Department
for Business
Innovation & Skills

CREATING THE FUTURE: A 2020 VISION FOR SCIENCE & RESEARCH

A Consultation on Proposals for Long-Term Capital Investment in Science & Research

APRIL 2014

Contents

Issued: 25 April 2014

Respond by: 4 July 2014

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This consultation is relevant to: the UK science, research and innovation communities.

Ministerial Foreword

1. Our ambition is to make the UK the best place in the world to do science and research. Science and research push back the frontiers of human knowledge, support the wealth and welfare of the nation, and contribute to our cultural richness.

2. With four of the world's top ten universities, and more Nobel prizes per capita than any other large nation, the UK punches well above its weight in terms of its research excellence. Only a handful of countries can compete with us in terms of the strength, breadth and depth of our scientific activities.

3. The UK will continue to support fundamental, curiosity-driven research, ensuring that research contributes to tackling the global and societal challenges we face. We already have a strong international reputation for the quality and range of our research facilities, but keeping up in the global race means maintaining this lead into the 2020s and beyond.

4. This is why the Government has made a long-term commitment to investment in science and research infrastructure: increasing capital investment in real terms to £1.1 billion in 2015-16 and growing this in line with inflation each year to 2020-21.

5. This unprecedented long-term capital commitment provides the ideal opportunity to take a strategic view of our world-leading science and research infrastructure. The stability generated by this long-term investment creates confidence, attracts world class researchers and research projects, and creates opportunities for leverage of investment from businesses, charities, and other sources. It enables us to plan and invest in large and long-term projects that would not otherwise have been possible.

6. We must maximise the benefit afforded by this unique opportunity for science and research. The aim of this consultation is to ensure the UK makes the most of this unprecedented opportunity by identifying strategic priorities for long-term science and research capital investment. We welcome your views on how best to take advantage of this historic opportunity.

Executive Summary

7. Our ambition is to make the UK the best place in the world to do science and research. This is why the Government is making a long-term commitment to invest in science and research infrastructure: increasing capital investment in real terms to £1.1 billion in 2015-16 and growing it in line with inflation each year to 2020-21.

This consultation seeks views on how the UK makes the most of this opportunity.

8. The Government will publish a Science Capital Roadmap, setting out its long-term strategic vision for a world-leading science and research infrastructure in the autumn. We are seeking evidence on two key questions in order to inform the development of this roadmap:

Q1: What balance should we strike between meeting capital requirements at the individual research project and institution level, relative to the need for large-scale investments at national and international levels?

9. Our world class research environment is underpinned by funding for the capital requirements of individual research projects and institutions, (ie. research institutes and universities). This investment is delivered through Research Councils UK (RCUK) and the four Higher Education (HE) funding bodies. To complement this, strategic decision making at the national and international level is often required to coordinate investments in the national interest. This consultation seeks views on how to balance these complementary needs.

Q2: What should be the UK's priorities for large scale capital investments in the national interest, including where appropriate collaborating in international projects?

10. The impressive strength and breadth of the UK research base means that we are presented with a huge range of potential investment opportunities. Demand inevitably outstrips funding. Therefore, there is a constant need to prioritise, and this consultation seeks your views to inform our approach. These strategic judgements require us to look first at what international competitors are investing in, and identifying where it is in the UK national interest to collaborate in international infrastructure projects. This may involve significant contributions to projects around the world or hosting them in the UK. Building on the recent RCUK Strategic Framework for Capital Investment, Investing for Growth, this consultation then seeks views on which of the important projects laid out in this consultation should be the highest priority, asking also **whether there are new potential high priority projects not identified here**.

Scope

11. The Government is committed to the Haldane Principle (Annex B1), recognising the role of Ministers in decisions on the distribution of funding between the Research Councils, the National Academies and Higher Education research funding; and in decisions that involve long term and large scale commitments of national significance. This

consultation seeks views to inform such decisions, noting that the geographical coverage of this consultation matches the geographical coverage of the long-term capital budget: **This is a UK-wide consultation about a UK-wide investment programme.**

12. Whilst this consultation focuses on capital infrastructure, a flexible highly-skilled workforce with state of the art technical skills and research leadership is required to enhance the excellence of the research base. Investment in skills, capability and resource to underpin capital investment are all crucial to the sustainability of research excellence and contribute to making the UK an attractive place to invest and grow businesses. The Government recognises that sustainability is a critical criterion in identifying capital investment priorities. Full consideration needs to be given to resource costs, ie. both operational costs and the research costs of using the infrastructure to its maximum potential – mindful of the need to balance capital intensive research with other potential calls on resource funding. In some cases this will be compensated by capital or resource savings through closing older, less technologically advanced infrastructures – renewal which is vital to ensuring the ongoing competitiveness of the UK research community.

13. While capital budgets have been set to 2021, resource budgets beyond 2016 will be considered as part of the 2015 Spending Review, (as with other areas of Government resource spending). Consequently, this consultation does not in itself represent a commitment to funding; rather, responses will inform the Science Capital Roadmap and decisions will be subject to the development of satisfactory business cases.

How to respond

14. When responding please state whether you are responding as an individual or representing the views of an organisation. If you are responding on behalf of an organisation, please make it clear who the organisation represents and, where applicable, how the views of members were assembled.

15. You should reply to this consultation using Citizen Space via: https://bisgovuk.citizenspace.com/digital/consultation-on-proposals-for-long-term-capital-in

16. Consultation opens on 25th April 2014, closing on 4th July 2014

17. You may make printed copies of this document without seeking permission.

18. BIS consultations are digital by default but if required printed copies of the consultation document can be obtained by emailing:

    science.capital@bis.gsi.gov.uk

Confidentiality & Data Protection

19. Information provided in response to this consultation, including personal information, may be subject to publication or release to other parties or to disclosure in accordance with the access to information regimes (these are primarily the Freedom of Information Act 2000 (FOIA), the Data Protection Act 1998 (DPA) and the Environmental Information Regulations 2004). If you want information, including personal data that you provide to be treated as confidential, please be aware that, under the FOIA, there is a statutory Code of Practice with which public authorities must comply and which deals, amongst other things, with obligations of confidence.

20. In view of this it would be helpful if you could explain to us why you regard the information you have provided as confidential. If we receive a request for disclosure of the information we will take full account of your explanation, but we cannot give an assurance that confidentiality can be maintained in all circumstances. An automatic confidentiality disclaimer generated by your IT system will not, of itself, be regarded as binding on the Department.

Help with queries

21. Questions about the policy issues raised in the document can be addressed to: science.capital@bis.gsi.gov.uk

Introduction

22. From life-saving anti-cancer drugs to the global information superhighway, science and research underpin social and economic progress. This is driven by the natural human instinct of curiosity: How does that work? What would happen if I did this? Intellectual inquiry for its own sake is a public good and brings many benefits by leading us to the unexpected.

23. Today we take for granted technology that would have been science fiction only a few decades ago. The world marvelled at Arthur C Clarke's vision of a newspad in his 1968 novel 2001: A Space Odyssey (see box). You may now be reading this consultation on one. Yet the researchers who made this possible weren't, until very recently, trying to create one of the world's most successful consumer products. They were driven by curiosity – because research is interesting and worthwhile in and of itself.

The Economic Case for Science and Research

24. With science and research shaping the future in this way, the economic case for investment in science and research is overwhelming. As Vannevar Bush argued in Science, The Endless Frontier[1], basic research is *"the pacemaker of technological progress"*. The critical role of the state in investing in the nation's science and research infrastructure is clear.

25. Similarly, the evidence on the impact of R&D expenditure on economic growth overwhelmingly points to varied but high returns. Solow (1957)[2] proposed that economic growth was, in the long run, driven by technological growth through its positive impact on labour productivity. The new growth literature emphasises the role of technological change in boosting growth: Aghion and Howitt (2007)[3] estimate that Total Factor Productivity (a measure of technological change) accounted for about 70% of UK economic growth between 1960 and 2000. Economic growth theory holds that long-run growth rate is driven by the rate of technological change, which is in turn driven by investment in R&D – ie. investment in R&D determines long-term growth.e case for investment is clear. It is reflected in this Government's promise in Spending Review

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[1] *Vannevar Bush, 1945. "Science, the Endless Frontier: a Report to the President".*
[2] *Robert M Solow, 1957. "Technical Change and the Aggregate Production Function".* Review of Economics and Statistics *(The MIT Press)*
[3] *Philippe Aghion & Peter Howitt, 2007. "Capital, innovation, and growth accounting," Oxford Review of Economic Policy, Oxford University Press, vol. 23(1), pages 79-93, Spring.*

2013[4] of a long-term capital settlement for science and research infrastructure.

"When he tired of official reports and memoranda and minutes, he would plug in his foolscap-size newspad into the ship's information circuit and scan the latest reports from Earth. One by one he would conjure up the world's major electronic papers... Switching to the display unit's short-term memory, he would hold the front page while he quickly searched the headlines and noted the items that interested him." Arthur C Clarke, 2001: A Space Odyssey

The technology that enables this comes from years of research in many initially unrelated fields:

- **Flat screen display technology:** George Gray from Hull University invented the first stable liquid crystal in the 1970s -then used in mobile displays. More recently Cambridge University developed light emitting polymers. Displays made from these are thinner, brighter and more efficient.
- **Touch screen technology:** The first touch screen devices were invented in the 1960s and 1970s at the Royal Radar Establishment and CERN, for use in air traffic control systems and as a way to control particle accelerators respectively. Hand-held touch-screen technologies started to really take off in 1990s and subsequently with the Apple iPhone in 2007.
- **World Wide Web:** Work on data transfer protocols led to Tim Berners-Lee inventing the World Wide Web in 1984 with the underpinning software and standards made freely available to all in 1993.
- **Wireless data transfer:** A mobile device works as an extremely sophisticated radio. In 1864 physicist James Clerk Maxwell published his theory of electromagnetism. Heinrich Hertz realised that if these ideas were right then it should be possible to send and detect electromagnetic radiation. The devices he built confirmed Maxwell's theory and are the precursors of the antennae in mobile devices.
- **GPS:** Originally created for military application in the 1960s and 1970s, GPS use for wider purposes surged in 2000s.
- **Battery:** The lithium Ion batteries introduced in mobile phones in the 1990s came from research at Oxford University, and Peter Wright's discovery of the first solid polymer electrolyte at University of Sheffield in 1973 is key to developing even smaller, lighter, solid-state batteries.
- **Plastic case:** Around 1870 Adolf von Baeyer discovered formaldehyde and phenol react to form a gooey material. Thirty years later chemist Leo Hendrik Baekeland used this research in his hunt for a substitute for natural shellac then used to insulate wires. He produced the first fully synthetic plastic in 1909.

[4] *https://www.gov.uk/government/topical-events/spending-round-2013*

29. This consultation explores how Government should deliver this landmark investment, seeking views to shape a Science Capital Roadmap, to be published as part of a wider Science and Innovation Strategy with the Autumn Statement 2014.

Commitment to the UK Research Base

30. The UK is widely recognised as punching well above its weight in terms of its research excellence. While the UK represents just 1% of global population, 4% of researchers and 3% of R&D expenditure, it accounts for over 6% of published articles, just under 12% of citations, and 16% of the world's highest quality articles. And this is a story of growth. The UK's share of the top 1% most cited publications in the world increased from 15% to 16% from 2008 to 2012. The UK's research base is remarkable for its strength and depth across a huge breadth of research fields. Only a handful of countries can compete with the UK in terms of the breadth of its research excellence.

31. In the global knowledge economy the UK must continue to support fundamental, curiosity driven research, and also ensure that, where possible, research contributes to tackling the challenges facing businesses and public services. Our research base plays a pivotal role in supporting our industrial strategy, for example through the commitment to the "eight great technologies[5]". UK research already has a strong international reputation for the quality and range of its research facilities, but keeping up in the global race means maintaining this strength in the depth and breadth of the UK research base into the 2020s and beyond.

32. With a long-term capital budget for science and research, the Government is committing to building the science and research infrastructure of the 2020s.

33. As the House of Lords' Select Committee on Science & Technology recognise in their 2013 report, Scientific Infrastructure[6], "sustained and efficient future investment in scientific infrastructure [is essential] to ensure that UK research is able to remain internationally competitive" and "efficient investment in scientific infrastructure requires long-term planning and transparent decision making".

34. In return for the Government's long-term commitment, comes a challenge to the research community. Greater investment requires

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[5] *http://www.policyexchange.org.uk/images/publications/eight%20great%20technologies.pdf*
[6] *http://www.publications.parliament.uk/pa/ld201314/ldselect/ldsctech/76/7602.htm*

greater collaboration, better equipment sharing, and improved access for industry – ie. making the nation's science even more accessible. The research base must also do more to leverage business and charity funding, and to ensure that efficiencies are realised. This consultation also explores how meeting this challenge will allow us all to gain maximum benefit from this investment.

Key Decisions

Q1: What balance should we strike between meeting capital requirements at the individual research project and institution level, relative to the need for large-scale investments at the national and international levels?

35. The total science and research capital budget envelope will rise to £1.1bn pa in 2015-16, rising in line with inflation to 2020-21. With the 2015-16 budget already fully committed, this consultation focuses on the five year budget covering 2016-21, **the total size of which is £5.9bn**.

36. Section 1 of this consultation examines how this budget provides the opportunity to commit to the provision of a **world class research environment** in the UK. It focuses on investment at the individual research project and institution level, through the Research Councils and Higher Education (HE) funding bodies. The role of collaboration, equipment sharing, accessibility, and leverage of investment from businesses, charities and other sources is also explored.

37. Section 2 of this consultation sets out how this needs to be balanced against the need for large-scale investments at the national and international levels. It considers some of the current priorities for investment in **major national and international projects**. This involves the Research Councils and UK Space Agency, with strategic decision making at the Government level.

38. Striking the right balance between these spending channels is a strategic judgement. This consultation seeks views on what this balance should be from 2016-21, and what factors should be taken into account in making this judgement.

39. For illustrative purposes, science and research capital budget allocated through these three routes (Research Councils; HE funding bodies; major projects) has varied over 2011-15 as follows[7][8][9][10][11]:

- Research Councils (excluding major projects): from £240m in 2011-12[12]; to £192m in 2014-15[13]

[7] *http://www.bis.gov.uk/assets/biscore/science/docs/a/10-1356-allocation-of-science-and-research-funding-2011-2015.pdf*
[8] *https://www.gov.uk/government/publications/budget-2011*
[9] *https://www.gov.uk/government/publications/autumn-statement-2011*
[10] *https://www.gov.uk/government/publications/budget-2012*
[11] *https://www.gov.uk/government/topical-events/autumn-statement-2012*

- Higher Education funding bodies (excluding UK RPIF): from £140m in 2011-12[14]; to £189m in 2014-15[15]

- Major Projects (through Research Councils, UK RPIF, UKSA): from £139 in 2012-13[16]; to £660m in 2014-15[17]

40. The level of capital investment in the first two categories will not necessarily be determined by recent past practice, which includes a period when capital funding was constrained. The Higher Education Funding Council for England (HEFCE) is updating its analysis of HEI research capital needs in parallel with this consultation. Research Councils UK will be undertaking a similar analysis for their own capital spend. This could lead to higher indicative requirements which would then need to be weighed against the budget for major projects.

41. The recommendations from these projects will form important inputs to this consultation on capital investment in science and research. For this reason the final balance of spend will be determined following the consultation. However here we present a range of illustrative scenarios on possible division of the total budget between spend at the individual research project and institution level through the Research Councils and HE funding bodies and major projects in the period 2016-21. This would leave a range of £1.7 – 4.1bn for investment at the national and international level.

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[12] SR 2010 Allocations booklet: £240m
[13] SR 2010 Allocations booklet: £181m; Autumn Statement 2011 (for capital maintenance) £11m;
[14] SR2010 Allocations booklet (HEI Capital HEFCE; HEI Research Capital England, Scotland, Wales, N Ireland): £140m
[15] SR2010 Allocations booklet (HEI Capital HEFCE; HEI Research Capital England, Scotland, Wales, N Ireland): £189m
[16] SR 2010 Allocations booklet (LFCF): £61m; Autumn Statement 2011: £73m; Autumn Statement 2012: £4m
[17] SR 2010 Allocations booklet (LFCF): £128m; Autumn Statement 2011: £76m; Budget 2012: £190m; Autumn Statement 2012: £266m

Science & Research Capital Budget: 2016-21 - £5.9bn	**Scenario 1**	**Scenario 2**	**Scenario 3**
Indicative funding through Research Councils at the individual research project level	£2.1bn (£420m pa)	£1.5bn (£300m pa)	£1.0bn (£190m pa)
Indicative funding through HE funding bodies at the institution level	£2.1bn (420m pa)	£1.5bn (£300m pa)	£0.7bn (£140m pa)
Remainder: Indicative funding available for major projects	**£1.7bn***	**£2.9bn***	**£4.1bn***

* NB. Totals may not match due to rounding.

42. Note also that where commitments to major project spend from 2016-21 already exist, these will also need to be met from this envelope. This is explained in more detail on the next page.

Q2: What should be the UK's priorities for large scale capital investments in the national interest, including where appropriate collaborating in international projects?

43. In addition to ensuring the provision of a world class research environment across the research estate, there are complementary requirements for large-scale investments at the national and international levels. The long-term capital settlement provides a unique opportunity to invest in new national, or international, infrastructure projects which might not otherwise be possible.

44. Section 2 of this consultation explores some of the current priorities for investment in **major national and international projects**. It starts by looking internationally at what competitors are investing in, identifying where it is in the UK's national interest to collaborate in international infrastructure projects. Then it looks across the UK research base, and explores different, competing priorities for major capital investment. In this context, investment in projects requiring a distributed structure, as well as those focused on a single facility, are considered.

Science & Research Capital Budget: 2016-21, Indicative funding available for major projects	**£1.7-4.1bn**	
Current commitments, of which:	£982m	
Ongoing commitments: European Space Agency		£200m
SR13 commitments: UK RPIF; Met Office satellites and supercomputer		£175m
Autumn Statement 2013 commitment: Quantum technologies; Higgs Institute		£40m
March 2014 announcements: European Spallation Source, M3 Space Mission (PLATO) Square Kilometre Array, Turing Institute		£342m est.
April 2014 announcement: new polar flagship and associated capital and resource spend, subject to tender		£225m est.
Indicative funding available for further major projects	**£0.7 – 3.1bn***	

45. This consultation seeks views on what the UK's priorities for investment should be in major national and international projects. The potential funding envelope is likely to sum to over £1.7 billion pounds in the 2016-21 period – depending on the eventual split between funding at institutional and project level and major projects.

46. Input on the factors that should be taken into account in prioritising projects is also sought. Proposed criteria, which are based on those used to allocate resource budgets at SR2010 and SR2013, are set out in Annex B2, and this consultation invites views on these. **What should the criteria for prioritising projects look like?**

* NB. Totals may not match due to rounding

47. The indicative envelope for further major projects is £0.7 – 3.1 bn. This takes into account funding for major projects which has already been committed in the period, (primarily in 2016-17). There will be some opportunities requiring early decisions and earmarking of funding. This is as a result of the speed of scientific development and in the case of international collaborations, political commitment and UK aspiration. As announced last month, these include decisions to earmark funding for the European Spallation Source, Square Kilometre Array, Turing Institute and M3 Space Mission (PLATO). Further details of these projects are included in the document that follows. And alongside this consultation an indicative £225m has been earmarked for a new polar flagship and associated equipment and services for the UK. Where necessary, Ministers may announce some further capital commitments before the Autumn Statement 2014.

SECTION 1: A World Class Research Environment

Q1: What balance should we strike between meeting capital requirements at the individual research project and institution level, relative to the need for large-scale investments at national and international levels?

1.1: A Commitment to a World Class Research Environment

48. A productive research environment is the foundation for scientific success: world-leading researchers need the right environment to deliver world-leading research.

49. The 2016-21 science and research capital budget provides the opportunity to give a commitment to providing UK researchers with a world-class research environment. The funding route for delivering on such a commitment would be primarily at the individual research project and institution level, through the Research Councils and HE funding bodies. In return the research community will be challenged to seek greater collaboration, better equipment sharing and improved access for industry.

50. **How can we maximise collaboration, equipment sharing, and access to industry to ensure we make the most of this investment?**

51. This consultation focuses on how capital spend can deliver a world-class research environment. At the same time, getting the culture of an institution right is as important as getting the physical infrastructure right.

52. A successful research culture is one that nurtures talent. World-class facilities are nothing without highly skilled and motivated people making use of them. This starts with research students and an institutional commitment to providing a good learning and teaching environment. It continues with a focus on a high quality and diverse career ladder to deliver high quality expertise throughout the institution.

53. Building on this, a successful research culture is one that supports broad intellectual exchange, both within and across disciplines, as well as the encouragement of collaboration – both within the UK and internationally, and between academia, industry and the third sector.

All this adds up to a high quality research culture, which in turn attracts and retains the best talent.

State of the Art Equipment

54. Moving on to the physical aspects of a world class research environment, many scientific researchers need access to state-of-the-art equipment.

55. Investing in a well equipped research environment means investing in the tools to keep UK research at the cutting edge. The world class research environment of the 2020s will not look like the world class research environment of today: continual upgrade is required to meet the challenges of tomorrow. For example:

    - 'Third generation' DNA sequencing equipment, which allows faster and cheaper reading of genetic codes. (Oxford Nanopore Ltd are one of the leaders in the development of this technology).
    - Super resolution microscopes capable of generating dynamic high quality, high resolution images of a wide range of human, plant, animal and microbial samples.
    - Ultrashort, ultrafast pulsed lasers for materials research.
    - Next generation atomic and molecular fabrication facilities.
    - Desktop X-ray.
    - Next generation computing infrastructure.

56. Early acquisition of, and researcher access to, such new technologies is needed to ensure competitive advantage for the UK. This can enhance the research benefits, promote equipment sharing and more efficient usage, and drive further technological development. The positive impact on research productivity of upgrading equipment and facilities is very real. For example, using the leading-edge technology of the time, the first human genome was sequenced at a cost of around $1bn. Current leading-edge technology brings the cost down to less than $1,000.

57. New research equipment is provided by a wide range of innovative SMEs; procurement can therefore promote growth in these high-tech industries and enhance export opportunities, as with the Oxford Nanopore example above.

Access to Major Facilities

58. Across many disciplines, access to world class facilities is critical to delivering world class research. For example, the Large Hadron Collider is the only science facility worldwide that could have discovered the Higgs boson; and state of the art research ships and

planes enable us to better monitor and understand our natural environment. (Section 2 looks further at the need for specialist facilities like this which require investment at the national or international level.)

Royal Research Ship Discovery

RRS Discovery is a state-of-the art platform for world-leading oceanographic research and represents a £75m investment in frontier science by the Department for Business Innovation & Skills. Commissioned by the Natural Environment Research Council (NERC) and operated on NERC's behalf by NERC's National Oceanography Centre (NOC) for the United Kingdom's marine science community, Discovery's wide capability allows deep-ocean research in the remotest and least hospitable parts of our planet, from tropical seas to polar waters.

59. In addition, across many disciplines, particularly in the arts, humanities and social sciences, access to leading libraries, museums and research collections is essential. The Higher Education Funding Council for England (HEFCE) provides specific funding to support researcher access to key information for their research. This includes support for:

- The UK Research Reserve (UKRR) in partnership with the British Library and higher education libraries;
- Funding for national research libraries that contain collections of exceptional importance; and
- The Museums and Galleries Fund to support museums and galleries whose collections are of wide research significance.

60. The research infrastructure environment supported by institutional capital funding has been shown to play a key role in attracting world class researchers to the UK. According to the report, Evaluation of Research Capital Funding (SRIF2006-08)[18]:

[18] *Higher Education Funding Council for England (HEFCE), 2012.* Evaluation of Research Capital Funding (SRIF2006-08) to higher education institutions 2006-2008: report by PACEC to the four UK higher education funding bodies and the Department for Business Innovation and Skills.

"The availability of high quality infrastructure appears to be a major factor in attracting and retaining high calibre staff at UK HEIs, and subsequently in driving high quality, multi-disciplinary research, and the wider competitiveness of the UK research base. With this in mind, the message from users that limited access due to unsatisfied demand continues to be a substantial issue suggests that there remains plenty of room for further investment in UK research infrastructure."

Complementary Project-level and Institution-Level Funding

61. Even within disciplines, what an individual researcher will require from their research environment varies significantly. Institution-level and project-level funding complement each other to support the diversity required across the 150-plus universities and research institutes in the UK.

62. As an example of this, biology and chemistry researchers typically require 'wet laboratories' for their experiments. Wet laboratories are so called because they enable the safe handling of chemicals, drugs, and biological materials in liquid or gas form. They require direct ventilation and pure sources of water or gases, which need to be sourced, stored and disposed of safely. However, that is where the generalisations end. Even where researchers are focused on understanding the same disease, their strength *is that they will often adopt very different approaches*. Consequently, their equipment needs will vary depending on their programme of research – from DNA sequencers to incubators through to high performance computing. Some of these will be used full-time in one laboratory. Other larger pieces of equipment, such as electron microscopes and complex analytical machines, may be shared by a number of labs, and often across institutions. Some of the funding for this equipment will be provided at the institution level (ie. via HE funding bodies to universities), while some will be provided at the project level (ie. via Research Councils to researchers).

63. A world-class research environment requires funding at both the project and institution level. In the UK this involves the Research Councils and HE funding bodies. Research Councils support both the specific equipment needs of individual peer-reviewed research projects, and the associated maintenance requirements through the principle of full economic costing. Higher Education funding bodies support the capital needs of universities in proportion to the amounts of Quality Related (QR) funding they receive from them.

64. The total requirement of the HE estate for research capital through these two channels will be driven by a number of factors, including:

- size and use of the HE estate;
- the condition of the estate and previous investment levels;

- levels of external investment;
- financial position of the sector; and
- requisite capital-labour mix.

65. The most recent thorough analysis of these factors in the UK was commissioned by HEFCE from JM Consulting, summarised in their 2006 report 'Future Needs for Capital Funding in Higher Education'[19]. The Government has asked HEFCE to commission an update of this work. This reflects changes in the HE research environment since 2006 - in particular assessing the impact of the introduction of full economic costing. There has also been a trend towards greater collaboration in research – at institutional, regional, national and international levels. This consultation is keen to hear views on other factors which should be taken into account in updating this work. The update will be completed in time to inform the Science Capital Roadmap.

66. **What factors should we consider when determining the research capital requirement of the HE estate?**

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[19] *JM Consulting Ltd (2006).* Future needs for capital funding in higher education.

1.2: Collaboration and Equipment Sharing

67. A commitment to a world class research environment comes with a challenge to the research community. Greater investment needs to be matched with greater collaboration, better equipment sharing, and improved access for industry – ie. making the nation's science even more accessible and efficient. The research base must also do more to lever business and charity funding, and to ensure that all available efficiencies are realised. This will allow us to gain maximum benefit from taxpayers' investment. These issues are explored further in the rest of Section 1.

68. As set out in the BIS/N8 report, Making the Best Better[20], universities have a strong and growing track record of delivering with increasing efficiency – with over £1 billion in efficiency savings delivered by the sector over the last ten years. One of the key features is collaboration and equipment sharing. A recent report[21] by Professor Luke Georghiou found three main benefits from equipment sharing: it can create concentrations of research activity between universities and industry; it can increase efficiency by reducing the number of items that need to be purchased and obtaining higher load factors on existing items; and finally it allows capital items too large for a single institution to be purchased.

69. Investment in capital infrastructure has a major role to play both in enhancing research capabilities that underpin research, and in driving advances in sectors critical to the economy. The UK research base has responded to these challenges and led the way in promoting efficient use of assets consistent with the principles of the Wakeham report[22]. Co-ordinated partnership investment is an important way to both deliver efficiencies and increase 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 in research.

70. Regional collaborative networks of universities play a key role in sharing, and RCUK funding has accelerated progress on compiling asset databases with shared registers of research equipment for the N8[23], M5[24], SE5[25] and GW4[26] groups of universities. Over 10,000

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[20] *http://www.n8research.org.uk/news/2013/5/universities-rise-to-the-efficiency-challenge*
21 http://www.n8research.org.uk/assets/14137%20N8%20Sharing%20for%20Excellence%20and%20Growth%20Report_WEB.pdf

[22] *Financial Sustainability in Full Economic Costing of Research in UK Higher Education', June 2010.*
[23] *The N8 universities are Durham, Lancaster, Leeds, Liverpool, Manchester, Newcastle, Sheffield and York.*
[24] *The M5 universities are Aston, Birmingham, Leicester, Loughborough, Nottingham and Warwick.*

items of research equipment have been catalogued on asset registers through the work of these cluster groups, providing a significant resource to support both national capital investment planning and also to support business access to publicly funded research facilities. Research Councils are supporting this effort, for example, in setting up the UK HE Facilities and Equipment Sharing Network, UNIQUIP, in conjunction with others. Through the efficiency review led by Professor Sir Ian Diamond, Government are asking the sector to look further at how, working together, the UK can make the most of science capital funding by ensuring researchers have access to state-of-the-art research equipment.

71. Collaboration across institutions like this is particularly evident where institutions are collaborating to purchase state-of-the-art equipment which would be neither affordable nor perhaps fully utilised by one institution alone. For example:

- The N8 universities all benefit from a shared £3.25m high performance computing facility, giving both researchers and industrial users access to larger and higher specification machines than would otherwise be possible.
- The Midlands Physics Alliance, a strategic alliance of the Physics and Astronomy Departments at the Universities of Birmingham, Nottingham and Warwick, has established the £9m Midlands Ultracold Atom Research Centre.
- The National Oceanography Centre has established a £20m National Marine Equipment Pool, the largest centralised marine scientific equipment pool in Europe. It consists of a wide range of reusable equipment - from small shallow water systems to one of the world's deepest diving remotely operated vehicles - which support marine research at sea across the UK research community.

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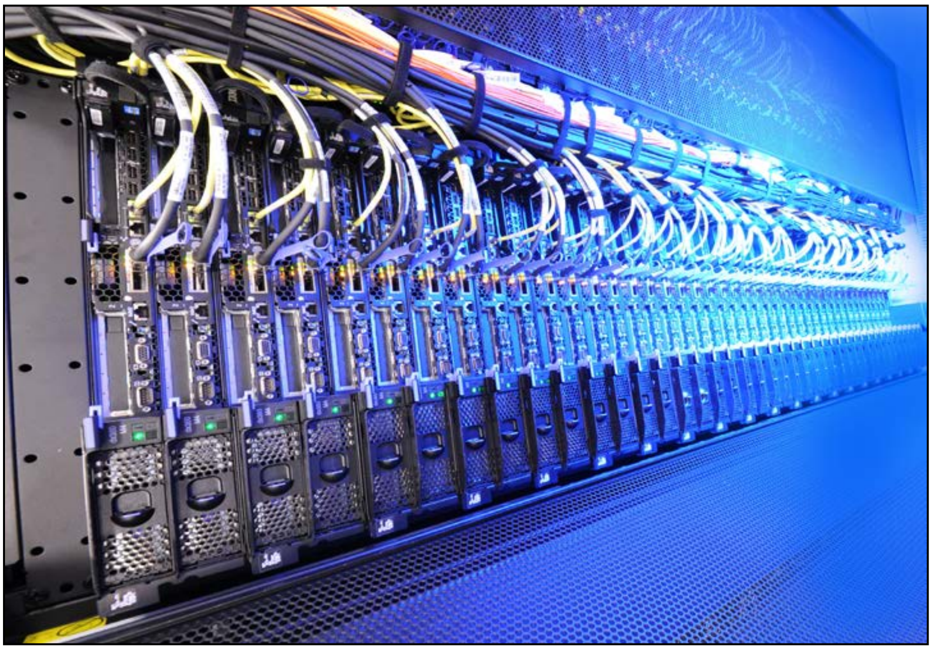
[25] *The SE5 universities are Cambridge, Imperial, Oxford, Southampton and UCL.*
[26] *The GW4 universities are Bath, Bristol, Cardiff and Exeter.*



Supercomputer at the STFC Daresbury Hartree Facility. Credit: STFC.

72. Such clusters allow universities to make the most of their assets in order to remain at the leading edge of scientific excellence. But they are also of significant interest to industry. For example, the London Centre for Nanotechnology was established as a shared facility for Imperial and UCL researchers, and now attracts significant interest from companies including the National Grid and BAE Systems, through access to state-of-the-art equipment and the sharing of research and technical expertise.

73. The challenge is to build on this strong position, which is why BIS have commissioned Professor Sir Ian Diamond to work with Universities UK, Research Councils, HEFCE and other key stakeholders to update his review of the efficiency of the sector and advise on further ways to improve efficiency. His review will report in early 2015, with an interim report in July this year, ensuring the sector is as efficient as it can be in taking advantage of the long-term capital settlement.

1.3: Accessibility and Proximity to Discovery

74. Getting the most out of what is put into the research system is about much more than doing the same for less. It is also about delivering ever more excellent impactful research within constrained resources. The clusters forming around state of the art facilities like the London Centre for Nanotechnology show the importance of making accessibility central from the start. Asset registers also help, as does the recently launched Research Councils UK (RCUK) Gateway to Research[27], which is breaking ground in making information about publicly funded research from the seven Research Councils (RCs) and the Technology Strategy Board (TSB) freely accessible. It is proving to be a revolutionary tool in connecting businesses, in particular SMEs, with researchers. In the UK there are a wide range of companies that co-locate their own research and innovation within universities. Examples are in Annex B3.

75. Taking accessibility one step further, Research Councils have been leading the development of campuses around their strategically funded institutes – at Aberystwyth, Babraham, Cambridge, Daresbury, Edinburgh, Harwell Oxford, Norwich, Pirbright, Rothamsted and Southampton. The four largest are being developed as Research and Innovation Campuses at Babraham, Daresbury, Harwell Oxford and Norwich. Based around major, internationally leading and long-term investments in research capability, significant business and commercial activity is increasingly present at these locations, attracted by the substantial research capabilities on the campuses, and the extraordinary potential to develop as focal points for national and international innovation in their fields. These Research and Innovation Campuses represent a major opportunity within the UK to deliver impact from research, leading to the growth of new and emerging companies and encouraging global businesses.

[27] *http://gtr.rcuk.ac.uk/*

Greenhouses at JIC in Norwich. Credit: JIC Bioimaging

The unique features of these campuses, which make them national assets are:

- Established presence of substantial, internationally leading and long-term research base and national research capability
- Long term strategic commitment from one or more Research Councils
- Significant business and commercial presence on the campus, attracted by and able to access the research capabilities and focus of the research base
- A degree of influence by Research Councils or Government departments on behalf of the UK so as to ensure:
    - The future direction and development of the research and innovation campus
    - There is a contribution to national strategy in research and innovation
    - There is a national, rather than institutional, focus

Diamond at dusk. Credit: Courtesy of Diamond Light Source.

76. These campuses are thriving environments for businesses, industry and universities in biomedical and life sciences research, energy, security, food and agriscience, climate and the environment. They offer access to advanced facilities and scientific services, a culture of collaboration and innovation to support the creation and growth of new businesses, and access to a unique training environment and world-leading expertise. And they are magnets for significant inward investment. For example, Element Six (formerly De Beers Industrial Diamond), are the world leader in synthetic diamonds, and are investing £20m at the Harwell Oxford campus to construct the world's largest and most sophisticated synthetic diamond supermaterials research centre[28].

77. The Research Councils emphasise 'proximity to discovery', complementing the development of campuses by ensuring technologically advanced infrastructure is available more widely at centres of research excellence to attract company co-location. Ensuring researchers have access to advanced facilities as well as access to world leading scientific and technical expertise is essential for the UK to be the partner of choice globally. Proximity to discovery will create the environment that will:

- Enhance and maintain the existing research base, in order to attract multinational industry to co-locate and drive economic growth
- Provide much needed flexibility to underpin the academic delivery of the industrial strategies

[28] *http://www.e6.com/wps/wcm/connect/e6_content_en/home/about+us/news/news+2012/global+synthetic+diamond+innovation+centre+to+be+built+in+the+uk*

- Catalyse development of new technologies, including the Eight Great Technologies[29]
- Train the next generation of researchers in cutting edge technologies
- Sustain the UK's leadership position in the global research race.

78. The Cambridge Biomedical Campus - managed by the University of Cambridge is home to the Medical Research Council (MRC) Laboratory for Molecular Biology, Addenbrookes Hospital and the University's medical school. It is one of the world's leading biotechnology clusters, and will soon also be hosting the global research and corporate headquarters of pharmaceuticals giant, AstraZeneca.

Laboratory of Molecular Biology, Cambridge - exterior design. (Building now completed).

79. Research Councils' campuses are key national assets in a much broader network of science, research and innovation infrastructure which provide support to help develop new high-tech businesses. Including Research Council campuses, Catapults, other PSREs and Government-supported science parks, a map of this ecosystem is provided in Annex B4.

80. It is recognised that many science parks provide a critical role offering accommodation on flexible terms and access to networks and technical expertise for product and service development alongside advice to develop the business. Beyond those supported by the Research Councils, many science parks have formal links with other centres of knowledge creation, e.g. Public Sector Research

[29] *https://www.gov.uk/government/publications/eight-great-technologies-infographics*

Establishments, universities and other Higher Education Institutions (HEIs). These links are crucial in enhancing the science park's ability to attract investment. Some projects presenting unique opportunities for public investment in campus development through the Research Councils are listed in Section 2.10.

81. There are additionally a number of Research and Technology Organisations (RTOs) and Independent Research Organisations (IROs) which play an important part in the UK innovation and research system. Some IROs are eligible for research council grant funding in recognition of the role they play in conducting excellent research[30].

82. **This consultation would like views and evidence on whether there is a case for extending science & research capital to RTO and IRO organisations – subject to state aids and other considerations.**

[30] *http://www.rcuk.ac.uk/funding/eligibilityforrcs/*

Public Sector Research Establishments (PSREs)

83. PSREs are a diverse collection of public bodies carrying out research. This research supports a wide range of Government objectives, including informing policy making, statutory and regulatory functions and providing a national strategic resource in key areas of scientific research. They can also provide emergency response services. They interact with businesses across a wide array of innovation-related functions.

84. Government recognises that a well functioning research and innovation ecosystem needs to include a well functioning network of PSREs, which act as repositories of expertise and capability. Many PSREs are directly sponsored by various Government departments and include for example, Defra bodies such as AHVLA and FERA, and BIS bodies including the Met Office and the National Physical Laboratory. In order to assist departments when reviewing PSREs, guidance has been issued, based on expert advice provided by the Manchester Institute of Innovation Research. This guidance aims to ensure that the full range of impacts of a PSRE is taken into account when deciding on its future.

85. Given the specialist nature of the work of individual PSREs, their links to the academic community are often highly focused. In addition, they collaborate with Research Council funded institutes where they have common interests, for example:

    - The Biotechnology and Biological Sciences Research Council (BBSRC), Natural Environment Research Council (NERC) and Food and Environment Research Agency (FERA) work together on the Insect Pollinators Initiative, which seeks to understand the factors contributing to the decline in pollinator populations.
    - BBSRC and the Department for Environment, Food and Rural Affairs (DEFRA) are jointly funding research programmes seeking to understand the epidemiology, biology and genomics of Ash Dieback, and together with the Economic and Social Research Centre (ESRC), NERC, Forestry Commission, and Scottish Government are supporting research into wider aspects of tree health and plant biosecurity.
    - The Engineering and Physical Sciences Research Council (EPSRC) and the National Nuclear Laboratory (NNL) collaborate closely on nuclear energy related R&D.
    - The joint MRC - Public Health England Centre for Environment and Health brings together a number of leading research groups related to the diverse fields of environment and health to promote interdisciplinary research.
    - NERC and the Met Office have formed a strategic partnership to enhance the UK’s capability in weather and climate prediction. This includes the joint operation of a world-leading research aircraft, and

shared computing and data management facilities.
- STFC and the UK Atomic Energy Authority (UKAEA) are working together to develop the Harwell Science and Innovation Campus.

86. Given these shared interests, Government invite PSREs to engage with this consultation as a key user community. There are further opportunities here to invest in our science parks and PSREs.

1.4: Leverage

87. As shown by the examples of Element Six and AstraZeneca highlighted above, investment in public scientific infrastructure also leverages significant private investment. The report, Leverage from public funding of science and research[31], examines how public funding of science and research leverages additional investment from industry, charity and overseas. Of the £26.4 billion spent on research and development in the UK, only 33% comes from public funds, with an unusually high 18% from overseas an indicator of the UK's global standing and confidence in its research strength. In total, business, charities and other organizations spend £3.3bn pa with UK HEIs. The UK is also very successful in leveraging European science and research funds, receiving €4.4 billion from European Framework Programme 7, equivalent to 15% of the total fund and second only to Germany.

88. Government has a range of policies that stimulate activities that generate leverage from the private and charitable sectors. In terms of capital funding, the most significant is the UK Research Partnership Investment Fund[32], launched in 2012 and administered by HEFCE. £300 million of capital investment is leveraging in more than £800 million of private investment from businesses and charities. For example:

    - University of Surrey 5G Centre - £11.6 million from UK RPIF, has leveraged more than £30 million from a consortium of mobile communications global industry leaders. The new collaborative international research centre will support the development of 5th generation cellular communications. The 5G Centre and associated test bed facilities, construction of which has already started, will provide real-time experimental facilities to underpin the development of new mobile broadband internet products and services.
    - University of Liverpool Materials Innovation Factory - £11 million from UK RPIF, has leveraged £22 million from Unilever. The state-of-the-art materials chemistry research hub will provide an unparalleled suite of open-access facilities. It will help accelerate research and reduce new product discovery times relevant to a range of sectors including sustainable energy, home and personal care, pharmaceuticals, paint and coatings, thus helping to drive economic growth and international competitiveness.

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[31] *http://www.rcuk.ac.uk/media/news/130715/*
[32] *https://www.hefce.ac.uk/whatwedo/rsrch/howfundr/ukrpif/*

89. The success of UK RPIF was recognised in the 2013 Spending Review settlement which provided a further £100m pa at least, in 2015-16 and 2016-17. An overview of UK RPIF projects is provided at Annex B5, broadly showing around £100m public funding for infrastructure in the life and medical sciences delivering £265m leveraged funding, and £200m public funding for infrastructure in the engineering and physical sciences delivering an additional £560m leveraged funding.

90. Collaboration with our European partners can also offer funding opportunities to develop infrastructures and support access to existing facilities both to UK researchers going abroad and European researchers wishing to pursue projects in the UK. Horizon 2020, the EU's funding programme for research and innovation for 2014-20, has a total budget of some € 80bn in current prices; of this some € 2.5 bn is dedicated to research infrastructures. This will support the development of the ESFRI roadmap, foster the innovation potential of European infrastructures and their human capital and reinforce European research infrastructure policy and international collaboration.

91. The European Investment Bank can also fund loans for science & research projects, deciding on a project by project basis, taking into account considerations such as project objectives, duration, guarantees required, location of the project (e.g. if in a deprived area) and the project partners .

Summary: A World Class Research Environment

Q1: What balance should we strike between meeting capital requirements at the individual research project and institution level, relative to the need for large-scale investments at national and international levels?

92. A world class research environment is essential to delivering world-class research. The 2016-21 science and research capital budget provides the opportunity to give a commitment to a world class research environment across the UK research base, primarily through funding at the individual research project and institution level through Research Councils and HE funding bodies – although this also needs to be balanced against the complementary need for large-scale capital investments at the national and international levels.

93. Striking the right balance between these spending channels is a strategic judgement, and this consultation seeks views on what this balance should be from 2016-21, and what factors should be taken into account in making this judgement. For illustrative purposes, applying a similar range of spending figures to recent years through the Research Councils and HE funding bodies would provide a range of £1.7-2.3bn for investment at the individual research project and institution level, leaving £3.6-4.1bn for investment at the national and international level:

Science & Research Capital Budget: 2016-21 - £5.9bn	**Scenario 1**	**Scenario 2**	**Scenario 3**
Indicative funding through Research Councils at the individual research project level	£2.1bn (£420m pa)	£1.5bn (£300m pa)	£1.0bn (£190m pa)
Indicative funding through HE funding bodies at the institution level	£2.1bn (420m pa)	£1.5bn (£300m pa)	£0.7bn (£140m pa)
Remainder: Indicative funding available for major projects	**£1.7bn***	**£2.9bn***	**£4.1bn***

* NB. Totals may not match due to rounding

94. It should be clear that a commitment to a world class research environment comes with an efficiency challenge to the research community – in terms of increasing collaboration, better equipment sharing, improving access for industry and doing more to leverage business and charity funding.

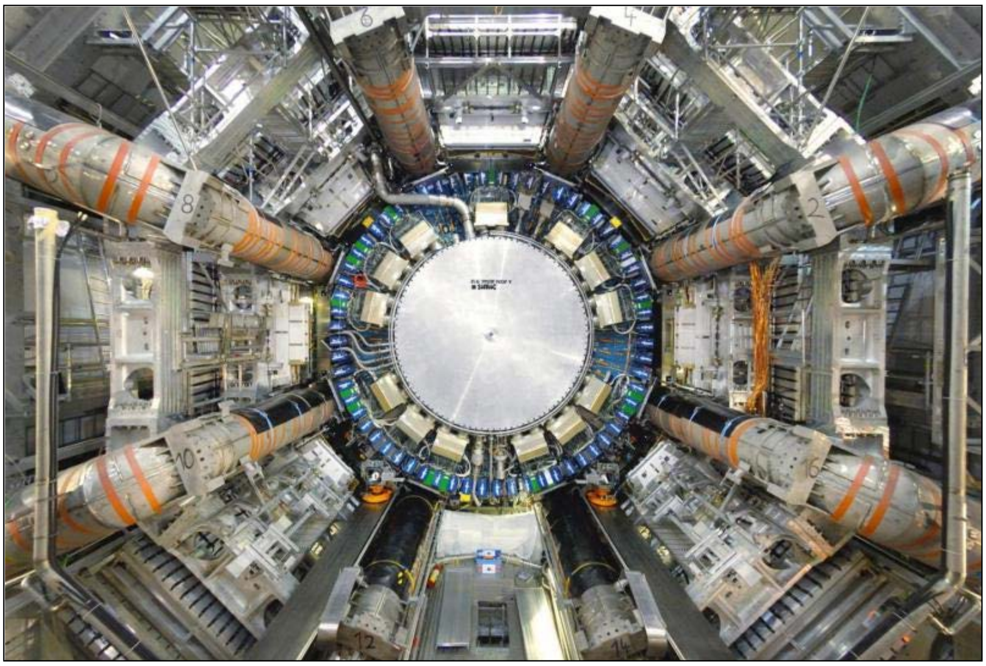
95. Section 2 of this consultation goes on to explore some of the current priorities for investment in **major national and international projects**, largely through the Research Councils and UK Space Agency, where strategic decisions are required by Ministers.

SECTION 2: Science Strategy for Major New Projects

Q2: What should be the UK's priorities for large scale capital investments in the national interest, including where appropriate collaborating in international projects?

2.1: A Strategic Approach to Major New Science and Research Infrastructure

96. Alongside the provision of a world class research environment there are large scale strategic investments which, because of their scale, require separate consideration and decision. Some of these are national decisions, some international; some are of sufficient size to require the pooling of resources, (eg. the Large Hadron Collider), some require the coordination of resources to maximise impact, (eg. the Life study).



Large Hadron Collider, CERN - ATLAS detector.

97. Human curiosity is limitless – the variety of research projects that could address that curiosity is similarly vast. Section 2 of this consultation asks for views on how the Government should prioritise. Building on the approach set out in the RCUK Strategic Framework for Capital Investment, Investing for Growth, this section looks across the UK research base, exploring where opportunities exist for capital investment at the national or international level – with details of

specific potential major projects set out in Annex A. **Respondents are also asked to identify and prioritise any further strategically important projects not included in Annex A.**

98. A strategic approach to investing in major national and international projects requires us first to look internationally at what competitors are investing in, and identifying where it is in the UK national interest to collaborate in international infrastructure projects – either leading or making significant contributions to projects based overseas or hosting them in the UK. UK research is recognised internationally as excellent and, as such, there are areas where the UK should play an international leadership role in driving forward aspirational and ambitious research. This is investment which will enable us to capitalise on the UK's ability to drive and lead research worldwide for the benefit of the nation. As such, science and research infrastructure forms an integral part of national infrastructure in the National Infrastructure Plan[33], recognising that a strategic approach to planning major science and research infrastructure is in the national interest.

99. In developing this strategic approach, the Government starts from a broad view of current and proposed science and research infrastructure projects, both nationally and internationally, (see Section 2.2 and Annexes B6 and B7). In Annex A, a list of individual projects is set out, building on the work that went into the RCUK Strategic Framework for Capital Investment, Investing for Growth. This consultation invites views on how to prioritise from within this list, on whether there are other priorities not identified here, and on what factors should be taken into account in prioritising. Suggested criteria based on those used by Government to allocate the resource budgets at Spending Round 2010 and Spending Round 2013 are set out in Annex B2. Decisions on some projects are time-critical, and may need to be taken before the results of this consultation are known.

100. In setting out priorities, a full consideration of affordability in the round must be made – taking account of operational costs and the costs of the research projects using the facilities; and recognising that new state-of-the-art facilities may mean decommissioning old, less efficient facilities. For example:

- The Synchrotron Radiation Source (SRS) at Daresbury was the world's first second generation multi-user X-ray synchrotron radiation facility. The facility ceased operations in 2008 after 28 years of operation and two million hours of science. The SRS and its staff played a key role in the establishment of the

[33] *https://www.gov.uk/government/collections/national-infrastructure-plan*

UK's third generation light source – the Diamond Light Source at Harwell Oxford – which became operational in January 2007. SRS closed in 2008 after a two-year overlap with Diamond which took over as the UK's national synchrotron radiation source.

- The former Particle Physics & Astronomy Research Council agreed in 2001 to wind down operations of island telescopes on the Canary Islands and Hawaii as part of UK accession to the European Southern Observatory (ESO) organisation. The UK became the tenth member of ESO in July 2002. Membership of ESO gives UK astronomers access to world-class telescopes in Chile such as the Very Large Telescope (VLT), the world's most advanced visible-light astronomical observatory.

The Paranal platform photographed in January 2007. The four main Very Large Telescope (VLT) units can be seen, as well the four auxiliary telescopes. Credit: ESO/H.H.Heyer

101. To give a sense of the scale of prioritisation required, this consultation alone sets out well over £5bn of potential investment, against an illustrative envelope of £0.7-3.1bn once capital investment at the individual research project or institution level is taken into account.

102. In prioritising, Government recognises it is imperative to consider not only what science and research infrastructure is a strategic priority for investment now, but also how to maintain flexibility to accommodate changes in priorities as science evolves. For this reason, this

consultation proposes not allocating all the capital investment for the period 2016-21 ahead of time, but maintaining a proportion which will remain unallocated until the second half of this decade.

103. **Should we maintain a proportion of unallocated capital funding to respond to emerging priorities in the second half of this decade?**

2.2 Overview of International Science and Research Infrastructure

104. Considering priorities for major new investments in science and research infrastructure needs to take into account the existing landscape. This is both in terms of international collaborations and current national science and research infrastructure projects. This section explores the international landscape.

105. International collaboration is essential in tackling complex science and research challenges which would be unaffordable without a pooling of resources and/or that require coordination of effort. Some collaborative activities will require significant capital investment in a single project or infrastructure while other research areas, such as climate monitoring, rely on networked activities. For example:

- The European contribution alone to the International Thermonuclear Experimental Reactor (ITER), to be hosted in Cadarache, France will be €6.6 billion.
- An international consortium of geneticists working in the United States, UK, France, Japan and elsewhere, worked collaboratively over 13 years resulting in publication of the draft human genome in 2000, at a combined cost estimated at around $1bn.

106. There are a wide variety of international meetings where priorities and proposals for long-term large-scale strategic international collaboration in science and research are discussed and agreed. These include the G8, European Strategy Forum on Research Infrastructures (ESFRI), OECD, CERN, European Atomic Energy Community (Euratom), and the Consultative Group on International Agricultural Research (CGIAR), amongst others.

107. Discussion in these meetings enables agreement on joint research priorities, leading to coordination of investment amongst international partners. For example, the 2013 G8 Science Ministers Statement[34] recognised that alongside the familiar challenges of energy security and climate change, the challenge of antimicrobial drug resistance required concerted research focus. Other global challenges which were recognised included how to translate basic science to personalised and regenerative medicine, the ageing population and neurodegenerative diseases. The European Strategy Forum on Research Infrastructures (ESFRI) Roadmap 2010[35] sets out a variety

[34] https://www.gov.uk/government/news/g8-science-ministers-statement
[35] http://ec.europa.eu/research/infrastructures/pdf/esfri-strategy_report_and_roadmap.pdf#view=fit&pagemode=none

of potential collaborative projects across scientific disciplines. The roadmap approach has led to international collaborations such as ELIXIR, (the European Life Science Infrastructure for Biological Information, whose central coordinating hub is based in Hinxton, Cambridge). The Square Kilometre Array and European Spallation Source (see Section 2.3) also appear prominently on this ESFRI Roadmap.

108. Annex B6 sets out the largest international research projects of today, proposed or in operation. The very largest projects under development are described briefly below :

i. Globally unique projects that require pooling of resources in one place to deliver

- *ITER (International Thermonuclear Experimental Reactor): Under Construction*
  Host: France

  ITER is an international research and engineering project designed to prove the scientific and technological feasibility of a full-scale fusion power reactor. It is an experimental step between today's studies of plasma physics and future electricity-producing fusion power plants.

- *ALMA (Atacama Large Millimetre Array): Under Construction*
  Host: Chile

  An array of 66 telescopes in the high Atacama desert of northern Chile, constructed by a global partnership between the European Southern Observatory, north American and east Asian partners. The array will explore in unprecedented detail the origins of the Universe and the early development of stars and galaxies.

ii. Globally unique federations of projects requiring global sharing and exchange of data

- *Argo programme (Ocean monitoring): In Operation*
  NERC's National Oceanography Centre and the Met Office are UK partners in a global observing system that measures the temperature and salinity of the upper 2,000m of the oceans, provided in near real time for climate and oceanographic research.

- *Global Earth Observation System of Systems (GEO): Under Development*
  International coordination of earth observation systems with the goal of improved understanding of the Earth's complex environment.

iii. International Projects: Where only two or three exist in the world

Beyond such globally unique projects there are a number of projects, which are not unique, but only two or three exist in the world. These include:

- X-ray free electron lasers (Hamburg, Germany; Stanford, USA; and Harima, Japan)
- Neutron spallation sources (Oak Ridge, USA; Tokai, Japan; ISIS, UK; plus proposed European Spallation Source – see Annex A4)
- Gravitational wave observatories (Advanced LIGO, USA; Advanced Virgo, Italy; Kagra, Japan)
- 30-metre class telescopes (Proposed Thirty Metre Telescope, Hawaii, USA; Giant Magellan Telescope, Chile; and European-Extremely Large Telescope, Chile)

2.3: Opportunities for Large-Scale International Collaboration in Science and Research Infrastructure

109. Science is increasingly a global endeavour. This means that identifying UK priorities for capital investment in science and research infrastructure in the strategic national interest requires us to work with international partners. We need to identify where it is in the UK national interest to collaborate in international infrastructure projects, and where it is in the UK interest to seek to position ourselves nationally to provide global leadership. In many instances the UK's world-leading research position means UK leadership will be the driver for new developments in infrastructure, even though the physical location may be elsewhere. This can involve making significant contributions to projects around the world, thus enabling access for UK researchers, or sometimes hosting them in the UK. For example:

- UK researchers were central to the discovery of the Higgs boson by researchers working on the Large Hadron Collider, which is located beneath the French-Swiss border near Geneva, Switzerland.
- The Joint European Torus, located in Culham, Oxfordshire, was the first place in the world to conduct a controlled release of fusion energy, showing the potential viability of nuclear fusion reactors as a future energy source.

110. The driver for involvement in international projects is that it is the best way to conduct the research. It is also in the UK national interest to maintain a steady stream of big infrastructure projects in the UK to maintain the engineering and project management capability to build such projects in the future. The long-term science and research capital settlement provides a unique opportunity not just to engage with, but host, such major international projects. This section therefore looks at opportunities for UK investment in 'one of a kind' major international collaborations, where the UK may play a role as a leading or key partner. **This consultation welcomes views on whether these are the right priorities for investment on this scale at the international level; as well as views on potential UK involvement in major global collaborations not identified here.**

2.3.1. Square Kilometre Array

UK intention to invest announced March 2014.

Estimated costs: Around £100m subject to international negotiations

Delivery partners: UK, Canada, Netherlands, Italy, Germany, Australia, China, New Zealand, South Africa, Sweden. (Observers from France, Japan, Korea and USA.)

The Square Kilometre Array will be the world's largest and most sensitive radio telescope. With the site divided between Southern Africa and Australia, the total collecting area of the telescope, spread across many receivers, will be approximately one square kilometre giving 50 times the sensitivity, and 10,000 times the survey speed of the best current-day telescopes. The project will focus on: studying the formation of the first objects in the Universe – the first stars and galaxies; probing cosmology – understanding Dark Energy and how galaxies evolve to what we see today; and testing Einstein's theories – the search for gravitational waves. Outside astrophysics, SKA will be an exceptionally powerful solar system science tool and a tool for astrobiology, undertaking studies of planetary and space weather, tracking of asteroids and spacecraft, as well as conducting the most sensitive search yet for intelligent life elsewhere in the Universe.

Innovation in electronics, software, and computing are central to realising the SKA. Transformational changes are required in electronics and in computing. The science requirements of the facility are acting as a driver for innovation in components and in associated software development – supported by large ICT industry companies. By 2023, the Square Kilometre Array project will generate 1300 billion gigabytes of data each month, (enough to fill 40 billion iPads). Processing such a flood of data will require computers over a thousand times faster than today's.

The UK hosts the headquarters of the current engineering phase of the worldwide Project office at Jodrell Bank and chairs the SKA Organisation Board thereby playing a significant role in the development of the project. As announced last month, UK investment will ensure that the UK continues to play a leading role through the construction and operation phases.

2.3.2. New Capability at the Large Hadron Collider, CERN: Beyond the Higgs

Estimated costs: Subject to international negotiation

Delivery partners: CERN has 20 European member states, including the UK; as well as non-member states including the USA, Japan and China.

The Large Hadron Collider at CERN is the world's foremost particle physics facility for research at the energy frontier and its exploitation is among the highest priorities for the UK's particle physics programme for the next decade and beyond. It has started to shed light on some of the big questions about our universe with the recent discovery of a new particle - the Higgs boson, for which Peter Higgs was awarded the 2013 Nobel Prize in Physics with François Englert. The discovery of the Higgs boson opens up new windows for particle physics including whether this particle behaves exactly as expected or whether its properties instead provide hints of other new phenomena; and emphasises the need to search directly for particles that could explain the 'dark matter' that seems to make up the bulk of the material in our universe but is nonetheless not explained adequately by current theories. The UK and other member states' invest in this resource through the CERN subscription.

The CERN member states have developed a European Strategy for Particle Physics[36] which sets out a vision for the development of the field. Over the next two years the energy of the LHC will be doubled. Its collision rate will be increased to search for new particles and interactions and to probe the characteristics and properties of the Higgs boson. The LHC will be further upgraded in 2018 and will remain the world's highest energy accelerator until at least 2030. Complementary national investment is needed to upgrade the LHC detectors to fully exploit these new capabilities and opportunities. UK groups are playing key roles in both the scientific and technical leadership of these experiments and providing many of the key technical advances. The results from the next phase of the LHC will inform the capabilities required of future colliders. The LHC detector upgrades programme is part of an international collaborative effort at CERN. The European Strategy foresees planning for an International Linear Collider and long baseline neutrino projects as part of a global strategy.

2.3.3. International Space Station (ISS) Exploitation Programme

Estimated costs: Subject to international negotiation

Delivery partners: 20 international partners including the UK.

The ISS Exploitation programme funds the operations cost of the International Space Station (ISS). The UK's 20M€ one-off contribution at the ESA Council of Ministers in 2012[37] has opened up new industrial opportunities, allowed UK scientists to lead experiments and influenced the selection of Tim Peake's mission[38]. A continued subscription would allow the UK to build on and significantly extend these opportunities.

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36 *http://council.web.cern.ch/council/en/EuropeanStrategy/esc-e-106.pdf*
37 *http://news.bis.gov.uk/Press-Releases/UK-secures-1-2-billion-package-of-space-investment-683b9.aspx*
38 *http://www.esa.int/Our_Activities/Human_Spaceflight/ESA_astronaut_Timothy_Peake_set_for_Space_Station*

Photo: ESA/NASA - STS-130 crew member Endeavour

Tim Peake's mission represents a major opportunity to inspire young people to take up STEM subjects, both through the dedicated education programme the UK Space Agency is developing, and by providing a high-profile role model for STEM careers. It also provides a rare, highly-visible and international platform to demonstrate UK technological expertise and leadership in scientific research.

Importantly, additional ongoing subscription to ISS will allow future enhancement of the terminal with a new phased antenna array, provided by UK industry.

A longer term commitment to this programme would also allow the science community to make full use of the UK's ELIPS subscription: ELIPS covers all microgravity facilities, but only countries subscribing to both ELIPS and ISS may lead ISS experiments. ELIPS, the European Life and Physical Sciences programme funds science conducted on the ISS and other space-analogue platforms, which mimic one or more aspect of the space environment (microgravity, extreme vacuum, isolation, radiation, etc). In the one year the UK has participated in the programme, there has been a strong uptake from the science community, especially in the fields of materials science, biomedicine and astrobiology.

2.4: UK Science and Research Infrastructure Priorities

111. This section looks across the UK science and research landscape, exploring priorities for major capital investment principally at the UK level. Details of potential projects are in Annex A.

Big Data in the 'Exabyte Age'

112. One area where the rate of technological advance is acutely felt, in terms of impact on infrastructure needs across all research disciplines, is in the field of big data and e-infrastructure. We are entering what is called the 'Exabyte Age'. 2.5 billion Gigabytes, or 2.5 Exabytes of data, are generated daily. Enabling mankind to maximise value from this data deluge will need creative and substantial investment. This spans data analytics, management and infrastructure. We need to build a co-ordinated, open-access ecosystem of computational resources - an e-infrastructure - that drives knowledge generation from data.

113. The importance which the Government, the research community and industry place on this is underlined by the creation of the e-Infrastructure Leadership Council (ELC)[39] and Information Economy Council[40]. This is echoed at the European level by the creation of PRACE, the Partnership for Advanced Computing in Europe.

"One of the greatest opportunities and threats facing businesses and researchers today is big data. The potential impact of big data, whether harvested from the real world or generated by High Performance Computing (HPC) based modelling and simulation, is so significant that it will transform all areas of business, government and research. Sustained investment in our HPC and e- infrastructure is therefore essential if the UK is to remain globally competitive in science and business." Dominic Tildesley, Co-Chair, e-Infrastructure Leadership Council

114. The UK is a world leader in many research areas at the forefront of the big data revolution. This includes genomics; structural biology; bioinformatics; clinical and population data analysis; climate modelling; computational fluid dynamics; and molecular modelling. The UK's world-leading industry in sectors from automotive and aerospace, to pharmaceuticals and fast-moving consumer goods, all set to benefit.

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[39] *https://www.gov.uk/government/policy-advisory-groups/e-infrastructure-leadership-council*
[40] *http://www.techuk.org/about/information-economy-council*

With the e-Infrastructure Leadership Council taking an holistic view in developing the business cases for future investments, the UK is well placed to deliver major growth which will impact across the economy. We are committed to realising the ambitions of the Government's White Paper on Open Data[41]. In March 2014, the Government announced funding of £42m for the Alan Turing Institute, a new national institute which will undertake new research in ways of collecting, organising and analysing big data.

115. Some specific priorities where, in particular, the UK will need to sustain and enhance the significant investments of recent years to maintain its international position, are set out in Annex A1.

Understanding the Universe

116. Curiosity about our place in the universe has focused minds since Neolithic times. Whether or not this makes it the world's oldest research field, it attracts the same curiosity today, from the hunt for extra-terrestrial life to the mysteries of the origins of the universe and the search for first light.

117. The UK has a strong research programme, funded by STFC, in astronomy, nuclear and particle physics, aimed at understanding the evolution of the universe, its fundamental constituents and their interactions, the extremes of the universe, and how stars and planetary systems develop. To address these fundamental questions requires access to a range of facilities and infrastructures: including telescopes provided through our membership of international organisations such as the European Southern Observatory; data from space missions; access to nuclear physics facilities; and participation in global collaborative particle physics experiments at CERN, in the US, and in Japan. STFC works closely with the UK Space Agency on the scientific priorities for investment in space missions.

118. The UK's civil space priorities are set out in the UK Civil Space Strategy[42] (July 2012) supported by two key reports, the UK Space Innovation and Growth Strategy Growth Action Plan[43] and the National Space Technology Strategy for the UK[44]. Responsibility for delivering these priorities rests with the UK Space Agency. Based on these

[41] *https://www.gov.uk/government/publications/open-data-white-paper-unleashing-the-potential*
[42] *http://www.bis.gov.uk/assets/ukspaceagency/docs/uk-space-agency-civil-space-strategy.pdf*
[43] *http://www.bis.gov.uk/assets/ukspaceagency/docs-2013/igs-action-plan.pdf*
[44] *https://connect.innovateuk.org/documents/2965388/3745022/The+National+Space+Technology+Strategy+-+2012+Update_v2.pdf/e9002000-22a4-40aa-b341-5b4490ce9801*

priorities and Government's industrial strategy the UK Space Agency propose to concentrate on investment with demonstrable impact that:

- Creates a stronger industry able to sell more abroad attracts more private investment through increased industry co-funding
- Benefits society at large e.g. through better weather forecasting and by providing key data to underpin evidence-based policy and its use in managing environment, climate and security challenges
- Develops the horizontal foundations of UK competitiveness through excellence in science and technology
- Positions UK industry to win contracts in EU and EUMETSAT space programmes in which the UK is already committed to invest
- Exploits the new ESA facility at Harwell Oxford (ECSAT) with 100 skilled ESA staff as part of the globally significant Harwell Oxford space cluster.

119. The UK's primary delivery partner in delivering these commitments is the European Space Agency, in which the UK collaborates with European partners. ESA commitments are negotiated at Ministerial level, with the next ESA Council of Ministers meetings in December 2014 and 2016 agreeing investment beyond the current commitment period ending 2017-18. Some specific priorities for investment in this area are set out in more detail in Annex A2, starting with a discussion of potential priorities for this ESA Programme.

Understanding Our Planet

120. Moving from exploring the outer reaches of the universe to exploring our own planet, it is often said that scientists know more about the surface of the moon than our own planet's ocean floor. Understanding our own planet provides huge research challenges in itself.

121. This includes understanding systems such as the atmosphere, oceans and land, and how they interact. This in turn will lead to better understanding of key issues such as climate change and its effects. This is a challenge which the UK is well set to respond to as world-leader in environmental sciences research, building on the opportunities provided by new developments in sensor and information technologies.

122. Suggested capital priorities for addressing this historic challenge from ocean going ships to satellite observation are set out in more detail in Annex A3.

Understanding How Materials Behave

123. At the micro-scale, the UK has a continuing need, across research disciplines, for investment in state of the art infrastructure and instrumentation to help further understand how materials behave and why. From advanced materials to living materials, this research underpins the highest priority research projects across an extensive research profile. It covers advanced materials, synthetic biology, robotics, and quantum technologies. It also links closely to the needs of industry, for example through the Technology Strategy Board's Catapults and building on growing co-location of academia with industry on research campuses. This was described in more detail in Section 1.3.

124. For example, while developments in medicine and life sciences have benefited from technological advances in imaging technologies, there are still many areas where investment could aid development, such as electron microscopy and high-throughput imaging. Similarly, high power lasers have led to numerous scientific discoveries and have the potential to be applied in various areas of business, from industrial R&D to screening in airports, given the opportunity and investment for further research and development.

125. In addition to investment in major facilities and equipment, smaller individual pieces of infrastructure are vital in enabling the research objectives of leading academic and industrial research teams. They will ensure the UK's leading researchers remain internationally competitive. Specific priorities, covering both large facilities and mid-range equipment, are set out in more detail in Annex A4. Key industrial users would include major R&D investors in, although not limited to, the life sciences, aerospace and advanced materials sectors.

Grand Challenges

126. Building on the scientific understanding developed across all these areas of scientific enquiry enables us to consider how scientists and engineers can use this understanding to address the grand challenges of our age. Two such challenges are set out below, with specific projects set out in more detail in Annex A5. However, the Government is keen to hear also about capital requirements relating to other grand challenges.

Energy Security and Resilience:

127. Responding to environmental change poses specific challenges to society in terms of energy security and infrastructure resilience. From efficiently exploiting carbon-based energy sources whilst minimising environmental impact, and safely harnessing the energy produced by nuclear fission and fusion. to ensuring that energy, water, transport, digital communications and waste disposal networks are reliable and ready for tomorrow's challenges. The research perimeter is wide, and dedicated research infrastructure will be needed to ensure the country can tackle these challenges*.*

Innovation in Manufacturing:

128. High value manufacturing capability in the UK is critically reliant on advanced materials and material innovations[45]. Sectors highlighted as priorities in the Government's Industrial Strategy all rely on materials, and materials embedded into new products are a major component of UK exports and valued at about £50bn per annum[46].

Campuses

129. As set out in Section 1.3, research campuses are thriving environments for bringing together publicly and privately funded research in ways which are of mutual benefit. Specific projects for Research Council led campus development are set out in Annex A6.

Public Engagement

130. Curiosity or challenge-directed research plays an important role in stimulating public interest – witness the massive media interest in the discovery of the Higgs boson. It is the same interest that drives the massive citizen science engagement in projects from the Met Office's Weather Observation Website to the UK Ladybird Survey[47].

131. It is important to build on public interest and build public understanding of, and engagement with, science. The Government is interested in exploring innovative ways to do more of all of this, building on and better utilising existing science engagement infrastructure to inspire, engage and involve the public in scientific research and development. For example, major capital investments such as the Large Hadron Collider have a major role to play in attracting public interest in science

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[45] *BIS Growth Review Framework for Advanced Manufacturing (December 2010) http://www.bis.gov.uk/assets/BISCore/business-sectors/docs/g/10-1297-growth-review-framework-for-advanced-manufacturing.pdf*
[46] *http://www.ukadvancedengineering.com/marketing/advanced-materials/ accessed 03 April 2012*
[47] *http://www.ceh.ac.uk/news/news_archive/documents/guidetocitizenscience_version2_interactiveweb.pdf*

and in return for investment there is an imperative for the research community to engage the public in such projects.

132. In addition, the Government wishes to consider where there is value in capital investment specifically focused on public engagement. An example is set out in Annex A7. Where public resources are not already available, one approach could be to provide support for capital investment for inspirational and engaging science programmes across the UK. This would target organisations unable to access capital investment from other public sources.

Summary: Major New Projects

Q2: What should be the UK's priorities for large scale capital investments in the national interest, including where appropriate collaborating in international projects?

133. There is no shortage of fascinating and important research infrastructure projects which would push the boundaries of research, unlock the potential of future technologies, and advance understanding of the world about us. The list set out here is inevitably incomplete. The Government would like to hear of other large-scale investments that might take priority.

134. As a result of the UK's research strength in breadth, there is a need to prioritise. An illustrative envelope for investment in major new projects at the national and international levels is £0.7-3.1 bn. This is based on a similar range of capital investment at the individual research project and institution level through Research Councils and HE funding bodies as in previous years, and once funding for new projects which has already been committed (primarily in 2016-17) is taken into account. To give a sense of the scale of prioritisation required, the estimated total capital value of the further major new projects set out in this section, which are competing for investment within this envelope alongside any new ideas, comes to over £5bn. As such, this consultation seeks views on what should be the priorities within the envelope agreed, recognising that consideration also needs to be given to the resource costs of operating and using the facilities.

Capital Projects: ideas for consideration	**Indicative Capital Costs (£m) subject to business case**	
Priority projects already announced:		
2.3.1 Square Kilometre Array		~100
2.2 M3 Space Mission (PLATO)		25
3.1 New Polar Research Shi p and associated capital and resource spend		225
4.1 European Spallation Source		~165
Large Scale International projects, including:	Subject to negotiation*	
New Capability at the Large Hadron Collider		*
International Space Station Exploitation Programme		*
1. Big Data projects, including:	>1,900	
1.1. National e-Infrastructure		290
1.2. Bridging the Genotype to Phenotype Gap		1100
1.3. From Big Data to Medical Insight and Impact		150
1.4. High-throughput Medical Research		200
1.5. Environmental Big Data Research and Innovation Centres		70
1.6. International Data Integration Platform		15
1.7. Longitudinal Studies		40
1.8. International Centre for New Forms of Data		15
1.9. UK Data Service and Administrative Data Service		25

Capital Projects: ideas for consideration	**Indicative Capital Costs (£m) subject to business case**	
1.10. Bio-social Data Service		25
1.11. Big Data Centre for the Creative Economy		17
1.12. Digital Transformation in the Arts & Humanities		18
1.13. Heritage Science		16
2. Understanding the Universe projects, including:	>300	
2.1 European Space Agency Programme		*
2.3. Space Data - Ground Stations and Analysis		35
2.4. Space Data - Exploitation		15
2.5. National Spaceport and Space Propulsion Facility		60
2.6. Planetary Sample Curation Facility		45
2.7. TRUTHS		150
2.8 Large Synoptic Survey Telescope		*
2.9 Long Baseline Neutrino Experiments		*
2.10 Advanced Capabilities in Nuclear Physics		15
3. Understanding our Planet projects, including:	150	
3.2. Environmental Observing Systems Research & Innovation Centre		130
3.3. Jason - CS		20
4. Understanding How Materials Behave projects, including:	>800	

Capital Projects: ideas for consideration	**Indicative Capital Costs (£m) subject to business case**	
4.2 Neutron capability		*
4.3 Synchrotron capability		*
4.4. Sapphire: UK Free Electron Laser		450
4.5. Central Laser Facility		90
4.6. Capabilities in next generation imaging technologies and High-throughput genomics and bioscience		200
4.7. Mid-range National Analytical Facilities		55
5. Grand Challenge projects, including:	>900	
5.1. Energy Security & Innovation Centre		80
5.2 DEMO Design Centre		*
5.3. MAST Upgrade		40
5.4. National Nuclear Users Facility (£10m for 6 years)		60
5.5. Sustainability & Resilience of National Infrastructure		300
5.6. Innovative Production Processes		125
5.7. Engineering Structures & Systems		40
5.8. Infrastructure to Support Industrial Biotechnology Innovation		230
6. Campus projects, including:	1,270	
6.1. Research Council Campus Development		420
6.2. Global Science Gateway - Harwell Oxford		400

Capital Projects: ideas for consideration	**Indicative Capital Costs (£m) subject to business case**	
6.3. Campus Development for Medical Research		275
6.4. UK Soil Management Innovation Centre		100
6.5. Water Security Innovation Centre		75
7. Public Engagement projects, including:	40	
7.1. 'Inspiring Science' Capital Investment Fund		22
7.2. Connecting Research and Communities		18
TOTAL	**>5,600***	

** Ondicative costs for some projects are not listed due to commercial sensitivities.*

Conclusion

135. This consultation has set out the need for capital investment at the individual research project, institution, national and international levels and seeks your views on two key questions:

Q1: What balance should we strike between meeting capital requirements at the individual research project and institution level, relative to the need for large-scale investments at national and international levels?

Q2: What should be the UK's priorities for large scale capital investments in the national interest, including where appropriate collaborating in international projects?

There are also a number of sub-questions which will inform these key decisions. These are highlighted throughout the document and summarised below:

A World-Class Research Environment:

- How can we maximise collaboration, equipment sharing, and access to industry to ensure we make the most of this investment?
- What factors should we consider when determining the research capital requirement of the HE estate?
- Should – subject to state aids and other considerations - science & research capital should be extended to RTO and IRO organisations when there are wider benefits for doing so?

Science Strategy for Major New Projects:

- What should the criteria for prioritising projects look like?
- Are there new potential high priority projects which are not identified in this document?
- Should we maintain a proportion of unallocated capital funding to respond to emerging priorities in the second half of this decade?
- Are the major international projects identified in the consultation the right priorities for this scale of investment at the international level? Are there other opportunities for UK involvement in major global collaborations?

136. Responses will inform a Science Capital Roadmap. This will be published at Autumn Statement 2014 as part of the Science and Innovation Strategy, which was announced by the Chancellor of the Exchequer at Autumn Statement 2013. There will be some cases where decisions are time-sensitive and need to be taken before this point.

137. As recommended in the report of the House of Lords' Select Committee on Science & Technology, *Scientific Infrastructure*, BIS has established a Ministerial Advisory Group on science and innovation strategy, which will help shape the Science Capital Roadmap which Government will be developing in response to this consultation. Final investment decisions on any of the projects listed here would be subject to the agreement of a satisfactory business case.

Annex A: Indicative Major Projects For Consideration

Annex A1: Big Data in the 'Exabyte Age'

1.1. National e-Infrastructure

Estimated capital cost: £290m

Estimated operational costs: £25m pa

Delivery partners: RCUK, TSB, HE funding bodies, universities

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. Continuing sustained investment is essential in all aspects of hardware, software and data storage, along with investment in the associated skills and training, to give the required infrastructure to support the research.

Investment will deliver:

- Regional High Performance Computing (HPC) Centres. Further investment in hardware upgrades/expansion plus funding for software and business development support, to allow the regional centres to build on their successful progress in providing access for industrial users.
- Integrated national HPC services. In addition to on-going investments in hardware and associated operational costs to support the wide range of research that requires HPC, e.g. services such as ARCHER (the Advanced Research Computing High End Resource), DiRAC (Distributed Research utilising Advanced Computing), and MoNSOON (the Met Office and NERC Supercomputing Nodes), the scope for investing in infrastructure and supporting services to provide an integrated whole should be explored, potentially with industrial co-funding.
- Hartree Centre. Investment in the Hartree Centre at the STFC's Daresbury campus, to work in collaboration with the academic and industrial communities to develop and deploy new software for the next generation of supercomputers, and to enable collaborators to harness the power and potential of such cutting-edge computing capabilities.
- Data infrastructure. Investment in data storage and networking to ensure previous investments in research using data have the

most up-to-date infrastructure.

Big Data: Biomedical and Life Sciences

1.2. Bridging the Genotype to Phenotype Gap

Estimated cost profile: £1.1bn (Scalable)

Estimated p.a. operational costs: £30m pa

Delivery partners: RCUK

Just as the genome describes all of an organism's genetic material, so phenotype describes all of the traits and physical characteristics that an organism exhibits – as shaped by both its genotype and environment. The UK has been at the forefront of the genomics revolution, which has greatly increased the ability of the biosciences to interrogate the genotypes of plants, microbes, animals and man – (it took 10 years to sequence the human genome, which can now be accomplished in less than a day) – UK bioscience now is poised to address the next big challenge of understanding how genotype influences and controls phenotype, including the effects of external factors (e.g. diet, environment).

Bridging this genotype to phenotype gap will greatly enhance our fundamental understanding of biological systems benefiting the development of: crops and livestock with improved traits, e.g. increased resistance to disease; micro-organisms capable of producing defined molecules, e.g. chemicals, bioactives, and biofuels; improving health throughout life, e.g. better understanding of the influence of diet on health and ageing; and advance stratification and experimental studies in man. Delivering these benefits will require investment in a very wide range of infrastructures including e-infrastructure, improved national research facilities and transformational technologies, which if done wisely will keep the UK in a world-leading position. This will require significant investment in distributed, but integrated infrastructure, building on previous excellence and investment.

- £210m - Investment in e-infrastructure will support the data-driven approaches required to bridge the genotype/phenotype gap. Investment to enable the standardisation, management, access, distribution, analysis and integration of data, as well as computational capacity, including HPC at Hartree needed for simulation and modelling, will be critical. Data centres for the biological and medical sciences, including a Centre of Excellence in crop genomics and bioinformatics, linking with ELIXIR (see Section 2.2), and other big data centres for example in disease areas including dementia are prime exemplars. Securing UK leadership of Systems Bioscience in Europe (ISBE) would provide the opportunity for the UK to drive related developments across Europe.

- £690m - The infrastructure of key national facilities and strategically-funded institutes across a range of disciplines will need improvement in order to maintain and enhance our world-leading research capabilities in genomics and phenomics. Exemplars are state-of-the-art facilities for: plant growth and phenotyping; modern imaging of large animals; plant and animal biosecurity; clinical and biomedical imaging; further development of instrumented farm platforms and replacement laboratory facilities, including a new integrated Centre of excellence in Food, Nutrition and Health.

- £200m - Unlocking the genotype to phenotype challenge will require that researchers have access to a range of transformational technologies delivering greater resolution and detection capabilities. Imaging equipment enabling measurement of single molecules through to high throughput, field-scale automated phenotyping and whole body human imaging will be needed. Analysis and integration of the data generated will be key, with the e-infrastructure investments detailed above being essential.

1.3. From Big Data to Medical Insight and Impact

Estimated capital cost: £150m

Estimated operational costs: Subject to negotiation with potential international partners

Delivery partners: RCUK, Department of Health, devolved administrations, international partners, TSB, RCUK, Genomics England, business

Significant investments have already been made in supporting e-Health Research through the Farr Institute and in Medical Bioinformatics. These investments set the foundations for UK leadership in exploiting highly complex, rich, biomedical data in a range of sectors: in changing clinical practice and the clinical environment; in population and public health work including major contributions to tackling major health challenges such as dementia; in guiding pharmaceutical R&D; and in new diagnostics, monitoring and informatics industries. For the future, significant transformational gains will come from the ability to handle unstructured data (research data), the integration of wide scale heterogeneous data and in providing systematic connectivity across centres to generate a truly integrated network – a platform to linked and validated data.

In parallel, we should aim for further development of infrastructure:

- To increase the speed and ease networking and data integration across UK centres of excellence
- To create incubator space for new commercial and public-service

translational partnerships
- To allow UK centres of excellence to become the hubs for international partnerships
- To further develop data sets – including cohorts, clinical data, and biomedical data – and methods, with investments in acquisition, annotation and linkage with convergence of standards.

1.4. High-throughput Medical Research

Estimated capital cost: £200m

Estimated operational costs: £75m pa

Delivery partners: RCUK

In the big data era, with increasing capability to link complex biomedical data to health records and outcomes, the UK is uniquely placed to enhance its international lead. Innovative high-throughput technologies will enable the generation of big data sets derived from high-throughput genetic, genomic, proteomic, and metabolomic analysis, which if linked to big data from the clinical world of health records and outcomes, provides a unique opportunity to improve our understanding of the prediction and stratification of disease across populations.

The application of these emerging high-throughput technologies to existing data/resources from cohorts, tissue and model organism collections will require investment in their development if we are to harness these opportunities between 2016-21. Ensuring investments are interconnected and that data acquisition is robust, data is well annotated and linked is essential in facilitating wide scale integration of this heterogeneous data. Such investment would further build UK global leadership in medical research and enhance partnerships and leverage with industry and the charitable sector.

Big Data and Environmental Sciences

1.5. Environmental big data research and innovation centres

Estimated capital cost: £70m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK

The UK is preeminent in environmental science, and is viewed as leading scientifically in many aspects of environmental informatics. Developments in big data analytics and advanced computing will enable the development of new products and services that address the needs of business, government and society directly to manage our environment effectively.

To deliver this will require investment in data capture, storage and management, to data analytics and exploitation. The ambition would be to see the UK lead, not only in environmental science, but also in the economic exploitation of that science, with a community trained in the areas of big data that are leading to high economic growth and impact.

Big Data in the Social Sciences

1.6. International Data Integration Platform (IDIP)

Estimated capital cost: £15m

Estimated operational costs: Subject to negotiation with potential international partners

Delivery partners: RCUK, Government Departments, industry

Underpinning the objectives of the Information Economy Strategy and the Data Capability Strategy, there is significant potential for the UK to lead the global effort in integrating new forms of data – from customer transactions, administrative systems, monitoring and sensing devices, internet usage and social media – and their potential for linkage to existing longitudinal or population health datasets. Working with international partners, IDIP would establish new methods and data resources that will enable truly multidisciplinary research to be conducted – whether this is new cohorts that examine and track the progress of young people as they transition through education into adulthood and employment, or exploring the concept of digital personhood. The Platform will establish an international programme of comparative analyses, sharing experience in mining the research potential of these new forms of data and using the wide range of data resources to facilitate new and innovative research programmes.

1.7. Longitudinal studies – integrating the biosocial across the lifecourse

Estimated capital cost: £40m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK, Wellcome Trust, Nuffield Foundation, International Partner Agencies

The UK has a unique, world-leading collection of longitudinal studies spanning 65 years which follow the life trajectories of families and individuals. The Life Study, a new birth cohort starting in 2014 and covering over 80,000 infants and their mothers, will strengthen this series in highly innovative ways, bringing together social, economic and biological measures to deepen our understanding of early childhood health and development. Opportunities exist for the collection of robust empirical evidence on the diverse roles of fathers and other co-parents relevant to future outcomes for their children. Data collection alongside that collected for the mothers and children and/or record linkage provide significant opportunities for new insights over the lifecourse of the role of both parents on their children.

The enhancement of other studies, including the Millennium Cohort and Understanding Society, for example through large scale addition of biological samples and responsible linkage to administrative data sources will radically extend our capacity to understand the key influences that affect people's life chances and shape policy intervention to improve life outcomes. The existing 1970 birth cohort will be enhanced to establish a biosocial resource that enables a truly interdisciplinary approach by use among the international scientific community. This and further biosocial data collection for the 1958 and 1946 cohorts will allow cross-cohort comparisons and lifecourse research and fill an important gap in data on middle age and beyond. The emerging enhancements of the Longitudinal Study of Young People in England will also cover an existing gap in longitudinal studies covering earlier adulthood.

The UK portfolio of cohort and longitudinal studies is being more closely integrated and harmonised through the establishment of the Cohort and Longitudinal Studies Enhancement Resources programme (CLOSER). More widely, opportunities exist for the UK to establish a lead role in coordination and enhancement of international comparative longitudinal studies, such as the Generations and Gender Programme, the Survey of Health, Ageing and Retirement in Europe (SHARE) and household panel studies and in birth cohort studies.

1.8. International Centre for New Forms of Data

Estimated capital cost: £15m

Estimated operational costs: Subject to negotiation with potential international partners

Delivery partners: RCUK, HM Government, business

Underpinning the objectives of the Information Economy Strategy[48] and the

[48] https://www.gov.uk/government/publications/information-economy-strategy

Data Capability Strategy[49], there is significant potential for the UK to lead the global effort in integrating new forms of data – whether born digital, geospatial, NHS, transactional Administrative Data or existing longitudinal or population health datasets. Working with international partners, the Centre will establish new methods and data resources that will enable truly multidisciplinary research to be conducted – whether this is new cohorts that examine and track the progress of young people as they transition through education into adulthood and employment, or exploring the concept of digital personhood. The centre will establish an international programme of comparative analyses, using the full range of data resources – whether current or in yet-to-be imagined form.

1.9. UK Data Service and Administrative Data Service

Estimated capital cost: £25m

Estimated operational costs: £2m pa

Delivery partners: RCUK

Together, the UK Data Service and the Administrative Data Service form 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. The Administrative Data Service enables safe and secure access to Administrative Data held by Government Departments, for the purposes of high quality social scientific research.   Further funding would drive forward seamless access to the burgeoning volume of social and economic data through enhanced, data discovery, metadata standards and new software platforms. There is significant potential for the UK Data Service and Administrative Data Service to seamlessly integrate with existing bio and medical informatics investments (ELIXIR, 100,000 genomes project and the Farr Institute) giving the UK an unprecedented world class data environment with which to address the most challenging economic, health and societal issues.

1.10. Bio-social Data Service

Estimated capital cost: £5m pa capital

[49] *https://www.gov.uk/government/publications/uk-data-capability-strategy*

Estimated operational costs: £2m pa

Delivery partners: RCUK

The Bio-social Data service would bring together data infrastructures in the social sciences (administrative data) with those in the biomedical sciences (clinical data). In the social sciences, the UK Data Service and the Administrative Data Service form a critical part of the UK social and economic data infrastructure. In the biological and medical sciences data infrastructures are being extended and enhanced to provide access to health data and to facilitate research in what is termed the 'omics (genomics, phenomics, etc.). Database systems and data sharing platforms such as ELIXIR, the 100,000 Genomes project and the Farr Institute are transforming research within these scientific areas. The Bio-social Data Service will build on these developments through the seamless integration of these existing services giving the UK an unprecedented world-class data environment with which to address the most challenging economic, health and societal issues.

Big Data in the Arts and Humanities

1.11. Big Data Centre for the Creative Economy

Estimated capital cost: £17m

Estimated operational costs: £2m pa

Delivery partners: RCUK

This project would support the development, creation and creative exploitation/re-use of big data sets in the arts and humanities by both academic researchers and those in the creative and cultural industries. Investment would enable follow-on from projects such as Brighton Fuse – a real-time study of the working of a successful creative cluster growing at c.17% annually – in sector- and location-specific contexts and in partnership with the LEPS, as steered by independent research on the heightened economic and civic value of the creative sector.

1.12. Digital Transformation Clusters in the Arts & Humanities

Estimated capital cost: £18m

Estimated operational costs: £1m pa

Delivery partners: RCUK

This project would enable the creative and innovation-driven exploitation of a wide variety of archival content (objects, traditional text etc) through building on capacity supported through existing projects such as Internet of Things (visual, multi-sensory, sound etc). This has impact in particular in the Design research base where existing RCUK investments are developing new approaches to the 'living archive' as well as collaborations with national infrastructure assets like the National Archives, the British Library and other Independent Research Organisations. There is potential for leveraged funding from commercial partners through AHRC's Knowledge Exchange Hubs for the Creative Economy and user-economy organisations emerging through the current Cultural Value Project (2012-14). A separate element in this strand is work with corporate archives where there is significant scope for leveraged funding. Large scale corporate bodies have extensive archival histories and repositories that have begun to be explored through recent small scale pilot work under the RCUK Digital Transformations theme. Often providing unique sources of archival materials relating to spheres such as creativity, design, cultural heritage and social history, these archives are a potential source of revitalised creative histories for contemporary business cultures.

1.13. Heritage Science

Estimated capital cost: £16m

Estimated operational costs: £1-1.5m pa

Delivery partners: RCUK

Enhancing the UK's position at the forefront of the emerging field of heritage studies 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. £10m capital investment would enable heritage researchers to take advantage of 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. Further capital investment of £6m for the development of two to three Centres for Heritage Science Studies would provide the high tech scanning and mapping equipment, as well as co-ordinating the sort of mobile facilities needed for on-site analysis as well as funding for projects to pilot/ demonstrate the use of these technologies, and explore the usage of the heritage artefacts themselves.

Annex A2: Understanding the Universe

2.1. European Space Agency Programme (Decision Points in 2014 and 2016)

Estimated costs: Subject to international negotiation

Delivery partners: UK Space Agency, European Space Agency

The UK's current commitment to ESA of £100m per annum runs until 2017-18. The next two European Space Agency (ESA) Council of Ministers meetings will be held in December 2014 and in 2016. These determine multi-year commitments from 2017 to continue existing projects, and to start new ones.

The fundamental rationale for ESA membership is for the UK to participate in and benefit from projects it would be unable to fund on its own; and from this develop mutually beneficial collaborations and world-class scientific and industrial capacity.

ESA Ministerial 2014: The next ESA Ministerial will not address the full set of ESA programme (science, Earth observation, telecoms etc.) but is expected to focus only on key decisions requiring urgent decision comprising: continued funding of the International Space Station (ISS); completion of funding for the exobiology on Mars (ExoMars) project; and the start of the next European launch vehicle. While the UK has interests in the first two it does not intend to participate in the third.

ESA Ministerial 2016: By the time of the 2016 Ministerial, many of the UK's existing commitments to ESA will come to the end of their current phase. The choices made at the ESA Ministerial will set the UK's strategy for the current decade and – for some key decisions on major new projects – could determine our space industry's growth for decades to come.

A balanced package of investment at C-Min 2016 will reinforce the success of a sector that now contributes over £9bn to the UK economy. While it is too early to define specific proposals, activities are likely to build on existing programmes:

- **ESA's mandatory programme** including the General Budget and the highly successful Space Science Programme which has produced world class projects such as Herschel, and Planck.
- **Telecommunications (ARTES)** which develops and exploits satellites for telecommunications and their application in commercial services including Alphasat and Hylas 1. Most of this programme is jointly funded with industry (50-50) and thus is market led.
- The **Earth Observation Envelope Programme (EOEP)** which builds spacecraft to study the Earth from space and exploits the data returned. The UK has gained strong scientific and industrial benefit from the current phase on missions such as Cryosat, SWARM and EarthCARE.

- **Global Monitoring of the Environment and Security (GMES)** is part of the European contribution to the global effort to develop long term Earth observation data sets for both public policy use and commercial exploitation.
- The **Mars Robotic Programme (MREP),** a science-driven roadmap for breakthrough technology such as robotics and nuclear batteries for missions leading to a future international Mars Sample Return scientific mission.
- **The International Space Station (ISS) programme,** focussed on utilisation and exploitation of technology and science aboard the ISS and preparing for future human exploration of the Moon, Mars and beyond – see Section 2.3.
- **The European Life and Physical Sciences Programme (ELIPS)** exploits the space environment for fundamental and applied science. Benefits include insights into human ageing and new materials for jet engines.
- **Generic Support Technology Programme (GSTP)** takes early phase space technology R&D across the 'valley of death' into practical application. The programme benefits SMEs who work with European partners and take advantage of ESA's recognised technical and quality standards to create high value products.
- ESA's **Space Situational Awareness (SSA)** programme, which develops means to monitor and mitigate hazards caused to space and terrestrial infrastructure by space weather and space debris.

2.2. M3 Space Mission

UK intention to invest announced March 2014.

Estimated costs: £25m

Delivery partners: UK Space Agency, European Space Agency

The European Space Agency's next major space science mission, Plato, has been selected as the third Medium-class mission ('M3') in its 'Cosmic Vision' programme.

Plato

Plato is a mission to detect Earth like planets by observing thousands of stars simultaneously, and the characterisation of their atmospheres addressing the potential suitability for life and indeed, looking for signs of life. When combined with dedicated follow up observations with other space based telescopes such as the James Webb Space Telescope, and ground based facilities such as the European Extremely Large Telescope (E-ELT), we would be able to characterise and detect life signatures. Plato is under UK scientific leadership with the UK hosting the largest exoplanet research community in Europe.

With UK investment, the UK Space Agency will run an open competition, inviting bids from industry to provide the system engineering management.

The successful bidder will be selected on the basis of technical competence and availability of a suitably experienced and co-located team, as well as cost-effectiveness and geo-return considerations.

2.3. Space Data – Ground Stations and Analysis

Estimated capital cost: £35m

Estimated operational costs: Subject to detailed business case

Delivery partners: UK Space Agency

A ten year plan to produce a coordinated network of ground stations for reception of space data (£17m) is foreseen to integrate and update the range of existing facilities at Borden, Hampshire; Goonhilly, Cornwall; Harwell Oxford; and Chilton, Oxfordshire, into a national infrastructure.

Investment in the Climate and Environmental Monitoring from Space (CEMS) facility at Harwell Oxford (£9M) would allow the UK to extract maximum value from the EU's GMES 'Copernicus' programme. It will also enable wider international collaboration in using space to understand climate change and develop operational services.

Similarly, sustained investment in hardware and software to maintain the UK's capability in specialist data processing systems for space science (£9m) will support current and future major observatory class such as JWST and Euclid, due for launch in 2018 and 2020 respectively. Processing the data into a usable form for scientific analysis is a leading challenge in automated management and analysis of huge and complex datasets. The wider applicability of the techniques developed to implement this challenge in industry and broader areas of science (e.g. medicine) is large.

2.4. Space Data – Exploitation

Estimated capital cost: £16m

Estimated operational costs: Subject to detailed business case

Delivery partners: UK Space Agency

A facility for the exploitation of space data for commercial and civil security applications (£16M) would promote downstream applications of space data including those that require civil security measures. Public regulated service (PRS) applications show very high potential value and UK has technology solutions under current programme R&D. There is a fit with DSTL interest in

NovaSAR and other applications development, and the facility would be important in developing radar and other advanced analysis.

2.5. National Spaceport and Space Propulsion Facility

Estimated capital cost: £30-60m

Estimated operational costs: Subject to detailed business case

Delivery partners: UK Space Agency

A national spaceport (£25-50M) is identified by the Space IGS Growth Action Plan as an enabler to new markets, such as space tourism and low cost access to space complementary to the UK expertise in small satellites. A current National Space Technology Programme study has identified the requirements and a parallel activity is analysing the regulatory environment. After the US, the UK has the best chance to be the second country in the world to enable spaceplane operations.

A national space propulsion facility (£6M) for R&D and production testing of thrusters in a simulated space environment would support the growth of several UK companies.

2.6. Planetary Sample Curation Facility

Estimated capital cost: £25-45m

Estimated operational costs: Subject to detailed business case

Delivery partners: UK Space Agency

A planetary sample curation facility (£25-45M plus co-funding with ESA/EU) to house and study planetary material returned from the Solar System will be needed in the 2020s, and the UK has both the scientific and technological capability to stake a claim for the European facility, one of perhaps two or three that would be built worldwide. This would place the UK at the heart of global space exploration in the 21st Century.

2.7. TRUTHS

Estimated capital cost: £150m

Estimated operational costs: Subject to detailed business case

Delivery partners: UKSA

There is a recognised need for a space-born system for radiometric calibration. With the extent of earth-observation from space, the system would improve accuracy and reliability of datasets upon which current and future climate studies will be based.

2.8. Large Synoptic Survey Telescope (LSST)

Estimated costs: Subject to international negotiation

Delivery partners: RCUK, USA and other international partners

The Large Synoptic Survey telescope to be built in Chile will revolutionise astronomy by undertaking a unique sky survey in six wavebands to produce a dataset 1,000 times larger than its predecessors, opening up large scale stuffy for the first time, building on the knowledge provided by the current ESA Gaia mission. LSST participation will be pivotal in the array of southern hemisphere facilities in the 2020s. It is complementary to the Square Kilometre Array and European-Extremely Large Telescope, and will have science reach covering cosmology, exoplanet and asteroid searches, and black holes studies. Its 3.2bn pixel camera (expected to use UK-made detectors under contract) will obtain photometry of 4 billion galaxies. The enormous data challenge will require several, fully synchronised data centres to enable early recognition of the most interesting transient objects. Scientific participation in the LSST for the UK astronomy community would potentially include the development of a European data centre, based in the UK, in collaboration with France. This would target investment in a priority area where the UK has existing expertise and guarantee a UK-lead in early science**.**

2.9. Long Baseline Neutrino Experiments

Estimated costs: Subject to international negotiation

Delivery partners: RCUK, USA, Japan and other international partners

The European Strategy for Particle Physics identified the strong scientific case for a long baseline neutrino programme and recommended that Europe should explore the possibility of major participation in leading next generation long baseline neutrino projects in the US and Japan. UK groups are collaborating to produce a coherent plan for future UK participation in this programme. Two potential projects are being developed, the Long Baseline Neutrino Experiment in the US, and the T2HK neutrino experiment in Japan, which could further our understanding of the matter-antimatter asymmetry in the universe. Both experiments have a wide scientific programme studying atmospheric neutrinos, neutrinos from supernovae and increasing the sensitivity to detection of proton decay. The different technologies of the two experiments give powerful arguments for both approaches, although it is likely that UK groups will focus on one of the two following the current R&D phase**.**

2.10. Advanced Capabilities in Nuclear Physics

Estimated capital cost: £10-15m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK, US DOE, CERN

STFC funds an active experimental and theoretical nuclear physics programme, which is dependent on its great success at winning time competitively at a wide range of international facilities. There are three near term opportunities to collaborate in the construction of new, or upgrade of existing, facilities that will give the UK continued access to world leading capabilities:

- Upgrades of the Thomas Jefferson National Accelerator Facility in the US will double the accelerator energy to address fundamental questions on how quarks acquire mass. This upgrade will include the provision of new experimental equipment to benefit from the increased accelerator energy.
- ALICE (A Large Ion Collider Experiment) is a heavy ion detector at the Large Hadron Collider, designed to address the physics of strongly interacting matter using nucleus-nucleus collisions. It is preparing for a major upgrade, both to the detector and the associated software and computing, to take advantage of the increased luminosity from the LHC upgrade planned for 2018-19.
- Exploitation of the heavy ion storage ring at the ISOLDE (Isotope mass Separator On-line facility) accelerator at CERN will enable the study of a range of radioactive nuclei to unrivalled energy resolution and sensitivity.

In each case the UK research would focus on areas of expertise, such as sensor and electronics design, mechanical and cooling design and data processing.

Annex A3: Understanding our Planet

3.1. New Polar Research Ship

Intention to invest announced April 2014

Estimated capital cost: £225m (for polar flagship and associated capital and resource spend)

Estimated operational costs: £14m pa (Subject to business case approval)

Delivery partners: RCUK

Investment in a new ice-strengthened ship will keep the UK amongst world leading nations for research in the Polar regions by providing a world class scientific platform, supporting a wide range of oceanographic, marine ecosystem and marine geosciences research, as well as logistics support. Such a ship also is crucial to delivering the Government's policy for a regional British presence in Antarctica.

The replacement ship, part of the NERC British Antarctic Survey's (BAS) infrastructure, is needed to deliver RCUK science requirements including with university partners. It will be consistent with new international maritime requirements for safe operation in polar waters, provide a marine capability that is more cost effective and provide greater value for money than other options. As operational costs will be less than the current polar research fleet, the project will save money relative to current spending.

Image of proposed new polar research ship

3.2. Environmental Observing Systems Research & Innovation Centre

Estimated capital cost: £130m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK

A comprehensive integrated sensing, analysis and data infrastructure for the environment to inform decisions and drive growth. It would span the rural and urban terrestrial environment, extending to the upper atmosphere, as well as coastal and marine resources, and will deliver information to businesses, researchers and citizens. Building on the wealth of expertise in environmental sciences and technology it will enable the UK to protect and enhance the services provided by the natural environment. Working with industry, the investment will exploit and develop new technological approaches to environmental observations and analysis. By exploiting environmental open access big data to make informed decisions, it will benefit key industrial sectors including energy, agriculture, and water. For example a national network of sensors could contribute to flood and weather forecasting, as well as drought and pollution monitoring. Creating open access data will drive innovation and new businesses in the environmental sector developing new products and services (e.g. around planning, environmental impact, payment for ecosystem services, and offsetting). Over the long term this approach has been estimated to have the potential to save the UK economy up to £20 billion annually from protection of ecosystem services[50].

3.3. Jason - Continuity of Service (Jason-CS): Continuing accurate sea-level measurements for science and operations

Estimated capital cost: £20m

Estimated operational costs: Subject to detailed business case

Delivery partners: UK Space Agency, Met Office

Mean Sea Level is arguably the best indicator for global warming, and the Jason satellite series is the only mechanism for providing this critical dataset to sufficient accuracy. These measures have high scientific and operational value. The clarity of the evidence for climate change obtained from Jason

[50] *UK National Ecosystem Assessment,* Human Well-being: Economic Values from Ecosystems

gives us a good benchmark for measuring our confidence in climate models, and provides opportunities to avoid unnecessary adaptation costs. UK Government spends hundreds of millions of pounds every year on flood defences. Better prediction of coastal sea level rise will reduce the risk of unexpectedly high flood damages, or conversely allow a longer-term approach to the engineering of sea defences. There are also benefits to other application areas such as oceanography and seasonal weather forecasting.

The Jason series of satellites provide sea level data on a global scale and is a joint partnership between Europe and the USA going back to 1992. Jason-CS is the next stage in the implementation of this series and follows on from UK investments in Jason 2 and 3. The European component of the partnership will be jointly implemented by EUMETSAT, ESA and the EU. This capital proposal covers the EUMETSAT contribution. The Met Office represents the UK at EUMETSAT, who will open the subscription for Jason CS funding in late 2014 (CS standing for ‘Continuity of Service’). This will be the first time a Jason subscription will be opened since the formation of the UK Space Agency. Jason CS involves a pair of satellites operating for 14 years up to 2031. ESA has an R&D programme for Jason CS to which the UK already subscribed at the 2012 Ministerial.

Annex A4: Understanding How Materials Behave

4.1. European Spallation Source
UK intention to invest announced March 2014.

Estimated costs: Around 10% of the funding subject to international negotiations (could be around £165m up to 2020/21)

Delivery partners: Sweden, Denmark and European partners

The European Spallation Source (ESS) is a proposed new powerful neutron source to be built in Sweden. It will be one of the largest science and technology infrastructure projects in the world and will cost €1.8bn to construct. As a continuous neutron source it will in time become the leading continuous neutron source in Europe (superceding the Institut Laue-Langevin), and complement the pulsed ISIS neutron source at Harwell Oxford. ESS is a pan-European project involving around 15 European countries, with Sweden and Denmark as host nations. The ESS facility will be built in Lund, whilst the ESS Data Management and Software Centre Centre will be located in Copenhagen.

A neutron source and its complementary detection instruments, enable scientists to see and understand basic atomic structures and forces. It can be compared with a giant microscope for the study of different materials. Neutrons are excellent for probing materials on the molecular level – everything from motors and medicine, to plastics and proteins. Detailed studies are dependent on how many neutrons can be produced by a neutron source. This is a significant limitation for existing sources based on nuclear reactors. As a result, scientists and engineers have developed a new generation of neutron sources based on particle accelerators and spallation technology.

4.2. Neutron capability – ISIS and Institut Laue-Langevin

Estimated costs: Subject to international negotiation

Delivery Partners: RCUK, International partners at ILL.

Neutrons and muons provide unique information at the atomic and molecular level of the structure and dynamics of condensed matter (solids, liquids, glasses etc.) in fields as diverse as Physics, Chemistry, Life Sciences, Materials Science, Earth Sciences and Engineering. UK users have access to the ISIS pulsed spallation source at Harwell Oxford and through UK membership of the complementary ILL reactor source in Grenoble.

Continual maintenance and upgrades of the ISIS and ILL facilities (in advance of the potential construction of ESS) are required to ensure that UK researchers have access to internationally competitive instruments. A programme of minor upgrades at ISIS is required across the science areas in optics, detectors, sample environment, robotics, automation and software, to improve capability and efficiency. ILL has identified a number of items following a recent 2011 Instrument Review that would enhance their capabilities, and a programme of instrument upgrades will be put forward in 2014.

State of the art neutronics, engineering and instrument development at the ISIS Target Station 2 (TS2) project has realised huge scientific benefits for nanoscale science, generating new capabilities. These advances can be readily transferred to upgrade the Target Station 1 with a relatively short lead time delivering productivity increase across the current suite of 20 instruments with no increase in operating costs.

On completion of ISIS TS2 Phase 2 instrumentation there will be 27 instruments at ISIS. Phase 3 would allow an additional 3 to 4 instruments to be constructed. Choice of these instruments would be subject to user consultation and peer review; however current priorities identified by the user community include:

- an engineering diffraction instrument where there is demonstrated industrial/academic collaboration interest in improved capability for non-destructive residual stress and materials testing measurements which are now entirely limited by capacity for applications in energy, aerospace and automotive;
- chemical spectroscopy to support the EPSRC funded catalysis hub at Harwell Oxford with additional applications in energy; and
- quasi-elastic scattering.

4.3. Synchotron capability – Diamond and ESRF

Estimated costs: Subject to international negotiation

Delivery partners: RCUK, International partners in ESRF

Synchrotron sources like the Diamond Light Source at Harwell Oxford produce brilliant beams of light across a large energy range and are used across a wide scope of research areas from biological crystallography, to heritage science, environmental science and engineering. The UK has reclaimed its position at the state-of-the-art in this area with the success of Diamond – the opportunity now exists to move into a real position of international leadership. Diamond requires continual investment in capital to maintain its current capability through planned replacements and efficiency improvements, and in upgrades to add new capabilities.

The European Synchrotron Radiation Facility (ESRF) in Grenoble, France, is one of the world's leading synchrotron radiation facilities (and most powerful in Europe); it has been at the forefront of international research for over 20 years and delivers high impact science for its partners. The UK is currently a

14% shareholder, paying 10.5% of costs. Phase 2 of the Upgrade programme includes improvements to the accelerator complex, the public beamline portfolio and a dedicated programme to develop advanced optics, detectors and software. The upgrade of the accelerator complex has the potential to greatly improve the operating parameters of the facility and reduce the power consumption. A similar upgrade of the Diamond machine optics lattice will enable the facility to remain world leading into the 2020s with an order of magnitude increase in beam brilliance.

4.4. Sapphire: UK Free Electron Laser

Estimated capital cost: Approx. £450m

Estimated operational costs: Approx. £45m pa

Delivery partners: RCUK

An X-ray free electron laser is a synchrotron facility which can generate ultra-short X-ray pulses, a billion times brighter than conventional X-ray sources, with similar properties to those of laser light. Enabling scientists to map molecular structures at atomic detail, this would offer, for example, the potential for a paradigm shift in our ability to solve protein structures for very small crystals such as those available for membrane proteins – which are targeted by over 50% of currently available small molecule based drugs. It is therefore of acute industrial and medical interest and will give access to capabilities that cannot be provided through synchrotrons, in a complementary technique.

Sited at Harwell Oxford, combining the pulsed electron beam of the FEL with the continuous light beam-lines of the world-leading Diamond Light Source, would allow researchers to use beams from both facilities at the same time to study their samples, and explore new research frontiers.

4.5. Central Laser Facility

Estimated costs: £90m, excluding operational capital

Delivery partners: RCUK

The Central Laser Facility (CLF) operates five state of the art laser based facilities, supporting research in areas including high energy density plasma physics, laser plasma interactions, atomic and condensed matter, time resolved spectroscopy and biological sciences. Operational capital is required on an ongoing basis to maintain these as state of the art, with a minor upgrade programme, including upgrades to the Octopus suite serving mainly the biomedical and plant sciences, the Ultra laser supporting studies of dynamic processes from chemistry to structural biology, and the Artemis facility with applications in atomic and molecular physics. A second target area on the Gemini facility driven by the DiPOLE technology (diode pumped technology), would focus on applications in extreme photonics.

To keep the UK's world leading status in high power laser science requires an upgrade of the power of the Vulcan laser by a factor of 20. This would produce the highest power and highest intensity laser in the world, and would extend laboratory plasma physics into the astrophysical domain. Theoretical studies in recent years have shown that the predicted intensities would access new physics and enable new science in materials research, fusion energy and plasma probing. In addition to the national facilities there are also pressing needs to establish regional attosecond sources and to strengthen the laser capabilities in leading research groups in physics, chemistry, engineering and increasingly biology.

The Centre for Interdisciplinary Research in Imaging and Spectroscopy would be housed in the Research Complex at Harwell Oxford and expand the laser based microscopy techniques on Octopus, develop faster time coverage through an Ultra upgrade, and invest in imaging and image processing, working across the facilities at RAL to drive and exploit multi-modal techniques with Diamond and ISIS. This would have a particular focus on industrial applications.

4.6.Capabilities in next generation imaging technologies and High-throughput genomics and bioscience

Estimated capital cost: £200m

Estimated operational costs: £50m pa

Delivery partners: RCUK

Detailed structural information about the molecular targets of drugs and the biological consequence of their action is invaluable for designing new drugs and therapies and for molecular pathology. 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, whole-human molecular imaging, sensing and single cell science.

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.

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.

4.7. Mid-range Regional Analytical Facilities

Estimated capital cost: £55m

Estimated operational costs: £50m pa

Delivery partners: RCUK

These research facilities provide a wide range of specialist services and instrumentation to the academic and industrial research community. They include:

- techniques such as nuclear magnetic resonance (NMR), electron microscopy, and crystallography;
- experimental facilities such as a dark fibre network, and a wave tank;
- loan pools for lasers and engineering equipment; and
- services such as computational software and databases.

As well as providing a cost-effective and professional way of delivering these services, the facilities would provide researchers with access to cutting-edge equipment and expert support that would not be available to them locally. Continuing investment is needed in both capital and operational costs.

Annex A5: Grand Challenges

Energy Security and Resilience

5.1. Energy Security & Innovation Centre

Estimated capital cost: £80m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK

Through a partnership between research and industry, this would strengthen UK leadership in subsurface technologies to contribute to UK energy security. An Energy Security and Innovation Centre would enable research on the impact of new energy sources including shale gas drilling and associated hydraulic fracturing as well as processes related to carbon and waste storage. The infrastructure will allow the subsurface to be monitored and exploited particularly for energy and waste disposal. The UK would develop a unique package of monitoring capability and novel technology that would benefit industry by maximising efficiency of extraction and subsurface management. This knowhow and data would also stimulate additional investment and speed new technology energy options to commercialisation, this in a global market in which this investment would provide a competitive advantage for British expertise and a major export.

5.2. DEMO Design Centre

Estimated costs: Subject to international negotiation

Delivery partners: UK Atomic Energy Authority, Euratom and other partners

The design of DEMO (the first fusion electricity generating plant, which is due to succeed ITER) will require a wide range of engineering skills, many of which already exist at the UK Atomic Energy Authority’s Culham Centre for Fusion Energy, because of its role in modifying and operating JET, in addition to the specific fusion technology skills developed within the RCUK programme.

We anticipate that Euratom will instigate the design of DEMO, possibly at more than one centre across Europe, and that the UK will bid to host a centre. It will require housing in a suitable modern building with state-of-the art design studios (including virtual prototyping), engineering workshops and laboratories. The funding of the operation would be provided jointly by the UK as host nation and Europe as part of Horizon 2020 and its successor Framework Programme. There would also be involvement by UK industry, allowing the development of key expertise which can be exploited as fusion becomes commercialised (post-DEMO).

5.3. MAST Upgrade

Estimated capital cost: £40m

Estimated operational costs: Subject to detailed business case

Delivery partners: UK Atomic Energy Authority, RCUK

MAST (Mega Amp Spherical Tokamak) is a fusion project designed and built at the Culham Centre for Fusion Energy, and operational since 2000. It is currently being upgraded, with operation due to start again in 2015. The upgrade of additional components would bring MAST to a new level for developing first class practical and innovative scientists (for non-fusion as well as fusion research) and ensuring that the UK retains strategically influential and attractive state-of-the-art fusion capabilities. The scientists, based in UK universities and at CCFE, who will make ITER succeed in the 2020s and beyond, will need a solid basis in tokamak science and technology and MAST will provide key parts of this directly, and through CCFE's links to larger international facilities. The complex multi-disciplinary nature of fusion R&D provides a special set of widely applicable skills. CCFE's proposal to provide the UK with a major DEMO/power plant design centre is predicated on an integrated physics, technology and engineering capability.

By extending MAST's capability the UK will be able to contribute strongly to decisions on the optimal design parameters and plasma operating regimes for DEMO/Power Plants and prove the viability of the spherical tokamak plasma at the heart of a Component Test Facility. The developments would include: a cryoplant, more flexible plasma heating and optimisation systems, enhancements to plasma diagnostics, and improvements in hardware and staffing infrastructure to apply university-developed instrumentation and other projects and enhance local and remote participation in experiments and modelling. UK funds are likely to leverage EU funding as MAST is recognised as a key EU fusion research facility.

5.4. National Nuclear Users Facility (NNUF)

Estimated capital cost: £60m

Estimated operational costs: Rising from £5M to £15M pa

Delivery partners: RCUK and the NNUF partners

The NNUF was established to support the Government Nuclear Industrial Strategy launched in March 2013. It acts as a multi-site user facility in nuclear science and technology for researchers from universities, research institutes, industry and other organisations across the widest possible range of nuclear energy research, science and technology capabilities. The initial investment of £15M to establish the NNUF announced in March 2013 extends to March 2015. This funding supports new user facilities at CCFE, the University of Manchester Dalton Cumbrian Facility (DCF) and the NNL Central Laboratory at Sellafield for the irradiation and post-irradiation examination of advanced materials for lifetime extension, new build and future generations of fission and fusion nuclear power plant.

Further funding would extend the capabilities of the NNUF, both enhancing the initial investments that support nuclear materials research and allowing capital investment in other key areas of nuclear energy research, science and technology, across the full nuclear lifecycle for current and future nuclear reactor systems. This extension of the NNUF mandate to fields such as uranium and plutonium recycling and reuse; spent fuel management; plutonium disposition, instrumentation, small modular reactors, Generation IV systems and geological disposal is essential to meet present and future nuclear energy challenges. A survey of user needs was held in 2013 and discussed at the Nuclear Academics meeting in Birmingham in September. Proposals will now be prioritised with the help of other universities who are joining the NNUF steering committee. The funding will also be used to expand and exploit research and engineering relationships with key international partners in nuclear technology.

A world-leading NNUF supporting research and development across the whole nuclear landscape will provide both the economic impact derived from the translation of research to high technology and the training of graduate scientists, technicians and engineers needed by a renascent nuclear industry, Government and universities in the coming decades. Capital investment of at least £10M per year for this six year period, together with resource funding ramping up from £5M to £15M per year for operations, training and knowledge transfer, is needed to establish and exploit the major change in research infrastructure needed to deliver the Government’s nuclear strategy.

5.5. Centre of Excellence for Sustainability & Resilience of National Infrastructure

Estimated capital cost: £300m

Estimated operational costs: £30m pa

Delivery partners: Research Councils, TSB, BIS

Reliable infrastructure (energy, water, transport, digital communications and waste disposal networks and facilities) is essential for the economy and society to flourish. However, a complex mix of multiple sectors, public bodies, private companies and regulators are involved, with a mix of engineering, social, financial and environmental challenges. There is no single coordinating institute or centre of excellence at a national level which can bring the study of these strands of infrastructure together to deliver the research outcomes and impact that the UK needs. The Research Councils have been working together to ensure that UK capability in the research base is world leading and delivering impact in some specific areas of need. However it is now clear that an interdisciplinary Centre of Excellence coordinating and defining the approach in this area is urgently required. Working across industry, regulators and Government the outputs would provide an evidence base to inform prioritisation of future capital spend on national infrastructure projects in order to deliver a sustainable and resilient future infrastructure.

Capital investment in a national centre would be focused on a need to strengthen the understanding of and capability in interdependency, systems thinking, resilience, social acceptability and use of observational data – leading to new routes to exploitation and commercial and social impact. Topics to be researched might include:

- Science – optimisation mathematics, epidemiology, low loss electrical conductors, magnetics, soil mechanics, fluid mechanics, tribology, web science, energy storage, applied complexity science.
- Technologies – sensors, composites, tunnelling, adaptive systems, plastic electronics, data mining, advanced mobile communications technologies.
- Engineering – design, resilience, low carbon, operational management, intelligent transport systems, large scale human – vehicle interface design, underground engineering, water management systems, complex systems analysis and systems thinking, supply chain resilience, real time monitoring sites, sensor systems to allow real time monitoring within cities.

Capital investment would allow a central facility to collate, manage and host a range of data sets on UK civil infrastructure; would enhance the UK's test facilities; and accelerate development of digital and visualisation technologies.

Innovation in Manufacturing

5.6. Innovative Production Processes

Estimated capital cost: £125m

Estimated operational costs: £250m pa

Delivery partners: Research Councils, TSB, BIS

Manufacturing has a key role in the generation of long-term economic growth and jobs for the UK. Future industrial success will depend upon the deployment of innovative products by UK companies, using new manufacturing technologies, processes and systems to maintain competitive advantage and enable that growth. Examples of such innovative production technologies include continuous flow production, laser processing systems, industrial bio-processing and multifunctional additive layer manufacturing. Investment would allow the development of a number of world class research platforms, organised around unique research instrumentation and infrastructure. The facilities provided by this investment would complement the existing facilities in the Catapults, particularly the High Value Manufacturing Catapult, and would be closely linked to the work of the Automotive Council and the Aerospace Growth Partnership.

5.7. Engineering Structures & Systems

Estimated capital cost: £40m

Estimated operational costs: £35m pa

Delivery partners: Research Councils, industry

Future engineering structures will be stronger, lighter, cheaper and able to monitor their own ‘health’. Such structures range in scale and complexity, from buildings, aircraft engines and wind turbines to everyday appliances in the home and workplace. Innovation in creative design, intelligent lifetime monitoring and efficiency of use is essential to advances in the construction, automotive, energy and aerospace sectors, where sophisticated structures are increasingly required to be developed. The aim is to create unique advanced mechanical test capabilities in collaboration with key companies, that will allow industry to capitalise on the UK’s expertise in the dynamic behaviour of complex structures, emerging new materials, advanced sensors and analysis methods.

5.8. Infrastructure to Support Industrial Biotechnology Innovation

Estimated capital cost: £230m

Estimated operational costs: £30m pa

Delivery partners: RCUK, TSB

Industrial Biotechnology uses biology to produce new materials and products, and to change existing ones. From green energy, biofuels, chemicals and materials through to medicines - Industrial Biotechnology has the potential to deliver transformational products and processes which will drive growth of the bioeconomy in the UK.

Infrastructure and facilities are essential to enabling the demonstration of novel bio-renewable routes to industrial production of high value commodities, for example bioenergy, chemicals and antibiotics, as well as the extraction of high value components from novel feedstocks (e.g. municipal waste) and the production of liquid biofuels from non-food crops. For example, UK bioprocessing plants need to be maintained at the leading edge to enable adoption and development of novel technologies, leading to new processes and products. UK companies – small and medium sized in particular – will need to be able to access such bioprocessing plants, so as to translate research outcomes into practice, enabling company growth and opportunities for export. For new technologies and processes to be adopted by companies a range of demonstration facilities will also be needed. Investment will ensure the UK develops a strong network of appropriate industrial biotechnology capabilities.

Annex A6: Campuses

6.1. Research Council Campus Development

Estimated capital cost: £420m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK, TSB

Research Council investment in campuses developed around their strategically-funded institutes, are a significant route to ensuring that there is both immediate and long-term impact from research. These campuses include existing BBSRC campuses at Aberystwyth, Babraham, Edinburgh, Norwich, Pirbright and Rothamsted; STFC campuses at Daresbury and Harwell Oxford; and could include proposed NERC campuses to be based around a proposed UK soil management innovation centre; and a proposed water security and innovation centre – set out separately and below. Further infrastructure development will enable user access to research, company incubation and support capacity at the various research and innovation campuses across the UK.

Start-up companies, SMEs, larger companies and multinationals, international research and user partners would be able to access the outstanding research capabilities at these campuses. To achieve this specialist facilities would be developed, such as ‘research hotels’ (where visiting researchers can work for variable periods of time) and dedicated user space (for example for early company incubation), all underpinned by the necessary infrastructure to ensure that research can be translated into impact.

Investment would be made in a range of research and innovation campuses across the UK. For example, BBSRC would seek to invest up to £200m in its six existing research and innovation campuses over a 6-year window. Development of the Rothamsted campus would require investment of £50m for strategic business facilities; ‘hotel’ laboratory space for visiting researchers; IT intense company space; and accommodation for visiting researchers and company staff. Investment of £30m in the Pirbright Campus would enable the establishment of innovation facilities, e.g. ‘hotel’ research space, that could be used flexibly by businesses and visiting industrial researchers, enabling them to benefit from co-location with the world-leading researchers and high containment facilities at Pirbright Institute.

Investment in the Harwell Oxford campus would include an extension to the Research complex, business focussed activities building on the expertise in accelerator, imaging, laser and computing technologies, a student village, hostel and business incubation facilities and a new public engagement centre.

Investment in the Daresbury Science and Innovation campus focuses on STFC's expertise in computing, accelerator R&D and detector technologies. New investments would build on previous government investment in these areas in collaboration with industry. Specific deliverables at Daresbury include:

- Hartree centre – hardware upgrades to the development and demonstration computing systems and for the energy efficient computing research capabilities (£80m)
- Compact Linear accelerator centre investment in CLARA, a new compact linear accelerator at Daresbury that builds on existing investments to enable the development of cheaper and compact accelerators for applications in healthcare, security and energy and to support innovative future science facilities including a future X-ray free electron laser (£35m)
- Technology hub lab space for industrial collaborations (£5m)

Additionally, seed fund provision of £100M would support very early start-ups at research and innovation campuses arising from Research Council investments in focused areas such as industrial biotechnology, or deriving from the neutron and synchrotron facilities at Harwell.

6.2. Global Science Gateway - Harwell Oxford

Estimated capital cost: £400m+ (excluding projects covered elsewhere in Annex A4)

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK, UK Atomic Energy Authority, TSB

The opportunity exists at Harwell Oxford to go beyond the developments outlined above, through building on the already world-class capabilities at the Harwell Oxford and Culham sites to develop the cluster as a Global Science Gateway. The gateway would be based on and strengthen the capabilities of the two campuses, and could incorporate separate investments which have been outlined in Annex A4 in the Diamond Light Source, the ISIS neutron source, the Central Laser Facility, the Culham fusion research facilities, and new projects such as Sapphire.

New investments would focus on creating a world-unique capability focused on two of the key technologies of the 21st century – materials and energy. Two flagship projects – a new free-electron light source and a new, international energy materials irradiation facility, would be built. Each of these builds on an existing capability at the site – the Diamond Light Source and the ISIS neutron source. A series of modest and affordable upgrades to existing facilities would ensure that they remain at the cutting edge for the next decades. A new energy research centre aimed at novel materials and energy storage with the goal of making the campus energy-independent would be complemented by a number of interdisciplinary research centres and significant investment to increase the university and student presence on site, with a student village and space for a university science department.

Proposals include:

- Sapphire, an entirely new accelerator-based free electron laser light source aimed at ultra-high brightness and ultra-short timescales (£450m). See Annex A4.
- A new high-current proton synchrotron which would service both an upgrade to the ISIS spallation neutron source to develop it as a European facility in partnership with the European Spallation Source. See Annex A4.
- An upgrade to the Diamond Light Source to take advantage of new developments in accelerator techniques and increase its intensity by a factor of ten (£50m). See Annex A4.
- An upgrade to the Vulcan high power laser by a factor of 20, to maintain its position as the highest-power laser in the world (£30m). See Annex A4.
- Centre for Advanced Laser Technology and Applications, for laser driven radiation sources, a new class of sources for industrial, security and medical imaging (£20m)
- Centre for Research in imaging and spectroscopy (£20m)
- A student village to bring PhD students and postdoctoral researchers to the site (£80m)
- A UK materials science centre (£50m)
- A university physical science building (aimed at relocating a major research activity from a nearby campus) (£30m)
- An extension to the RCUK research complex at Harwell (£100m)
- An extension to the existing Science hostel (£30m)
- An alternative energy centre aimed at research in energy storage and novel energy materials, and with the exciting goal of making the campus itself energy-independent (£50m)
- A new public engagement centre (£30m)

Aerial photo of Harwell Oxford campus

6.3. Campus development for Medical Research

Estimated capital cost: £275m

Estimated operational costs: £ 60m pa

Delivery partners: RCUK, TSB, Department of Health

Bringing together expertise from academia, industry and the NHS, in campuses such as the Cambridge Biomedical Campus, to foster discovery, medical research and translation is central to ensuring economic and health benefits from UK's medical research. The capacity for close but flexible and open partnerships is a priority for existing UK industry, and a key attractor for inward investment. It can also enhance the speed and productivity of academic research by bringing new resources and expertise into play. The UK's major academic medical campuses will need further investment, and increased strategic coordination and cooperation, to maximize their potential as foci for leveraging international investment into the UK, as well as centres of scientific excellence. In particular:

- Greater flexibility in rapid small/medium scale capital investment will allow translational partnerships with industry – especially SMEs - to develop more rapidly.
- The UK can increase the impact of its biomedical research strengths with a stronger research and innovation profile in academic molecular pathology and commercial diagnostics development. This will need new infrastructure as well as programmatic funding.
- Translational facilities for preclinical work in partnership with industry will need further development as new technologies come into use; and as industry R&D becomes more open and integrated.
- Technologies for human clinical research will be greatly strengthened by new funding in 2015/16, but by 2019/20, we will need further investments to maintain the pace of discovery and translational research.

6.4. UK Soil Management Innovation Centre

Estimated capital cost: £100m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK

The main focus of the centre will be to exploit the existing expertise in the UK to deal with real life issues affecting Government, business and society in the critical zone of human interaction at the terrestrial surface of the planet. It will build on the UK's lead in development, use and integration of state of the art technologies, training and informatics.

A soil management innovation centre would enhance the description and understanding of the complex abiotic and biotic interactions that take place in soil and translate observational and experimental data into knowledge of how to manage our land surface (especially our soils) for future food, water and environmental security and for societal well-being. Soils and the land surface are where most business and industries interact with the environment: soils underpin our £172bn/year food and drink chain (3.7 million jobs), and drive UK growth in the new bio-economy already worth 1.5 trillion euro in the EU alone. Translating knowledge of soil/ land surface status, properties and functions will have significant financial benefits to many sectors of business and society.

6.5. Water Security and Innovation Centre

Estimated capital cost: £75m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK

Water is an enabling resource underpinning about 20% of the UK economy including water-dependent industry sectors such as food, agriculture, food and fisheries, mining and quarrying, construction, utilities and leisure. Water resources are expected to become more limited as the global population increases and uncertainty regarding potential climate change also means water security is a high risk to the UK.

Increased access to knowledge is required to meet the growing demand to better coordinate the delivery of ecosystem services and the management of natural capital. The UK already has expertise in agriculture, soils and freshwater systems. An Innovation Centre coupled with a water test bed, to test emerging technologies on near-real world situations, could stimulate new technologies for testing and application in the UK economy.

Annex A7: Public Engagement

7.1. 'Inspiring Science' Capital Investment Fund

Estimated capital cost: £22m

Estimated operational costs: N/A

Delivery partners: tbc

Funding could be used to support capital investment for inspirational and involving hands-on science exhibitions and programmes across the UK. This would be open to, amongst others, Science and Discovery Centres **and other visitor attractions with a unique role in involving the public in science** that cannot access capital investment from other public sources.

7.2. Connecting Research and Communities

Estimated capital cost: £18m

Estimated operational costs: Subject to detailed business case

Delivery partners: RCUK

The AHRC-led RCUK programme on Connected Communities has funded a range of projects to develop research capacity and capability within an interdisciplinary community of researchers and users. These awards are underpinned by research excellence in engaging with communities and non-academic partners on themes such as mobility, engagement, civic identity, communities and technology.

Communities play a vital role in the long term economic, social and cultural prosperity of the UK both in domestic and international terms. Capital spend would enhance community engagement with current research capabilities, and enable community use of research-led e-infrastructure in the co-production of research – thus enriching both research and public engagement. For example, recent work has enabled the development of new approaches to crowdsourcing.

Annex B1: Statement of Principles

The Role of Ministers

Ministers have a key role to play in science and research funding. There are some strategic decisions which must be made by Ministers, albeit informed by external advice and the prevailing fiscal situation; these include the overall size of the funding for science and research; its distribution between the large scale capital projects, Research Councils, Higher Education funding bodies, UK Space Agency and others; and making strategic decisions in the national interest.

In addition, it is clear that for some infrastructure needs, strategic decision making by Ministers is required to coordinate investments in the national interest. This includes making long term or large scale commitments of national significance, and looking internationally to determine where it is in the UK national interest to collaborate in international infrastructure projects. In making these decisions, Ministers will be informed by expert advice.

Every Government will have some key national strategic priorities such as addressing the challenges of an ageing population, energy supply or climate change. It is appropriate for Ministers to ask Research Councils to consider how best they can contribute to these priorities, in an affordable way and without crowding out other areas of their missions. But it is for the Research Councils to decide on the specific projects and people to fund within these priorities, free from Ministerial interference.

The Role of Expert Advice

It is important that Ministers, where they are involved in making strategic decisions on the funding of research, take account of advice from a wide variety of expert sources including academia and industry, both nationally and internationally.

Sources of expert advice include:

- Research Councils
- Higher Education Funding Councils
- The Council for Science and Technology
- The Chief Scientific Adviser's Committee
- The Royal Society
- The Royal Academy of Engineering
- The British Academy
- The Academy of Medical Sciences
- The Confederation for British Industry

The Haldane Principle

While it is right for Ministers to make high level strategic decisions, there are areas where Ministers should have no input. The Haldane Principle means that decisions on individual research proposals are best taken by researchers themselves through peer review. Ministers should not decide which individual research projects should be funded nor which researchers should receive the money. The Coalition Government supports this principle as vital for the protection of academic independence and excellence.

The Haldane Principle applies to science and research which the Government funds through the Research Councils and National Academies. HEFCE has statutory independence.[51] The Haldane Principle does not apply to the research budgets of government departments, which are used to fund research to support their departmental policies and objectives. That said, departments work closely with the Research Councils to ensure that the research they fund is aligned with that funded by the science and research base and delivers maximum value to the taxpayer. More generally, Research Councils need to ensure that the views of those with an interest in the potential outcomes of the research are sought when setting their overall priorities.

The Government values the multiplicity and variety of sources of funding from the public, private and charitable sectors. These contribute to the provision of a rich and diverse environment supporting the research community across all disciplines.

Overall, excellence is and must remain the driver of funding decisions, and it is only by funding excellent research that the maximum benefits will be secured for the nation.

[51] *The Further and Higher Education Act 1992 states that the Secretary of State may not attach terms and conditions on grants to HEFCE which are framed by reference to: particular courses of study, programmes of research, the criteria for the selection and appointment of academic staff or the admission of students.*

Annex B2: Proposed criteria for prioritisation

Affordability

Affordability is core, and this is about more than how much capital budget is required to build the project. As with all areas of Government spending, science spending priorities must be justified in the context of other non-science priorities. It also requires consideration of the resource budget required to use the facility – both operational costs and the project costs for the research which uses the facility. As set out above, this may involve moving resources from old in-use facilities to the new facilities.

Excellence

Research excellence is our nation's competitive advantage, and capital investment in science and research infrastructure must support that. This can mean ensuring world-leading researchers have access to world-leading infrastructure, both in the UK and abroad, and also ensuring funding is targeted towards proven centres of excellence, with appropriate critical mass and multi-disciplinary capacity to compete with the best internationally.

Impact

Investment in capital infrastructure has a major role to play both to enhance research capabilities that underpin research, but also in driving economic growth and addressing societal challenges. HM Government's Industrial Strategy recognises that to invest and grow, business needs long term certainty and a government that behaves more like a business, sticking to long-term plans to tackle economic weakness and instability. One of the areas where the Strategy recognises that Government action can have a real and early impact is on the development and adoption of new technologies. For example, the Government has set out eight great emerging technologies that can propel the UK to future growth.

Skills

One of the key roles of the publicly funded research base is to maintain a supply of highly skilled people to the economy. From ensuring these people are trained to know how to use the best equipment, to ensuring a supply of early adopters of new technologies, capital investment in equipment and facilities is essential.

Efficiency & Leverage

Ensuring the best value for money in capital investment, decisions clearly need to take account of the impact on efficiency – for example, new, faster equipment can mean more efficient use of research time. Equally, attracting leveraged funding from collaboration with charities, business and other funders of research will be taken into account.

Annex B3: Examples of companies co-locating with Universities

Airbus - *Bristol*

Boeing – *Sheffield*

Dyson - *Newcastle*

Red Hat – *Newcastle*

GKN – *Bristol; Bath*

GSK – *Cambridge; Dundee; Nottingham*

HP - *Bristol*

JLR - *Warwick*

TATA – *Warwick*

Lloyd's Register - *Southampton*

Nissan – *Cranfield*

Nokia - *Cambridge*

Toshiba – *Cambridge*

Rolls-Royce – *Numerous locations through the Rolls-Royce University Technology Centres programme*

Seagate – *Queens University, Belfast*

Bombardier – *Queens University, Belfast*

Unilever – *Liverpool*

Annex B4: Overview of UK Science, Research and Innovation Infrastructure

https://maps.google.co.uk/maps/ms?msid=208893700638187294005.0004f1bf753dbd99a87b1&msa=0&ll=53.67068,-0.373535&spn=8.050178,16.940918&source=gplus-ogsb

Map of Government-supported science, research and innovation infrastructure in the UK as at February 2014. The organisations and locations presented are departmental PSREs; Research Council Institutes and former Institutes; Catapults; and science parks and innovation campuses that are owned or supported by Research Councils and Government.

Annex B5: List of UK RPIF Projects

Institution name	Bid focus	Funding	Co-Investment	Partners	Region	Discipline
Brunel University	*Structural integrity research centre*	*£15m*	*£45m*	*TWI and other companies*	*London*	*Engineering*
Imperial College London	*Imperial West Technology Campus*	*£35m*	*£90m*	*Voreda*	*London*	*Materials*
King's College London	*Research and innovation in Cancer*	*£15m*	*£32.6m*	*Guy's & St Thomas' Charity, Patrick Muraca, Nuclea Biotechnologie, Dimbleby Cancer*	*London*	*Cancer Studies*
Queen's University Belfast	*Institute of Health Sciences*	*£10.5m*	*£21.7m*	*Charities including Atlantic Philanthropies, Wellcome-Wolfson, Sir Jules Thorn Charitable Trust*	*Northern Ireland*	*Health sciences*
Swansea University	*Energy Safety Research Institute*	*£11.7m*	*£23.3m*	*British Petroleum and TATA Steel Europe*	*Wales*	*Energy Safety*
University College London	*Centre for Children's Rare Disease Research*	*£10m*	*£74.8m*	*Great Ormond Street Hospital*	*London*	*Childrens diseases*
University College London	*The Institute of Immunity and Transplantation (IIT)*	*£11.1m*	*£22.2m*	*Royal Free Charity*	*London*	*Medicine (Immunology)*
University of Birmingham	*Casting and simulation research facility*	*£20m*	*£40m*	*Rolls-Royce*	*West Midlands*	*Materials engineering*
University of Cambridge	*The Maxwell Centre*	*£21m*	*£42.1m*	*Winton Programme for the Physics of Sustainability, Hitachi Ltd, Hershel Smith Trust Fund and*	*East*	*Physics*

Institution name	Bid focus	Funding	Co-Investment	Partners	Region	Discipline
				others		
University of Dundee	Centre for Translational and Interdisciplinary Research	£11.9m	£26m	Wellcome Trust and others	Scotland	Life Sciences
University of Glasgow	Clinical research facilities for stratified medicine	£10m	£20.6m	Wellcome Trust, Pebble Appeal, Life Technologies and others	Scotland	Medicine - chronic diseases
University of Liverpool	Materials Innovation Factory	£11m	£22m	Unilever	North West	Materials chemistry
University of Manchester	Paterson Institute for Cancer Research	£12.8m	£25.6m	The Christie Hospital and Cancer Research UK	North West	Cancer studies
University of Manchester	Multi-disciplinary Characterisation Facility (MCF)	£18m	£99.2m	BP, NNL, Rolls Royce	North West	Materials Science and Engineering
University of Nottingham	Centre of Excellence in Sustainable Chemistry	£10.4m	£21m	GlaxoSmithKline and others	East Midlands	Chemistry
University of Oxford	Big Data Institute	£10m	£20m	Li Ka Shing Foundation	South East	Stats - data for human health
University of Oxford	Target Discovery Institute	£10m	£22m	Consortium including Synergy Health, Cancer Research UK, Roche Diagnostics, GE Healthcare	South East	Medicine (Clinical)
University of Sheffield	The AMRC Factory 2050	£10m	£33.1m	Advanced Manufacturing Research Centre	Yorkshire & Humber	Engineering
University of Southampton	Experimentation facilities in engineering science	£10m	£22.1m	Lloyds Register	South East	Engineering

Institution name	*Bid focus*	*Funding*	*Co-Investment*	*Partners*	*Region*	*Discipline*
University of Strathclyde	*Continuous Manufacturing and Crystallisation Research for Pharmaceutical Products*	*£11.4m*	*£22.9m*	*GCK, CRUK, Astrazeneca and others*	*Scotland*	*Chemistry/ Pharmacology - manufacturing*
University of Surrey	*5G Centre*	*£11.6m*	*£23.3m*	*Many of the mobile communications global industry leaders*	*South East*	*Electronic & electrical engineering*
University of Warwick	*National Automotive Innovation Campus*	*£15m*	*£77m*	*Jaguar Land Rover and Tata Motors European Technical Centre*	*West Midlands*	*Engineering, Chemistry & others*
Total		***£301m***	***£826m***			

Annex B6: Overview of Current and Proposed Major International Research Infrastructure Projects

This annex provides an overview of current and proposed major international research infrastructure projects, illustrating the range and type of activity:

Big Data

ANAEE (European Infrastructure for Analysis and Experimentation on Ecosystems)
Animal Genotype-to-Phenotype Facilities
Aquaculture Facilities
ELIXIR
Euro-BioImaging
Food and Nutrition Facilities
Infrastructure for Systems Biology Europe - ISBE
International Centre for new forms of data
Plant Genotype-to-Phenotype Facilities
PRACE

Understanding Our Universe

Advanced LIGO
Aeolus
ALMA - Atacama large millimetre array at ESO
Cassini/Huygens
CTA - Cherenkov telescope Array
Copernicus
Cryosat
DES - dark energy survey
EarthCARE
E-ELT - European extremely large telescope
Einstein telescope - proposed 3rd generation gravitational wave observatory
EUCLID
ExoMars
FAIR – Facility for antiproton and ion research
g-2 at Fermilab - precision muon experiment
GAIA
Galileo
International linear collider
International Space Station
ISOL - future nuclear physics facility
James Webb Space Telescope
J-lab upgrade at Jefferson lab
JUICE
The Second Large ESA mission
LHC upgrades
LSST - Large Synoptic survey telescope
Long baseline neutrino experiment

Lux-Zeplin - Dark matter experiment

M3: The Third Medium-sized ESA mission
Neutrino experiment at J-PARC
SWARM
Solar Orbiter
SKA - Square kilometre Array

Understanding our Planet

ARGO global ocean observing system and EURO-ARGO
BIOMASS ESA satellite mission for forest biomass and carbon
ECCSEL (European Carbon dioxide Capture and Storage Laboratory Infrastructure)
EISCAT (European Incoherent Scatter Scientific Association) and EISCAT_3D
EMBRC (European Marine Biological Resource Centre)
EMSO (European Multidisciplinary Seafloor Observatory)
EPOS (European Plate Observing System)
IAGOS (In-service Aircraft for a Global Observing System)
ICOS (Integrated Carbon Observing System)
IPICS (International Partnership for Ice Coring Science)
Lifewatch (E-Science Infrastructure for Biodiversity & Ecosystem Research)
METOP and METEOSAT weather satellites
North Atlantic Porcupine Abyssal Plain observatory
OFEG (Ocean Facilities Exchange Group)
Partnership for Observation of the Global Oceans
RAPID - Climate change array transatlantic marine observing system
SIOS (Svalbard Integrated Earth Observing System)

Understanding How Materials Behave

ELI - European Light infrastructure
ESS - European spallation source
ESRF Upgrade
FAIR - Facility for antiproton and ion research
ILL upgrade
XFEL - Free electron laser UK based FEL (UK-based – see Annex A4)

Annex B7: Overview of Current Major Publicly Funded UK Research Infrastructure Projects

This annex provides an overview of current major publicly funded UK research infrastructure projects, illustrating the range and type of activity:

Big Data

Administrative Data Research Network
ARCHER
Consumer Data Research Centre
Data Research Centre for Smart Analytics
Dirac computing infrastructure
E-Health Research Centres and Farr Institute
Life Study
NERC Big Data Environmental Information Initiative
Understanding Society study
UK Dementia platform
UK Regenerative Medicine platform
Urban Big Data Research Centre

Understanding our Universe

ALMA (Atacama Large Millimetre Array) – at the European Southern Observatory, Chile
Harwell Oxford Space facilities

Understanding our Planet

British Antarctic Survey's (BAS) Halley VI Research Station
British Geological Survey's (BGS) Keyworth Redevelopment
Sir Charles Lyell Centre for Earth and Marine Sciences, Edinburgh
Climate and Environmental Monitoring from Space Facility
International Ocean Discovery Programme (IODP)
National Centre for Atmospheric Science's (NCAS) Large Atmospheric Research Aircraft
NOC National Marine Equipment Pool
Royal Research Ship Discovery - Launched 2013

Understanding How Materials Behave

Diamond Phase III
Higgs Institute
ISIS TS2 Phase II
National Graphene Institute
Rutherford Appleton Laboratory refurbishment

Campuses

Aberystwyth campus developments
Babraham Research and Innovation campus
BAS Innovation Centre, Cambridge
Edinburgh campus developments
Francis Crick Institute
Harwell Oxford Space Science Cluster
NOC Autonomy Enterprise Zone Innovation Hub, Plymouth
Norwich Research Park – Centrum building
Pirbright Institute - High containment animal research facilities
Rothamsted campus developments

Annex C1: Consultation principles

The principles that Government departments and other public bodies should adopt for engaging stakeholders when developing policy and legislation are set out in the consultation principles.

http://www.cabinetoffice.gov.uk/sites/default/files/resources/Consultation-Principles.pdf

Comments or complaints on the conduct of this consultation

If you wish to comment on the conduct of this consultation or make a complaint about the way this consultation has been conducted, please write to:

John Conway,
BIS Consultation Co-ordinator,
1 Victoria Street,
London
SW1H 0ET

Telephone John on 020 7215 6402
or e-mail to: john.conway@bis.gsi.gov.uk

However if you wish to comment on the specific policy proposals you should contact the policy lead (see how to respond).

Annex C2: List of Individuals/Organisations consulted

We expect this consultation to be of interest to the following groups:

- Government Departments and Agencies
- Research Councils
- Research Institutes
- Public and Private Research Bodies
- Devolved Administrations
- Regional special interest groups
- Funding Councils
- National Academies
- Professional Institutes
- Universities UK
- University representative groups
- Confederation of British Industry
- Trade Associations
- Major Research Charities
- Universities
- Industry
- SMEs
- Individual researchers from universities, research institutes or industry

All other individuals and organisations are welcome to respond. We would also welcome suggestions of others who may wish to be involved in this consultation.

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Any enquiries regarding this publication should be sent to:

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BIS/14/757