorporate these within a more complete and consistently implemented skills pipeline.
- Providing a third cohort for our eight data-intensive science Centres for Doctoral Training (CDTs) spanning 19 academic institutions.
- Supporting one or more CDTs in priority areas such as: detector/instrument development, including applications to robotics; medical physics, including proton/hadron beam therapy; advanced acceleration; nuclear physics input to the nuclear industry; and development and application of free-electron lasers.
- Supporting individuals to broker greater industrial collaboration and industrial sponsorship of studentships and fund industrial placements for Doctoral Training Partnership (DTP) studentships, increasing the industrial relevance of PhD projects, accelerating the transition of students into industry and helping our studentship funding to go further.
- Funding a cohort of fellowships to support researchers who are returning to research, have caring responsibilities or face geographic constraints on their work, to diversify our postdoctoral cohort and ultimately the pipeline of talent reaching leadership roles.
- Funding a cohort of research software engineers to meet the ever-increasing demand for professional support for software development to analyse large, complex data sets and to meet the need for advanced data analysis skills and machine learning.
- Producing an implementation plan by autumn 2019 from the STFC Balance of Programme (Skills) review recommendations.

Apprentice training

Our award-winning apprenticeship programme, recognised by the Institution of Engineering and Technology, provides opportunities to work on leading international science projects. One such project, including apprentices from our Daresbury Laboratory, involved re-purposing a hospital magnetic resonance imaging (MRI) scanner to study atomic nuclei at CERN. A superconducting magnet from a decommissioned MRI scanner was shipped from Australia to CERN where it was modified for use on the laboratory's ISOLDE instrument, a nuclear physics facility that provides both low-energy and high-energy re-accelerated radioactive beams to observe the properties of atomic nuclei.

PhDs

We support a rolling cohort of around 800 PhD studentships in particle physics, nuclear physics and astronomy. A further 125 students are supported through eight CDTs in data-intensive science and a number of studentships are funded jointly through our national laboratory departments and university partners. Our students are highly prized by industry and commerce for their first-hand experience of manipulating large data sets to solve complex problems. Around a third of our postgraduates enter the private sector immediately on completion of their PhD, with over 70% of these taking on a role in software development, data analysis, engineering or finance.

3.2 STRATEGIC THEMES

We will transform the way we achieve our strategic goals by focusing on six strategic themes.

3.2.1 DEVELOPING ADVANCED TECHNOLOGIES

Novel and disruptive technologies, driven by our science

Long-term strategic goal

Develop the disruptive and novel technologies required to meet the ambitious goals of our research priorities, fully leveraging our collaboration with international partners.

Context

The construction of the ATLAS detector underground at CERN, exploitation of Diamond and ISIS in the UK, development of the ESS in Sweden and detection of gravitational waves from distant colliding stars at LIGO all involve highly sophisticated technologies developed by STFC and our partners. Operating at the leading edge of technological and engineering possibilities, pursuit of our science requires us to develop advanced and sometimes disruptive technologies that can open up novel applications to address the most important industrial and societal challenges of our time, including the Grand Challenges set out in the Industrial Strategy.

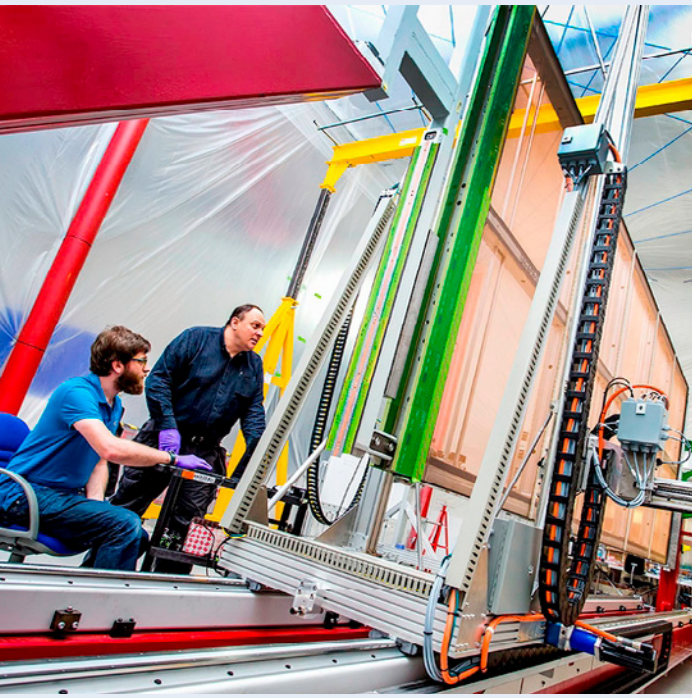
Our distinctive capabilities

Five key technology areas are central to our core, long-term mission:

- detectors and instrumentation
- accelerators
- specialist engineering, such as cryogenics suitable for extreme environments, including space
- optics
- e-infrastructure, including software and algorithms[1].

Our needs in these areas cannot be met cost-effectively and reliably on the open market. We need to develop our own world-class capabilities. To ensure a reliable and timely supply of these technologies, we continue to sustain a critical mass of technology and engineering capabilities at our user facilities and national laboratories,

1 Because of its rapid growth and importance, e-infrastructure is specifically addressed through our data-intensive science strategic theme.



Delivering key components for ProtoDUNE

An essential piece of DUNE, a US$500 million global science project based in the USA, has been built at our Daresbury Laboratory. Two prototype Anode Plane Assemblies (APAs) are now in use in the ProtoDUNE detector at CERN, which will study the differences between neutrinos and antineutrinos in a bid to understand how the Universe came to be made up of matter. The APAs are the first such anode planes to have been built in the UK. Construction also involved the universities of Manchester, Liverpool, Sheffield and Lancaster.

Cryo-EM

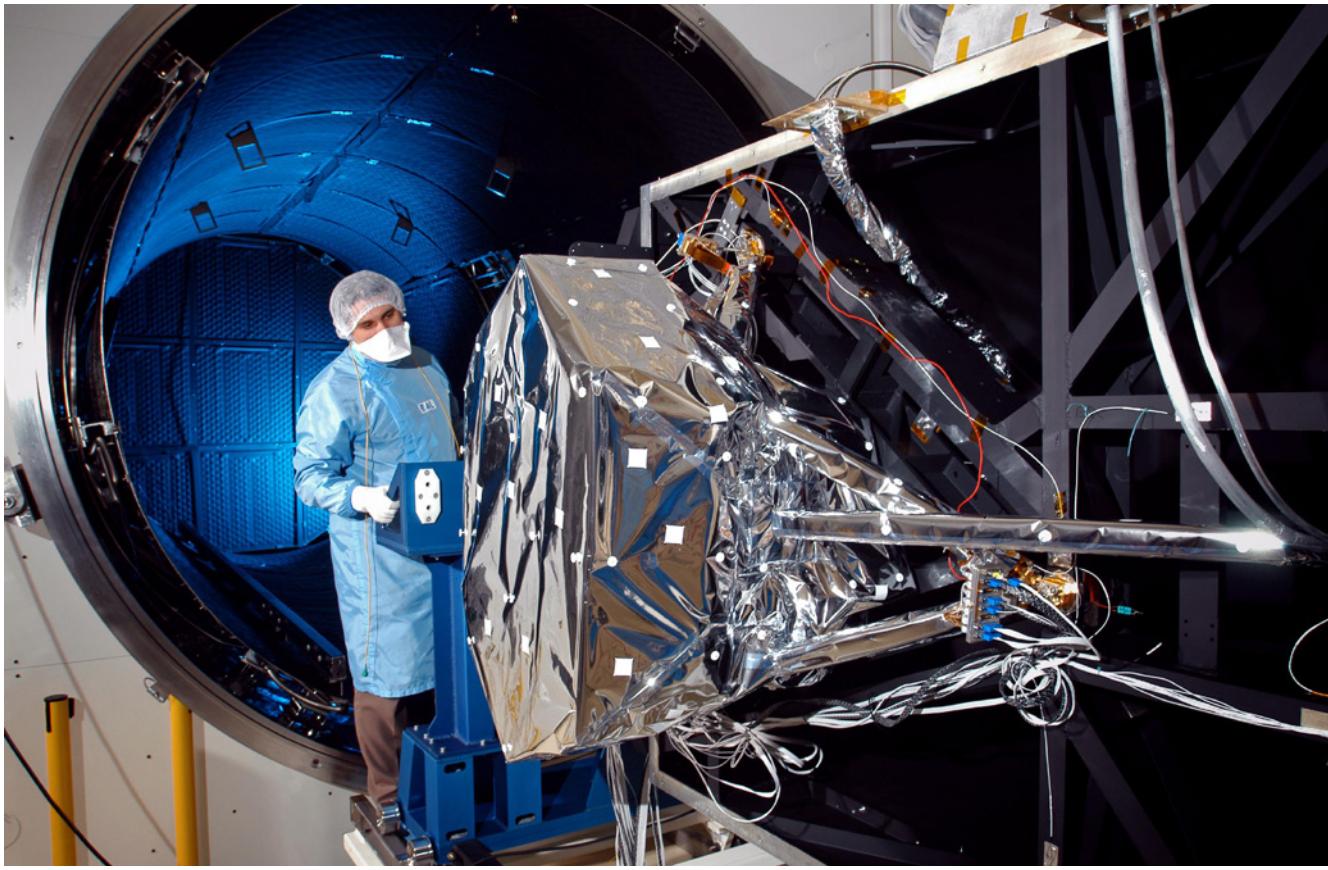
In 2017, UK researcher Richard Henderson received a Nobel Prize in developing Cryo-EM to determine the high-resolution structure of biomolecules in solution. This breakthrough has transformed structural biology and aided drug development. We worked with Professor Henderson to develop the high-resolution electron camera systems now required for this technique. These ‘sensors’ are based on systems originally designed by our technologists to support our space science and particle physics experiments, and are now found in several of the world’s leading electron microscopes.

complementing the capabilities in our partner universities.

The breadth and integrated nature of our programmes allows substantial cross-fertilisation of ideas and technologies, providing broad-based impact across multiple fields. Examples include the translation of sensor and detector technology from satellite systems to our user facilities, and application of cryogenics expertise from our high-energy physics programme to underpin a new generation of high-power lasers for industrial and scientific applications.

Our contribution as part of UKRI

We are world-renowned as a supplier of leading research instrumentation, engineering and facilities and have built an enviable track record in this area. Driven by increasing complexity and cost, the recent shift to fewer, more complex instruments and experiments involving global partners has meant the need to strengthen our design, project management and systems engineering expertise. This brings UK researchers considerable influence, securing high-profile leadership roles in international science projects and providing a place at the forefront of data exploitation. Crucially, it also brings competitive advantage to the UK by providing access to a wealth of emerging, disruptive technologies and expertise applicable to commercial and public-policy challenges, for example through spin-out companies such as KEIT Ltd and Cobalt Light Systems and through our work to enable breakthrough technologies such as Cryo-EM.



Long-term ambitions

- Driven by our scientific priorities, seize new opportunities to develop advanced and disruptive technologies that support novel applications in multidisciplinary science and real-world challenges, including new quantum technologies and advanced sensors and detection systems.
- Co-design ambitious and strategic programmes with partner organisations that lead the world in developing and exploiting technology flowing from our programme.
- Strengthen UK leadership, expertise and skills in novel technologies and support their translation into marketable products, working with partners in UKRI, government departments and industry.

Near-term actions

- In the field of disruptive technologies, improve the performance of energy-resolving X-ray systems to achieve MHz readout required by current and future facilities as their intensity increases. New high-rate readout systems will open up new scientific opportunities. The Front-End Electronics and Detectors (FEEDER) project, supported through our Centre for Instrumentation, is developing the first generation of systems capable of observing high-energy X-rays at these rates.
- In the sphere of strategic programmes, initiate a programme of work with university and industry partners to meet the imaging challenges of the Rosalind Franklin Institute. New sensor capabilities are required for several of the Rosalind Franklin Institute research themes, including correlated imaging and imaging with sound and light.
- In the area of new products, deliver the next-generation Cryo-EM camera to the Cambridge Laboratory for Molecular Biology. This project, a collaboration with the Cambridge Laboratory for Molecular Biology, the Max Planck Institute and FEI-Thermofisher, aims to significantly improve the performance of the most powerful cryogenic electron microscopes.
- Also in the field of new products, deploy mid-infrared waveguide technologies developed by us in collaboration with Heriot-Watt University in new instruments across multiple application areas. RAL Space will work with King's College Hospital to develop a carbon isotope measurement system based around waveguide and integrated with microelectromechanical systems technology, with the potential to detect the early onset of sepsis.

3.2.2 DATA-INTENSIVE SCIENCE

Positioning the UK as a world-leader in the analysis of large data sets

Long-term strategic goal

Bring together high-performance computing, data analytics and machine learning to respond to the data challenge from our research programmes and industry, and in doing so develop confidence in these new methods to accelerate their adoption in UK businesses of all sizes, supporting the AI and Data Grand Challenge.

Context

Whether hosting the SKA, developing the earliest animated visualisation of mathematical data for the Open University back in 1970, or processing 15-terabyte individual tomographic images from Diamond Light Source in 2018, we have been at the forefront of data-intensive research for decades. As part of UKRI we will remain a major transformative force, finding new ways to extract value and knowledge from huge data sets, addressing the challenges set out in the UK's Industrial Strategy.

Our distinctive capabilities

Our approach is driven by the needs of the world's 'big science' projects that consistently push the boundaries and demand innovation in computing capability to cope with the exponential growth in the volume, speed and variety of research data. CERN has hosted some of the world's first 'big data' projects and breakthroughs such as the discovery of the Higgs boson would have been unimaginable without scientific and technical expertise in cutting-edge computation, storage, networks and software operating together across national boundaries. Initiatives such as the SKA and the Copernicus Earth-observation programme are expected to produce 100-fold increases in data rates, massively stretching current capabilities and driving development to keep the UK at the forefront of computing technologies. Data from 'big science' provides a demanding test bed to develop and qualify new data-driven technologies without risking privacy or commercial confidentiality.

Our contribution as part of UKRI

Increasing numbers of scientists in the UK, from both academia and industry, rely on e-infrastructure to generate and analyse their research results. To address the challenge of extracting value and knowledge from research data sets that are now simply too big or too complex to be analysed in traditional ways, whether from large scientific facilities, model simulations, experiments or large-scale observation systems, we are developing and delivering innovative solutions. For example, the JASMIN 'super-data-cluster' for climate and Earth-system science, developed in partnership with NERC, combines a supercomputer and a data facility to bring processing power close to the data.

It is not only science that stands to reap big benefits from this approach. Predictive analysis of large, complex data sets and the application of machine learning and AI are transforming business and government decisions, finding new correlations, identifying trends and extracting value in ways unthinkable just a decade ago. By bridging academia and industry to tackle computational

challenges facing businesses, we are driving innovation, building skills and boosting productivity in spheres ranging from disease mapping and catastrophe modelling to fuel-cell design and product development, working with companies including Rolls-Royce, GSK and Unilever.

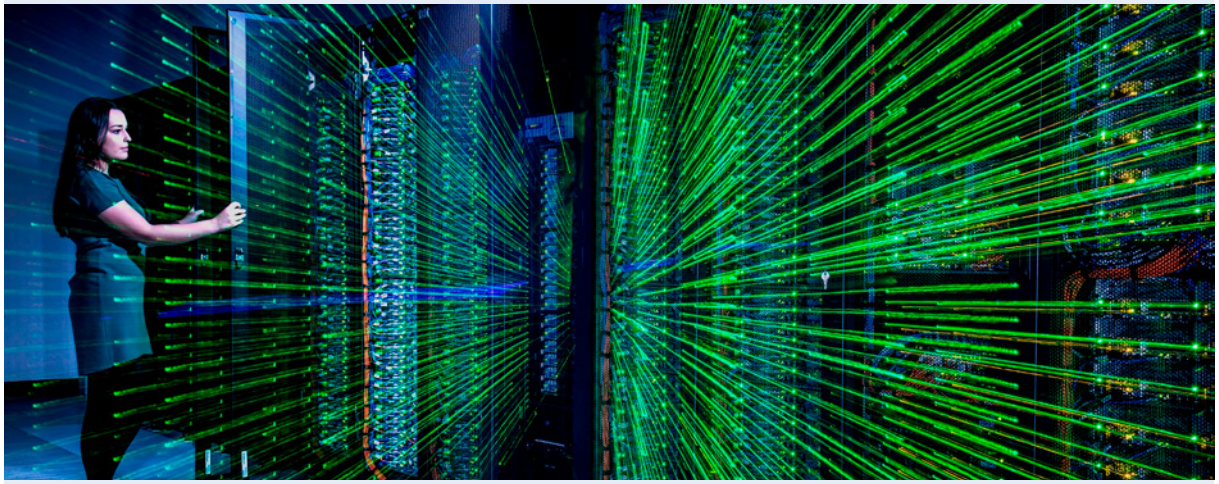
Long-term ambitions

- Advance the development and implementation of a coherent long-term UKRI e-infrastructure roadmap, positioning UK researchers at the forefront of the exascale computing and AI revolutions.
- Revolutionise future research by accelerating use of real-time data-processing and machine learning, modelling and simulation, and data analytics to maximise the utility of the vast data sets produced by our 'big science' projects and large-scale multidisciplinary facilities.
- Accelerate adoption of modern computing techniques in UK businesses of all sizes, by fully exploiting the Hartree Centre's position as a world-leading, industry-focused computing centre, bringing together high-performance computing, AI solutions, academia and industry partners.
- Transform the competitiveness of UK industry and the public sector by fast-tracking the adoption of new data-driven technologies that would scale up research capacity and stimulate the economy by:
  - accelerating adoption of secure and trusted AI and machine learning technologies to address complex industrial and societal problems
  - developing the next generation of technology experts able to apply research techniques in AI and high-performance computing in industrial contexts.

Near-term actions

- Develop the business case for Phase 4 of the Hartree Centre, building on the existing partnerships with academia and industry.
- Establish a national quantum computing centre in collaboration with EPSRC and university partners.
- Drive major advances in modelling and simulation for our frontier science programmes by securing the strategically important upgrade to our high-performance computing infrastructure, Distributed Research utilizing Advanced Computing (DiRAC) 3.

- Develop the coordination between the partners in IRIS (a self-organising coordination body that aims to create a common e-infrastructure for STFC science) to ensure important e-infrastructure capabilities are established and sustainable as an integral part of the UKRI e-infrastructure roadmap.
- Develop scientific software to support UKRI science communities and users of our facilities.
- Establish a collaborative centre for AI-based science and data analytics involving Diamond, ISIS and the Central Laser Facility, in collaboration with the Alan Turing Institute, as part of the EPSRC-led AI activity funded through the Strategic Priorities Fund.
- Exploit the complementary roles in AI and high-performance computing that span UKRI by developing deeper and large-scale collaborations between our Scientific Computing Department, the Hartree Centre and the Alan Turing Institute.
- Engage with researchers across UKRI and industrial partners to develop projects focused on the application of AI and high-performance computing which support the Industrial Strategy, including through the Industrial Strategy Challenge Fund.



Hartree and Unilever

Unilever is benefiting from our expertise in high-performance computing through its partnership with the Hartree Centre at our Daresbury Laboratory to accelerate its product discovery process. For example, Hartree worked with Unilever on the formulation of home and personal care products. Traditional laboratory stability tests typically take a time-consuming 8-12 weeks, but harnessing the supercomputers at Hartree reduced this to under an hour. High-performance computing capabilities, together with a specialist 3D visualisation suite, allow product developers to explore data and see otherwise elusive correlations. For a fast-moving consumer goods company, speed is critical in bringing products to market and providing competitive advantage.

Beyond the Standard Model of particle physics

A step change in the accuracy of theoretical predictions from the Standard Model is required to determine definitively whether discrepancies between experimental results and theoretical expectations are the signatures of previously unknown physics. Next-generation supercomputers and aggressively optimised software are needed to exploit upcoming flagship experimental searches at the High Luminosity LHC at CERN and other international experiments. This will maximise their impact and address fundamental questions such as why the Universe is not symmetric between matter and antimatter. Such approaches have been a long-term driver of supercomputing architectures and the UK has a leadership role in this area. For example, the University of Edinburgh's Peter Boyle, working on DiRAC, co-designed the BlueGeneQ chip which generated five joint patents with IBM. He is currently working with Intel on architecture co-design via the Edinburgh-based Manycore Architecture Design Team, one of only three such teams in the world.

3.2.3 RESEARCH AND INNOVATION CAMPUSES

Further developing clusters of excellence at our campuses to stimulate innovation and business growth

Long-term strategic goals

- Drive the innovation ecosystems at our national research and innovation campuses as a platform for the growth of high-tech businesses, contributing to the UK's aim to become the world's most innovative economy.
- Build on the successful Space Cluster model at Harwell as a driver for innovation and business development in focused areas aligned with the UK's Industrial Strategy, including health, energy, medical applications and AI.

Context

World-leading science and innovation converge at Sci-Tech Daresbury and Harwell in a unique, inherently multidisciplinary environment that fosters business growth and high-value jobs. We will accelerate the development of our campuses, optimising the contribution of the research facilities and laboratories as assets for UKRI, supporting collaboration, investment and economic growth, as part of the government's commitment to raise total investment in R&D to 2.4% of GDP and the ambition of prosperous communities throughout the UK.

Our distinctive capabilities

Since their launch as national research and innovation campuses in 2008, Sci-Tech Daresbury and Harwell have achieved remarkable success. They currently host over 300 high-tech enterprises and support more than 6,000 jobs. The campuses are home to large-scale research infrastructures and laboratories supporting multidisciplinary academic and industrial user communities and

new and established businesses. Both campuses continue to grow as locations of regional, national and international significance. The recent opening of the Higgs Centre for Innovation at the Royal Observatory Edinburgh, in collaboration with the University of Edinburgh, provides a further location to incubate satellite and data businesses.

Our contribution as part of UKRI

Our campuses provide a dynamic environment, hosting businesses at every stage of growth from technology start-ups through to SMEs and mature companies. They offer first-rate business support and incubation programmes to enable new ventures to develop and grow. Flexible access to high-end laboratory facilities provides a platform for the commercialisation of outputs from the research base, leading to enhanced exploitation of both our and universities' intellectual property. Co-location of micro-businesses with technical experts across the breadth of UK research and innovation offers an effective way for new companies to complement their internal resources and accelerate the development of their products and services.

The development of thematic clusters, started at Harwell and now extended to Daresbury, provides

a mechanism for sector-specific engagement. Involving a critical mass of public sector, academic and industrial organisations, they are a powerful attractor and a route to rapid commercialisation because of the range and concentration of multidisciplinary expertise and skills and the ease of collaboration. Harwell, Daresbury and Edinburgh form part of the wider network of UKRI campuses that can provide an effective mechanism for cross-sector working and engagement, to stimulate innovation and drive business growth.

Long-term ambitions

- Develop the strategy and masterplans for Harwell and Sci-Tech Daresbury with our public and private sector partners, to deliver on our ambitions for these to be globally significant locations for innovation, industry and research.
- Catalyse and anchor clusters of businesses and research organisations around our facilities and technology hubs on our campuses, driving economic growth in key high-tech sectors aligned to the Industrial Strategy and Local Industrial Strategies.
- Leverage international investment and provide a portal into the broader network of associated industrial collaborators by building on the platform of industrial engagement provided by our campus clusters and showcasing UK capabilities on an international stage.
- Extend our business support activities on the Daresbury and Harwell campuses to accelerate the scale-up of campus companies.
- Develop the campuses as skills factories, harnessing their unique environment to deliver training in the research, technical, engineering

Space Cluster at Harwell

This was the first cluster to be established on the Harwell campus following the arrival of ESA, the Satellite Applications Catapult and the UK Space Agency, alongside the longstanding activities of RAL Space. The presence of these anchor research organisations has attracted many companies to set up operations at Harwell. Since 2010 the cluster has grown to approaching 90 space organisations employing over 950 people. The number of employees has grown strongly over recent years and recorded 19% growth in 2018. Companies in the cluster range from start-ups, many of which have been through the ESA Business Incubation Centre, to multinationals such as Airbus and Lockheed Martin. Rezatec and Oxford Space Systems were start-ups at Harwell in 2013-14. They have used our offices and laboratory facilities for many years and in 2018 expanded into their own units on-site, demonstrating how the ecosystem is able to support company growth.

LPW Technology

Start-up LPW Technology began 11 years ago under Dr Phil Carroll on our Daresbury site. The company grew rapidly, moving off-site but remaining in the local area, and has become a market leader in the development, manufacture and supply of metal powder solutions for additive manufacturing. In 2016, it required additional high-tech laboratory space, which it found by returning to Sci-Tech Daresbury's new Campus Technology Hub building. Hard work, cutting-edge innovation and the right working environment proved a winning combination and in 2018 multinational advanced manufacturer Carpenter Limited acquired LPW Technology for US$81 million.

and computational skills needed to realise the UK's Industrial Strategy, deliver our research programme and provide world-leading facilities.

Near-term actions

- Further develop our national research and innovation campuses as a location for world-class science, providing strategic coordination across the institutes and integrating new developments into the fabric of the campuses. This will include:
  - construction of the Industrial Strategy Challenge Fund-supported National Satellite Test Facility, commencing construction in mid-2019 and becoming an operational facility by 2021
  - development of the multidisciplinary Rosalind Franklin Institute, with construction of the hub at Harwell campus commencing during 2019
  - commencing construction of Project Violet at Sci-Tech Daresbury, providing 3,900m^2 of grade A office accommodation
  - continuing to deliver the Harwell Campus Masterplan, including the next phase of development of 12,500m^2 of R&D laboratory and office space.
- Expand and further develop the business incubation provision on our campuses from the successful European Space Agency (ESA) and CERN programmes, currently supporting around 15 companies per year, to develop new incubation offerings aligned with our clusters. The 60 ESA Business Incubation Centre alumni have to date collectively secured more than £40 million in investment and created over 300 jobs.
- Launch during 2019 a new data-intensive research cluster at Sci-Tech Daresbury, anchored around the excellent research and innovation at the Hartree Centre and our Scientific Computing Department.
- Develop a national network and narrative to connect and showcase the national science and innovation campuses that highlights their potential as inward investment destinations, working with our UKRI partners, BBSRC and NERC, through the Common Approach to Campuses.
- With our campus partners and local stakeholders, including LEPs and associated groups, deliver the Skills Action Plan at Daresbury and develop a plan for Harwell to ensure a talent pipeline to meet growth plans.

3.2.4 SOLUTIONS FOR 21ST CENTURY CHALLENGES

Bringing our unique combination of facilities, technologies and skills to bear on real-world challenges

Long-term strategic goal

Realise the full potential of our science, technology and facilities to play their part in providing multidisciplinary solutions to industrial and societal challenges including the Industrial Strategy Grand Challenges.

Context

The science and technology required to address fundamental scientific challenges provides us with a rich mix of capabilities. We use these to develop impactful new approaches to tackling the complex and dynamic challenges of the 21st century, from developing the next generation of battery technologies to delivering cleaner energy systems or new plasma devices that destroy microbes in packaged fresh foods.

Our distinctive capabilities

Solving many of this century's challenges requires multidisciplinary solutions delivered through the sustained application of the best scientific minds. Harnessing the remarkable range, scale, sophistication and distinctiveness of our research, technologies and facilities can make a vital contribution to achieving successful outcomes. Since 2010 we have delivered a step change by expanding our challenge-led approach to fundamental science with dedicated funding and translational activities to tackle the challenges of the 21st century. We have invested in new multidisciplinary networks that draw upon our capabilities to address priority areas. Our projects have brought together STFC-funded researchers with broader science, technology and industry groups, attracted new users to our facilities and found new applications for our technologies and know-how. Recent examples include the Bridging for Innovators (B4I) scheme funded by the Industrial Strategy Challenge Fund. This scheme is helping companies to access our facilities and expertise to boost their productivity by overcoming an existing challenge in relation to processes, products or services.

Our contribution as part of UKRI

We are in a strong position to enable a challenge-led approach to research and innovation. Our campuses and facilities provide natural platforms for the identification and delivery of targeted solutions due to our remarkable breadth of capabilities and skills. We will build on these firm foundations and continue to grow centres of excellence in our community that can respond to challenges, generate real-world benefits, deliver competitive advantage for the UK in international markets, stimulate economic growth and create jobs. The innovative approaches needed to support the Industrial Strategy and pursue United Nations Sustainable Development Goals, tackling global development challenges, will demand amongst other things new technologies and research infrastructure. Through our programmes of support for networks, collaborative research and innovation we will broaden our approach, working with new and existing partners in academia, government and industry.

Long-term ambitions

- Build on the foundations established since 2010 to ensure we play our full part in supporting challenge-led research in complex multidisciplinary areas.
- Develop and pursue a coherent and strategic approach based around our inherently multidisciplinary research strengths, facilities and technological capabilities, including our expertise in 'big data' analytics.
- Grow the skills needed within our community to build multidisciplinary collaborative projects that address overseas development needs.

Near-term actions

- Complete the strategic review of our 21st Century Challenge activities during 2019, identifying key

challenges where we could make a difference at scale and ramp up our engagement with the Industrial Strategy Challenge Fund.

- Undertake an audit to determine the skills needed in-house to broker relationships and support the formation of multidisciplinary challenge-led projects drawing on the full range of our capabilities.
- Increase multidisciplinary research at our large national facilities – establishing a pilot to assess the feasibility of targeted allocation of a proportion of beam time to shared critical challenges facing UK society.
- Accelerate productive engagement between industry and our multidisciplinary facilities by increasing the visibility of our capabilities and technologies through targeted communications.
- Continue to engage with our community to grow our portfolio of Newton Fund and Global Challenges Research Fund (GCRF) projects.

STFC Food Network+

This brings together our researchers and facilities with research and industry in the agri-food sector. The network has built an interdisciplinary community including NERC and BBSRC-funded researchers, working to provide a sustainable, secure supply of safe, nutritious and affordable high-quality food using less land, with reduced inputs, in the context of global climate change and declining natural resources. It is highlighting and developing key opportunities for the research community, making a meaningful contribution to the food system, and has supported over 20 small projects covering areas such as forecasting crop yields, investigating the microstructure architecture of snacks, assuring the integrity of fruit juices and the application of cryogenics to food supply chains.

3.2.5 INSPIRING AND INVOLVING

Incredible science, inspirational people, astounding places

Long-term strategic goal

Use our stories, community and facilities to inspire people to explore science and technology, share their understanding and encourage the next generation to study and work in research and innovation.

Context

UKRI's vision is of a society where research is created, used, challenged, valued and shared by all. Attracting and building a skilled workforce is essential to this vision and to meeting the government's target to invest 2.4% of GDP in R&D by 2027. For our areas of science, this means sharing the curiosity, excitement and ambition that comes from making new discoveries about the Universe, developing the incredible technologies and facilities that make those discoveries a reality and explaining how the outcomes of our work deepen our understanding and can improve lives.

Our distinctive capabilities

We are recognised and sought after as a leader in STEM engagement. Our public engagement plays a specific but crucial role in growing the UK's STEM talent pool, helping young people and their families to see that modern STEM is exciting, relevant and diverse. From the discovery of the Higgs boson and the first dramatic observation of two neutron stars colliding, to building a rover vehicle with an autonomous navigation system that can explore the surface of Mars, our work seizes people's imaginations, encourages them to ask questions and inspires future generations of students to study and work in STEM subjects as a route to a hugely rewarding future.

Working with the ASDC

In partnership with the Association for Science and Discovery Centres (ASDC), we developed the ground-breaking Explore Your Universe programme. Over three phases spanning 2011-2018, this initiative delivered stories of our science and technology to an audience of 381,000 people right across the UK. Thanks to rigorous external evaluation, the programme has demonstrated that science centres can use our stories to raise aspirations for careers in science and technology which are equally engaging to both boys and girls. The fourth phase of Explore Your Universe began in November 2018, building community partnerships with science centres that will reach audiences who might not otherwise have the opportunity to engage with stories and people working in STEM.

Our contribution as part of UKRI

The range of activities and facilities in our laboratories and at our campuses provides us with a fantastic base from which people can experience the remarkable scale, ambition and achievement of UK and international science. We have welcomed tens of thousands of people, including thousands of school students and teachers, through the doors of our facilities in the past five years and the feedback we receive is overwhelmingly positive.

Long-term ambitions

- Inspire people to value and participate in scientific discovery through the awe and wonder of our frontier science, engineering and technology.
- Enhance public awareness of the economic, international and wider public benefits of investment in science and technology.
- Target hard-to-reach groups to increase the diversity of the future UK science and engineering community.
- Encourage the next generation to study and work in science and technology.

Near-term actions

- Deliver a national campaign to highlight the UK's major contributions to the James Webb Space Telescope (JWST), working across the UK STEM sector to demonstrate why the JWST's work is relevant and exciting.
- Evolve the pivotal role of Continuing Professional Development workshops for teachers that are integral to our programme, expanding the subject matter from space and astronomy by working in partnership with local and national partners such as STEM Learning and the Scottish Schools Education Research Centre.
- Implement new approaches to develop and support STEM leaders and influencers by continuing to appoint at least two new Leadership Fellows in Public Engagement in 2019 and doubling the membership of our public engagement early-career researcher network.
- Roll out our *Wonder* initiative to connect people from all backgrounds and engage new, under-served audiences from socioeconomically-deprived areas of the UK with our science and technology, across our whole engagement programme.
- Working across UKRI, develop and apply our approaches to effective evaluation of public engagement, sharing the learning and understanding that we generate with the STEM sector and beyond.

3.2.6 BUILDING INTERNATIONAL INFLUENCE

Promoting the UK through international research collaboration and leadership of international projects

Long-term strategic goal

Enhance the UK's reputation and influence through the delivery of world-leading research and innovation, attracting international investment and providing opportunities for UK companies.

Context

From the SKA in South Africa and Australia to DUNE in the USA and CERN in Europe, we play a vital role in the world's largest international science partnerships. Our experience in cultivating cross-border collaborations, coupled with our UK leadership in international policy forums, enables us to make an increasingly prominent contribution to the development of international collaborative research infrastructures. This is critical to the mission of UKRI, ensuring that UK researchers continue to be able to access leading-edge facilities and participate in world-leading projects.

Our distinctive capabilities

Global cooperation and collaboration enhance the quality of research and innovation. We have significant experience in this area, playing a key role in international research collaborations and research infrastructure policy forums such as the G7 Group of Senior Officials on Global Research Infrastructures (GSO) and the Organisation for Economic Cooperation and Development's (OECD's) Global Science Forum (GSF). We have an established reputation as a global leader in research, technology, engineering, facility operations and project management.

Our contribution as part of UKRI

We are able to view research infrastructures from the perspective of the Department for Business, Energy and Industrial Strategy (BEIS), as both a funding agency and a delivery partner. This gives us the ability to promote an integrated UK approach to research infrastructure policy internationally. Similarly, through our in-house design and operation of multiple major research infrastructures and programmes, we have deep insight into the perspectives of the user communities and the challenges of delivery. Alongside this, we play an important leadership role in developing governance and financial agreements for global projects, promoting opportunities for UK business to win commercial contracts and maximise industrial returns from our partner facilities overseas. As a result of all this, we can provide balanced and

experienced input to UKRI/BEIS to help inform policy and ensure the UK maximises its impact and influence on the global stage.

Long-term ambitions

- Bring together and facilitate global partnerships and collaborations to support the next big inspirational science projects, including the development of plans for new international scientific facilities to be hosted in the UK.
- Develop Boulby Underground Laboratory into a world-class facility that could potentially host a major international project in fundamental science.
- Leverage our global research leadership in large-scale international projects to promote the UK on the international stage.
- Attract more investment from international partners to work on shared global programmes, invest in UK-based facilities and support the UK's International Research and Innovation Strategy.

Near-term actions

- Play a lead role for the UK on OECD GSF research infrastructure expert groups and represent wider UKRI policy interests, such as open science and open data, in the wider international policy forum.
- Use our six-month chairmanship of the GSO to raise visibility of the GSO Framework with policymakers around the world to spread good practice and strengthen the criterion on monitoring socioeconomic impact of global research infrastructures.
- Foster bilateral international partnerships to deliver shared goals.
- Support the delivery of the new Fund for International Collaboration by becoming the lead international partner for the delivery of the:
  - Advanced Instrumentation Testbed (AIT)/ Water Cherenkov Monitor for Antineutrinos (WATCHMAN) project, as both a large-scale demonstrator of a remote monitoring technique and a technology platform
  - ALIGO+ project to upgrade the Nobel Prize winning LIGO gravitational-wave observatories.

UK-US Science and Technology Agreement

Under the new UK-US Science and Technology Agreement, we are investing in three large international science projects. DUNE is a £65 million investment in a US$500 million global science project based in the USA. This collaboration, currently involving over 1,000 scientists across 31 countries, will study the properties of neutrinos to understand more about how the Universe works and why matter exists at all. AIT/WATCHMAN is a £33 million UK-US project to install and operate a 3,000 tonne detector at Boulby from 2019-2024. It will demonstrate and develop antineutrino detection systems for remote reactor monitoring for nuclear defence and non-proliferation purposes. ALIGO+ is a US$30 million upgrade to the Nobel Prize winning large-scale astrophysics experiment and observatory in the USA, which will develop gravitational-wave observations as an astronomical tool. The project will leverage UK technical leadership to strengthen the UK-US strategic partnership in research and innovation. The UK's participation in ALIGO+ and AIT/WATCHMAN is being supported through the Fund for International Collaboration.

3.3 STRATEGIC ENABLERS

We will enable the successful delivery of our goals and themes by fostering collaboration, working together with our research partners and creating an outstanding organisation.

3.3.1 FOSTERING COLLABORATION

Building stronger research and innovation partnerships across multiple disciplines

Long-term strategic goal

Maximise the opportunities enabled by the creation of UKRI to build stronger interdisciplinary research and innovation partnerships.

Our distinctive capabilities

Collaboration underpins everything we do and is vital to accomplishing our science and innovation goals and those of our partners. We work with thousands of stakeholders within the UK and across the world to deliver our programme. We build long-term relationships with a variety of industrial partners to enable UK business to leverage the capabilities and expertise developed to meet our science goals to address challenges in their business. We also work with our campus joint-venture partners and other local and regional partners to support research and innovation-led economic growth across the UK. Only by building the right collaborative teams will we continue to be able to create opportunities for UK businesses, leverage new sources of funding and strengthen our current capabilities.

Our contribution as part of UKRI

Our world-leading facilities support the research of multiple UKRI communities, including those working in biological science, physics, chemistry and materials science. Our scientists and technologists collaborate with researchers in the university community across many disciplines, constantly driving new infrastructure capabilities that deliver high-quality research outcomes. Working closely with our industrial partners, we complement and enhance their in-house research capabilities and provide access to our unique skills and techniques that can accelerate product development, inform their strategic roadmaps and deliver competitive advantage.

Long-term ambitions

- Build mutually beneficial relationships with industry to exploit and improve the impact from the UK research base, supporting the government's commitment to increase total investment in R&D to 2.4% of GDP by 2027.
- Leverage complementary skills in our extended networks, including the university community, to grow and enhance collaborations with our industrial users.
- Establish scientific and technological collaborations in countries that are not our traditional partners to grow capability, strengthen the global community for our domains and improve outcomes for developing countries, supporting the UK's International Research and Innovation Strategy.

Near-term actions

- Use our B4I programme, funded through the Industrial Strategy Challenge Fund, to grow the industrial user community for our large-scale facilities by lowering the barriers to access, especially for the UK SME community.
- Agree and deliver a programme of work with our strategic industrial partners to translate techniques from the science base to meet their real-world challenges.
- Develop partnerships with established organisations in specific sectors with complementary offerings to help position our facilities to address the challenges faced by companies in those markets.
- Enhance our engagement across government to unlock the potential of our expertise and technology to help deliver their goals, for example via projects such as EPAC funded through the Strategic Priorities Fund.

3.3.2 WORKING TOGETHER WITH OUR RESEARCH PARTNERS

Identifying strategic priorities and delivering a shared vision with our community

Long-term strategic goal

Ensure UK-funded researchers continue to deliver world-leading research and innovation by identifying long-term science priorities, setting high expectations and equipping, empowering and ensuring an inclusive culture which values and encourages diversity.

Our distinctive capabilities

Our thriving community of over 6,000 people includes the researchers and students that we fund, the academic, industrial and international users of our facilities and our 2,000 staff. They are recognised for their expertise, their collaborative work and delivering major national and international projects that further both our reputation and that of the UK. For example, through the Developing a World Class Research Programme initiative, we worked with our community to identify new world-class science and technology proposals for potential future investment, shaping our long-term science priorities and growing our future ambitions.

Our contribution as part of UKRI

To maintain UK science leadership, we will continue to engage with our community and our UKRI partners to identify long-term science priorities, set high expectations and ensure a culture where everyone's contribution is valued. By driving continuous improvement across the UK research and innovation community, we will build and maintain national research capability and international competitiveness as a core part of the UK research endeavour. We are committed to removing barriers that stand in the way of a more diverse research base and that affect wellbeing, opening up our processes and decision-making, encouraging flexibility in career pathways and embedding inclusivity in all aspects of our work.

Long-term ambitions

- Ensure that UK-funded researchers remain at the forefront of global pioneering discoveries by:
  - continuing to provide strategic leadership, identifying the brightest ideas and highest-priority areas for investment in our frontier science and facilities
  - taking a strategic lead in promoting, championing and implementing UKRI equality, diversity and inclusion (EDI) policies and practices, removing barriers wherever we can.

Near-term actions

- Work with our research community to identify long-term scientific priorities by:
  - undertaking a Balance of Programme review in 2019-20 of our frontier research programme to define a balanced programme across our science spectrum
  - completing programme evaluations in computing, nuclear physics, particle astrophysics, astronomy, particle physics and accelerators by June 2019, to identify scientific priorities and ensure an appropriate balance between construction and exploitation in each science area
  - delivering, in 2019, a strategic review on the light source capabilities required by UK researchers up to 2035.
- Establish our external EDI advisory panel by spring 2019 to advise us on our inclusive workplace practices, policies and processes, working in partnership with the UKRI EDI External Advisory Group.
- Develop our EDI action plan by spring 2019 to ensure we can attract, retain and develop the diverse talent we need to meet our 21st century objectives.
- Take proactive steps towards achieving at least 30% representation of the under-represented gender on all our panels and committees, working across councils to share best practice.

3.3.3 CREATING AN OUTSTANDING ORGANISATION

Capabilities for an outstanding and inclusive research and innovation organisation

Long-term strategic goal

Build on our strengths in long-term scientific and technological planning, international leadership and managing world-leading facilities, laboratories and campuses to help UKRI create the best environment for research and innovation.

Our distinctive capabilities

Our science and facilities are long-term, collaborative endeavours. We work strategically with our community and a range of international partners to identify priorities and maximise the benefits for UK research and innovation. A programme of this nature cannot be operated on the basis of short-term grant funding. It requires the ability to plan and commit funding for the longer term and sustain our R&D at the forefront of technology. Maintaining and refreshing detector, target and accelerator technology and delivering the e-infrastructure capability necessary for data storage, simulation and analysis are essential if the UK is to retain state-of-the-art facilities and experiments. To do this we must also be able to motivate and attract expert staff and sustain the agility and foresight to respond to new opportunities.

Our contribution as part of UKRI

We bring great strengths to UKRI through capabilities developed in managing a diverse portfolio of complex, long-term international projects, developing and operating world-leading multidisciplinary user facilities and laboratories, and working through public-private joint ventures to develop flourishing research and innovation campuses where world-leading science, innovation and entrepreneurship converge. The UKRI transformation programme provides an opportunity to share and build on these strengths, across the entire organisation. For example, our project managers, scientists and engineers are recognised internationally for their expertise and reliability. We also bring great expertise in running scientific estates and campuses, vital to optimising our investments and ensuring we remain a safe, stimulating and rewarding place to work.

Long-term ambitions

- Create an outstanding and inclusive working environment within UKRI based on our shared values of collaboration, innovation, integrity and excellence.
- Ensure we maintain the highest standards of integrity, oversight and accountability to sustain the capabilities of an outstanding and inclusive research and innovation organisation.

Near-term actions

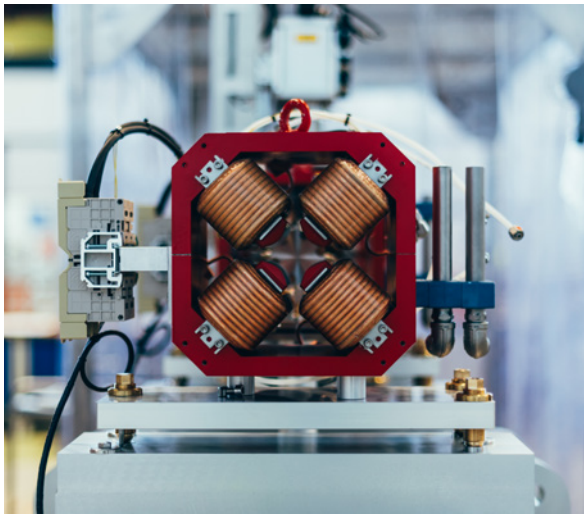
- Play an active part in the UKRI transformation programme, helping to develop UKRI as an outstanding organisation.
- Continue to strengthen and document our internal management and governance practices, with clear accountability, transparent processes and constructive dialogue to ensure effective interfaces within UKRI.
- Contribute to the development of project and portfolio management within UKRI, building on our Strategic Portfolio Management Office (SPMO) and project management framework.
- Continue to refurbish and improve the working environment across our estates as well as delivering and integrating major new-builds such as the National Satellite Test Facility and the Rosalind Franklin Institute.
- Develop organisational practices and cultures that support the attraction, development and retention of a diverse community, with progress to be measured against existing baselines.

4. Delivering and being accountable as an outstanding organisation

Efficient and effective operations

Within UKRI, responsibility is delegated to individual councils for scientific, research and innovation activity in their domain-specific areas. For us these are particle physics, astronomy, nuclear physics, space science and the provision and operation of research facilities. Management authority flows through the Executive Chair and Executive Board, our main decision-making body with responsibility for managing day-to-day activities and the delegated budget. STFC Council provides guidance and oversight of our programme. STFC Council and the Executive Board are jointly responsible for the development of our DP, with STFC Council supporting and challenging the Executive Chair to ensure effective delivery of our mission and formally signing off the DP. Our Executive Board is responsible for the effective management and monitoring of our mission and associated commitments, as articulated through the DP. Our internal governance structure has been agreed by STFC Council and the Executive Board, and is available as a public document. We are strengthening management processes to ensure the most efficient delivery of our main activities and enabling effective tracking of progress.

In considering research policies and investments, we value and consider the advice of our many external stakeholders and harness this through discipline- and area-specific advisory bodies that report to STFC Council and input to strategic reviews. Through high-level balance of programme evaluations we review our research, skills and innovation programmes. More detailed project-level programme evaluations consider the funded activities and priorities within our frontier science programme. We also undertake cross-cutting strategic reviews of our five key technologies: e-infrastructure; detectors and instrumentation; accelerators; specialist engineering; and optics. This provides a framework within which our Executive Board can make strategic investment decisions on a 5-10 year planning horizon.



Measuring progress against the UKRI success framework and our plan

We are developing a performance framework that will allow us to track progress towards the ambitions and delivery of the near-term actions set out in this DP. These ambitions and actions are aligned with and contribute to the overall objectives of UKRI. They will also drive the strategies, action plans and key performance indicators developed to monitor progress within STFC.

The framework is structured around a suite of short, medium and longer-term measures of progress, aligned against UKRI's strategic objectives. Shorter-term input and activity indicators/outputs will include, for example, funding inputs, progress against actions and project milestones, facility usage metrics and metrics related to support for business and knowledge transfer. In the medium term we will track progress against relevant outcomes, for example publications, measures of

research quality, training, patents and licensing income, new business spin-outs and start-ups, new tools/techniques applied to societal challenges, and diversity of talent being attracted to and progressing through STFC. These short and medium-term progress measures will be related to the longer-term impacts we are seeking in terms of pushing the frontiers of knowledge, delivering economic growth and generating social and cultural impacts.

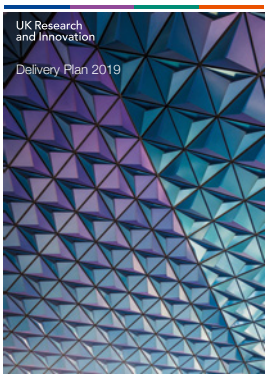
Performance-monitoring information will be drawn from a range of sources, including project-monitoring reports, facility and departmental reporting, campus statistics and surveys, bibliometric studies, Research Excellence Framework (REF) submissions, and interim and final evaluation reports. We already have a strong track record of evaluating the impact of our activities. These include completed studies, studies currently in progress and future planned work, as shown in the table below.

Impact evaluation studies: completed, in-progress and planned			
Evaluation stage	**National Facilities**	**Major projects/ Programmes**	**New funding streams**
Completed	Daresbury Synchrotron Radiation Source ISIS Neutron and Muon Source	Cryogenics Sci-Tech Daresbury Campus Hartree Centre Phase 1&2 Square Kilometre Array (Baseline)	
In-progress	Diamond Light Source	Collaborative Computational Projects CERN UK impact	National Satellite Test Facility Bridging 4 Innovators
Planning stage	Central Laser Facility ISIS Target Station 2	LBNF/DUNE European Spallation Source ATLAS/CMS Upgrade Hartree Centre (10 years)	Qubesat Extreme Photonics Applications Centre Newton Fund and GCRF projects New Strategic Priorities Fund projects

5. Financial allocation

STFC, £m		2019-20
Research and Innovation Budgets		**413.0**
Science Infrastructure Capital		**196.3**
ODA		**8.0**
	GCRF	3.5
	Newton Fund	4.5
NPIF		**118.6**
o/w	ISCF	47.2
	Skills	4.0
	Other	60.1
	Funds For International Collaboration	6.4
	Strategic Priorities Fund	0.8
STFC Programme		**735.8**

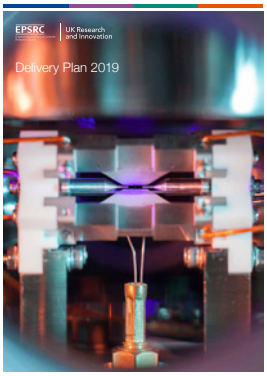
UK Research and Innovation Delivery Plans



UKRI

AHRC

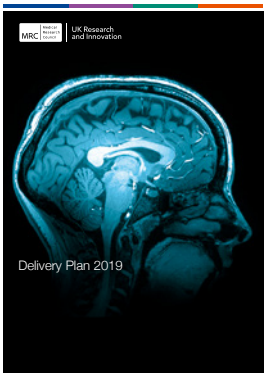
BBSRC



EPSRC

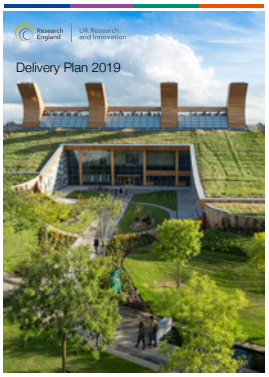
ESRC

Innovate UK



MRC

NERC



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