“Investment in research capital is essential to ensure that the UK has the best available resources to stimulate growth and support the wellbeing of the nation. Industry benefits greatly from capital investment through access to advanced facilities as well as access to world-leading scientific and technical expertise. Ensuring that such capital investment is maintained in order to fund new, cutting edge facilities and attract the best expertise to work with business and industry is vital to the future growth and competitiveness of UK business and Industry as well as to the UK as a whole.”

James Fothergill,
Head of Education & Skills, Confederation of British Industries (CBI)
Foreword from the Minister of State for Universities and Science

The Rt Hon David Willetts MP

UK science and research has a global reputation for excellence. With 3% of the world’s researchers, we generate 6% of the world’s academic articles, 11% of citations, and 14% of the most cited papers, second only to the US. With four of the top ten universities in the world, and 77 Nobel prizes in science and technology, we have a lot to be proud of, and our universities are playing a critical role in helping UK business benefit from this research excellence – the World Economic Forum’s Global Competitiveness Report recently ranked the UK second in the world for the strength of its university-business collaboration.

This world-leading research strength is a source of competitive advantage for the UK internationally, and a key building block of future economic growth. We should recognise that this research excellence has its roots in past investments in science and research, which sought above all to expand the frontiers of human knowledge and tackle the great challenges facing humanity. This demonstrates the importance of stable and sustained funding of science and research, and of the long-term ringfence around the Government’s science and research budget. Put simply, the internet, mobile communications and life sciences revolutions would not have been possible without earlier investments in the fundamental science and research behind these technologies.

The investments we are making now are necessary to sustain this performance into the future, and keep the UK at the forefront of tomorrow’s technological revolutions. Long-term thinking is essential to securing the current strength of the UK research base into the future. In autumn 2010, the Research Councils set out their key capital priorities in their Large Facilities Roadmap – in which we have since invested almost £400M together. I am therefore grateful that Research Councils have worked with their academic and business communities to develop this new strategic framework to plan future investments in research.

Science and research are at the heart of our growth agenda.
Foreword from the Chair of Research Councils UK

Professor Rick Rylance

The global landscape for research is fluid, dynamic and intensely competitive. The UK is recognised as a world leader in research and is ranked second globally but our ability to sustain this leadership position is far from inevitable. Unlocking research opportunities requires both highly technical and often expensive infrastructure. Return on investment is often far more substantial than the initial investment alone, delivering value over a sustained period of time and across a wide range of disciplines. The future prosperity of UK research and its contribution to growth is not secured by simply retaining the status quo; we must create competitive advantage through continuous investment in innovative research and infrastructure.

Economic pressures have led to a reduction in capital funding for research but the need for investment has not diminished. The rate of technological advance is accelerating, often following advances in computing. Investment in capital infrastructure has a major role to play both to enhance research capabilities that underpin research and to drive advances in sectors critical to the economy. Research Councils have responded to these challenges and have led the way in promoting efficient use of assets consistent with the principles of the Wakeham report. Co-ordinated partnership investment is also an important way to deliver efficiencies, increasing the depth of reach and impact of investments through sharing of equipment and the co-creation of knowledge and skills. This is essential to ensure research can continue to play a pivotal role in supporting and driving economic growth in the UK and in ensuring the UK can remain a global leader.

Research Councils have placed capital planning at the heart of their research strategies and it is important for Councils to continue to be able to make strategic capital investment decisions. Researchers will always look to access the very best facilities to deliver excellent research and will move internationally if facilities are not available in their home country or through global partnerships. The UK therefore needs to invest to retain, foster and develop its national research capability, and to continue to lead and attract investment.

Whilst this document focuses on capital infrastructure needs, we are acutely aware that a flexible highly-skilled workforce with state of the art technical skills and research leadership is required across all career stages to enhance the excellence of the research base and deliver benefits for the UK economy. Investment in skills, capacity and capability are all crucial to the sustainability of research excellence and contribute to making the UK an attractive place to invest and grow businesses.

I am delighted to present the first Research Councils UK (RCUK) Strategic Framework for Capital Investment, the development of which has been informed by the strategic plans of the Research Councils; input from the research community through an RCUK consultation; and by working with a mix of strategic advisors from across the Research Councils. The drafting of this Framework has also been informed by partnerships with a range of UK agencies with an interest in capital investment for research, including the UK Funding Councils; the Technology Strategy Board and the UK Space Agency.

This document is presented as a strategic framework against which Research Councils will plan future investments in the UK’s capital infrastructure for research – an infrastructure essential for the future sustainability of UK research competitiveness and to support the UK in maximising its innovation potential and driving economic growth.

This document does not present prioritised funding requests: rather it provides a strategic framework against which future investment decisions can be made, in a way which is flexible and adapts to developing research priorities.

The Framework looks at UK research investment needs through two lenses:

- the development of the underpinning national capital infrastructure for research which supports the breadth of the UK’s wide capability for research and technology development; and
- the creation of a national capital infrastructure for research capable of tackling the highest priority research and technology challenges and opportunities of tomorrow.

These aims are not mutually exclusive – each will work with the other.

In parallel to the production of the Framework, Research Councils are undertaking more in-depth analysis to develop further the areas highlighted in the report.

3 National Infrastructure Plan (2011): HMS Treasury/Infrastructure UK.
Contents

SECTION 1
Overview of Framework Structure 7

SECTION 2
UK National Capability for Research 9

This section of the Framework identifies core national needs for ‘underpinning’ infrastructure, required to provide state of the art equipment essential for resilience across the entire UK research base.

2.1 E-infrastructure 10
2.2 National research facilities 13
2.3 New and transformative equipment for world-leading research 16

SECTION 3
Research Challenges and Opportunities for Capital Investment 20

This section of the Framework presents a number of major research challenges and opportunities where the UK either has an international lead in research, or is poised to take this position. These challenges all drive advances in sectors critical to the economy. Opportunities for capital investment are highlighted against a general introduction to each area.

3.1 Understanding how the natural world works 21
3.2 Food and water security 24
3.3 Health, disease and ageing 27
3.4 Population change and diversity 29
3.5 Energy 31
3.6 Manufacturing: from atoms to aeroplanes 33
3.7 Synthetic biology 36

SECTION 4
Annexes 38

I. Capital investment consultation overview 38
II. Advisory and project team details 38
1

OVERVIEW OF FRAMEWORK STRUCTURE

This Framework is presented in two sections, but the interrelated nature of the sections cannot be overemphasised.

The development of core state of the art capital infrastructure drives transformative research. Similarly, research challenges drive the development of novel approaches and new technologies. This ‘push’ and ‘pull’ relationship is a critical part of the research landscape; neither of these processes can be considered in isolation. Additional and parallel investment in skilled people and resource are also key to deliver both national research capability and sustainability of investment.
1 OVERVIEW OF FRAMEWORK STRUCTURE

UK National Capability for Research – ‘underpinning’ capital investment needs

- Skilled people
- E-infrastructure
- National research facilities
- New and transformative equipment

Research Challenges and Opportunities for Capital Investment

- Understanding how the natural world works
- Food and water security
- Health, disease and ageing
- Population change and diversity
- Energy
- Manufacturing
- Synthetic biology

An illustration of the interrelationship between the two sections of this Framework.
2

UK NATIONAL CAPABILITY FOR RESEARCH

This section identifies core national needs for ‘underpinning’ infrastructure required to provide state of the art equipment essential for resilience across the entire UK research base. Investment is required not only to enable the UK to respond to emerging research challenges identified in the next section but also to ensure that the UK is well positioned as a competitive world-leading research partner able to keep pace with rapidly developing technology. This section highlights where such investment is crucial for the UK.

Many of the examples outlined within the section also illustrate key opportunities for coordination at the national and regional and local university levels. This is important in the context of helping to ensure that future investments are “joined-up” to regional and national strategic drivers as the scale of need stretches beyond the ability of individual organisations to finance, procure and provide the necessary support infrastructures. As well as maintaining the competitiveness of the UK Research Base, equipment sharing will deliver benefits in increased capability, accessibility and sustainability.
2.1 E-INFRASTRUCTURE

THE RATE OF TECHNOLOGICAL ADVANCE IS ACCELERATING, often following advances in computing. Investment is required to build a co-ordinated, open-access infrastructure to drive knowledge generation from data. The UK is a world leader in many areas, including genomics, structural biology, clinical and population data, bioinformatics, climate modelling, computational fluid dynamics, and molecular modelling. The UK’s world-leading industry in the automotive and aerospace, pharmaceutical, fast-moving consumer goods, process industries as well as health and digital media sectors would all benefit from access to e-infrastructure to drive their growth.

Research across a wide range of disciplines requires an ecosystem of computational resources (e-infrastructure) that can allow distributed collaboration and computation, large scale simulation and analysis, and fast access to data and facilities, along with the leading-edge skills, methods and tools required to exploit the potential that this offers for the creation of knowledge. Investment in infrastructure to capture data flows, convert data to information and derive new knowledge and understanding will liberate the potential of ‘big data’ to benefit business, provide better public services and to advance research.

Several reports have identified the need to take an holistic view of the entire ecosystem to enable an integrated approach to investment, and found that ongoing sustained investment is essential in all aspects of hardware, software and data storage, along with investment in the associated skills and training to enable these.

The recently established E-infrastructure Leadership Council (ELC) is taking such an holistic view, and is developing the business case for future investments. RCUK is also currently developing its own complementary integrated set of priorities for e-infrastructure for research, and we will work closely with ELC to ensure linkage.

In developing these priorities, we will address the requirements in all of the six strands shown in the figure below; some require capital investment (and indeed the recent £145M for capital in this area allowed investment in several key priorities), but resource investment is also required.
For instance in the area of software, the UK has an internationally envied reputation for investing in software engineering and support, so that the hardware that we have is utilised in the most efficient way to maximise research outputs, but this area is very people-intensive rather than capital intensive. Ongoing investment to allow developments at all levels of the software stack is a clear priority in order to fully utilise current investments and to put the UK in a position to exploit next generation computing architectures.

Every day the world creates 2.5 Exabytes of data – equivalent to over 40M iPads worth of information. Capturing value from this data deluge – for economic growth and social benefits such as improved health – requires improvements in data management. The world is experiencing a ‘big data’ revolution – and with the right investments, the UK is well placed to deliver the ambitions of the Government’s White Paper on Open Data. From DNA sequences to data on health records, food security, climate, and transactions generated by customer loyalty cards, these datasets are treasure troves of valuable information. The UK has some of the world’s best and most complete healthcare, social, environmental and food security related data, combined with world-leading strengths in the software development and algorithm research needed to make sense of these massive datasets.

Investment in computational infrastructure to capture data flows, convert data to information and derive new knowledge and understanding will liberate the potential of ‘big data’ to benefit business, provide better public services and to advance research. Building on recent investments in e-infrastructure, this would also catalyse industrial contributions on a similar scale.

In terms of computing hardware, investment will be needed across the whole pyramid:

- National/international service
- Specialist clusters e.g. DiRAC for particle physics, astronomy/cosmology
  MONSoN for climate modelling
- Regional clusters
- University/industry clusters
- Desktop/lab-based systems

The e-IAG report (see footnote 6) recognised that the current model of provision at the mid-range level, where each research-intensive institution invested in its own high performance computing (HPC) hardware was not optimal under the increasing need for efficiencies outlined in the Wakeham review. Further coordination at the regional and local university levels is required to ensure that future investments are “joined-up” to regional and national strategic drivers. Leading on from this there is a clear and developing need for sharing of hardware resources, especially as the scale of requirement stretches beyond the ability of individual organisations to finance, procure and provide the necessary support infrastructures. As well as maintaining the competitiveness of the UK Research Base, equipment sharing will deliver concomitant benefits in increased accessibility, robustness with respect to network security, integrity, system resilience and efficiency savings in excess of current arrangements.

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Data and Software Centres: The challenges in data processing, storage and curation for many research areas are immense. Projects such as the radioastronomy Square Kilometre Array, and the Large Hadron Collider (LHC) at CERN have large data processing and storage requirements, with a need for new code development and hardening, with upgrades to code bases. The development of new algorithms and codes is key to exploiting developments in hardware technology and ensuring both science return and the adoption of these capabilities throughout industry.

Digital Transformations in the Arts and Humanities: In the context of the ‘infinite archive’ and the potential for technologies to open up new ways to explore historic artefacts, data and heritage and to support the development of new research-based creative outputs, it is vital that the UK’s world-leading arts and humanities researchers are able to exploit the potential of high-quality e-infrastructure. Supporting opportunities for researchers to experiment with historic data, develop and test novel analytical methods and tools, along with improved access to archival resources, and the development of the skills, capabilities and cross-disciplinary approaches required to support such activities remain a high priority for investment. Research innovation and harnessing the creative potential of digital and other technologies is vital to the UK’s cultural ecosystem and the vibrant creative economy that it sustains. Capital investment in this field has the potential to generate a wide range of often unanticipated outcomes, building on past successes which have led to, for example, software innovations, exhibitions, performances, games, media (film, TV, radio etc) outputs, and other forms of digital content and creative outputs.

E-infrastructure for Bioscience: Investment is required to build a co-ordinated, open-access infrastructure to drive knowledge generation from genotype (simple ‘big-data’) to phenotype (massively complex ‘big data’) to ensure that strategic areas including animal disease, crop protection, bioenergy and health have access to a suite of informatics technologies that can be both generically enabling and, where required, tailored to meet specific strategic needs. The platform will co-localise data, compute power, software, training and expert support so will require substantive capital and recurrent investment. It will be integrated with the main European repositories residing at the European Bioinformatics Institute and other European centres through the ELIXIR federated project. The challenges posed by life science data are recognised across the world and the Head of the US National Science Foundation’s Biological Directorate recently stated that ‘There are…major priorities such as big data and we are going to deal with the explosion in types’. It is clear that to remain a global player investment is required.

Regional clusters: The recent investment of £10M identified outstanding research collaboration. There is a need to build on this investment further to galvanise the changed behaviour and to couple with this funding for software development. The Centres funded under the recent call will develop commercial, service-oriented usage models for their industrial users, lowering the barriers to industrial entry, and it would be the intention to build this requirement into future calls.

The UK Data Service: This forms a critical part of the UK social and economic data infrastructure, collecting, ingesting, storing and providing tools to access an unrivalled range of national and international social and economic data sets to over 23,000 users drawn from academia, government departments and beyond. UK Defence Statistics will build upon and extend upon the work of the current Economic and Social Data Service. Further funding of the service remains a future capital priority, with major opportunities to drive forward seamless access to the burgeoning volume of social and economic data through enhanced, data discovery, metadata standards and new software platforms.

UK investment in national/international HPC: As HPC becomes more powerful and it is possible to model more complex problems in greater detail, simulation becomes an increasingly essential tool. The research community needs access to leading edge technology to ensure that the UK’s research effort remains competitive, and so further ongoing investment in HPC infrastructure as part of the e-infrastructure investment at the national or international level is necessary to meet a wide range of scientific requirements.
2.2 NATIONAL RESEARCH FACILITIES

The UK research community requires a range of leading edge capabilities and technologies to support its world-leading research programmes. Whilst many of these capabilities can be embedded in individual laboratories or provided on a regional scale, some are of such a specialist nature that they require a single national investment. Research Councils support many such facilities and provide access to technologies through a number of mechanisms including Institutes, Units and Centres, national service facilities and innovation centres. Partnerships with business also provide access to state of the art capability for small companies alongside major research investments. Continued development of this national infrastructure is essential to enable the UK to compete on an international basis.

The Research Councils maintain a sustainable national infrastructure at a world-leading level; this enables cost effective access to key capabilities, the provision of specialist expertise and support to maximise the efficiency and effectiveness for the academic and industrial users. Research Campuses are also becoming major centres for innovation in the UK, bringing together the academic and industrial communities to create stimulating research environments for collaborative programmes, and for business to access expertise and infrastructure.

The Research Councils are responsible for the operation of three large national facilities, all on the Harwell Campus. These facilities provide structural and functional information at the molecular level in areas such as materials science, chemistry, and biological crystallography and have a broad remit across the entire research base. The Diamond Light Source is the UK’s national synchrotron facility and complements the UK membership of the European Synchrotron Radiation Facility (ESRF) facility in Grenoble. The UK currently has unrivalled access to the world’s top facilities for research using neutron scattering and muon spectroscopy, with ISIS being a world-leading accelerator-based facility. The Central Laser Facility is a world-leading provider of high power ultra-intense lasers for use by the scientific community.

An important element of national infrastructure is major platforms on which equipment and instrumentation for environmental research and observation are mounted. These platforms include satellites, research ships and aircraft, unmanned vessels and polar bases. Regular investment is required to renew or replace the platforms themselves and the integral instrumentation for measurement and analysis. Robotic and autonomous vehicles and technologies can address pressing issues in marine science, can deliver on the monitoring requirements demanded in UK law, and can lead to a new generation of naval craft. The UK has a base of creative researchers and innovative companies targeting robotic vehicles, their sensors and control systems. Further investment will lead to growth in markets supporting offshore energy industries, defence and environmental monitoring.

Innovation centres that provide research access for small companies and sit alongside major Research Council investments enable developing businesses to access state of the art capability. They foster an impact driven, multidisciplinary research environment and maximise access to advanced research capability. The direct translation to growth and jobs is enhanced by the effect of creating clusters of developing business around particular research capabilities, drawing on the research infrastructure and the flow of skilled people created. Further investment in campuses, building on the success of existing models is envisaged over the coming years.

Continued development of both national infrastructure and campuses will be essential to maintain the quality and quantity of the UK’s research output and to enable industry to compete on an international basis.

Domesticated animals are an integral part of human life, as food, companions, sport, for working, and in research. The livestock breeding industry is a major source of UK competitiveness – for example, 70% of the world’s broiler chickens are from breeding stock supplied by British companies. Key to retaining and developing this industry in the UK is a leading research capability in animal disease research, and people trained in the right technologies and skills in livestock, particularly veterinary scientists.
Animals are only ever used in research where no other alternative is possible and where the research is both ethically and scientifically justified; research programmes must follow the highest standards of animal care and welfare. The use of animals in bio-medical research however remains essential.

A number of national research infrastructure needs for the 21st Century are provided in the examples below.

**Infrastructure for animal research:** Planned investment in the repair and renewal of animal facilities is needed to ensure standards of operation keep pace with contemporary best practice and that high-level containment facilities for essential research on virulent animal and human disease are maintained to the highest levels of security. Investments in facilities in national centres need to be complemented with smaller scale/lower containment level facilities.

**Innovation campus development:** Campus developments will include the provision of buildings, joint facilities and infrastructure to promote co-location of industrial and academic groups. Examples include a laser hub at Harwell with the academic community working with laser suppliers on novel industrial applications for security scanning, and developing technology that will leverage inward investment.

**Large Facilities:** For all these facilities it is essential to have continuing investment in upgrades and renewals to keep them at the forefront of leading edge technology.

**Diamond Synchotron:** Investment priorities for Diamond include an additional physical sciences beamline, an electron microscopy facility and an extension to the synchrotron building to provide additional laboratory space.

**ISIS:** Priorities for investment for incremental upgrades to ISIS include: optimisation of the original target-moderator system, further development of instrumentation, refurbishment of the linear accelerator; and investments in remote handling and off line test facilities – all of which will deliver increased productivity.

**Central Laser Facility:** Vulcan is a powerful, versatile, Nd:glass laser system. The Vulcan 10PW development is a key upgrade to maintain leadership between current available laser facilities and future large facility projects and would give the UK a unique scientific capability and maintain world-leading technology and expertise to drive inward investment. The special properties of the X-rays produced by the Gemini laser make them ideally suited to producing high resolution images in industrial applications.

**Major Platforms for environmental research and observation:**

Current priorities for investment include:

- renewal of world-class aircraft capability for atmospheric measurements
- instrumentation for deployment on Unmanned Aerial Vehicles
- enhancing capability and imaging instrumentation for aircraft operating globally, including polar regions
- renewal of ice-strengthened ship capability for polar research and logistics
- antarctic base upgrading to provide state-of-the-art facilities, to meet health and safety requirements and for energy efficiencies.
National Centre for disease characterisation: An opportunity exists to establish a unique world-leading national centre for rat genomics to catalyse major advances in understanding the molecular mechanisms and the interplay of genetic and environmental factors in disease. The rat is an excellent physiological model for some human conditions; this combined with an established wealth of pharmacological data and an ability to undertake detailed imaging would offer unrivalled opportunities to advance our understanding of disease, including for example cardiovascular and metabolic disorders.

Research Council establishments: Research Institutes and Units are at the forefront of delivering National Capability. Our approach to improving and renewing infrastructure is to continually seek to enhance value for money, increase efficiencies and reduce the carbon footprint.

Specific projects include:

• Scientific infrastructure initiatives to achieve enduring savings in operating costs and reduction in carbon footprints including the use of photovoltaic cells, sea water cooling, and new schemes such as solar thermal and wind power for Antarctic stations, rainwater harvesting and full building management systems.

• Long-term maintenance initiatives that seek to manage infrastructure failure through a proactive and pre-emptive risk-based approach to building refurbishment and replacement, together with power and networking upgrades.

Robotics and autonomous vehicles: Prior capital investments in robotic and autonomous vehicles have developed capability that can now be replicated to address pressing issues in marine science, deliver on the monitoring requirements demanded in UK law, and can inspire a new generation of naval craft. The UK has a base of creative researchers and innovative companies targeting robotic vehicles, their sensors and control systems. Further investment will lead to growth in markets supporting offshore energy industries, defence and environmental monitoring.

UK leadership in heritage science: Enhancing the UK’s position at the forefront of the emerging field of heritage science requires integrated access to a wide range of advanced tools, facilities, instruments and sensors to support inter-disciplinary approaches capable of addressing heritage science problems that cannot be tackled by one technique alone. An important emerging need is to take advantage of recent developments in handheld, portable and transportable, non-destructive and non-invasive scientific analytical equipment to enable on-site analysis on location at museums, historic properties and archaeological sites where, for reasons of size, weight, fragility, importance, value or context, heritage assets cannot be sampled or moved.
2.3 NEW AND TRANSFORMATIVE EQUIPMENT FOR WORLD-LEADING RESEARCH

EARLY ACQUISITION OF NEW RESEARCH TECHNOLOGIES IS A MAJOR REQUIREMENT OF THE RESEARCH BASE to maintain research and innovation capability. Researchers require access to state of the art instrumentation to underpin cutting-edge research, generate exciting scientific discoveries and to build an effective national capability to sustain high-quality research. The UK needs to invest in this area to retain, foster and develop the capability that will maintain its international lead and attract inward investment.

National facilities provide access to expensive unique resource and capability, but a healthy research landscape also requires a bedrock of ‘mid-range’ state of the art equipment to ensure the UK’s research base remains competitive in an international research context. Techniques are used in a complementary fashion providing different data to triangulate understanding and results.

In addition to keeping pace with necessary upgrades of laboratory resources, developments in instrumentation technology, IT and automation are producing a constant stream of new tools that transform the speed, resolution and accuracy at which research can be accomplished. Instrumentation in its broadest definition is a key building block of collaborations at a multidisciplinary level – where groundbreaking technologies that change how we live and interact are often discovered – and more importantly, at the industrial level, where exploratory research is required to overcome commercial challenges.

A technological advanced infrastructure base is also essential to ensure the next generation of scientists are highly-skilled as they enter the workforce. Scientists need to be highly competent in using such instrumentation, be adaptable to different types of equipment and be able to interpret results that may significantly enhance the competitiveness of the business. The UK university research environment is well-placed to provide such training and has regained its position of being equipped with leading edge instrumentation through previous investments such as the Capital Infrastructure Fund and building of Diamond. However, investment needs to be continuous with rigorous criteria to ensure resources deliver best value and ensure it is targeted to national need (not on a cyclical basis to play catch up) to maximise capability.

Human resource will drive much of the discovery but the lack of state-of-the-art infrastructure will be a key limiting factor if upgrades and new instrument development does not keep pace with our competitors.

Underpinning all this is the need for early acquisition of new research technologies for the research base. It can take more than two years for technologies developed abroad to be used widely for advanced research in the UK, during which time competitive advantage is lost. Some of the delays, such as export barriers,
are difficult to avoid but others – particularly the funding, procurement, operational set-up and training barriers – can be greatly reduced by a focused programme of early acquisition in which national centres of capability are resourced to get new mid-range instrumentation as early as possible.

Apart from maintaining the competitiveness of the leading centres, this provides a resource of knowledge, expertise and training that assists take-up of new technology in the wider research base and industry.

The UK has a strong industrial base in some areas of research instrumentation (mass spectrometry, for example) and a very strong record in developing software and other tools to make the best use of advanced technologies. An example of the latter is protein structure determination, where the competitiveness of the UK research base, and of pharmaceutical research drawing from it, is based on very selective access to the most advanced technology combined with a world lead in developing computational tools to use it. These tools are themselves a major commercial success story. Moreover, many jobs in the suppliers of reagents and consumables are in turn sustained by the use of advanced research technologies in the public and private sectors.

This virtuous cycle of investment and return can best be maintained by the support from the Research Councils to the major research institutions to acquire the latest technologies and explore their use and potential as soon as possible after they come to market, in a context of appropriate strategies for training, wide access and industrial engagement.

Imaging technologies are central platforms that drive fundamental research in virtually all disciplines across the biological and medical sciences. Visualising cells and tissues by light and electron microscopy has led to more discoveries than any other technology. Without replenishing and updating imaging technologies there is a high risk that the UK will seriously weaken its competitive position.

By seeing how a system looks, function can be understood and comparison made between healthy and unhealthy systems whether they are plant, animal or human and whether they are single cells, tissues, whole organisms or populations. In biology, visualising cells and tissues by light and electron microscopy has led to more discoveries than any other technology. In medicine, a suite of technologies such as magnetic resonance imaging (MRI), positron emission tomography (PET) and x-ray computed tomography (CT) has provided insight into the function and metabolism of organisms allowing the visualisation of the effectiveness of new targeted therapies.

The 2012 world university rankings for life sciences and clinical/preclinical and health sciences show yet again that the UK is second in the world to the US with 3 and 4 UK institutions appearing in the top 10. Building on this strong track-record in academic research in the past decade, UK university bioscience departments have generated over 200 spin-out companies. Thus our global academic standing and innovation potential relies heavily on a broad swath of cutting-edge biological and medical imaging technologies that are required on a day-to-day basis by researchers but which can be extremely costly to provide.

Without replenishing and updating imaging technologies there is a high risk that the UK will seriously weaken its competitive position. While a next generation microscopy initiative will go some way to filling a gap in imaging for recent biomedical research its budget of £18M is somewhat dwarfed against developments in the European Research Area. For example, France recently budgeted €66M for a co-ordinated and harmonised network of bio-imaging covering photonic and electronic cellular bio-imaging and imaging for pre-clinical, clinical and population studies. Furthermore, very-large scale investment is underway in Germany where the biological and medical imaging communities have submitted a proposal for a distributed and co-ordinated national infrastructure for advanced imaging technologies to the Federal Ministry of Research and Education.

The UK needs to invest to retain, foster and develop capability that will maintain its international lead and attract investment.
Key (but not exclusive) areas where investment is needed are:

- MRI
- electron microscopy
- super-resolution microscopy
- high-throughput imaging
- bio-imaging repositories to support sharing and management of data.

As with all new technologies, capital investment needs to go alongside investment in associated trained capability and data capture, management and distribution resources. A number of areas ripe for investment are outlined.

**Accelerator facilities:** Particle accelerators are at the heart of physical science research in many areas, and have wide applications in other areas such as medical scanners, PET imaging and security screening technologies. Investment in new technologies and the development of test facilities will enable the development of compact and cheaper accelerators to increase their applications in the medical and security fields in collaboration with industry:

- Synchrotron sources accelerate electrons to near light-speed producing brilliant beams of light across a large energy range for a wide range of research including chemistry, cultural heritage, earth sciences, engineering, environmental science, life sciences, physics and material science for both academia and industry. UK community needs are delivered mainly by access to the ESRF in Grenoble and through the Diamond Light Source at Harwell. Investment priorities for Diamond include an additional engineering beamline and additional infrastructure to maximise the applications of the current beamlines in imaging and cryo-electron microscopy (EM), and planned upgrades to ESRF.
- The Electron Beam Test Facility (EBTF) at Daresbury enables the study of short pulse free electron lasers which open science up to new areas by providing very intense and extremely short pulses of light. The UK is not currently a formal partner in any international facility, and it does not have its own national user facility. Lack of guaranteed access to a free-electron laser (FEL) facility is putting the UK scientific community at a disadvantage against its international competitors and leaves the UK unable to realise the opportunities for leveraging investment into the UK through research and development (R&D) partnerships. Investment in underpinning accelerator R&D will help position the UK to play a significant role in future FEL facilities.
- The Muon Ionisation Cooling Experiment (MICE) at RAL is an international collaboration of particle and accelerator physicists from Europe, the US and Japan. Continued investment in further phases of this experiment and its exploitation will develop key technologies for future muon colliders and a neutrino ‘factory’ to address fundamental questions on the nature of matter.

**Chemistry Research Infrastructure:** The instrumentation infrastructure demanded by research-led Chemistry and associated disciplines requires continuous reinvestment. The UK’s leading departments plan to form a national co-ordinated network to collaborate on a co-ordinated rolling national upgrade programme of the “core four” techniques: mass spectrometry, nuclear magnetic resonance spectroscopy (NMR), x-ray diffraction, and atomic-level microscopy. The instrumental infrastructure to be purchased underpins a large sector of Chemistry research, and is characterised by multi-users, multi-applications and impact across materials, synthesis, chemical biology, structure and function of chemical entities.
**Dark Fibre Facility:** Research into high capacity communications networks cannot be carried out without access to the optical transmission fibre itself, particularly if it is to make impact both within the research community and in exploitation via industry. This is because the performance requirements on optical communications become ever more demanding, so does the need to demonstrate reliability in the face of variations in real deployed fibre networks, with their consequent imperfections in transmission. A new and upgraded Dark Fibre Facility is required, where technological innovations can be tested in realistic transmission conditions, going beyond what is possible in the laboratory environment, so that successful operations can be demonstrated in real systems. Currently this is delivered in an ad-hoc manner at a limited set of universities on the Aurora dark fibre network. A capital investment would allow greater impact from this important research in this area (a current portfolio of over £21M).

**Helium liquefiers:** Liquid helium is one of the main consumable costs on grants in Condensed Matter Physics (CMP). Being able to do CMP at low temperatures opens up the quantum realm which can lead to step changes in our understanding of fundamental physics and makes the development of future technology, such as quantum computing, possible.

Efficient management of this non-renewable, essential and irreplaceable resource is essential in reducing research and energy costs for both universities and funding bodies, but also in addressing the predictions that world-wide stocks will run out by the end of the century. Whilst cryogen-free options now exist for most pieces of equipment, they are considerably less efficient than a properly managed helium liquefaction and gas recovery system. It is estimated that five or six helium recovery and liquefaction systems are needed UK-wide to supplement those already installed.

**High Power Lasers:** are unparalleled tools for new scientific discoveries in the most extreme of conditions, conditions that where (if) they naturally exist only do so “off planet” and that cannot be established on Earth in a controlled manner in any other way. Experimental exploration of some of the most successful and fundamental scientific theories will be enabled in regimes hitherto inaccessible. The production of high energy X-rays in compact/reduced cost laser systems will lead to lower cost systems that can be applied in for example:

- use of laser systems for screening for banned liquids at airports/illegal goods in transport
- compact/reduced cost laser systems
- medical imaging

Continued investment in high power laser capability will maintain UK technology leads and give UK researchers a unique scientific capability.

**High-throughput genomics and bioscience:** Automated and robotic technologies provide the capability to sequence or screen very large numbers of samples automatically and, through the use of standardised laboratory information systems (LIMS) to store and share the outputs globally. “Robot scientists” can repeat and refine experiments to test hypotheses and undertake predictive modelling. Investment in automated high-throughput bioscience facilities, in parallel with e-science infrastructure investment and appropriate training will radically increase the speed with which bioscience can be progressed and opens up the possibility to pursue large scale and complex problems with techniques hitherto confined to simple models.

**National capabilities in next generation imaging technologies:** Detailed structural information about the molecular targets of drugs and the biological consequence of their action is invaluable for designing new drugs and therapies, imaging technologies are also critically important for the development of new advanced materials (e.g. for energy and health), nanotechnology, earth sciences and biological applications more generally. There are many exciting new advances in the complementary imaging technologies including small animal in vivo imaging Nuclear Magnetic Resonance (solid and liquid), cryo Electron Microscopy, next generation microscopy and single cell mass cytometry. A national programme of infrastructure investment is needed to establish national capability in these next generation technologies to maintain the UK at the scientific cutting edge. Bioimaging UK is one example of an investment for a distributed bioimaging infrastructure proposal that will provide the latest technologies in distributed technical hubs for academic and industrial collaborative access, with an underpinning open-access data repository to enable comparative studies and generate research efficiencies.

**Neutron capability:** Neutrons provide information about the arrangement and movement of the atomic building blocks and have become an important tool for many disciplines, such as physics, chemistry, biology and materials sciences. The areas of application are becoming ever wider, including areas as diverse as proteins and biological processes within cell membranes, studies involving catalysts, batteries and magnetic substances, and assessments of the service life of turbine blades in jet engines.

A coherent approach to the provision of neutron sources in Europe is needed to meet the science needs of UK researchers including the continued operation and upgrades to the ILL facility in Grenoble, in which the UK is a partner, and the world-leading ISIS facility in the UK. The planned new European Spallation Source (ESS) is being designed to provide an order of magnitude increase in detection capabilities for European researchers with opportunities for UK participation in its construction and exploitation.
This section presents a number of major research challenges and opportunities where the UK either has an international lead in research, or is poised to take this position. These challenges all drive advances in sectors critical to the economy.

Opportunities for capital investment are highlighted against a general introduction to each area. The exemplars are intended to be illustrative of the range and breadth of investment needs and opportunities, which means that the list of examples is not exhaustive. Relative priorities evolve as new research and technological innovation impact the pace of change and research develops.
3.1 UNDERSTANDING HOW THE NATURAL WORLD WORKS

UNDERSTANDING HOW THE NATURAL WORLD WORKS REQUIRES RESEARCH across both space and time, from understanding the basic building blocks of the universe to the complex natural environment of our planet Earth. Capital investment will push the boundaries of capabilities and keep the UK at the forefront of global research in disciplines such as particle physics and astronomy. This will enable the UK to protect and enhance the services provided by our natural environment, and access the new markets in the green economy.

Technology that is developed to address fundamental research challenges pushes innovation in ways that rapidly become commonplace – the invention of the world wide web, of touch screens (from particle physics) and of wi-fi (from radio astronomy) are just three recent examples. From the earliest times people have tried to understand the workings of the universe we live in. This is true of both our local environment on and within the Earth, and the visible near, and far, Universe.

The present health of our planet is vital for human welfare. The natural environment enhances or provides business, Government and society at large with the essential resources and beneficial services to sustain life, economic growth and societal well-being. These include: food; energy; minerals; clean air and water; regulation of flood, climate and disease; and mental and physical health. The provision of these resources and services is under threat. Human activities are causing large-scale change that is detrimentally affecting climate, land use and biodiversity. Rapid economic and population growth are putting increasing pressure on the economy, society and the environment, creating a ‘perfect storm’ of water, food and energy shortages. Changing climate and water cycle (floods and droughts), together with other natural hazards, are widely recognised to be among the greatest threats to the sustainability of life on Earth. Observation and measurement of the environment are necessary for understanding and mitigating these hazards, and new opportunities are provided by developments in sensor and information technologies.

Understanding biological diversity and the factors affecting its maintenance and change, particularly in the context of agriculture and other aspects of land use, is also key, and requires improved access to collections and to experimental facilities to understand agro-environmental dynamics from the molecular to the ecological scale.

The vision is for an integrated sensing and analysis system for the UK environment, providing comprehensive co-ordinated measurements and analyses of sufficient accuracy and resolution to forecast environmental conditions. This more profound understanding of environmental conditions and their susceptibility to change will form a more robust basis for the setting and implementation of successful policies, and help de-risk business investment. The exploitation of recent technological advances in sensors and networks, and the environmental information generated, will help create new economic opportunities and markets. For example, carbon goods and services globally are estimated to grow to over £4Tn by 201510.

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Capital investment will push the boundaries of sensitivity and detection capabilities to enable the UK to protect and enhance the services provided by our natural environment, to access the new markets in the green economy.

As we look beyond our own planet, there are key research questions at the heart of our understanding of the structure and function of the known and unknown universe. How did the universe begin and how is it evolving? How do stars and planetary systems develop and is life unique to our planet? What are the fundamental constituents of the universe and how do they interact? And how can we explore and understand the extremes of the universe?

We are now at the point where we can recreate, in our experiments, the conditions that existed one trillionth of a second after the big bang, and where we can detect the fluctuations in the cosmic microwave background that seeded the formation of galaxies. The technology that is developed to address fundamental research challenges pushes innovation in ways that rapidly become commonplace – invention of the world wide web; of capacitive touch screens (from particle physics); and of wi-fi (from radio astronomy), are just three recent examples.

Astronomy investment is focussed on two capabilities: radio and optical astronomy. Construction of the two European priority infrastructures will give access to a wide range of cutting edge research, and will reap significant benefits for UK industry in construction contracts and the joint development of key technologies such as data processing, optics and energy efficient power distribution. They will allow the full exploitation of the data from current investments in space missions.

Particle astrophysics addresses the research questions through the study of the fundamental constituents of the Universe, key global priorities being the study of dark energy, dark matter, gravitational waves and high energy cosmic rays.

The UK is making a significant contribution in the area of neutrino physics. A variety of dedicated facilities are needed for the next generation neutrino oscillation experiments - these may increase the understanding of physics beyond the Standard Model, our current best description of the fundamental particles and forces.

Involvement in R&D for the next generation detectors will position the UK to participate in some of the most important unanswered questions in science.

**Astronomy infrastructure – Square Kilometre Array (SKA):** This is the next generation global-scale radio-astronomy facility that will be based on a dual site of South Africa and Australia. With a headquarters at Jodrell Bank in the UK, it will study the formation and evolution of galaxies, dark energy, and the formation of planetary systems.

**Earthsense:** A whole-system health-check for the environment that will provide an integrated national infrastructure, driving international synergies to observe and analyse how the interconnected air-land-ice-water components of our environment control future living conditions and natural hazards. Key elements include:

- an Environmental Virtual Observatory will develop cloud-enabled environmental monitoring and catchment modelling technologies to provide improved web-based access to catchment information and predictions
- the UK component of the Integrated Carbon Observing System, which will provide the European infrastructure for determining the greenhouse gas balance of Europe
- instrumentation and telemetering of up to ten networks of low-cost sensors across a wide range of geological, chemical, physical and biological parameters for the major UK ecosystems
- integration of land and seafloor seismic monitoring networks, volcano observatories and experimental laboratories for more sensitive sensing systems, across Europe.

Application of recent technological advances in sensors and networks will help create new markets in renewable energy, carbon and water management, ecosystems services and trading. Whole-system environmental information generated will stimulate new markets in environmental and hazard managements, and lead to transformed public services that protect vulnerable people, places and infrastructure from environmental shocks (and so avoiding future costs).
European Extremely Large Telescope (E-ELT):
The E-ELT telescope is being developed by the European Southern Observatory, of which the UK is one of 15 Member States. The sensitivity of this telescope will make possible for the first time, the direct observation of planets around other suns beyond our solar system and will give major insights into black holes and galaxy formation, and will keep UK astronomers at the forefront of global research.

Incoherent Scatter Radar: European Incoherent Scatter Scientific Association (EISCAT), an international infrastructure based in Europe, studies the upper atmosphere, ionosphere and geospace. EISCAT_3D is the next generation research radar for studies of the high-latitude upper atmosphere and the near-Earth regions of geospace. It is major upgrade to the technical abilities of the existing radars, combining greatly increased sensitivity and flexibility, allowing the use of new techniques such as volumetric imaging and interferometry.

Understanding the way in which energy couples from the Sun and solar wind into the geospace environment is needed not only for furthering atmospheric science and plasma physics, but also for providing new insight into issues such as global change and space weather. EISCAT 3_D will be the world’s most advanced and capable incoherent scatter radar facility.

Particle astrophysics and neutrino experiments: Priorities in particle astrophysics are exploitation of the advanced LIGO and future ground-based Gravitational Wave Detectors, dark matter detection and high energy cosmic rays. R&D is beginning within Europe for a third-generation gravitational-wave detector, the Einstein Telescope (ET), identified by European funding agencies as a high-priority future infrastructure that will make precision measurements as part of a global network. Dark Matter, believed to comprise around 21% of the universe, has as yet, not been directly detected. Involvement in R&D for the next generation detectors will position the UK to participate in one of the most important unanswered questions in science. High energy particles from the cosmos provide information about extreme astrophysical environments; the UK is involved in the preparatory phase for the

Capital investment will push the boundaries of capabilities and keep the UK at the forefront of global research in disciplines such as particle physics and astronomy.

Cherenkov Telescope Array (CTA) Observatory, which will give an order of magnitude increased sensitivity than current gamma ray telescopes.

The UK is making a significant contribution in the area of neutrino physics. There are a number of international design studies underway into the next generation neutrino oscillation experiments, which will allow physicists to gain a greater understanding of neutrinos and how they change type which will shed light on our understanding of physics beyond the Standard Model. A variety of dedicated facilities are needed to study low background particle and nuclear physics.

Particle and nuclear physics: The Large Hadron Collider at CERN is the world’s highest energy collider. Its research programme is aimed at elucidating the nature of mass and understanding the prevalence of matter in the Universe, and results so far include confirming the first discovery of a Higgs Boson-like particle. Investment in the LHC upgrade programme and other international projects for the next generation high energy colliders is an essential part of continuing to explore and understand the fundamental nature of the universe and fully exploiting the potential of the UK’s investment in a field where the UK is a world leader.

The UK has a leading programme of research in nuclear physics despite having no UK based facilities. The FAIR facility, in Germany, will be the premier international nuclear fragmentation facility in the world for the study of nuclei and nuclear matter. Building on the UK’s participation in the NuStar experiment at FAIR, high priority opportunities to broaden the UK research programme include investment in a storage ring facility for HIE-ISOLDE at CERN, an upgrade of the NuSTAR experiment at FAIR, an upgrade to the ALICE detector at CERN, the AGATA spectrometer and an upgrade to the JLab facility in the US.
3.2 FOOD AND WATER SECURITY

GLOBAL FOOD PRODUCTION WILL NEED TO INCREASE BY OVER 40% BY 2030, and 70% by 2050\(^1\). Yet water is expected to become scarcer, and there is increasing competition for land, putting added pressure on production. The UK will not be immune to the humanitarian and global security pressures created if humankind fails to address these issues, and domestically the UK faces the same issues in sustaining and increasing our own food production, as well as the need to improve ageing water distribution infrastructure and the conservation of water. The UK can significantly contribute to these challenges at present, but needs capital investment to exploit and maintain this capability.

Global demand for food is rising because of population growth; increasing affluence; and changing diets. In addition, climate change will reduce the reliability of food supply through altered weather patterns and increased pressure from pests and diseases. To meet Millennium Development Goals\(^12\) on world hunger, agriculture will need to produce more food from the same or less land, using less water; energy and other inputs, and reducing waste and adverse environmental impacts including greenhouse gas emissions.

The UK has strength across the major areas of bioscience, agricultural, environmental and food research able to contribute to this challenge. The advent of research tools and infrastructure which enable large scale integrated and multidisciplinary research to tackle these complex problems, and the existence of world-class centres for plant, animal, crop, environmental and agro-economic research within the UK, places us at the forefront of the field. Developing an integrated understanding of the factors underpinning the sustainable productivity of crop plants and farm animals, to increase the efficiency of production and minimise negative environmental impacts as well as improve nutrition and minimise waste, has huge commercial potential. This will translate into new crop plant varieties and improved animal traits for production and welfare; new technologies for pest and disease control and resistance; and novel agricultural and environmental sensing technologies.

The scale and complexity of integrated food security research challenges the conventional model for competitive bioscience research. To take basic research through to application in the field and to the fork requires sustained large-scale networks linking basic and applied researchers; industry; farmers; and the policy and regulatory frameworks, nationally and internationally. Technologically advanced solutions require extensive understanding of human and environmental safety issues and careful analysis of public perception and economic impact.

\(^1\) UNEP synthesis report (2012) Avoiding Future Famines: Strengthening the Ecological Foundation of Food Security through Sustainable Food Systems.

\(^2\) www.endpoverty2015.org/en/goals
The main capital investment requirements are to resource key centres of national capability in:

- high-throughput data acquisition technologies and the associated data analysis, including robust real-time environmental-sensing technologies for use at field; farm; and landscape scales, and tools to secure and analyse the variation in the complex genomes of livestock and crops
- phenomics – the automated acquisition of multiple correlated measurements of factors in plant development during the growth cycle, in glasshouse and field environments
- farm scale and environmental experimental platforms – field facilities instrumented to measure inputs and outputs to enable interventions examining, for example, animal interactions; or the rhizosphere and soil structure; or designed to test particular farming practices and technologies
- containment, field and veterinary facilities for farm animal research
- storage and distribution capability to enable sharing; integration; and modelling of large standardised datasets nationally and internationally.

Realisation of economic and social benefit from investments to improve food security is highly dependent on extensive cooperation with the major industries and development aid providers in the context of robust international agreements.

Water is a resource in increasingly limited supply and the global situation will worsen as climate changes, populations grow, and a higher and higher percentage of this population lives in urban centres. Lack of drinkable water threatens the health of a substantial part of the world population. The World Economic Forum has identified water as one of the most significant threats to the global economy and society\(^\text{13}\). It estimates that water problems in the next five to ten years could cost the global economy $250bn if no action is taken to secure supplies; deliver water to people and business (including agriculture;) and reduce the commercial demands on water supply from energy; manufacturing; and agribusiness. In the UK there is a particular need to improve ageing water distribution infrastructure and improve the conservation and distribution of water.

**Countering the threats of animal-borne disease:**
An estimated £450M and 10,000 agricultural jobs in the UK were saved in the UK in 2008 as result of a successful vaccination strategy against the midge-borne bluetongue virus affecting livestock. This was based on epidemiological modelling, with host-pathogen interaction and vaccinology research with industry using a platform of technologies and capabilities provided within the Institute for Animal Health and through collaboration. Further investment in both high throughput data acquisition technologies and high-level containment facilities will speed up both molecular epidemiology for outbreak analysis and the capability to develop vaccines, enabling more rapid responses to farm animal and zoonotic threats worldwide.

**Farm- and Landscape-scale Platforms:** A pioneering farm-scale research facility in Devon opened in 2012, and provides the ability to examine on a farm scale the productivity and environmental impacts of arable and livestock farming under a range of different agricultural practices. The effectiveness and impact of this work will be considerably improved by further measuring stations in the

area around North Wyke, and the coordination and enhancement of existing, and creation of additional, UK instrumented farm facilities, supplemented by supporting a wider network of part-instrumented ones. These will enable effective translation of research between landscapes, including eastern arable and northern upland areas.

This is allied to a need for further specialist soil research facilities, together with access to complementary European facilities. New e-science-based approaches to research, particularly crowd-sourcing and citizen science, offer real potential to involve large numbers of farmers, growers, consumers etc directly in the research. Doubling wheat yield in the UK by 2020 would generate £1.5bn at the farm gate - www.allaboutwheat.info/production.html

**Water technology and innovation test bed:**
A pre-market technology and innovation test-bed for the UK’s water research is needed to provide the lead the private sector needs to de-risk innovation in this area. It would also allow proper multi-disciplinary working across Research Councils allowing the research to be translated into market leadership in areas such as sensor technologies; high level consultancy; food production; waste treatment for example self-cleaning sewers; and ecosystem services.

The need for such a test-bed is identified in the UK Water Research & Innovation Framework (UKWRIF, 2012), developed by RCUK, GO-science, UK Collaborative for Development Sciences, and the water industry. The water sector is likely to be worth $500Bn in the next few years, with potential costs to the global economy of more than $250Bn if corrective measures not taken (World Economic Forum). With the establishment of such a test-bed now, the UK could take advantage of time-limited EU technology and innovation opportunity funds, taking an international lead in driving infrastructure networks; water efficiency in homes and business; water-resource management; and market regulation and governance. It would also take forward elements of HM Treasury’s Infrastructure plans for the UK water sector.

**Wheat:**
The world’s most important food crop – but improvements in yield have not kept pace with other grain crops in recent years. Resources are needed to sustain an internationally co-ordinated effort to apply understanding from modern molecular biology and genetics, in which the UK has a world-leading community, to improving wheat yield globally and to inform improved sustainable varieties for the UK. This needs the infrastructure for large scale and long term integrated laboratory, greenhouse and field experiments to develop the pre-competitive germplasm which will be the building blocks for transformative wheat varieties. This will build on the emerging genome sequence information on wheat. The international consortia to achieve this, linked extensively to industry, are being developed, and the whole endeavour underpinned by a worldwide framework of data and information sharing initiated by the UK.

The United Nations Food and Agriculture Organisation (UN FAO) forecasts that global food production will need to increase by over 40% by 2030, and 70% by 2050.

The United Nations Food and Agriculture Organisation (UN FAO) forecasts that global food production will need to increase by over 40% by 2030, and 70% by 2050.
3.3 HEALTH DISEASE AND AGEING

NEW INFECTIONS CONTINUE TO EMERGE AND DESPITE MAJOR ADVANCES IN CONTROL, remain a major cause of mortality worldwide. In addition, non-communicable diseases – including for example diabetes, cancer, cardiovascular disease and mental disorders – account for a large proportion of the burden of disease. As the population ages we need new approaches to understanding the biology of health, ageing and how it relates to frailty and disease. Understanding the complex interplay between genetics, development, diet and life events or lifestyles requires a significant research effort across a range of disciplines. The UK has particular research strengths in this area that require capital investment.

The UK life science industry is one of the world leaders; it is the third largest contributor to economic growth in the UK with more than 4,000 companies, employing around 160,000 people and with a total annual turnover of over £50Bn. Its success is key to future economic growth and to our goal to rebalance the economy. Globally the industry is changing with more focus on collaboration, out-sourcing of research and earlier clinical trials with patients.

Unlocking research opportunities often requires both highly technical and expensive infrastructure, with returns often far more substantial than the initial investment alone, delivering value over a sustained period of time and across a wide range of disciplines. The investments required for research in health, disease and ageing are no exception. A recurring theme across the Life Sciences sector is the power of combination of data, as for example, genome sequencing becomes a commodity and literature publication rates spiral. The combination of such massive amounts of literature data and knowledge, combined with technological advancements in (for example) imaging means that a competitive Life Sciences sector is well placed to harvest and exploit these resources.

This requires not only investigation of our ‘life course’ perspective in large cohort studies, particularly to understand the biological, environmental and socio-economic factors that dispose towards a healthier lifespan but also linking population biology with a greater understanding of disease processes themselves. Major advances in technological capability enable us to address questions that were previously not tractable. For example, it is now possible to gain detailed structural information about the molecular targets of drugs and the biological consequence of their action, which is invaluable for designing new drugs and therapies. Exciting new advances in imaging technologies reveal unprecedented information at atomic, molecular and cellular levels in order to understand how the targets function on their own, with other molecules and with the rest of the cell or organism and how drugs bind them and affect their function.

The UK has particular strengths that should be built upon. A number of examples of investment opportunities are highlighted here.

A National Framework for Biomedical Informatics Infrastructure: The UK has some of the world’s best and most complete biomedical, healthcare and social data. Investment is required to build a co-ordinated, open-access infrastructure to drive knowledge generation from genotype (simple ‘big-data’) to phenotype (massively complex ‘big data’) to ensure that health research has access to a suite of informatics technologies that can be both generically enabling and, where required, tailored to
meet specific strategic needs. It is clear that to remain a global player substantive capital and recurrent investment is required to develop a national biomedical informatics infrastructure including co-localisation of data, compute power, software, training and expert support. Such a framework will complement existing and planned investments for example those planned at the European Bioinformatics Institute, including the UK’s contribution to ELIXIR; and the Health Departments’ development of health data sets and related informatics, as outlined in the Life Sciences Strategy (Dec 2011).

Food health and the gut: Food related disease imposes an unsustainable health burden worldwide. The Cabinet Office Food Matters report estimated that the total cost to the UK in terms of both treatment/care costs and lost productivity is up to £8Bn per year. Key to understanding how to deliver healthy and nutritious food is an understanding of the interaction of food and the gut. Modern bioscience technologies enable a fuller understanding of digestive process and the role of food composition; the gut microbiota; food pathogens; immunology; and the many other factors involved in gut function. In combination with technologies for plant and animal breeding, and advanced microbiology and bio-processing, improvements to food products to introduce healthier diets are possible. The location of such facilities in combination with the clinical infrastructure required to support trials provides the ability to explore the role of the gut in the maintenance of health.

Longitudinal analysis of ageing: Understanding how individuals age over time is fundamental to our understanding of how the interplay between, genes, environment and lifestyles influences people’s health. Large-scale studies, such as the English Longitudinal Study of Ageing (ELSA), have already started to chart the relationship between social economic factors (e.g. economic status; retirement plans; family and household structure, and physical and mental health) might predict health and well being in later life. Further capital funding is required to extend existing studies and to invest in new studies with different health challenges facing different populations to promote healthy living in older age.

As the population ages we need new approaches to understanding the biology of health, ageing and how it relates to frailty and disease.

Nano-enabled Healthcare Technology Facility: Nano-enabled technologies continue to offer great potential to the Health and Life sciences market, and rapid advances are being in the field of targeted therapeutics and diagnostics. However the life sciences environment is highly regulated one, and there is a need within the innovation pipeline for investment in improved good manufacturing practice (GMP) facilities that can provide the practical and technical support specific to production of nano-enabled technologies, that will enable the next generation drug delivery systems.

National Facility for Medical Robotics: Medical robotics is a rapidly developing field with commercial growth of around 50% annually worldwide. The UK has a strong track record in pioneering medical robotics both technically and clinically. Research into surgical robotics is intrinsically multi-disciplinary, involving not only collaboration between clinical and engineering specialists, but a very wide spectrum of engineering and science technologies. Investment in a national preclinical research facility will ensure that the UK’s research can have a direct clinical translation impact with a significant potential in establishing an international niche in the medical devices sector for the UK.

Regenerative Medicine: is set to transform cell- and tissue-based therapies. Tissue engineering is the generation of a renewable source of transplantable tissue by combining the principles of engineering, physical science and medicine. Scientists are pursuing both replacement and regeneration techniques for repairing human tissue. Capital investment in high throughput & automated technologies for safety assessment of cells, for preclinical work and scale-up for drug screening and toxicology are required, in addition to investment in new technology for discovery, for the UK to retain its world-leading position.

Estimates have been made that the predicted commercial market for tissue engineered products will rise exponentially. Some estimates have been made that predict the value of the cell therapy industry could rise from circa £250M in 2008 to over £20Bn by 2025.
3.4 POPULATION CHANGE AND DIVERSITY

The challenges facing human populations are highly complex and diverse, and the capacity to unravel and understand them is driven by the availability of high quality data, ranging from the DNA sequencing and socio-economic databases through to information on climate change and zoonotic diseases. The challenge that lies ahead is how best to capture and connect the wide range of disparate data sources which are fundamental to driving innovative, interdisciplinary research and fuelling social, economic and cultural prosperity. Capital investment is needed to continue investment in the UK’s internationally renowned longitudinal datasets, and to create new integrated large scale databases to explore the dynamics of population change and diversity.

The UK has world-leading data infrastructure in many areas including social, behavioural, health and population based data. Unprecedented opportunities now exist to enhance these resources through data sharing and combining data to generate new knowledge; this will drive research discovery; spur on innovation and growth; to improve policy interventions; and fuel public service reform.

The appetite for opening up and integrating data has never been greater. Reports from the Royal Society and the Organisation for Economic Co-operation and Development (OECD) Global Science Forum15 underline the critical need to share data and exploit data in new ways in the face of global social and economic challenges. The Government’s own commitment to ‘open data’ provides an major opportunity to enhance existing large data resources and build new ones. Rapid developments in information and communication technologies continue to create opportunities to link and re-interpret historic population data and to harvest, store and harness for research purposes other sources of increasingly ‘born digital’ data either already held by organisations or generated in experimental settings as well as the oceans of information spread across the web. Capturing and converting these vast bodies of information into knowledge has the potential to fundamentally revolutionise our understanding of our society, helping to promote social and economic prosperity through greater transparency.

The study of human and animal populations is complementary; understanding animal populations underpins and informs not only our understanding of human populations but our knowledge of major livestock species and their care. The association between mankind and wild and domesticated animal species is a key factor in the development of civilisation and society since earliest times. Zoonotic diseases – infections transmitted from animals to humans – represent some of the most dangerous threats to mankind at present and understanding how the movement of animal populations and their interaction with human populations contributes to epidemiology is of vital importance.

Working with data routinely generated to support the activities of public sector bodies for example, patient health records; tax records; job seekers allowance; and educational progress is challenging. The linkage of this data would radically enhance the capacity to understand social economic change and human behaviour as well as to inform public policy and drive excellence in public services. However, ensuring these data are anonymised and the identity of individuals is protected remains a major legal, cultural and technical challenge.

A similar challenge exists with private sector organisations which hold huge customer datasets - for example, loyalty cards; mobile phone records; energy usage data, and information on how they themselves operate and perform. These can be reluctant to share data even when it is no longer commercially sensitive but could of considerable research value in understanding the drivers behind lifestyle choices, consumer behaviour, economic performance, innovation and growth.

Our priorities for the developing the UK population data infrastructure include the Biomedical Informatics Institute mentioned in the previous section and the following:

**Administrative data centres:** To drive forward responsible data sharing it will be imperative to establish a national network of Administrative Data Centres. Overseen by a series of data access advisory boards, the centres will facilitate the anonymised linkage of personal administrative records in safe and secure settings. Using public data drawn from right across government the centres will they to provide critical new insights for combating poverty, poor mental and physical health and the drivers of criminal behaviours.

**Business data:** The formation of new private sector organisations will be critical to fuelling economic recovery and driving forward future UK innovation and growth. Yet our understanding of how successful new organisations are created, operate and succeed in the face of fierce global competition is hampered by fragmented and underutilised information about their structure, activities and performance. There is a pressing need to bring together and provide new software tools to support enhanced access to core organisational survey data such as the Workplace Employment Relations Survey, the Annual Survey of Hours and Earnings, UK Innovation Survey (UKIS) and the National Employer Skills Survey. This must be accompanied by the creation of new data resources, including facilities that will support access to customer databases and held by major retailers, utilities and other companies to understand customer choice and behaviours and to more effectively target goods and services.

**Longitudinal studies:** The UK has a unique, world-leading collection of longitudinal studies spanning 65 years which follow the life trajectories of families and individuals. New investments such as the Life Study will strengthen this series bringing together social, economic and biological measures to deepen our understanding of early childhood health and development. The enhancing of other studies, including the Millennium Cohort and Understanding Society, through the for example large scale addition of biological samples and responsible linkage to administrative data sources with radically extend our capacity to understand the key influences that affect people’s life chances and shape policy intervention to improve life outcomes.

**Materials collections and data:** Making research data and materials available to users is essential to deliver faster progress in research, better value for money and higher quality research. RCUK has developed data policy principles and is committed to promoting greater access to and use of data in ways that are equitable, ethical and efficient. Specific capital investment is required to catalyse progress.
3.5 ENERGY

RESEARCH IS THE KEY TO ACHIEVING AN AFFORDABLE LOW-CARBON ENERGY FUTURE, while preserving our natural resources, the environment, and our quality of life. The UK commitment and investment in renewable energy research and deployment has helped to make renewable energy possible. Now we have a different challenge. We need to ensure that renewable energy is sustainable from an ecosystem, societal and financial perspective. Capital investments in cutting edge research facilities and small scale demonstration projects are vital to make low carbon and renewable energy sources financially sustainable.

Science and engineering research is the key to achieving an affordable low-carbon energy future while preserving our natural resources, the environment and our quality of life. The £0.5Bn energy portfolio covers the gamut of speculative and user-led energy research, from carbon capture to biofuels, solar, tidal and wind energy to low-carbon transport.

Renewables (including biorenewables and bioenergy) are now the world’s fastest growing energy source. The UK has played a leading role at the forefront of this green energy revolution through our world-leading research and industrial base in low carbon technologies leading to job and wealth creation for the UK. We have gone from virtually no capacity for (bio) renewables, to seeing them provide almost 10 per cent of total UK electricity needs in 2011. This is due not just to advances in the understanding of the technologies themselves but also in the manufacturing processes which enable the infrastructure to be produced. Both aspects are enabled by the UK Research Base.

Energy research is the key to achieving sustainable renewable technologies, a major component being the creation of cutting edge research facilities through targeted capital investment in areas such as nuclear; off-shore wind; fuel cells; as well as solar and bioenergy capability and carbon capture and storage (CCS). Farm and landscape-scale experimental platforms will provide the capability to study the mechanisms whereby carbon is retained in soils – the largest natural mechanism for CCS. The capital investments required are addressed in section 4.2.

Nuclear Energy research is a key focus for the Research Councils. A report commissioned by the Technology Strategy Board found that in order for the UK to maintain its nuclear industry heritage and status as well as benefit from the global nuclear renaissance, public sector investment in R&D and technology development will be essential and can be justified.

Thus, capital investments in cutting edge research facilities and small scale demonstration projects, coupled with the support of projects to accelerate the deployment of alternative energy technologies are vital to make low carbon energy sources financially sustainable.

Biofuels and Bioproducts: The development of crops as both biofuels and as the source of substitutes for petrochemicals in manufacturing requires demonstration-scale field and processing facilities and biorefineries. These would not only enable improvements in the productivity of bio-energy crops but allow consideration of the management of environmental impact and

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the development of harvesting, transportation, processing and manufacturing technologies. Contained photoreactor facilities e.g. for algal and bacterial light energy conversion studies are needed to advance technologies to harness the exceptional capability of light-harvesting organisms to convert solar energy to useable power sources.

**Carbon capture and storage (CCS):** In partnership with the DECC, RCUK recently announced a £13M investment to establish a UK CCS Research Centre that will enable academics, industry, regulators and others to co-develop improved CCS technologies. Further capital investment in this area to demonstrate the viability in both capture and storage technologies, such as injection facilities will enable the efficient deployment of new technologies in an area where the UK lead could deliver a vast overseas market.

**Energy production – nuclear, solar, off-shore wind:** Capital investment in a new Materials Research Facility (MRF) for fusion and fission R&D, for use by universities and industry, as new nuclear build takes place in the UK, would potentially give the UK a lead in this vital area. A solar device test facility, based at a leading solar research centre within the UK would enable the UK strengths in photonics to be exploited in the production of cost-effective photovoltaic devices. A floating off-shore deep water wind turbine test facility would enable the development of the next generation of deep water deployment wind turbines.

**Energy Storage for the Nation:** UK electricity demand peaks at around 60 GW, whilst we generate around 400,000 GWh a year in the UK. Accelerating the development of national scale electricity storage promises massive benefits – in terms of savings on UK energy spend (up to £10Bn a year by 2050); environmental benefits; and enabling UK business to exploit these technologies internationally, while reducing this country’s carbon footprint to a level that would set standards within the western world. Capital investment would create dedicated R&D facilities to develop and test new grid scale storage technologies, integrated within a new UK Centre for National Scale Energy Storage. This will bring together industrial partners and academia to ensure we make the most of the advantages brought by our exceptional research and technology base in this field.

**Fuel cells for automotive applications:** The UK’s technology leadership, at the forefront of advanced energy storage materials research, would be further enhanced through a material scale/pilot line facility to enable promising chemistries to move from small scale ‘gram’ level fabrication at university laboratory level to ‘kilogram’ level suitable for battery/vehicle testing. A facility that enabled this scale-up would act as a focal point and catalyst for aligning academic research, with industry needs maintaining companies at the leading edge of technology with its associated benefits to the UK economy.
3.6 MANUFACTURING: FROM ATOMS TO AEROPLANES

THE UK’S FUTURE ROLE IN MANUFACTURING IS DEPENDENT ON THE UNIVERSITY RESEARCH BASE creating new opportunities. As pace gathers to rebalance the economy from the financial sector towards technology-led innovation, these areas of research must once again take centre-stage. The opportunity for growth arises from the continuous development and exploitation of new technologies. Research that underpins manufacturing is highly capital intensive and very dependent upon advanced instrumentation; lack of state-of-the-art infrastructure will be a key limiting factor if upgrades and new instrument development does not keep pace with our competitors.

There is a spectrum of research that underpins the UK’s economy, from fundamental, high-risk Physical Sciences research, through Engineering research targeted at global challenges and shaping people’s lives, to research leading to the development and deployment of new manufacturing technologies. Approaching £300M is invested per annum in these research fields.

Manufacturing is a cornerstone of the Government’s growth agenda. The BIS Growth Review Framework for Advanced Manufacturing identified that “Manufacturing is the UK’s third largest sector in the market economy, after business services and retail in terms of share of UK GDP. In 2009, manufacturing contributed some £140 billion in gross value added to the economy and employed some 2.6 million people. The UK is the sixth largest manufacturer globally by output, and a leading exporter of technology intensive manufacturing goods.” The UK’s future role in manufacturing is dependent on the research base creating new opportunities.

A recent survey by employment specialist Giant Group indicated that engineering companies are performing better than the average across all sectors of the UK economy. The focus on future infrastructure, energy, manufacturing and automotive sectors has strengthened the outlook for British engineering businesses. The Engineering UK 2012 report also highlighted the value of the engineering sector, stating: “It generated £1.15 trillion in turnover in the year ending March 2010: 24.9% of the turnover of all businesses in the UK. The sector also employed 5.6 million people across 551,520 enterprises.”

Independent evaluations, including an economic impact assessment by DTZ Consultancy, have shown the value of manufacturing research to the UK economy and society. This work estimates that gross impact is sixteen times the investment and that, given time, the overall impact is likely to further increase. It also concluded that a significant number of new technologies and products were brought to market as a result of the funding. Investment into the research base is vital for stimulating future economic growth in the UK. One example is Additive Manufacturing, where the UK has one of the most established research bases, making the UK a centre for early technology investigation and adoption.

The understanding of physics and chemistry at the atomic level is fundamental so that potential phenomena can be exploited across the relevant industrial sectors that are key to the UK economy. The potential impact of this fundamental research is wide ranging, leading to developments in areas such as quantum technologies, healthcare, catalysis, energy generation and sustainability.

Capital investment has a major role to play to enhance university research capabilities that underpin a range of sectors. The development of novel/innovative manufacturing technologies will usually require a combination of bespoke and specialist instrumentation. Much of the equipment – particularly for

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17 Press release (09 May 2012): Number of engineering businesses falls just 2.3% since start of economic downturn (Giant Group).
18 www.engineeringuk.com/what_we_do/education_-_skills/engineering_uk_12.cfm
laboratory-scale and pre-production concept demonstrators – is beyond that which is expected for a typical “well found” laboratory. In addition, continuous investment is needed in small but fundamental items of equipment. Human resource will drive much of the discovery but the lack of state-of-the-art infrastructure will be a key limiting factor if upgrades and new instrument development does not keep pace with our competitors.

There are many important research challenges in this theme, some of which are indicated below.

The UK has an emerging strength in continuous/flow chemical production, which represents a paradigm shift from traditional “batch based” production for high value chemical products. There is a real opportunity to position the UK as a leading centre which can increase competitiveness of UK chemical and pharmaceutical manufacturers. In addition, the successful design and implementation of catalysts has been at the heart of the chemical processes operated so successfully within the UK. Innovation in catalysis is core to meeting many of the key questions facing society as a whole today i.e. energy, sustainability, reduction of atmospheric CO2 and efficiency of water utilisation.

Advanced Materials innovation and fabrication is instrumental in the generation of long-term economic growth and jobs for the UK. Investing now in an integrated fashion will help generate a new wave of materials innovation, thus enabling a broad range of UK industrial sectors to benefit directly. The design, fabrication, characterisation, processing and manufacturing of advanced materials systems requires sophisticated imaging, metrology and materials characterisation capability. The field of metamaterials (a combination of metallic or semiconductor materials, advances in nanofabrication technologies, and transformation optics can lead to novel artificial media which can control and manipulate light in unexpected ways) is at a vital stage in its growth, with a rapidly expanding fundamental science base, exciting links and synergy with graphene research, and huge opportunities to begin to transform the science into new technologies, with potential major impacts on telecommunications, security, biomedical and bio-sensing. The UK is already a world leader in this area and investment in this next phase would cement our position. Composites manufacturing research in the UK has a high international recognition and has also been identified as a critical enabling technology in developing a low energy economy, for instance in weight reduction in transport applications. This aligns to the High Value Manufacturing (HVM) Catapult through the National Composites Centre.

Industrial biotechnology is rapidly expanding the areas of manufacturing where biological processes and materials can provide new or alternative raw materials, processes and products, underpinning a move from a hydrocarbon-based manufacturing economy to a more sustainable carbohydrate-based one. Application areas include chemicals and pharmaceuticals, textiles, construction materials, packaging, mining, electronics, food and animal feed, and substitutes for petrochemicals, rare metals and minerals and animal products. Research in this sector requires access to a wide range of bioscience research tools (including sequencing, proteomics, imaging and small molecule synthesis) large facilities access, and access to bioreactor and other scale up facilities, extensive modelling resources and a truly interdisciplinary research environment.

**Autonomous Robots:** Robots acting independently of human control – which can learn, adapt and take decisions – will revolutionise our economy and society. The UK is well placed to take a lead in developing these technologies for sectors as diverse as healthcare, manufacturing and aerospace. The UK has world-leading strengths in the underlying science and engineering contributing to these systems, and there is strong industrial demand for research. Current research partners include BAE Systems, DSTL, Schlumberger, Ford, Rolls Royce and Airbus. Capital investment, aligned with industry contributions of a similar scale, will provide centres of excellence with the cutting edge facilities and training to ensure the UK provides an attractive home for the robotics industry of tomorrow.
As pace gathers to rebalance the economy from the financial sector towards technology-led innovation, these areas of research must once again take centre-stage.

‘Dial-a-molecule’: The vision is that in 20-40 years, scientists will be able to deliver any desired molecule within a timeframe useful to the end-user, using safe, economically viable and sustainable processes. At the moment, making complex molecules can take many man-years and can act as the rate-limiting step in developing products. High-throughput automated hardware and software for carrying out and studying reactions will allow fast efficient access to innovative products with novel functionality, and will ultimately enable industry to deliver them using effective sustainable processes.

Innovative production technologies: The UK’s future role in manufacturing is dependent on the research base creating new manufacturing opportunities – examples where research is starting to achieve industrial deployment include additive manufacturing, net shape manufacturing and industrial biotechnology. Manufacturing research, like manufacturing itself, is highly capital intensive and very dependent upon advanced instrumentation. The development of novel/innovative manufacturing technologies will usually require a combination of bespoke and specialist instrumentation to address manufacturing issues such as repeatability, quality control, cost effectiveness, safety, scalability and adaptive design. Much of the equipment – particularly for laboratory-scale and pre-production concept demonstrators – is beyond that which is expected for a typical “well found” laboratory. Areas of opportunity include advanced metrology, flow production, laser processing systems, resource efficient technologies, non-destructive evaluation and multifunctional additive layer manufacturing.

Nanofabrication: UK centres for research in nano-device engineering, fabrication and characterisation have an internationally leading reputation. Areas of opportunity include:

- The development of III-V semi-conducting materials (such as gallium nitride), their commercial importance is reinforced by the high-value markets where the technologies play a significant part. New low-cost manufacturing methods for light-emitting diodes based on UK research are now being pioneered by Plessey in the UK. A major opportunity also exists in the integration of “other materials” directly onto silicon chips. Absolutely crucial to maintaining world class activities semiconductors is the provision of state-of-the-art equipment and facilities for the characterisation of material and the fabrication into functional devices.
- The capability to accurately characterise other functional materials (magnets, ferroelectrics, polymers and composites etc). These materials will impact critical issues such as energy, healthcare and information technology. Infrastructure requirements include specialised materials preparation facilities and a suite of electron microscopy (transmission electron microscopy/scanning electron microscopy), atomic force microscopy, X-ray spectroscopy, nano-metrology facilities and specimen preparation laboratories.
- Nano-enabled technologies continue to offer great potential to the Health and Life sciences market, and rapid advances are being in the field of targeted therapeutics and diagnostics. However the life sciences environment is highly regulated one, and there is a need within the innovation pipeline for investment in improved GMP facilities that can provide the practical and technical support specific to production of nano-enabled technologies, that will enable the next generation of drug delivery systems and agents for image contrast improvement.

National Fluid Mechanics Facility: UK has a prestigious tradition in fluid mechanics and remains a world leader in this field. For experimental work, wind tunnel provision needs to be rationalised and co-ordinated to provide state of the art shared experimental facilities with a complete range of capabilities, available for both academic and industrial users. This will drive innovation across a broad range of sectors (aerospace, automotive, civil, chemical, marine, energy, environmental, medical). Such experimental facilities are capable of generating huge amounts of data which requires e-infrastructure and network capacity for data storage and analysis. Besides experimental studies, modern fluid dynamics research also relies on computational modelling using the UK’s HPC infrastructure.
SYNTHETIC BIOLOGY HAS THE POTENTIAL TO DELIVER IMPORTANT NEW APPLICATIONS and improve existing industrial processes – resulting in economic growth and job creation. Synthetic Biology is the design and engineering of biologically based parts, devices and systems as well as the redesign of existing natural biological systems for useful purposes. Industrial sectors positioned to benefit from synthetic biology approaches include energy, chemicals and healthcare.

The UK Synthetic Biology Roadmap\(^\text{20}\) highlights a host of features that taken together make the UK an excellent place to progress the area. These include: a healthy ecosystem for new and established businesses; a strong academic base in synthetic biology linked to a very strong innovation culture and heritage across the life sciences, engineering and physical sciences; and a strong internationally networked industrial base in application areas for synthetic biology. However, there are significant gaps in the availability of and access to cutting edge infrastructure that undermines these other success factors and that in time will seriously weaken the UK’s overall competitive position. This was explicitly recognised in the UK roadmap and its first, key recommendation: ‘to invest in a network of multidisciplinary centres to establish an outstanding UK synthetic biology resource…. sufficient resources should be deployed within the UK to ensure availability of research capacity and a full spectrum of essential facilities.’

\(^{20}\) A synthetic biology roadmap for the UK (2012) RCUK publication.
Funding for synthetic biology research has been consistently applied by the UK Research Councils since 2007 and it now totals more than £62M. Building a network of multidisciplinary centres and ensuring availability of a full spectrum of essential facilities will require new ways of working between researchers in academia and industry working within a frame work of responsible, open innovation. Investments should play to UK strengths and input from the synthetic biology innovation community has identified a broad range of needs of which some are:

- facilities dedicated to synthetic gene synthesis and synthetic chromosome assembly
- a central repository for synthetic genes and engineered organisms
- design methods and tools: high-throughput screening, analytical methods, improved cellular control systems
- synthesis techniques: DNA synthesis technologies, DNA sequencing and synthetic genomes
- computation, modelling, data: Bioinformatics, engineering and computational modelling (e.g. CAD)
- extension and refurbishment of existing facilities including new wet and dry labs and work areas designed for product development and responsible innovation.
- scale up facilities – such as pilot plants
- fully technically supported user access entry-level ‘incubator space’
- a biorenewables robotics platforms incorporating automated colony picking, cell growth, enzyme isolation and enzyme analysis, automated sample preparation and analysis by gas chromatography mass spectrometry (GCMS), liquid chromatography mass spectrometry (LCMS) and NMR
- enclosed photobioreactor systems and pilot plants for algal biorefinaries and production platforms.

New capital investment for synthetic biology should seek to capitalise on existing complementary cutting edge infrastructures.

New capital investment for synthetic biology should seek to capitalise on existing complementary cutting edge infrastructures.

**Synthetic Biology – Harnessing the Bioeconomy Revolution:** New capital investment for synthetic biology will build on existing complementary cutting edge infrastructures including DNA sequencing and the major UK investments in e-infrastructure and in bioinformatics facilities. This will underpin the development of centres of excellence – to build our skilled research community and to accelerate technology to market – to ensure that we maintain the UK’s competitiveness in this key technology as it bursts into the market.
ANNEX I:
Capital Investment Consultation overview

To inform the development of this Framework, RCUK invited views on capital investment needs for the nation from those working in UK universities, research organisations and wider research and business (February to May 2012).

Respondents were invited to comment on:
- significant capital investments required in the next 10 years to ensure a sustainable national capability for research; and
- key challenges in ensuring this capital investment.

Three-hundred responses were received to the consultation, and a summary of these (by sector) is shown below (multiple submissions were made by many organisations – not shown).

Responses to the consultation have been used to develop all aspects of the RCUK Framework, and have informed the preparation of case studies and examples highlighted for future investment presented in the document. Particularly strong responses (volume and breadth of need) were received in relation to: e-infrastructure (including HPC and data storage); refurbishment projects to maintain capability; training & capacity development; the development of research tools; Biobanks; state of the art facilities & technology platforms; imaging including microscopy, mass spectrometry, NMR and MRI; and Synthetic Biology.

Research Councils have, and will, continue to use the valuable information submitted to the consultation to further develop detailed submissions and advice to UK Government for priorities for Capital Investment.

ANNEX II:
Advisory Group and Project Team details

Project Board and Team members:
- Dr Alf Game (BBSRC)
- Dr Anne-Marie Coriat (MRC, Chair of RCUK Research Group)
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- Dr Michael Schultz (NERC)
- Dr Saffron Townsend (RCUK Strategy Unit)
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- Miss Sarah Townsend (RCUK Strategy Unit)

External Advisory Group members:
- Mrs Alison Starr (GE Aviation, EPSRC Strategic Advisory Network)
- Professor David Boxer (Institute of Food Research)
- Professor George Lafferty (University of Manchester, STFC Science Board)
- Professor Geraint Vaughan (University of Manchester, NERC Science and Innovation Strategy Board)
- Professor Hugh Perry (University of Southampton, Chair MRC Neurosciences and Mental Health Board)
- Professor John Hobcraft (University of York, ESRC Strategic Advisor)
- Professor Martin Dove (Queen Mary University, London, STFC Science Board)
- Professor Mike Goosey (BBSRC Council)
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- Professor Stephen Hill (University of Nottingham, MRC Molecular and Cellular Medicine Board)
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